PRINCIPLES OF TEXTILE TESTING

An Introduction to Physical Methods of Testing Textile Fibres, Yarns and Fabrics

J. E. BOOTH, B.Sc., F.T.I.
Lately Senior Lecturer in Textile Technology
Bolton Institute of Technology

BUTTERWORTHS
London Boston Durban Singapore Sydney Toronto Wellington

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Associations

The British Cotton Industry Research Association
The British Standards Institution
The British Rayon Research Association
The British Jute Trade Research Association
The Pakistan Jute Association
The Empire Cotton Growing Corporation
The Linen Industry Research Association
The Wool Industries Research Association
The International Wool Secretariat
The Hosiery and Allied Trades Research Association
The Society of Dyers and Colourists
The Textile Institute

Testing Machinery and Instrument Manufacturers

W. and T. Avery Ltd
Cambridge Instrument Co. Ltd
Cook and Co. Ltd
Courtaulds Ltd
Dawe Instruments Ltd
Samuel Denison and Son Ltd
Diamond Industry Supply Assoc. Ltd
Fielden Electronics Ltd
Goodbrand and Co. Ltd
James H. Heal and Co. Ltd
Imperial Chemical Industries Ltd, Fibres Division
Macpherson (Textile Engineers) Ltd
Negretti and Zambra Ltd
Newmark (London) Distributors Ltd
Platt Bros. (Sales) Ltd
Reynolds and Branson Ltd
J. L. Shaw Electronics Ltd
Shirley Developments Ltd
Smiths Industrial Instruments Ltd
G. W. Thornton Ltd
Tootal Broadhurst Lee Co. Ltd

I

INTRODUCTION TO TESTING

TO THOSE engaged in the production, distribution, and consumption of textiles, testing can be a valuable aid provided that the instruments and techniques are used effectively. When tests are made the results must be studied carefully so that the right course of action may be taken. Testing instruments cannot make decisions, and in the end some person has to interpret the data and issue the necessary instructions for future action. Testing is, therefore, a means to an end and not an end in itself. The fact that a material has been tested, no matter how accurately, does not enhance its technical quality.

Because testing has to be paid for, it is essential that the persons carrying out the tests are competent and technically qualified. Good advice to anyone who is considering the provision of a mill testing laboratory is to engage a first-class textile technologist. The man in charge of a mill testing laboratory must be part scientist, part statistician, part technologist, and part diplomat. His technical ability will enable him to direct the various testing schemes and to keep abreast of new developments in processing, testing instruments, and techniques. Diplomacy will be required when he has to 'put over' his findings to his colleagues both at management level and on the mill floor. This particular quality of the technologist is expecially valuable when the results are unfavourable or when, perhaps, they highlight somebody's mistake.

The variety of textile instruments available is large. Many of them are simple in principle and have been used in the textile industry for a long time. Some important instruments are relatively new, as also are commercial models of equipment developed in research laboratories. Electronic evenness testers and instruments based on air flow principles are typical examples of the latter. The choice of instruments and the testing techniques employed will be governed largely by the information required as well as by how accurate and detailed that information has to be. In a later chapter it will be shown that apparently contradictory results may be obtained by testing a particular property of a material on different types of testing machine.

It has been said that the subject of textile testing can be covered

by answering the 'W' questions: Why do we test? What do we test? When do we test? Who does the test? The remaining part of this introductory chapter will deal briefly with the first question—Why do we test? It is difficult to classify the reasons for testing because of overlapping. Nevertheless, some form of classification is a help in getting a broad view of the subject.

THE OBJECTIVES OF TESTING

Research

The road along which the research worker travels is characterised by cross-roads, fork-roads, bridges, and culs-de-sac. At each stage there is a choice of direction. The results of testing in research will help the scientist to decide which route to follow next. What appears to be sound theory is often disproved by experiment, and other lines of reasoning must then be pursued.

Selection of raw materials

'Raw materials' is a relative term; the raw material of the spinner is the fibre, the raw material of the weaver is yarn, and that of the finisher is cloth. One attribute common to most textile raw materials is their variation in quality. Fibres vary in length, colour, and fineness; yarns vary in count, strength, and twist; fabrics vary in threads per inch, freedom from faults, and shrinkage. Since prevention is better than cure it is sound policy to test the available raw materials to ensure the smooth running of production processes. Unsuitable material can be rejected or perhaps put to another use. The standards by which raw materials are accepted or rejected must be realistic, otherwise much will be rejected which in fact is good enough, or else large amounts of inferior material will find its way into the flow of production and cause trouble.

The testing of fibres is generally not so important when dealing with man-made fibres and man-made continuous filament yarns, because they are supplied to customers' requirements and their properties, including length, colour, and fineness are determined and controlled during their manufacture.

Process control

When processing goes out of control the amount of waste and the number of seconds increase, costs go up, and very often tempers too. Higher end-breakages in spinning and winding departments and excessive loom stops due to warp or weft breaks affect the operatives as well as production. A plan of production requires certain standard

levels to which materials in process must conform. Since it is impossible to maintain a chosen standard absolutely, limits on either side of the standard level are calculated and materials whose characteristics fall within these limits are allowed to pass forward to the next process. In a spinning mill the most common characteristic measured is the weight per unit length of the lap, sliver, roving, or yarn. The nominal hank or count is decided upon and control limits are calculated from test results. In brief, a 'quality control' scheme is operated.

For maximum effectiveness the 'process control' test should be close to the processing machinery. Quick answers are required to prevent excessive amounts of faulty material from getting through before detection. Further consideration of process control techniques will be given in a later chapter.

Process development

Process development may be considered as a form of applied research. The experimental work involved may be carried out in research institutes, in pilot plants within the boundaries of the mill, or perhaps on the actual processing machinery. In each case investigations into better, cheaper, and quicker methods of manipulating fibres and yarns are made. The success achieved is often measured by the improvement in one or more characteristics of the material delivered after change in machine design or setting. The effects of blending different materials may be the aim of the experiment. Most trials of this nature require the testing of the material produced and it is important to be quite clear which properties are to be measured to avoid unnecessary waste of time and money.

Product testing

If we could be absolutely certain that our choice of raw materials was right and that our system of process control had maintained the stipulated standard levels, then we could pack the end-products into cases with confidence, knowing that they would fulfil their intended purposes satisfactorily. Mill managers would sleep better at night if this pipe dream were a reality. Unfortunately our knowledge of the effect of the many variables possible in the structure of yarns and fabrics, including the effects of physical and chemical treatments, is limited. The more we find out, the more we learn how much there is still to discover. The testing of the product helps in the continual search for new knowledge. Sometimes a forecast of the probable performance in a subsequent process is required. A very old question of this type is 'How well will this yarn weave?' We are still

looking for a simple test which will give us an answer near enough to the truth.

The performance of a finished article in actual service could be the object of a product test. One thorny problem is the assessment of the resistance of a fabric to the 'wear and tear' of everyday use. We could try to imitate the kind of treatment meted out to the fabric, rubbing it against abrasives, wetting it and drying it, bending it, stretching it, creasing it, and so on. Such a test would indeed be complicated, and as someone once said, 'Imitative tests are a snare and a delusion!' Alternatively, we might subject the material to a series of laboratory tests, each of which tests only one property at a time.

Specification tests

There has been a growing demand in recent years for the production of textiles to meet specifications. Advantages claimed for the use of specifications include the prevention of deterioration in quality by manufacturers using inferior raw materials, the production of goods of known performance, and the opportunity for a manufacturer to produce exactly what is required by the customer. The third advantage assumes of course that the customer really knows what he wants and can frame a specification in the right way. Unfortunately the customer cannot always explain what he wants in precise terms. This leads to vague specifications capable of more than one interpretation and the finished product may be unsuitable for the intended purpose.

Nevertheless, specifications *are* framed and the materials are subjected to tests to prove whether they fall within the limits allowed in the specification.

One type of specification is a small sample of material accompanied with a request to 'reproduce this for me please'. Here again, suitable analysis techniques and testing are required plus the need to be aware of the inadequate size of the sample.

Several papers dealing with the problems associated with specifications are given in the references at the end of this chapter.

'TESTED QUALITY' SCHEMES

Another sphere in which testing plays an important part is in the operation of a 'Tested Quality' scheme. The materials tested are usually in the finished state, perhaps in the form of fabric, but also in the made-up state just as the eventual customer buys them.

The end-product is of course the result of all the care, or lack of care, which has been given to the choice of raw materials, the processing, the finishing, and the making up. The question now is whether the finished article will satisfy the customer's requirements both in serviceability and in price.

A number of organisations have been formed which test the performance of textiles. Some of these organisations are independent bodies who carry out tests on materials submitted by manufacturers and issue certification marks and allow the manufacturers to indicate on their labels that the goods have been tested and found satisfactory.

Other schemes are operated by large concerns whose objective is to help the manufacturer, the retailer, and the customer to gain the maximum satisfaction from their textiles. Such a scheme is the 'Tested-Quality' plan of Courtaulds Ltd. In this scheme the tests carried out on the materials and garments are related to their end-uses, e.g. swimsuits are tested for colour fastness to sea water and chlorinated water, and industrial overalls are tested for shrinkage in machine washings. Minimum performance standards have been set up and the article or fabric is rejected if the test results fall below these minima. The 'Courtaulds Tested-Quality' Mark is shown in Figure 1.1.

Figure 1.1. 'Courtaulds Tested-Quality' Mark

Some bodies test particular aspects of the materials. One example is the American Institute of Laundering, who issue their own 'Certified Washable Seal' to goods which launder to their standards.

The reader is recommended to study a paper read by Best-Gordon and Thomas at the Annual Conference of the Textile

Institute in 1957. The authors review the various types of organisation mentioned above and describe Courtaulds Tested-Quality Plan in detail.

An interesting development is the introduction of the trade mark 'Uster Analyzed', Figure 1.2, which signifies that the yarns being sold have been manufactured under an efficient quality-control system based on the Zellweger 'Uster' range of testing equipment (see *Uster News Bulletin*, No. 8 (August 1966)). Another trade mark is shown in Figure 1.3; this is the Wool Mark, which guarantees that the goods are made from, and possess the desirable attributes of, pure wool.

Figure 1.2. The 'Uster' trade mark
(By courtesy of Zellweger Ltd.)

Figure 1.3. The Wool Mark
(By courtesy of the International Wool Secretariat)

Recently, organisations which purport to represent the 'housewife' have begun to test all kinds of articles including textiles, so that different makers' goods can be either recommended as a 'good buy' or rejected. One may become a member by subscription and receive regular reports on the articles tested. One such organisation

is described by Roberts in an article 'How "Which" Works' (*Text. Inst. Ind.*, p. 13 (July 1963)).

In the preceding sections we have tried to answer the question 'Why do we test textiles?' It is not a complete answer, exciting reasons such as testing for the detection of criminals in police work have not been discussed, but it is evident that some form of testing is required at every stage of manufacture so that the finished article will prove satisfactory to the buyer, will maintain or enhance the reputation of the manufacturer, and will subsequently lead to repeat orders and continued prosperity.

Finally, after all the testing schemes have been decided upon and testing is under way, it must not be forgotten that the one who eventually keeps the machine or process on the right track is the textile technologist. Without his skill and experience the word 'control' can lose much of its meaning.

FURTHER READING

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2

THE ELEMENTS OF STATISTICS

IN a modern society, statistics are daily flung at the head of the ordinary citizen through the media of newspapers, radio, television, and the like. Governments, advertisers, and football pools promoters back up their policies, products, and successes by 'the figures' which presumably prove something or other. Over the years the subject of statistics has tended to get a bad name amongst ordinary people and the phrase 'You can prove anything with figures' is not uncommon. The misuse of statistics is not our concern in this chapter; instead we shall study the way in which the use of statistics can help in the sphere of textile testing.

Most tests on textile materials give results in the form of numbers, e.g. the count of a lea of yarn may be given as 36s cotton, and its strength as 60 lb. There are some subjective tests in which a numerical result is difficult to produce, e.g. one cloth may be judged softer in handle than another. Usually a series of tests is made on a group of individual items and the results from each test recorded and subsequently analysed by suitable methods. The use of statistical methods enables us to extract the maximum amount of information about the tested material from the available data and to use this information for such purposes as quality control, mill investigations, and research. Without an understanding of the elements of statistical methods, the study of testing methods and instruments becomes rather pointless since the instruments used are means to an end and are not ends in themselves.

The subject of statistics is wide indeed and it is clearly inadvisable to attempt to cover too much ground in one chapter. Therefore the aim of the following sections is to introduce the reader to the underlying principles and to illustrate them by examples drawn from the field of textiles. Several books on the subject are referred to and listed at the end of the chapter, and the serious student is recommended to read them.

The manufacture of textiles is largely a system of mass production; a spinning mill will produce thousands of ring bobbins every day, a weaving mill will weave hundreds of yards of fabric. To test every item would be impossible. Furthermore, many tests are destructive in character and this in itself limits the amount of testing. We there-

fore test *samples*. The whole bulk of the material available for testing is termed the *population*, and the *sample* is a relatively small number of individual members which is selected to represent that population. If every individual member of the population were identical we would be justified in testing just one item. The characteristics thus measured would be that of the population. Unfortunately in textiles, as in other industries, one of our major problems is that of *variation*. Fibres in the same bale of cotton vary in length and fineness, bobbins from the same frame vary in count and strength, and fabrics woven on the same loom vary in appearance and freedom from faults. It follows that in order to get an answer which represents the population, a sample must consist of a number of individuals. (An *individual* is one member of the population.)

The method of selecting the individuals to make up a sample should ensure that a *random sample* is obtained. In such a sample every individual in the population has an equal chance of being selected. By this means it is possible to eliminate *bias* in the sample. For instance, if we were testing a delivery of cotton to determine its length characteristics, any method of fibre selection which favoured the choice of the longer fibres would produce an optimistic result since the sample would be *length biased*. Sampling techniques for fibres and other forms of textiles will be discussed in greater detail in the next chapter and thus, for our present purposes, we will assume that the samples considered in the following sections are in fact random samples.

FREQUENCY DISTRIBUTIONS

Suppose the yarn from a certain ring frame is being tested to determine its count and to find out something about the count variation. Assume that 100 bobbins have been chosen at random and from each one a lea of yarn is taken and weighed accurately under standard testing conditions. The count is then calculated for each bobbin. Thus the available data are 100 count results. Table 2.1 shows one possible method of recording the results. By adding all the results together and dividing by 100 the *arithmetic mean* is obtained. This is usually called the *average*.

Let x_1, x_2, etc., be the individual values,
n be the total number of observations, and
$\bar{x}$ (x bar), be the arithmetic mean.

Then
$$\bar{x} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n}$$

Table 2.1. Count Test on 72s Cotton Yarn

Bobbin No.	*Count*
1	72·4
2	66·3
3	74·4
4	72·8
—	—
—	—
—	—
97	70·7
98	68·2
99	74·8
100	71·6
Total	7127·2
Average	71·27

In the example given in Table 2.1 the average count is 71·27s. This is useful information, but it does not indicate the variability of the yarn count, and it is difficult to digest 100 individual results. We need some method of compressing all the observations into some easily understood form without losing too much of the original information. The first step is to classify the observations into groups or classes and to draw up a table showing how many times values occur in each group. The *range* of the 100 values, i.e. the difference between the highest and the lowest values, is divided into sub-ranges called *class intervals*. The *class frequency* is then the number of values which occur in a class interval.

Table 2.2 shows the method used. A mark is made on the appropriate line for each test value. For example, a mark will be made in the class 71–72 for the value 72·4 (since 72·4 is less than 72·5). Similarly, the mark for the value 70·7 will be recorded in the 71–72 class because 70·7 is more than 70·5. It will be appreciated, therefore, that the limits of the classes are really 58·5–60·4, 60·5–62·4, and so on. It is useful to group the marks in fives for easier counting. This type of table is termed a *frequency distribution*, i.e. it shows the distribution of the class frequencies over the range of values. One feature of the distribution shown in Table 2.2 is that most of the values congregate around a central value, a feature which is shown by most distributions. Even in tabular form the frequency distribution indicates the variation of the characteristic being measured. It will be seen that the average has been calculated as follows:

$$\frac{\text{Sum of (class frequency} \times \text{mid-value of class interval)}}{\text{Total number of values}}$$

Table 2.2. Frequency Distribution of Count Test Values

Class interval		*Class frequency* f	*Class frequency* × *mid-value of class*
59–60	11	2	119·0
61–62		0	0·0
63–64	111	3	190·5
65–66	𝍸 1	6	393·0
67–68	𝍸 𝍸 1	11	742·5
69–70	𝍸 𝍸 𝍸 111	18	1251·0
71–72	𝍸 𝍸 𝍸 𝍸 111	23	1644·5
73–74	𝍸 𝍸 𝍸 1	16	1176·0
75–76	𝍸 𝍸 11	12	906·0
77–78	1111	4	310·0
79–80	111	3	238·5
81–82	11	2	163·0
	Totals	100	7134·0
	Average		71·34

Note. The marks of the frequency distribution are kept separate in groups of five for ease in counting and are recorded thus, 𝍸, i.e. four units plus a horizontal line to indicate the fifth unit.

The average value so obtained does not agree perfectly with the average value originally determined, 71·34 as against 71·27. This difference is due to the assumption made that the mean value in each class interval is equal to the mid-value, whereas in fact there will be slight differences. These errors due to grouping may be regarded as part of the loss of accuracy due to compression of information.

GRAPHICAL PRESENTATION OF DATA

Frequency distributions can be presented in several graphical forms, two of the more common being the *frequency polygon* and the *histogram*.

The frequency polygon. A convenient horizontal scale for the variable measured is chosen and the vertical scale is used for the frequency. The class frequency values are plotted over the mid-values of the class intervals and the points joined by straight lines to form a polygon. Table 2.2 is presented as a frequency polygon in Figure 2.1.

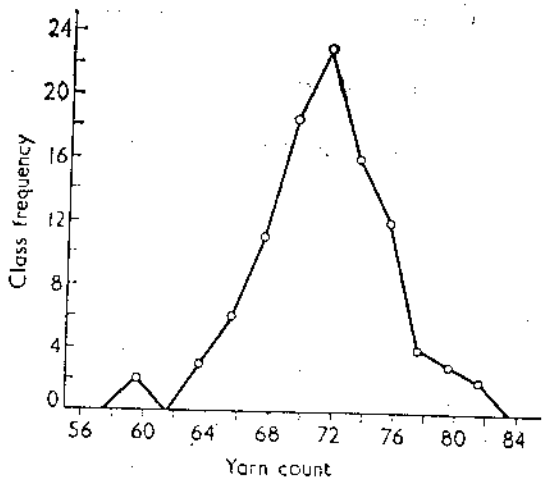


Figure 2.1. Frequency polygon of yarn count value in Table 2.2

The histogram. In a histogram the data are presented as a series of rectangles erected over the horizontal scale. The width of a rectangle is the class interval and its *area* represents the class frequency. When the class intervals are equal the widths of the rectangles are equal and it follows, therefore, that the *heights* of the rectangles will be proportional to the class frequencies. This simplifies examination of the histogram and so, in most cases, equal class intervals are employed.

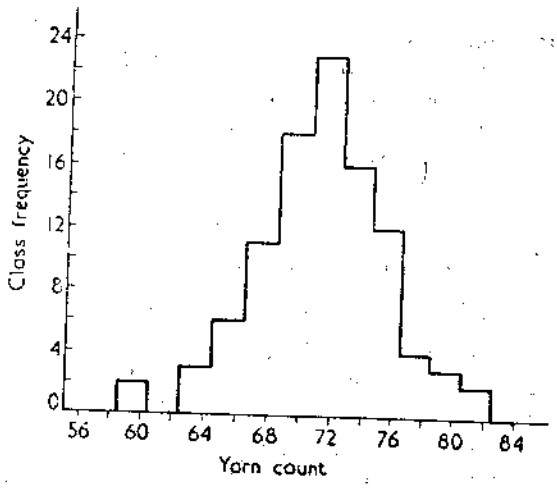


Figure 2.2. Histogram of yarn count values in Table 2.2

Figure 2.2 shows the construction of a histogram from the data in Table 2.2. The procedure is somewhat similar to that for the frequency polygon but instead of plotting points, horizontal lines are drawn at the corresponding frequencies, the lines extending across the limits of the class intervals. For example, the class frequency for the 69–70 class interval is 18. The horizontal line extends from 68·5 to 70·5. The several horizontals are joined as shown to form the histogram.

Both the frequency polygon and the histogram tell us the same story, but since the histogram shows the width of the groups more clearly it is perhaps the more popular.

The frequency curve. As the number of values becomes higher and the class intervals become smaller, both the frequency polygon and the histogram take on the appearance of a smooth curve which is known as a *frequency curve*. The area under the curve represents the total number of individuals. Hence the area enclosed by the curve, the horizontal axis and any two ordinates, is directly proportional to the number of individual values lying between the limits considered. This property of the frequency curve will be discussed in greater detail shortly.

All three graphical forms are used to provide the observer with information concerning the distribution of recorded values such as test results. We will now look at the shape of some types of distribution curves.

The symmetrical or bell-shaped distribution curve

This type of distribution curve, Figure 2.3, is symmetrical about a central value. One very important curve of this type is the normal distribution curve. The term 'normal' is used because so many naturally occurring sets of data produce this type of curve, but it must not be assumed that there is anything 'abnormal' about results which do not produce a normal curve. The mathematician Gauss did much work in this branch of mathematics and the normal distribution is often referred to as the *Gaussian distribution.*

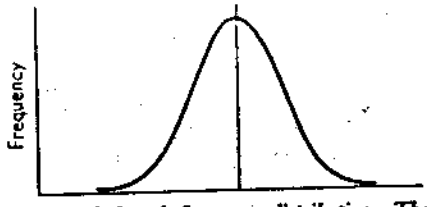


Figure 2.3. Symmetrical or bell-shaped frequency distribution. The normal or Gaussian distribution. The mean, mode, and median coincide

Examples of textile tests which produce normal or nearly normal distribution curves are count testing and yarn strength testing. The Uster single thread strength tester automatically produces a frequency distribution diagram in a special frame on the front panel of the instrument (see Figure 8.29, Chapter 8).

The moderately asymmetrical or skew distribution curve

As its title implies, the shape of this curve is not symmetrical about a central value; the 'hump' may lie towards the left or right, as shown in Figure 2.4. The skew is positive or negative. If the longer tail of the curve lies to the right, i.e. towards the higher values of the variable, the skewness is said to be positive. Figure 5.1 shows the frequency distribution of cotton fibre length, a moderately asymmetrical distribution with a negative skewness.

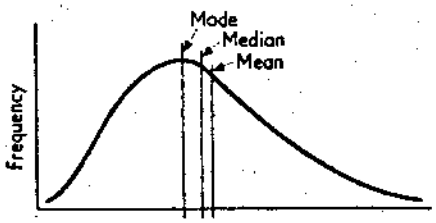


Figure 2.4. Moderately asymmetrical or skewed frequency distribution

Sometimes the distribution curve shows a high degree of asymmetry; an example is given in Figure 2.5 for the number of warp breaks per piece length of woven fabric which, in this case, gives a positive skew.

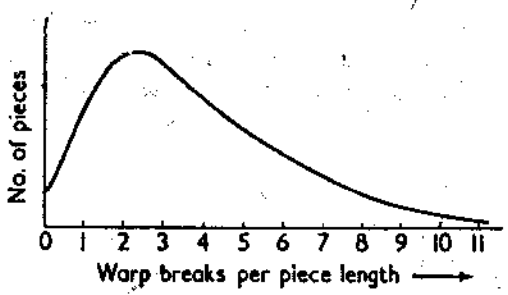


Figure 2.5. Asymmetrical frequency distribution, positively skewed, e.g. warp breaks per piece length woven on a loom

The bimodal distribution curve

Where a distribution curve has two modes or 'humps', as in Figure 2.6, it is termed bimodal. Such a distribution may indicate that the individual items tested or measured have come from two sources whose properties are different. If the bobbins from two spinning frames were mixed and tested for count, a bimodal distribution would result if the count of one frame were different to the count of the other.

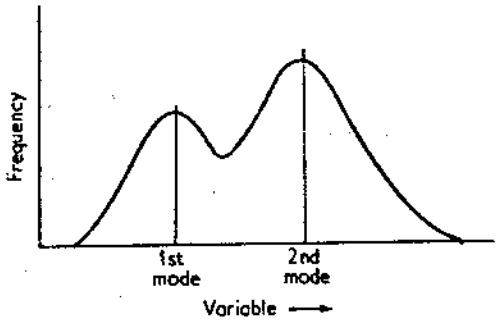


Figure 2.6. Bimodal frequency distribution

Other types of distribution curves

The extremely asymmetrical or J-shaped distribution and the U-shaped distribution are two forms of distributions which are not commonly found in textile testing. In the former the class frequencies are a maximum at one end of the range and a minimum at the other. In the latter there is a maximum at each end of the range and a minimum in the middle, giving a U-shaped curve. Discussion of these special types will be found in the standard textbooks on statistics.

Continuous and discontinuous variates

In the distribution curves discussed the horizontal scale has been graduated in terms of the variable being measured or tested, e.g. fibre length and warp breaks per piece length. The characteristic which varies is termed the 'variate'. Fibre length is an example of a 'continuous variate', i.e. it can be any value within certain limits. The number of warp breaks is an example of a 'discontinuous variate' since the number can only be one, two, three, and so on; we cannot have a fraction of a break.

AVERAGES AND OTHER METHODS OF LOCATION

The arithmetic mean or average

This measure has already been mentioned. It has the advantages of (1) being simple to understand, (2) being easy to calculate, and (3) using all the measurements. It is therefore the most popular method of locating a distribution.

Calculation of the arithmetic mean

We have seen earlier two methods of calculating the average (see Tables 2.1 and 2.2). Table 2.3 shows another method which saves some arithmetic labour.

Table 2.3. Simplified Calculation of the Arithmetic Mean

Data: 100 Test results used in Table 2.2

1	*2*	*3*	*4*
Class value x	x − A	*Class frequency* f	f(x − A)
59·5	−12	2	−24
61·5	−10	0	0
63·5	− 8	3	−24
65·5	− 6	6	−36
67·5	− 4	11	−44
69·5	− 2	18	−36
71·5	0	23	−164
73·5	2	16	32
75·5	4	12	48
77·5	6	4	24
79·5	8	3	24
81·5	10	2	20
			148

Let the *arbitrary mean A* = 71·5

Then the *arithmetic mean* $\bar{x} = A + \frac{\Sigma f(x - A)}{n}$

$$= 71{\cdot}5 + \left(\frac{-16}{100}\right)$$

$$= 71{\cdot}5 - 0{\cdot}16$$

Therefore, $\bar{x} = 71{\cdot}34$

Step 1. Draw up four columns, as shown.
Step 2. Choose a class value which appears to be about the average and call this the *arbitrary mean*, A.
Step 3. Fill in the columns with the required information.
Step 4. Add all the minus quantities in column 4.
Step 5. Add all the plus quantities in column 4.
Step 6. Calculate the correction to the value A by substituting in the formula

$$\frac{\Sigma f(x - A)}{n}$$

The Greek letter sigma, Σ, means 'the sum of'.
Step 7. Add the correction to the arbitrary mean A, noting the algebraic sign of the correction. This step produces the *arithmetic mean* or *average*, $\bar{x}$

The reader will notice that the error due to grouping is still present in this method.

The median

The *median* is the middle value of a series of values arranged in order of magnitude. The median divides the area under the frequency curve into two equal parts.

Example. Suppose fifteen threads have been tested for single thread strength in grams and the values noted down in order of increasing strength:

174 178 180 181 184 186 186 187 189 191 191
193 195 196 196

The median is the 8th value, 187 grams.
Should there be an even number of values, then the mean of the two middle values is taken :

147 149 151 151 152 153 153 154 155 156

The median is the sum of the 5th and 6th values divided by 2, i.e. $(152 + 153) \div 2 = 152{\cdot}5$ grams.

The mode

As its name implies, the *mode* is the most 'fashionable' value in the sense that it is the value which occurs most often. More academically, the mode is the value of the variable corresponding to the maximum frequency of the frequency curve. We shall come across this term again when discussing the Shirley photoelectric modal stapler, an instrument used for measuring the length characteristics of cottons.

The relationship between the methods of location

If the frequency curve is symmetrical, Figure 2.3, it follows that the mean, the median, and the mode will coincide. Where the curve is moderately asymmetrical, Figure 2.4, there is an interesting approximate relationship between the three values:

$$\text{mode} = \text{mean} - 3(\text{mean} - \text{median})$$

Example. Let the mean be 219·55 and the median be 219·38. Then the mode equals

$$219{\cdot}55 - 3(219{\cdot}55 - 219{\cdot}38)$$

i.e. 219·04.

Bimodal distribution

Sometimes the results of tests give a distribution curve with more than one hump, as in Figure 2.6. This often indicates that the individuals tested do not originate from the same source, e.g. mixed batches of yarn from different frames.

THE MEASUREMENT OF DISPERSION OR SCATTER

In order to describe the variability of the measured characteristic of the material tested, we can use several methods to indicate the dispersion or scatter of the values about the central value.

The range

The *range* is simply the difference between the highest and the lowest values. It has the advantage of being easy to calculate but the disadvantage of using only two of the available values. There is an important application which we shall discuss later and it concerns the calculation of the mean range from the ranges of a large number of small samples. It will be shown that the mean range is related to the other important measures of dispersion.

Example. Two sets of five warp-way strips of cloth are tested for strength and the results are as follows:

Strength of fabric A in pounds

120 118 124 122 116: Range 124–116; 8 lb.

Strength of fabric B in pounds

108 106 140 124 122: Range 140–106; 34 lb.

Both sets of results have a mean strength of 120 lb but clearly the strength of fabric B appears to be more variable than that of fabric A.

Mean range

The *mean range*, $\bar{w}_n$, is the mean of the ranges of a number of samples each of size n individuals.

Example. The following shows the method of calculating the mean range from five sets of four values:

24	21	18	23	Range	6
16	23	17	20	Range	7
24	19	14	21	Range	10
14	17	22	18	Range	8
21	20	22	17	Range	5
				Total	36

Therefore, mean range, $\bar{w}_n = 36 \div 5 = 7{\cdot}2$.

Percentage mean range

The *percentage mean range*, P.M.R., is the mean range, $\bar{w}_n$, expressed as a percentage of the mean, $\bar{x}$.

$$\text{P.M.R.} = \frac{\bar{w}_n \times 100}{\bar{x}}$$

In our last example the mean was 19·55 and the mean range was 7·2, therefore

$$\text{P.M.R.} = \frac{7{\cdot}2 \times 100}{19{\cdot}55} = 36{\cdot}8 \text{ per cent}$$

The inter-quartile range or quartile deviation (Figure 2.7)

This rather fearsome title is not as difficult to understand as it sounds. *Quartiles* divide the area under the frequency curve into quarters. A quarter of the population has values above the *upper quartile*, Q_2, and a quarter has values below the *lower quartile*, Q_1. The *inter-quartile range* (see Figure 2.7) is the difference between the upper and the lower quartile values. It will be appreciated that 50 per cent of the population values will lie between these two quartiles.

The reader is referred to the section in Chapter 5 which deals with the analysis of the comb sorter diagram for cotton. Here we use the interquartile range and express it as a percentage of the *effective staple length* in order to provide a measure of the dispersion or variability of the fibre length.

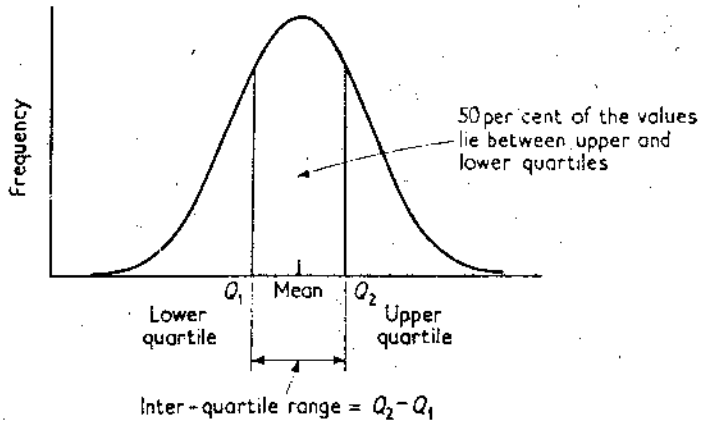


Figure 2.7. The inter-quartile range

The mean deviation

This measure of dispersion uses every observed value in its calculation and is therefore a more accurate indication of variation than the range. The *deviation* is the difference between each value and the arithmetic mean. The sum of the deviations, ignoring the sign of the difference, is calculated and divided by the total number of values considered. Hence,

$$\text{mean deviation} = \frac{\text{sum of the deviations from the mean}}{\text{total number of observations}}$$

(Note that the mean deviation has the units of the variable being measured.)

Using symbols,

$\bar{x}$ = arithmetic mean

x = observed value

n = number of observations

$$\text{Mean deviation} = \frac{\Sigma|x - \bar{x}|}{n}$$

$|x - \bar{x}|$ or 'modulus $x - \bar{x}$' means that the sign of the difference is ignored.

The percentage mean deviation

This is the mean deviation expressed as a percentage of the mean. As such it has no units but it does enable comparisons to be made between samples with different mean values.

Calculation of the mean deviation (see Table 2.4)

Step 1. Draw up two columns for the quantities x and $|x - \bar{x}|$.
Step 2. Fill in the values of x in column 1.
Step 3. Sum the x values and obtain the mean, $\bar{x}$
Step 4. Fill in column 2 with the quantities $|x - \bar{x}|$.
Step 5. Sum the values in column 2.
Step 6. Divide the sum of column 2 by the number of observations, n. This produces the mean deviation.
Step 7. If required, the *percentage mean deviation* is then obtained, i.e.

$$\text{P.M.D.} = \frac{\text{mean deviation}}{\text{mean}} \times 100$$

Table 2.4. Calculation of the Mean Deviation

1	*2*
Value x	*Deviation from mean* $\lvert x - \bar{x} \rvert$
27	2
22	3
24	1
29	4
31	6
21	4
23	2
20	5
32	7
21	4
250	38
$\bar{x} = 25$	$\Sigma\lvert x - \bar{x} \rvert = 38$

$$\text{Mean deviation} = \Sigma \frac{|x-\bar{x}|}{n} = \frac{38}{10} = 3{\cdot}8$$

$$\text{Percentage mean deviation } \frac{3{\cdot}8}{25} \times 100 = 15{\cdot}2 \text{ per cent}$$

The standard deviation

The most useful and therefore most widely used measure of dispersion is the *standard deviation*. Every value is used in its calculation. Although the arithmetic is a little more laborious than for the mean deviation, the use of the standard deviation is preferred.

Definition. The standard deviation is the square root of the mean of the squares of the deviations of the observations from their mean, i.e.

$$\text{Standard deviation } \sigma = \sqrt{\left(\frac{\Sigma(x - \bar{x})^2}{n - 1}\right)}$$

The symbol σ is the Greek letter sigma.

The standard deviation will have the same units as the variable being measured. By expressing the standard deviation as a percentage of the mean we obtain the *coefficient of variation*, C.V. %, or *V*.

$$\text{Coefficient of variation, } V = \frac{\sigma}{\bar{x}} \times 100$$

Variance and standard deviation

The variability of a set of results may be expressed by the *variance*. A formal definition of variance would be 'The sum of the squares of the deviations of the observations from their mean, divided by the total number of observations'. Thus,

$$\text{Variance} = \frac{\Sigma\ (x - \bar{x})^2}{n}$$

In practice, the denominator used is $n - 1$ instead of n, which explains why $n - 1$ appears in the formula given for the standard deviation in a previous paragraph. Brownlee (*Industrial Experimentation* (4th Edn.), p. 27, H.M.S.O.) gives the following explanation for this operation:

> In calculating $\Sigma\ (x - \bar{x})^2$ we should be calculating the sum of the squares of the deviations from the true mean of the population from which the sample is drawn. We have only an estimate of the mean, the mean of our sample, which will not in general be identical with the true mean of the whole population. The sum of the squares of the deviations from the mean of the sample will be smaller than the sum of the squares of the deviations from the true mean. To see this, suppose we have two observations 1 and 3, and that the true population mean is actually 1. The sum of the squares of the deviations from the true mean is $(1 - 1)^2 + (3 - 1)^2 = 4$: working from the true mean we would use n as the divisor to get the estimate of the variance as $4/2 = 2$. The sum of the squares of the deviations from the sample mean is $(2 - 1)^2 + (3 - 2)^2 = 2$: if we use n as the divisor the estimate of the variance is $2/2 = 1$, whereas if we use $(n - 1)$ as the divisor we get $2/(2 - 1) = 2$ as our estimate of the variance. It is apparent that the use of $(n - 1)$ instead of n as the divisor helps to compensate for the use of the sample mean instead of the true mean.

The number $(n - 1)$ is known as the degrees of freedom of the variance, and is used in making tests of significance in comparing one variance with another.

Variance has the useful property of being additive. This means that if a number of factors each introduce a certain amount of variation into a product, the total variance is the sum of the independent variances. Using the symbol σ^2, i.e. the standard deviation squared, to represent variance, this additive property may be indicated as follows:

Let σ_T^2 be the total variance, and

σ_1^2, σ_2^2, σ_3^2 . . . be variances due to separate causes.

Then, $$\sigma_T^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \ldots$$

Table 2.5. Calculation of the Standard Deviation

1	*2*	*3*
Cloth strength (lb)	*Deviation from mean strength*	*(Deviation)²*
x	$x - \bar{x}$	$(x - \bar{x})^2$
42	+0·2	0·04
39	−2·8	7·84
45	+3·2	10·24
47	+5·2	27·04
38	−3·8	14·44
39	−2·8	7·84
46	+4·2	17·64
44	+2·2	4·84
41	−0·8	0·64
37	−4·8	23·04
418		113·60
$\bar{x} = 41{\cdot}8$		

$$\Sigma(x - \bar{x})^2 = 113{\cdot}60$$

$$n - 1 = 10 - 1 = 9$$

$$\text{Variance} = \frac{113{\cdot}60}{9}$$

$$= 12{\cdot}62$$

$$\sigma = \sqrt{\text{variance}}$$

$$= \sqrt{12{\cdot}62}$$

Therefore,

Standard deviation = 3·55 lb

$$\text{Coefficient of variation} = \frac{100\ \sigma}{\bar{x}} = \frac{3{\cdot}55 \times 100}{41{\cdot}8}$$

$$= 8{\cdot}5 \text{ per cent}$$

One important use of this property is found in the study of irregularity in slivers, rovings, and yarns (see Chapter 9). A further point to note is that quantities derived from the variance, e.g. standard deviation, require squaring before they can be treated arithmetically (see examples given in significance tests).

*Calculation of the standard deviation**

Table 2.5 shows the direct method of obtaining the standard deviation from a set of ten test results of cloth strength.

Step 1. Prepare the three columns.
Step 2. Fill in column 1.
Step 3. Sum column 1 and calculate the mean $\bar{x}$.
Step 4. Fill in column 2.
Step 5. Square the deviations in column 2 and fill in column 3.
Step 6. Sum the squared deviations.
Step 7. Calculate the variance, i.e. the sum of the squared deviations divided by one less than the number of values.
Step 8. Take the square root of the variance to obtain the standard deviation.
Step 9. If required, calculate the coefficient of variation.

It will be noted that the deviations and their squares become rather awkward to manipulate. A simplified method may be used instead, see Table 2.6.

Simplified calculation of the standard deviation

Step 1. Prepare the three columns.
Step 2. Fill in column 1.
Step 3. Sum the values in column 1 and calculate the mean $\bar{x}$.
Step 4. Choose a *new origin* or *arbitrary mean* A, in this example to the nearest whole number, 42.
Step 5. Fill in column 2 with the values $\bar{x} - A$, noting the signs.
Step 6. Square the deviations and fill in column 3.
Step 7. Sum column 2.
Step 8. Sum column 3 and obtain the 'uncorrected sum of the squares'.
Step 9. Calculate the correction by squaring the sum of column 2 and dividing by the number of values n.

*Where a calculating machine is available, the following formula may be used:

$$\sigma = \sqrt{\left(\frac{\Sigma x^2 - n\bar{x}^2}{n-1}\right)}$$

Step 10. Subtract the correction from the uncorrected sum of the squares. This produces the 'corrected sum of the squares'.
Step 11. Calculate the variance.
Step 12. Calculate the standard deviation.

Table 2.6. Simplified Calculation of the Standard Deviation

1	*2*	*3*
Cloth strength (lb)	*Deviation from new origin*	*(Deviation)²*
x	$x - A$	$(x - A)^2$
42	0	0
39	−3	9
45	+3	9
47	+5	25
38	−4	16
39	−3	9
46	+4	16
44	+2	4
41	−1	1
37	−5	25
418	+14	114
$\bar{x} = 41{\cdot}8$	−16	
$A = 42$	−2	

Uncorrected sum of squares = 114

$$\text{Correction} = \frac{(-2)^2}{10} = 0{\cdot}4$$

Corrected sum of squares = 114 − 0·4
= 113·6

$$\text{Variance} = \frac{113{\cdot}6}{9} = 12{\cdot}62$$

Standard deviation = $\sqrt{12{\cdot}62}$
= 3·55 lb

This simplified method can be extended to data in the form of a grouped frequency distribution. To illustrate this the data from Table 2.2 are used, and the calculation is shown in Table 2.7. It is left to the reader to follow the method through for himself.

Table 2.7. Calculation of the Standard Deviation from a Grouped Frequency Distribution

1	*2*	*3*	*4*	*5*	*6*
Class value of count	*Frequency*	*Deviation from new origin*	*Deviation × frequency*	*(Deviation)²*	*(Deviation)² × f*
x	f	x − A	f(x − A)	(x − A)²	f(x − A)²
59·5	2	−12	−24	144	288
61·5	0	−10	0	100	0
63·5	3	− 8	−24	64	192
65·5	6	− 6	−36	36	216
67·5	11	− 4	−44	16	176
69·5	18	− 2	−36	4	72
71·5	23	0	−164	0	0
73·5	16	2	32	4	64
75·5	12	4	48	16	192
77·5	4	6	24	36	144
79·5	3	8	24	64	192
81·5	2	10	20	100	200
	100		148		1736
			−16		

New origin $A = 71{\cdot}5$

Therefore, Mean $\bar{x} = 71{\cdot}5 - \frac{16}{100} = 71{\cdot}34$

Uncorrected sum of squares = 1736

Correction $= \frac{(-16)^2}{100} = 2{\cdot}56$

Corrected sum of squares = 1736 − 2·56 = 1733·44

Variance* $= \frac{1733{\cdot}44}{100} = 17{\cdot}3344$

Standard deviation = √variance = 4·16

Coefficient of variation $= \frac{4{\cdot}16 \times 100}{71{\cdot}34} = 5{\cdot}8$ per cent

*For large samples, the difference between dividing by n and by $(n - 1)$ is small.

The comparison of frequency distributions

In the last few sections we have seen how frequency distributions can be located and how their tendency to spread may be assessed numerically. For many practical purposes the data are used for comparison, e.g. comparing the mean strength of two yarns or the variability in count of two yarns.

Figure 2.8 shows three pairs of frequency distribution curves. The first pair (a) is a comparison of averages using as an example the difference in the mean strength of two yarns spun with different twist factors. The second pair (b) shows a difference in the dispersion of the counts of a regular and an irregular yarn. The average count for both yarns is the same but the variability of the irregular yarn is indicated by the flatter and more widely spread distribution curve. The final pair (c) presents a more complex problem in which both means and the dispersions differ.

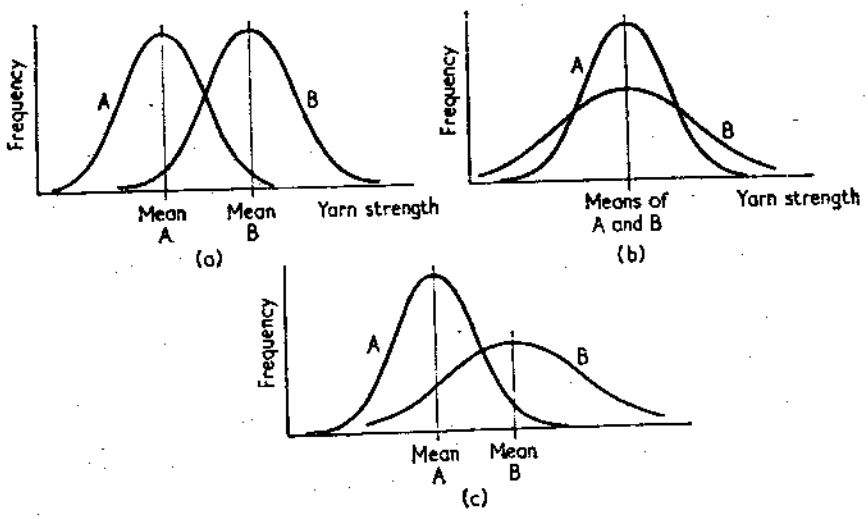


Figure 2.8. Comparison of frequency distributions: (a) Comparison of means, e.g. yarn strength of two yarns spun with different twist factors. Dispersions are similar but the means are different; (b) Comparison of dispersion. Yarn A more uniform in strength than yarn B. Mean strengths are equal; (c) Complex comparison of distributions. Both dispersions and means differ

THE NORMAL OR GAUSSIAN DISTRIBUTION CURVE

The remainder of this chapter is devoted to the methods by which comparisons of averages and dispersions can be made. Since all the methods are based on the properties of the normal distribution, we shall now examine this important frequency curve in greater detail.

One point must be made quite clear before going any further. The term 'normal' is used in a technical sense only, and observations which do *not* produce a 'normal' curve must not be considered as necessarily 'abnormal' results. In his book *Facts from Figures*, Moroney points out that the English mathematician De Moivre (of French origin) published his work on the normal curve in 1733, and that two other mathematicians, Gauss and Laplace, both derived similar conclusions independently. It is the name of Gauss, however, which is found in the description of the distribution.

Some properties of the normal distribution curve

(1) It is *symmetrical* about a central value.
(2) The central value is the arithmetic mean, the median, and the mode: they coincide.
(3) The curve has points of inflection at distances of plus and minus one standard deviation from the mean.
(4) The percentage of the area under the curve is related to the distances from the mean at which limits are chosen.
(5) The normal curve is completely defined by its mean and its standard deviation.

Taking the last property first, using the y axis for the frequency and the x axis for the variable, the equation of the curve shown in Figure 2.9 is

$$y = \frac{1}{\sigma\sqrt{(2\pi)}} \exp[-(x - \bar{x})^2/2\sigma^2]$$

where σ = the standard deviation,

y = the height of the curve at a point x,

$\bar{x}$ = the mean, and

exp is the base of Naperian logarithms.

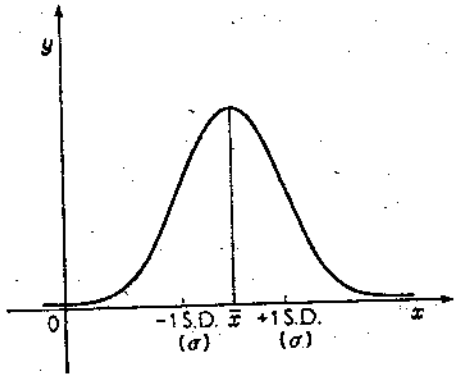


Figure 2.9. The normal distribution curve

On the right-hand side of the equation it will be noted that π is a constant, and thus the value of y depends on σ and $\bar{x}$, the standard deviation and the mean, respectively. We can therefore say that the curve is completely 'defined' by these two quantities. In mathematical language we would call them the 'parameters' of the curve.

If we use σ as a unit on the horizontal scale, the area under the curve between any given limits can be calculated in terms of the

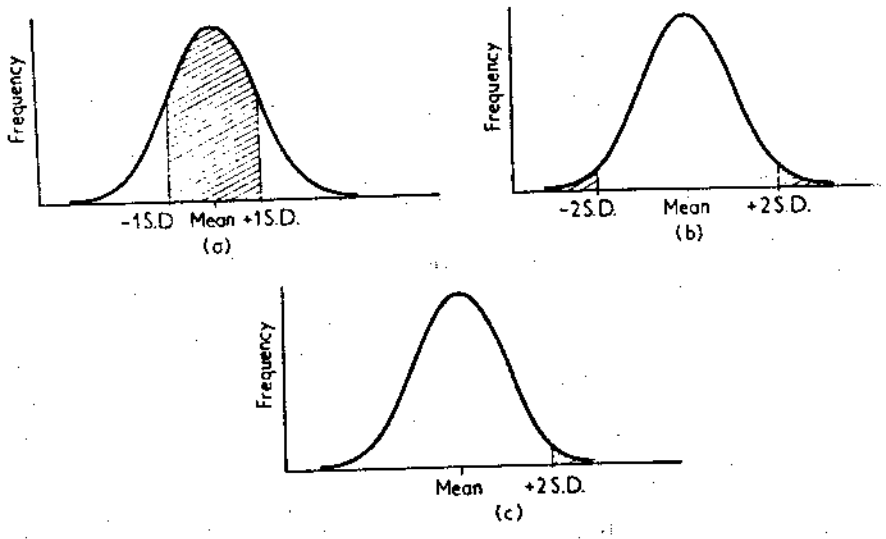


Figure 2.10. Some properties of the normal distribution: (a) 68 per cent of the total lies between the limits mean ± 1 S.D.; (b) 5 per cent of the total lies outside the limits mean ± 2 S.D.; (c) Probability. The chance of a test value falling outside the limit mean + 2 S.D. is about 1 in 40

proportion of the total area. Since the area under the curve represents frequencies or numbers of observations, it follows that we can calculate the proportion of the observations which lie between chosen limits. For instance, 68 per cent of the total area lies between the limits of mean ± 1 standard deviation, and therefore 68 per cent of the *observations* lie between these limits (see Figure 2.10).

An alternative approach is to consider the proportion of the observations which lie *outside* chosen limits, e.g. 32 per cent will lie outside the limits mean ± 1 standard deviation. This approach is useful when studying the chances of test values lying outside given limits. In the *Cambridge Elementary Statistical Tables* the first Table is the Normal Distribution Function. In this present chapter, Table 2.8 has been derived from the Cambridge Table. Using approxima-

Table 2.8(a). The Proportion of Values Lying Outside Chosen Limits on the Normal Frequency Curve

Number of standard deviations to the limits on each side of the mean	*Proportion of values lying outside the limits (per cent)*
0·0000	100·00
0·5244	60·00
1·0000	31·70
1·0364	30·00
1·9600	5·00
2·0000	4·56
3·0000	0·27
3·0902	0·20

(From Table 1, 'The Normal Distribution Function', C.E.S.T.)

Table 2.8(b). The Normal Distribution Function (see Figure 2.11)

Number of S.D.s from the mean	*Proportion of values lying inside the limit*
x	Φx
0·00	0·5000
1·00	0·8413
1·32	0·9066
1·64	0·9495
1·96	0·9750
2·58	0·99506

(From Table 1, 'The Normal Distribution Function', C.E.S.T.)

tions, we see that about a third or one in three values lie outside the limits mean $\pm$ 1σ, and that about one in 20 lie outside the limits mean $\pm$ 2σ. Only about three in 1,000 lie outside the limits mean $\pm$ 3σ.

Probability

Probability has a scale from nought to one. A probability of one indicates absolute certainty, and nought indicates absolute impossibility. By considering the total area under the normal curve as representing a probability of unity we can use limits based on the standard deviation to calculate the chance of a value lying inside or outside chosen limits. For instance, a test result has a one-in-twenty chance of lying outside the $\pm$ 2σ limits. Further, it has a one-in-forty chance of lying outside the +2σ limit. On concepts such as these quality control schemes are based and will be discussed later.

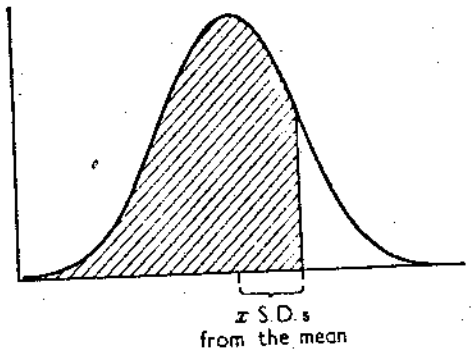


Figure 2.11. The normal distribution function (see Table 2.8(b)). The shaded area is the proportion of the total area under the curve given in column 2, Φx

The examples which follow illustrate how the foregoing ideas operate. The symbol σ will now be dropped and S.D. used in its place.

Example 1. Two hundred single thread tests are made on a yarn to determine its strength. The mean strength is 220 g and the standard deviation is 30 g. Calculate: (a) the coefficient of variation; (b) the number of specimens which had strengths between the limits mean $\pm$ 1·96 S.D. g; and (c) the number of specimens which had strengths below the value mean — 1·96 S.D. g.

(a)

$$\text{Coefficient of variation} = \frac{\text{standard deviation}}{\text{mean}} \times 100 \text{ per cent}$$

$$= \frac{30}{220} \times 100 \text{ per cent}$$

$$= 13{\cdot}6 \text{ per cent}$$

(b) From Table 2.8(a) we note that 95 per cent of the total number of results will lie between the limits mean ± 1·96 S.D. (because 5 per cent lie *outside*). Thus, 95 per cent of 200, i.e. 190 results, will lie between the given limits.

(c) In Table 2.8(a) the second column refers to the percentage proportion of the values lying outside both the plus and the minus limits. When we are considering only one of the limits the percentage proportion will be *half* the figure given. Thus the figure corresponding to the 1·96 S.D. limits is 5 per cent, and dividing by 2 we get 2·5 per cent. 2·5 per cent of 200 is 5, hence about five of the tested single threads had strengths of 161·2 g or less. In practice it is usually this 'tail' of weak strength values which gives trouble in processing.

Example 2. Count-tests on a certain yarn gave a mean of 39·84s and a standard deviation of 2·04. Calculate the proportion of count results below the value 36·50s.

Step 1. The difference, d, between the limit 36·5 and the mean is $39{\cdot}84 - 36{\cdot}50 = 3{\cdot}34$.

Step 2. Expressing the difference in terms of the standard deviation,

$$\frac{d}{\text{S.D.}} = \frac{3{\cdot}34}{2{\cdot}04} = 1{\cdot}64 \text{ approx.}$$

Step 3. Consulting a Normal Distribution Function Table (see Table 2.8(b)), we note that for a value of 1·64 S.D., 0·9495 is the fraction of the total area under the curve lying *inside* the limit. Hence the fraction lying outside is 1 — 0·9495 or 0·0505.

Step 4. Expressing 0·0505 as a percentage, we conclude that approximately 5 per cent of the count results were below 36·50s.

Standard deviation, mean deviation, mean range

These three characteristics of the normal distribution are related.

$$\text{Mean deviation} = \text{standard deviation} \times 0{\cdot}798$$

$$\text{Standard deviation} = \frac{\text{mean deviation}}{0{\cdot}798}$$

For convenience, 1/0·798 is taken as 5/4 or 1·25. Therefore,

$$\text{Standard deviation} = \text{mean deviation} \times 1{\cdot}25$$

Provided that the samples are random samples, the mean range $\bar{w}_n$ of a number of small samples, each of n individuals, can be used to give an estimate of the standard deviation.

$$\text{Mean range} \times a_n = \text{standard deviation}$$

The factor a_n depends on the size of the sample (see Table 2.9).

Two examples will serve to illustrate the above relationships between the three measures of dispersion.

Example 1. A yarn is tested for count in groups of four bobbins. The mean count is 37·9s and the mean range is 3·13. Calculate the proportion of the bobbins whose count is 2 or more different from the mean.

Table 2.9: Estimate of Standard Deviation from the Mean Range

Number of individuals in sample	*Mean range* $\times$ a_n *= standard deviation*
n	a_n
2	0·8862
3	0·5908
4	0·4857
5	0·4299
6	0·3946
7	0·3698
8	0·3512
9	0·3367
10	0·3249
11	0·3152
12	0·3069

Step 1. From Table 2.9, a_n for $n = 4$ is 0·4857. Therefore,

$$\text{S.D.} = \text{mean range} \times 0{\cdot}4857$$
$$= 3{\cdot}13 \times 0{\cdot}4857$$
$$= 1{\cdot}52$$

Step 2. Express the difference, d, of 2 counts in terms of the S.D.

$$\frac{d}{\text{S.D.}} = \frac{2}{1{\cdot}52} = 1{\cdot}32 \text{ approx.}$$

Step 3. Consult the Normal Distribution Function Table (Table 2.8(b)). It is noted that the proportion lying *inside* the limit corresponding to 1·32 S.D. is 0·9066, i.e. 0·0934 is the fraction lying *outside* the limit. Now this fraction lies outside the limit on *one* side of the mean only. Therefore to obtain the fraction lying outside the limits on *both* sides of the mean we have to double the value.

In our example the fraction of the values lying outside the limits will be

$$0{\cdot}0934 \times 2 = 0{\cdot}1868$$

Step 4. Expressing the fraction as a percentage we conclude that approximately 18·7 per cent of the bobbins are 2 or more counts different from the mean count of 37·9s.

Example 2. The mean range of the count test results on a 50s cotton yarn is 3·4. Four bobbins are tested in each sample. Calculate: (a) the standard deviation; (b) the coefficient of variation; (c) the mean deviation; and (d) the percentage mean deviation, P.M.D.

(a) Standard deviation $= \text{mean range} \times a_n$
$= 3{\cdot}4 \times 0{\cdot}4857$
$= 1{\cdot}65$

(b) Coefficient of variation $= \dfrac{\text{standard deviation}}{\text{mean}} \times 100$
$= \dfrac{1{\cdot}65}{50} \times 100$
$= 3{\cdot}3$ per cent

(c) Mean deviation $=$ standard deviation $\times 0{\cdot}798$
$= 1{\cdot}65 \times 0{\cdot}798$
$= 1{\cdot}316$

(d) P.M.D. $= \dfrac{\text{mean deviation}}{\text{mean}} \times 100 = \dfrac{1{\cdot}316}{50} \times 100$
$= 2{\cdot}6$ per cent

POPULATION VALUES AND SAMPLE VALUES

Earlier in this chapter it was stated that the *population* is the whole bulk of the material available for testing and that the *sample* is a relatively small fraction of that population. Sometimes the population is hypothetical; it does not exist in fact. For instance, the twenty bobbins spun on an experimental ring frame may be the only bobbins in existence spun under the experimental conditions. From tests on these bobbins, however, we may wish to estimate the characteristics of a large number of bobbins spun under the same conditions but in full-scale production. Again, the effect of a drip-dry finish on the tearing strength of a fabric may be investigated. A small quantity of treated fabric must then represent a hypothetical large amount of fabric.

Whether we have a large factual population or only a hypothetical population, the actual tests are made on a relatively small number of individual items. The information gained from the tests has to be related to the population. The handling of the data will depend on such factors as the object of the tests and the size of the sample. When we wish to confirm or disprove that a change in a processing method has had a real effect on some property of the material, perhaps its strength or its uniformity, then we carry out *significance tests* on the test results. The calculations differ slightly according to whether the sample is large or small, but the underlying principle is the same for both. Further modifications to the calculations are necessary when one sample is to be compared with another.

A second type of object in testing is the estimation of some characteristic of the population from the results of tests on a sample. From the sample results we can estimate the limits between which the population value will lie. These limits are termed *confidence intervals*, since the degree of confidence which we place in our estimate can be expressed in terms of probability.

Sampling distribution

Suppose we took a large number of random samples, each of n individuals, from a population which had a normal or nearly normal distribution and in each case the sample mean was calculated. We could then make a frequency distribution of the sample means. Such a *sampling distribution* would be of the normal type and would have its own standard deviation. A special term is used for this quantity: the standard deviation of a sampling distribution of the means is called the *standard error of the mean*.

A very important relationship exists between the standard error of the mean and the standard deviation of the population:

$$\text{Standard error of the mean} = \frac{\text{standard deviation of the population}}{\sqrt{n}}$$

where n is the number of individuals in the samples.

This relationship is a key factor in the work which follows. For a full explanation of the theory the reader is referred to the standard textbooks but for an explanation of the methods and calculations a series of examples is given through which the reader may work.

Significance testing of means

Example 1. Single mean with a large sample (n *greater than 30*). One hundred ring bobbins are tested for count and the mean count is found to be 34·2s. The frame is nominally spinning 34s. If the standard deviation of the sample is 0·62, can we conclude that the frame is really spinning off count?

Step 1. Calculate the standard error of the mean by using the standard deviation of the sample as an approximation of the S.D. of the population:

$$\text{S.E.} = \frac{\text{S.D. of population}}{\sqrt{n}}$$

$$= \frac{0{\cdot}62}{\sqrt{100}} = 0{\cdot}062$$

Step 2. Calculate the difference between the nominal mean and the sample mean and divide by the S.E.:

$$\frac{|\text{nominal mean} - \text{sample mean}|}{\text{standard error of the mean}}$$

$$= \frac{|34 - 34{\cdot}2|}{0{\cdot}062}$$

$$= 3{\cdot}2$$

Step 3. Compare the value obtained from Step 2 with the values 1·96 and 2·58:

$$3{\cdot}2 > 2{\cdot}58$$

Conclusion. The difference in count is *statistically significant* at the 1 per cent level. The frame is spinning 'off count'.

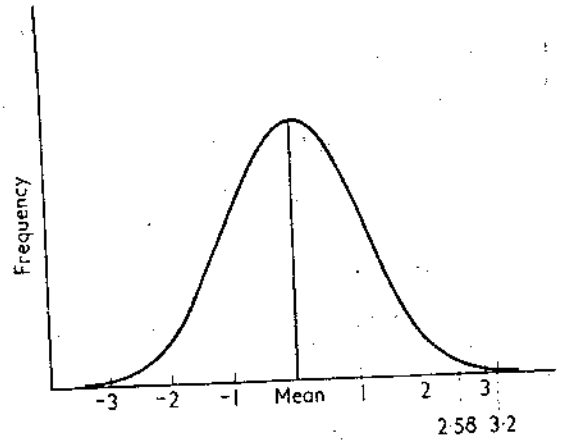


Figure 2.12. Significance testing of means. Horizontal scale in units of S.E.

To reach a conclusion we have noted that the value 3·2 was greater than 2·58. This value 3·2 is really the difference between the nominal and sample means expressed in terms of the standard error. A glance at Figure 2.12 will show that the chance of the sample mean lying outside the limit nominal mean ± 2·58 S.E. is only one in a hundred* if the population from which the sample was drawn had in fact a mean equal to the nominal mean. After deciding that there is a real difference, the ring frame would be adjusted. We would only be wrong in doing so about once in a hundred times—a reasonable risk.

If the value obtained in Step 2 had been, say, 2·2, i.e. somewhere between 1·96 and 2·58, we would conclude that the difference was significant at the 5 per cent level; the chance in this case being one in twenty. This evidence is not sufficiently convincing to warrant an adjustment to the frame. The interpretation of the results would be that there was an indication of a possible difference but that further testing would be necessary before a firm decision could be taken.

Example 2. Single mean with a small sample. Twelve mule cops are tested for count and the mean found to be 94·2s. The standard deviation of the twelve results is 2·2 counts. If the nominal count is 92s, is the mule spinning too fine?

*In Table 2.8(b) Φx for 2·58 is 0·99506, i.e. 99·506 per cent of the values lie inside the limit. Thus, 0·494 per cent lie *outside* on one side of the mean, i.e. 0·988 per cent on both sides of the mean; 0·988 is very nearly 1 per cent.

Step 1. Estimate the standard error of the mean by dividing the standard deviation of the sample by the square root of the number in the sample:

$$\text{S.E.} = \frac{2{\cdot}2}{\sqrt{12}}$$
$$= 0{\cdot}635$$

Step 2. Calculate the value of t:

$$t = \frac{|\text{nominal mean} - \text{sample mean}|}{\text{standard error}}$$
$$t = \frac{|92 - 94{\cdot}2|}{0{\cdot}635}$$
$$= 3{\cdot}47$$

Step 3. Consult the t Table (Table 2.10) for $\nu = n - 1$, then compare the value of t obtained in Step 2 with the 5 per cent and 1 per cent values for t.

$$\nu = 12 - 1 = 11$$
$$t = 2{\cdot}201 \text{ at the 5 per cent level}$$
$$= 3{\cdot}106 \text{ at the 1 per cent level}$$
$$3{\cdot}47 > 3{\cdot}106$$

Conclusion. Since 3·47 is greater than 3·106, we conclude that the mule is spinning too fine because the difference between the sample mean and the nominal mean is significant at the 1 per cent level.

The quantity ν (the Greek letter nu) is known as the number of 'degrees of freedom'. It is one less than the number in the sample. The reason for this subtraction is a little involved and has been mentioned earlier in this chapter (p. 22).

The value t has a sampling distribution of its own which is not normal even though the population from which the samples have been drawn has a normal distribution. Tables of t are available giving the values of t corresponding to values of ν (see Table 2.10). Opposite the values of ν two columns are seen, the 5 per cent and 1 per cent limits of significance. These limits are used in the following way:

Table 2.10. Significance Limits of t

Degrees of freedom ν	*Probability*	
	5 per cent	*1 per cent*
1	12·706	63·657
2	4·303	9·925
3	3·182	5·841
4	2·776	4·604
5	2·571	4·032
6	2·447	3·707
7	2·365	3·499
8	2·306	3·355
9	2·262	3·250
10	2·228	3·169
11	2·201	3·106
12	2·179	3·055
13	2·160	3·012
14	2·145	2·977
15	2·131	2·947
16	2·120	2·921
17	2·110	2·898
18	2·101	2·878
19	2·093	2·861
20	2·086	2·845
21	2·080	2·831
22	2·074	2·819
23	2·069	2·807
24	2·064	2·797
25	2·060	2·787
26	2·056	2·779
27	2·052	2·771
28	2·048	2·763
29	2·045	2·756
30	2·042	2·750
40	2·021	2·704
60	2·000	2·660
120	1·980	2·617
∞	1·960	2·576

(Abridged from Table III of 'Statistical Tables for Biological, Agricultural, and Medical Research' (R. A. Fisher and F. Yates) (Oliver and Boyd, Edinburgh). By courtesy of the Authors and Publishers.)

If t (as determined in Step 2) exceeds the 1 per cent value, then we conclude that a real difference exists and take the necessary action. For values of t significant only at the 5 per cent level there is some evidence of a difference, but not enough to require immediate action.

Example 3. Difference between the means of two large samples. Two yarns, each of 32s cotton count, were tested for lea strength. Thirty tests were made on each yarn and the following results were obtained:

	Yarn A	*Yarn B*
Number of tests	30 (n_1)	30 (n_2)
Mean lea strength (lb)	58 ($\bar{x}_1$)	65 ($\bar{x}_2$)
Standard deviation	7·8 (S.D.$_1$)	8·2 (S.D.$_2$)

Is there a real difference between the lea strengths?

Step 1. Calculate the standard error of the means, S.E.$_1$ and S.E.$_2$:

$$\text{S.E.}_1 = \frac{\text{S.D.}_1}{\sqrt{n_1}} = \frac{7{\cdot}8}{\sqrt{30}} = 1{\cdot}42$$

$$\text{S.E.}_2 = \frac{\text{S.D.}_2}{\sqrt{n_2}} = \frac{8{\cdot}2}{\sqrt{30}} = 1{\cdot}5$$

Step 2. Calculate the standard error of the difference between the means:

$$\text{S.E.}_{\text{diff}} = \sqrt{(\text{S.E.}_1^2 + \text{S.E.}_2^2)}$$

$$\text{S.E.}_{\text{diff}} = \sqrt{(1{\cdot}42^2 + 1{\cdot}5^2)} = 2{\cdot}06$$

Step 3. Calculate the ratio:

$$\frac{|\text{mean}_1 - \text{mean}_2|}{\text{S.E.}_{\text{diff}}} = \frac{|\bar{x}_1 - \bar{x}_2|}{\text{S.E.}_{\text{diff}}}$$

$$\frac{|58 - 65|}{2{\cdot}06} = \frac{7}{2{\cdot}06} = 3{\cdot}4$$

Step 4. Compare the value of this ratio with 1·96 and 2·58 (the interpretation of this comparison is similar to that in *Example 1*):

$$3{\cdot}4 > 2{\cdot}58$$

Conclusion. Since 3·4 is greater than 2·58, the difference between the mean lea strengths is significant at the 1 per cent level, i.e. a real difference exists.

Example 4. Difference between the means of two small samples. A fabric was tested for warp way tensile strength before and after a chemical treatment. In each case ten specimens were tested and the following results were obtained:

	Untreated fabric	*Treated fabric*
Number of tests	10 (n_1)	10 (n_2)
Mean strength (lb)	48 ($\bar{x}_1$)	46 ($\bar{x}_2$)
Standard deviation	4 (S.D.$_1$)	5 (S.D.$_2$)

Is there sufficient evidence to show that the chemical treatment has really weakened the fabric?

Step 1. Calculate S, the pooled estimate of the population standard deviation:

$$S = \sqrt{\left[\frac{(n_1 - 1)\text{S.D.}_1^2 + (n_2 - 1)\text{S.D.}_2^2}{n_1 + n_2 - 2}\right]}$$

$$\sqrt{\left[\frac{(9 \times 4^2) + (9 \times 5^2)}{10 + 10 - 2}\right]}$$

$$= 4{\cdot}53$$

Step 2. Calculate the value t from the equation

$$t = \frac{|\bar{x}_1 - \bar{x}_2|}{S\sqrt{(1/n_1 + 1/n_2)}}$$

$$= \frac{48 - 46}{4{\cdot}53\sqrt{(1/10 + 1/10)}}$$

$$= 1{\cdot}00 \text{ approx.}$$

Step 3. Consult the t Table using

$$\nu = n_1 + n_2 - 2$$

$$\nu = 18$$

$t = 2{\cdot}101$ at the 5 per cent level

$= 2{\cdot}878$ at the 1 per cent level

Step 4. Compare the value of t obtained in Step 2 with the 5 per cent and 1 per cent values for t:

1·00 is less than 2·101

Conclusion. Since 1·00 is less than the 5 per cent value of t, 2·101, there is insufficient evidence to prove that the chemical treatment has weakened the fabric.

Significance testing of dispersion

The examples in the previous sections have shown how the means of samples may be compared. We often wish to know whether one material is more variable than another, and therefore significance tests are made on the measures of dispersion, the standard deviation, and its related quantities.

Example 5. Single standard deviation with a large sample. A certain yarn has a mean strength of 42 lb when tested in lea form and its standard deviation is known to be 6·4 lb. Forty leas are tested and although the mean strength is not significantly different from 42 lb, the S.D. of the sample is 8·6 lb. Is the variability of the sample really greater than the bulk of the yarn?

Step 1. Calculate the S.E. of the standard deviation:

$$\text{S.E.} = \frac{\text{S.D. of sample}}{\sqrt{2n}}$$

$n = 40$

S.D. of sample $= 8{\cdot}6$

$$\text{S.E.} = \frac{8{\cdot}6}{\sqrt{(2 \times 40)}} = 0{\cdot}96$$

Step 2. Calculate the ratio

$$\frac{\text{difference between the S.D.s}}{\text{S.E. of the standard deviation}}$$

$$\frac{|6{\cdot}4 - 8{\cdot}6|}{0{\cdot}96} = 2{\cdot}3$$

Step 3. Compare the value of this ratio with the values 1·96 and 2·58, the 5 per cent and 1 per cent levels:
2·3 exceeds 1·96 but is less than 2·58

Conclusion. Although there is some evidence of a difference in variability it is only significant at the 5 per cent level.

Note that the standard error of the standard deviation is obtained by dividing the S.D. of the sample by $\sqrt{(2n)}$. Compare this with the calculation of the standard error of the mean, in which case we divide by $\sqrt{n}$.

Example 6. Single standard deviation with a small sample. The S.D. of the lea strength of a ring yarn is 1·5 lb, but a sample of nine bobbins from a doffing skip is tested and the S.D. of the sample is 2 lb. Is the ring frame producing a yarn whose strength is more variable than usual?

Step 1. Calculate the *variances* of the sample and the population:

$$\text{Variance} = \text{S.D.}^2$$

V_1, the sample variance, is $2{\cdot}0^2 = 4{\cdot}0$

V_2, the population variance, is $1{\cdot}5^2 = 2{\cdot}25$

Step 2. Calculate F, the variance ratio:

$$F = \frac{\text{variance expected to be greater}}{\text{variance expected to be smaller}}$$

$$= \frac{V_1}{V_2} = \frac{4}{2{\cdot}25} = 1{\cdot}78$$

Step 3. Consult the F or Variance Ratio Table (Tables 2.11(a) and (b)). Read off the values corresponding to the 5 per cent and 1 per cent significance levels for the degrees of freedom which apply:

(a) If F exceeds the 1 per cent value then the difference in variability is significant.

(*b*) If F lies between the 5 per cent and 1 per cent values then the evidence of a difference in variability is not conclusive.

In our example the degrees of freedom for the sample, ν_1, is $9 - 1$, i.e. 8. For the population ν_2 is very large and is therefore taken to be infinity, ∞.

Table 2.11(a). Variance or F *Ratios (5 per cent Significance Limits of* F)

ν_2 \ ν_1	1	2	3	4	5	6	8	12	24	∞
1	161·4	199·5	215·7	224·6	230·2	234·0	238·9	243·9	249·0	254·3
2	18·51	19·00	19·16	19·25	19·30	19·33	19·37	19·41	19·45	19·50
3	10·13	9·55	9·28	9·12	9·01	8·94	8·84	8·74	8·64	8·53
4	7·71	6·94	6·59	6·39	6·26	6·16	6·04	5·91	5·77	5·63
5	6·61	5·79	5·41	5·19	5·05	4·95	4·82	4·68	4·53	4·36
6	5·99	5·14	4·76	4·53	4·39	4·28	4·15	4·00	3·84	3·67
7	5·59	4·74	4·35	4·12	3·97	3·87	3·73	3·57	3·41	3·23
8	5·32	4·46	4·07	3·84	3·69	3·58	3·44	3·28	3·12	2·93
9	5·12	4·26	3·86	3·63	3·48	3·37	3·23	3·07	2·90	2·71
10	4·96	4·10	3·71	3·48	3·33	3·22	3·07	2·91	2·74	2·54
11	4·84	3·98	3·59	3·36	3·20	3·09	2·95	2·79	2·61	2·40
12	4·75	3·88	3·49	3·26	3·11	3·00	2·85	2·69	2·50	2·30
13	4·67	3·80	3·41	3·18	3·02	2·92	2·77	2·60	2·42	2·21
14	4·60	3·74	3·34	3·11	2·96	2·85	2·70	2·53	2·35	2·13
15	4·54	3·68	3·29	3·06	2·90	2·79	2·64	2·48	2·29	2·07
16	4·49	3·63	3·24	3·01	2·85	2·74	2·59	2·42	2·24	2·01
17	4·45	3·59	3·20	2·96	2·81	2·70	2·55	2·38	2·19	1·96
18	4·41	3·55	3·16	2·93	2·77	2·66	2·51	2·34	2·15	1·92
19	4·38	3·52	3·13	2·90	2·74	2·63	2·48	2·31	2·11	1·88
20	4·35	3·49	3·10	2·87	2·71	2·60	2·45	2·28	2·08	1·84
21	4·32	3·47	3·07	2·84	2·68	2·57	2·42	2·25	2·05	1·81
22	4·30	3·44	3·05	2·82	2·66	2·55	2·40	2·23	2·03	1·78
23	4·28	3·42	3·03	2·80	2·64	2·53	2·38	2·20	2·00	1·76
24	4·26	3·40	3·01	2·78	2·62	2·51	2·36	2·18	1·98	1·73
25	4·24	3·38	2·99	2·76	2·60	2·49	2·34	2·16	1·96	1·71
26	4·22	3·37	2·98	2·74	2·59	2·47	2·32	2·15	1·95	1·69
27	4·21	3·35	2·96	2·73	2·57	2·46	2·30	2·13	1·93	1·67
28	4·20	3·34	2·95	2·71	2·56	2·44	2·29	2·12	1·91	1·65
29	4·18	3·33	2·93	2·70	2·54	2·43	2·28	2·10	1·90	1·64
30	4·17	3·32	2·92	2·69	2·53	2·42	2·27	2·09	1·89	1·62
40	4·08	3·23	2·84	2·61	2·45	2·34	2·18	2·00	1·79	1·51
60	4·00	3·15	2·76	2·52	2·37	2·25	2·10	1·92	1·70	1·39
120	3·92	3·07	2·68	2·45	2·29	2·17	2·02	1·83	1·61	1·25
∞	3·84	2·99	2·60	2·37	2·21	2·09	1·94	1·75	1·52	1·00

(Abridged from Table V of 'Statistical Tables for Biological, Agricultural, and Medical Research' (R. A. Fisher and F. Yates) (Oliver and Boyd, Edinburgh). By courtesy of the Authors and Publishers.)

In the 5 per cent table the value corresponding to $\nu_1 = 8$ and $\nu_2 = \infty$ is 1·94.

In the 1 per cent table the value is 2·51.

Conclusion. Since 1·78 is less than 1·94 there is insufficient evidence to prove that the variability of the yarn is greater than usual.

Table 2.11(b). Variance or F *Ratios (1 per cent Significance Limits of* F)

ν_2 \ ν_1	1	2	3	4	5	6	8	12	24	∞
1	4052	4999	5403	5625	5764	5859	5981	6106	6234	6366
2	98·49	99·01	99·17	99·25	99·30	99·33	99·36	99·42	99·46	99·50
3	34·12	30·81	29·46	28·71	28·24	27·91	27·49	27·05	26·60	26·12
4	21·20	18·00	16·69	15·98	15·52	15·21	14·80	14·37	13·93	13·46
5	16·26	13·27	12·06	11·39	10·97	10·67	10·27	9·89	9·47	9·02
6	13·74	10·92	9·78	9·15	8·75	8·47	8·10	7·72	7·31	6·88
7	12·25	9·55	8·45	7·85	7·46	7·19	6·84	6·47	6·07	5·65
8	11·26	8·65	7·59	7·01	6·63	6·37	6·03	5·67	5·28	4·86
9	10·56	8·02	6·99	6·42	6·06	5·80	5·47	5·11	4·73	4·31
10	10·04	7·56	6·55	5·99	5·64	5·39	5·06	4·71	4·33	3·91
11	9·65	7·20	6·22	5·67	5·32	5·07	4·74	4·40	4·02	3·60
12	9·33	6·93	5·95	5·41	5·06	4·82	4·50	4·16	3·78	3·36
13	9·07	6·70	5·74	5·20	4·86	4·62	4·30	3·96	3·59	3·16
14	8·86	6·51	5·56	5·03	4·69	4·46	4·14	3·80	3·43	3·00
15	8·68	6·36	5·42	4·89	4·56	4·32	4·00	3·67	3·29	2·87
16	8·53	6·23	5·29	4·77	4·44	4·20	3·89	3·55	3·18	2·75
17	8·40	6·11	5·18	4·67	4·34	4·10	3·79	3·45	3·08	2·65
18	8·28	6·01	5·09	4·58	4·25	4·01	3·71	3·37	3·00	2·57
19	8·18	5·93	5·01	4·50	4·17	3·94	3·63	3·30	2·92	2·49
20	8·10	5·85	4·94	4·43	4·10	3·87	3·56	3·23	2·86	2·42
21	8·02	5·78	4·87	4·37	4·04	3·81	3·51	3·17	2·80	2·36
22	7·94	5·72	4·82	4·31	3·99	3·76	3·45	3·12	2·75	2·31
23	7·88	5·66	4·76	4·26	3·94	3·71	3·41	3·07	2·70	2·26
24	7·82	5·61	4·72	4·22	3·90	3·67	3·36	3·03	2·66	2·21
25	7·77	5·57	4·68	4·18	3·86	3·63	3·32	2·99	2·62	2·17
26	7·72	5·53	4·64	4·14	3·82	3·59	3·29	2·96	2·58	2·13
27	7·68	5·49	4·60	4·11	3·78	3·56	3·26	2·93	2·55	2·10
28	7·64	5·45	4·57	4·07	3·75	3·53	3·23	2·90	2·52	2·06
29	7·60	5·42	4·54	4·04	3·73	3·50	3·20	2·87	2·49	2·03
30	7·56	5·39	4·51	4·02	3·70	3·47	3·17	2·84	2·47	2·01
40	7·31	5·18	4·31	3·83	3·51	3·29	2·99	2·66	2·29	1·80
60	7·08	4·98	4·13	3·65	3·34	3·12	2·82	2·50	2·12	1·60
120	6·85	4·79	3·95	3·48	3·17	2·96	2·66	2·34	1·95	1·38
∞	6·64	4·60	3·78	3·32	3·02	2·80	2·51	2·18	1·79	1·00

(Abridged from Table V of 'Statistical Tables for Biological, Agricultural, and Medical Research' (R. A. Fisher and F. Yates) (Oliver and Boyd, Edinburgh). By courtesy of the Authors and Publishers.)

Example 7. Difference between the standard deviation of two large samples. Two yarns are tested for lea strength with the following results:

	Yarn A	*Yarn B*
Number of tests	32 (n_1)	32 (n_2)
Mean lea strength (lb)	58 $(\bar{x}_1)$	65 $(\bar{x}_2)$
Standard deviation	7·2 (S.D._1)	8·4 (S.D._2)

Is there a significant difference between the two S.D.s, i.e. is Yarn B more variable in lea strength than Yarn A?

Step 1. Calculate the standard error of the standard deviation for each sample:

$$\text{S.E.} = \frac{\text{S.D.}}{\sqrt{(2n)}}$$

$$\text{S.E.}_1 = \frac{7{\cdot}2}{\sqrt{64}} = 0{\cdot}9$$

$$\text{S.E.}_2 = \frac{8{\cdot}4}{\sqrt{64}} = 1{\cdot}05$$

Step 2. Calculate the standard error of the difference between the S.D.s:

$$\text{S.E.}_{\text{diff}} = \sqrt{(\text{S.E.}_1^2 + \text{S.E.}_2^2)}$$

$$\text{S.E.}_{\text{diff}} = \sqrt{(0{\cdot}9^2 + 1{\cdot}05^2)}$$

Let this be k. Therefore,

$$k = 1{\cdot}38$$

Step 3. Calculate the value

$$\frac{|\text{S.D.}_1 - \text{S.D.}_2|}{k}$$

$$\frac{|7{\cdot}2 - 8{\cdot}4|}{1{\cdot}38} = 0{\cdot}87$$

Step 4. Compare this value with 1·96 and 2·58, the 5 per cent and 1 per cent levels of significance:

0·87 is less than 1·96

Conclusion. Since 0·87 is less than 1·96 there is no significant difference between the two standard deviations.

Note. The equation $k = \sqrt{(\text{S.E.}_1^2 + \text{S.E.}_2^2)}$ could be rewritten by substituting $\text{S.D.}^2/2n$ for S.E.^2. Thus,

$$k = \sqrt{\left(\frac{\text{S.D.}_1^2}{2n_1} + \frac{\text{S.D.}_2^2}{2n_2}\right)}$$

and Steps 1 and 2 combined.

Example 8. Difference between the standard deviations of two small samples. The weft way strength of two samples of fabric were tested to see whether different weft yarns had affected the variability of the strength. Both samples were woven in the same loom using the same warp. The standard deviation for Sample A was calculated from nine test results and for Sample B from eleven results:

S.D. for Sample A was 6·5 lb
S.D. for Sample B was 7·9 lb

Sample B was expected to be more variable than Sample A, but do the results confirm this expectation?

Step 1. Calculate the variances of the two samples, $V = \text{S.D.}^2$:

Variance A $= 6{\cdot}5^2 = 42{\cdot}2$
Variance B $= 7{\cdot}9^2 = 62$

Step 2. Calculate the variance ratio

$$F = \frac{\text{variance expected to be greater}}{\text{variance expected to be smaller}}$$

$$= \frac{\text{variance B}}{\text{variance A}}$$

$$= \frac{62}{42{\cdot}2} = 1{\cdot}47$$

Step 3. Consult the F Tables: ν_1 is the number in the sample whose variance is expected to be greater, less one

$$\nu_1 = 11 - 1 = 10$$

ν_2 is one less than the number in the other sample

$$\nu_2 = 9 - 1 = 8$$

Note the corresponding values for the 5 per cent and 1 per cent levels:

5 per cent value $= 3{\cdot}35$
1 per cent value $= 5{\cdot}81$

Step 4. Compare the value of F calculated in Step 2 with the 5 per cent and 1 per cent values.

Conclusion. Since 1·47 is less than 3·35 the test results do not confirm the expectation that the weft used in Sample B has given a more variable fabric strength.

Example 9. In Example 8 we expected one of the samples to show greater variability than the other and calculated the variance ratio accordingly. There are times when we have no previous knowledge about the variability of either of the two samples and the question is merely 'Is there a difference in variability between Sample A and Sample B?'.

The F ratio then becomes

$$F = \frac{\text{larger variance}}{\text{smaller variance}}$$

Two yarns were tested for lea strength, nine leas being used from each yarn. The standard deviation for Yarn A was 3·6 lb and for Yarn B 8·2 lb. Is there a real difference between the variability of the lea strengths?

Step 1. Calculate the variance ratio

$$F = \frac{\text{larger variance}}{\text{smaller variance}}$$

$$= \frac{8{\cdot}2^2}{3{\cdot}6^2}$$

$$= 5{\cdot}19$$

Step 2. Consult the F Tables:

$$\nu_1 = 8$$
$$\nu_2 = 8$$
5 per cent value = 3·44
1 per cent value = 6·03

Step 3. Compare the calculated value of F with the 5 per cent and 1 per cent values:

5·19 is greater than 3·44 but less than 6·03

Conclusion. Because we have deliberately put the larger variance as the numerator when calculating the variance ratio, the chance of finding a real difference has been *doubled.*

Therefore the 5 per cent level is now considered as a 10 per cent level, and similarly the 1 per cent level considered as a 2 per cent level. Since F in our example is less than 6·03 the difference is not significant at the 2 per cent level.

In the Cambridge Elementary Statistical Tables there is a table for $2\frac{1}{2}$ per cent limits which we can treat as 5 per cent limits for this problem. The corresponding value is 4·43. Hence we can modify our conclusions and say that the difference is significant at the 5 per cent level since 5·19 is greater than 4·43, but the evidence of a real difference is not conclusive.

THE ESTIMATION OF POPULATION CHARACTERISTICS FROM SAMPLES AND THE USE OF CONFIDENCE INTERVALS

From the definition of a sample (a small number of the individual members of the population which is selected to represent the population) it follows that the results obtained from testing a sample will give *some* information about the population but not *complete* information. Hence the means and standard deviations derived from samples will only be *estimates* of the population values. We can express the estimate as a range within which the population value is expected to lie, and at the same time indicate the degree of confidence which may be placed in the estimate. Once again the size of the sample influences the calculations.

Example 10. Estimate of the population mean from a large sample. A yarn was tested for single thread strength and 100 tests made on the yarn. The mean strength was 220 g and the standard deviation 26 g. Estimate the 95 per cent and the 99 per cent confidence intervals of the population mean.

Step 1. Calculate the standard error of the mean:

$$\text{S.E.} = \frac{\text{S.D. of population}}{\sqrt{n}}$$

$$\text{S.E.} = \frac{26}{\sqrt{100}}$$

$$= 2{\cdot}6$$

Here we are using the S.D. of the sample as an approximation of the population S.D.

Step 2. Calculate the limits of confidence intervals:

The 95 per cent limits are 1·96 × S.E.

95 per cent limits = 2·6 × 1·96

= 5·1 g

The 99 per cent limits are 2·58 × S.E.

99 per cent limits = 2·6 × 2·58

= 6·7 g

Step 3. Express the estimate as sample mean ± confidence limits:

The 95 per cent confidence interval of the estimated population mean = 220 ± 5·1 g

The 99 per cent confidence interval of the estimated population mean = 220 ± 6·7 g

We are in fact saying that 95 times out of 100 we would be right in assuming that the population mean lay somewhere between 214·9 and 225·1 g, and that 99 times out of a 100 we would be correct in taking the population mean to be within the range 213·3 and 226·7 g.

Example 11. Estimate of the population standard deviation from a large sample. Using the information given in Example 10, estimate the 95 per cent confidence interval of the standard deviation of the population.

Step 1. Calculate the standard error of the S.D.:

$$\text{S.E.} = \frac{\text{S.D. of population}}{\sqrt{(2n)}}$$

$$\text{S.E.} = \frac{26}{\sqrt{200}}$$

$$= 1{\cdot}84$$

S.D. of sample is used as approximate S.D. of population.

Step 2. Calculate the 95 per cent confidence limits:

S.E. × 1·96

1·84 × 1·96

= 3·6

Step 3. Express the estimate of the population standard deviation as Sample S.D. ± S.E. × 1·96:

The 95 per cent confidence interval for the population S.D. is 26 ± 3·6 g

Hence, the S.D. of the population is expected to be within the range 29·6 and 22·4 at the 95 per cent confidence level.

Example 12. Estimate of the population mean from a small sample. Where only a small number of individuals is tested it will be appreciated that an estimate of a population characteristic will be less precise than when a large sample is available. Large samples are therefore preferred for this type of work. Nevertheless, on occasions an estimate has to be made from a small sample and the method is shown by an example.

Eleven ring bobbins are tested for lea strength. The mean is 50 lb and the standard deviation 6 lb. Estimate the 95 per cent confidence interval for the mean lea strength of the population.

Step 1. Calculate the standard error of the mean:

$$\text{S.E.} = \frac{\text{S.D.}}{\sqrt{n}}$$

$$\text{S.E.} = \frac{6}{\sqrt{11}}$$

$$= 1{\cdot}8 \text{ lb}$$

Step 2. Consult the t Tables for the value t corresponding to $\nu = n - 1$.

The 5 per cent Table is used (i.e. 100–95)

$$\nu = 11 - 1 = 10$$

$$t = 2{\cdot}228$$

Step 3. The confidence interval is given by

$$\text{Sample mean} \pm (t \times \text{S.E.})$$

$$\text{Confidence interval} = 50 \pm 2{\cdot}228 \times 1{\cdot}8$$

$$= 50 \pm 4 \text{ lb}$$

We have thus estimated that the mean lea strength of the bulk of the yarn will be between 46 and 54 lb.

Estimate and confidence intervals for differences between sample means

The principles used in the foregoing examples may be used to estimate the difference between the means of two samples. Again the calculations differ according to the sample size.

Example 13. Difference between the means of large samples. Fifty mule cops are tested for count from each of two mules.

Mean count of Yarn A, 82s with a standard deviation of 4

Mean count of Yarn B, 78s with a standard deviation of 5

Estimate the difference in mean count between the two mules at the 95 per cent level.

Step 1. Calculate S, the pooled estimate of the standard deviation:

$$S = \sqrt{\left[\frac{(n_1 - 1)\ \text{S.D.}_1^2 + (n_2 - 1)\ \text{S.D.}_2^2}{n_1 + n_2 - 2}\right]}$$

$$= \sqrt{\left[\frac{(49 \times 4^2) + (49 \times 5^2)}{50 + 50 - 2}\right]}$$

$$= 4{\cdot}52$$

Step 2. The 95 per cent confidence interval is given by

$$\bar{x}_1 - \bar{x}_2 \pm 1{\cdot}96\, S \sqrt{(1/n_1 + 1/n_2)}$$

$$(82 - 78) \pm 1{\cdot}96 \times 4{\cdot}52 \sqrt{(\tfrac{1}{50} + \tfrac{1}{50})}$$

$$= 4 \pm 1{\cdot}77$$

Step 3. Express the estimated difference as a range:

The 95 per cent confidence interval is from 2·23 to 5·77 counts.

We are thus concluding that the difference between the mean counts spun on the two mules is between 2·23 and 5·77 (at the 95 per cent level).

Example 14. Difference between the means using small samples. Ten warp way strips from fabric A and an equal number from fabric B were tested for tensile strength. The mean strength of A was 47 lb and the mean strength of B was 40 lb. The pooled estimate of the standard deviation was 6 lb. Calculate the 95 per cent confidence interval for the difference between the mean warp way strengths of the fabrics.

Step 1. Calculate the pooled estimate of the standard deviation:

S is given as 6 lb

Step 2. The 95 per cent confidence interval is given by

$$\bar{x}_1 - \bar{x}_2 \pm tS \sqrt{(1/n_1 + 1/n_2)}$$

t, from the t Tables, is for $\nu = n_1 + n_2 - 2$, in the 5 per cent Table.

$$\nu = 10 + 10 - 2 = 18$$

$$t = 2{\cdot}101$$

$$\bar{x}_1 - \bar{x}_2 = 7$$

$$2{\cdot}101 \times 6 \sqrt{\left(\frac{1}{10} + \frac{1}{10}\right)} = 5{\cdot}64$$

Therefore 95 per cent confidence interval $= 7 \pm 5{\cdot}64$ lb

Step 3. Express the difference between the means as a range:

The 95 per cent confidence interval of the difference between the means is from 1·36 to 12·64 lb

If the 99 per cent confidence interval had been required then the value of t would be noted from the 1 per cent table.

The limits quoted are sometimes referred to as the *limits of error.*

How many tests should be made?

Sometimes a number of tests is made on a material. After the results have been analysed and the estimates made of some population characteristic, it is found that the limits of error do not provide sufficiently precise information. Greater precision can be achieved by testing a larger sample. It is possible to calculate how large the sample must be to give a chosen degree of accuracy. (See also Tables 1 and 2 of British Standards Handbook No. 11.)

Example 15. The number of tests required to give the mean to an accuracy of P per cent at the 95 per cent confidence level. Thirty-six leas of a 32s cotton yarn were tested for lea strength and gave a mean strength of 65 lb with a standard deviation of 9 lb. The 95 per cent confidence interval was 65 ± 2·94 lb, giving a maximum error of approximately $4\frac{1}{2}$ per cent (percentage error = 2·94/65 × 100).

How many leas must be tested in order to reduce the error to 2 per cent?

Step 1. Calculate the coefficient of variation V:

$$V = \frac{100 \text{ S.D.}}{\text{mean}}$$

$$= \frac{100 \times 9}{65}$$

Step 2. Let N be the number of tests and P the percentage accuracy. Then,

$$N = \left(\frac{1{\cdot}96\ V}{P}\right)^2$$

$$= \left(\frac{1{\cdot}96 \times 100 \times 9}{2 \times 65}\right)^2$$

$$= 183 \text{ leas approx.}$$

Note that here we have used the S.D. of the sample as an approximation to the population value in order to calculate V. If V is known from previous testing it would be used directly in the formula.

Example 16. The number of tests required to give the standard deviation to an accuracy of Q per cent at the 95 per cent confidence level. The 95 per

cent confidence interval for the population standard deviation is given by

$$\text{Sample standard deviation} \pm 1{\cdot}96 \text{ standard error}$$

or

$$\text{Sample S.D.} \pm \frac{1{\cdot}96 \text{ sample S.D.}}{\sqrt{(2n)}}$$

Using the information given in Example 15, the confidence interval becomes

$$9 \pm \frac{1{\cdot}96 \times 9}{\sqrt{(2 \times 36)}} = 9 \pm 2{\cdot}05 \text{ lb}$$

Expressed as a percentage error, the maximum error is therefore

$$\frac{2{\cdot}05}{9} \times 100 = 22{\cdot}7 \text{ per cent}$$

How many tests would be necessary to reduce this percentage error to 10 per cent?

Step 1. Let Q per cent be the required maximum error and N the number of tests required:

$$Q = 10 \text{ per cent}$$

Step 2. Calculate N from the formula

$$2N = \left(\frac{196}{Q}\right)^2$$

$$2N = \left(\frac{196}{10}\right)^2$$

Therefore,

$$N = 192 \text{ leas}$$

QUALITY CONTROL CHARTS

One of the objects of testing is to detect changes in the product of the processing machinery. It has then to be decided whether the difference between the nominal value of the characteristic and the actual value of the tested sample is large enough to indicate that the population value is significantly different to the nominal. We have seen earlier how the population value can be estimated from the sample value; now we shall see how the principles discussed are put into practice.

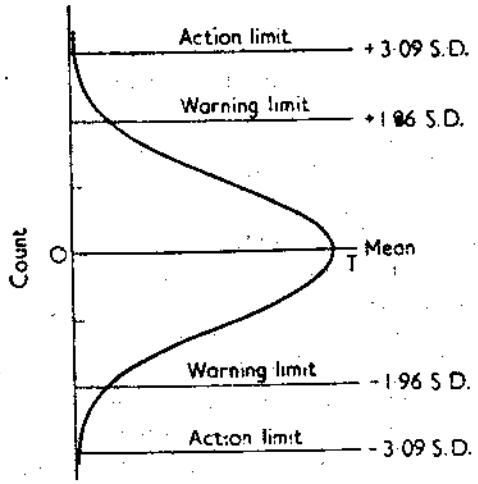


Figure 2.13. Control chart limits

A definition of the word 'quality' will be left until later; but for present purposes we will regard it as some particular characteristic of the product which we wish to control, the most common routine 'quality' being the hank or count of laps, slivers, rovings, and yarns.

A *control chart* is a convenient method of presenting routine testing results in a readily digested form. In Figure 2.13 the horizontal line OT represents time and the vertical line is marked in units in which the test value is expressed, e.g. *counts*. The horizontal line OT is at the *nominal value* of the variable measured, e.g. the desired count, and for the moment we will assume that the mean count equals the nominal count. Over the vertical scale the normal frequency distribution curve has been drawn in order to help in the explanation. From earlier theory we know that this curve may be regarded as a probability curve. Thus it is absolutely certain that a test value will lie somewhere under the curve, but what are its chances of lying outside selected limits?

Let us assume that the limits chosen are 1·96 and 3·09 standard deviations above and below the mean. Consider the 1·96 S.D. limits first. From Table 2.8(a) we note that 5 per cent of the values lie beyond the limits ± 1·96 S.D. In other words, 1 in 20 values will lie outside these limits, or 1 in 40 will lie outside the + 1·96 S.D. limit and 1 in 40 will lie outside the — 1·96 S.D. limit. Similarly, the chance of a value lying outside the + 3·09 S.D. limit is 1 in 1,000.

In significance tests we treat the 5 per cent level as indicative but not conclusive. In a similar way, we interpret a test value which falls

between the two limits; it could be a chance variation—the 1 in 40 chance. If, however, the test value lay outside the 3·09 limit, then it would be considered significantly different to the nominal value, and action taken. Thus the inner limits may be considered as *warning* limits and the outer limits as *action* limits.

In the argument above we have been considering an *individual* test value in relation to the frequency distribution of the population. In routine testing a sample of 1 is rare and tests are usually made on small numbers of individuals, e.g. four cops, and the mean of the four determined. However, we know that the distribution of the sample means is also a normal distribution, with its standard deviation called the standard error of the mean (see p. 35). We can therefore prepare a control chart based upon the S.E. of the mean, using 1·96 S.E. and 3·09 S.E. as the inner and outer limits respectively.

Consider a practical example: In a cotton condenser spinning mill the count is determined daily by selecting four ring bobbins at random, calculating the count by weighing half a lea of yarn from each bobbin, and then taking the mean of the four results. If the mean count over a number of weeks is 8s and the mean range is 1·8 counts, calculate the 1 in 40 and 1 in 1,000 limits for the mean count.

Step 1. Calculate the S.E. of the mean.

Table 2.9 enables the standard deviation of the *population* to be calculated from the mean range. In this example,

$$n = 4 \quad \text{and} \quad a_n = 0{\cdot}4857$$

Therefore,

$$\text{S.D. of population} = \text{mean range} \times a_n$$
$$= 1{\cdot}8 \times 0{\cdot}4857 = 0{\cdot}87$$

On p. 36 we noted the relation

$$\text{S.E.} = \frac{\text{S.D. of population}}{\sqrt{n}}$$

Hence we can estimate the standard error of the mean:

$$\text{S.E.} = \frac{0{\cdot}87}{\sqrt{4}} = 0{\cdot}435$$

Step 2. Calculate the limits

Inner limits (the 1 in 40 or *warning limits*)

$$= \pm 1{\cdot}96 \times 0{\cdot}435$$
$$= \pm 0{\cdot}86$$

Outer limits (the 1 in 1,000 or *action limits*)

$$= \pm 3{\cdot}09 \times 0{\cdot}435$$
$$= \pm 1{\cdot}34$$

One point to note here is that the limits are laid off from 8·0, the mean count, which in our case was the desired count. If the actual mean count had been, say, 8·1 we would still have laid off the limits from 8·0. In cases where the actual mean is not in such good agreement with the desired mean it is necessary first to find out why and then to make the required machine adjustment.

In the example given we first estimated the S.E. of the mean and then calculated the limits. Special Tables are available which enable the limits to be calculated without requiring the estimation of the S.E. (see Table 2.12(b)).

The mean range is multiplied by a factor, A, which corresponds to the sample size and the limits considered. In the last example the mean range was 1·8 counts and the sample size, n, was 4. For the warning limit, A_{40} is 0·476. Therefore

$$\text{Warning limits} = \text{Mean} \pm 1{\cdot}8 \times 0{\cdot}476$$
$$= \text{Mean} \pm 0{\cdot}86$$

For the action limit, $A_{1,000}$ is 0·750. Therefore

$$\text{Action limits} = \text{Mean} \pm 1{\cdot}8 \times 0{\cdot}750$$
$$= \text{Mean} \pm 1{\cdot}35$$

Table 2.12(a). Factors for Converting the Mean Range of Samples of n *into the Population Standard Deviation; S.D.* $= \bar{w}/d_n$

n	d_n
2	1·128
3	1·693
4	2·059
5	2·326
6	2·534
7	2·704
8	2·847
9	2·970
10	3·078
11	3·173
12	3·258

Table 2.12(b). Factors by which to Multiply the Mean Range of Samples of n in Order to Obtain the ± Distances of the 1 in 40 and 1 in 1,000 Limits from the Grand Average

Sample size n	*Inner limit* A_{40}	*Outer limit* $A_{1,000}$
2	1·229	1·937
3	0·668	1·054
4	0·476	0·750
5	0·377	0·594
6	0·316	0·498
7	0·274	0·432
8	0·244	0·384
9	0·220	0·347
10	0·202	0·317
11	0·185	0·294
12	0·174	0·274

Table 2.12(c). Control Chart Limits for Range. Factor by which to Multiply the Mean Range in Samples of Size n *in Order to Obtain the 1 in 40 and 1 in 1,000 Limits for the Range*

Sample size n	*Inner limit* D_{40}	*Outer limit* $D_{1,000}$
Upper limits:		
2	2·810	4·121
3	2·174	2·990
4	1·933	2·573
5	1·806	2·356
6	1·770	2·218
7	1·660	2·120
8	1·620	2·044
9	1·583	1·986
10	1·556	1·940
11	1·532	1·904
12	1·510	1·870
Lower limits:		
2	0·036	0·000
3	0·177	0·036
4	0·287	0·097
5	0·365	0·159
6	0·418	0·213
7	0·462	0·255
8	0·495	0·292
9	0·522	0·323
10	0·543	0·351

Range chart

Although we are interested in the way in which the average value fluctuates we can also study the variation in the spread of the test results. A range control chart enables this variation to be observed easily. An increase in the variation can be detected and steps taken to decrease it. A special Table is again used in the calculation of the limits (Table 2.12(c)).

The mean range is multiplied by a factor, D, corresponding to the size of the sample and the limit considered. Using the previous example again and referring to Table 2.12(c), the factor D_{40} for the warning limit is 1·933. Therefore

$$\begin{aligned}\text{Warning limit for the range} &= \text{mean range} \times D_{40}\\ &= 1{\cdot}8 \times 1{\cdot}933\\ &= 3{\cdot}48 \text{ counts}\end{aligned}$$

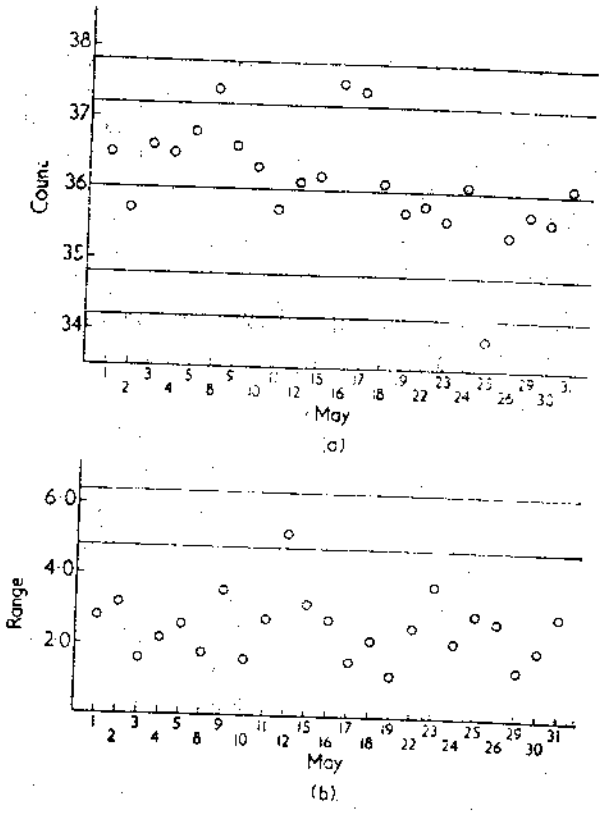
The factor $D_{1,000}$ for the action limit is 2·573. Therefore

$$\begin{aligned}\text{Action limit for the range} &= \text{mean range} \times D_{1,000}\\ &= 1{\cdot}8 \times 2{\cdot}573\\ &= 4{\cdot}65 \text{ counts}\end{aligned}$$

Since we are usually only interested in the high values of the range, the limits are drawn on one side only of the chart (see Figure 2.14).

The interpretation of control charts

Suppose that a pair of control charts have been prepared for a 36s cotton yarn. Four ring bobbins are taken at random from the yarn skip and the mean count and the range determined daily. The limits for the mean and the range have been established from previous test results. Figure 2.14 shows the two charts with a series of the daily results plotted. Consider the control chart for the mean. Until 8 May all the test results were inside the warning limits, but on 8 May the mean count of the sample fell between the warning and the action limits. On the next day, however, the mean count was back again inside the warning limits and therefore no action was taken. On 16 May and again on 17 May the mean count results were both between the warning and action limits. Two successive results beyond the 1 in 40 limits indicate that they are due to some 'assignable cause' and not merely to chance. Instructions to change the draft wheel were therefore issued. The effect was to bring the mean count back within the warning limits. The test on 25 May produced a value outside the action limit and therefore the necessary instructions were issued.



Nominal count: 36s Warning limits: ± 2 S.E.
Standard error: 0·6 Action limits: ± 3 S.E.
Mean range: 2·47
Inner limit: 2·47 × 1·933 = 4·8 approx.
Outer limit: 2·47 × 2·573 = 6·4 approx.

Figure 2.14. Quality control charts

Experience and common sense must be combined with statistics when interpreting the control chart. For instance, a run of mean count results which are very close to, but not outside, the warning limit could suggest that a change be made. Again, a series of results drifting towards the warning limit would suggest that a change in time would prevent the next from lying outside the limit. The old adage of prevention being better than cure applies to quality control too.

The choice of limits

In the previous sections the warning and action limits have been calculated using the factors 1·96 and 3·09. In practice, the factors are often taken as 2 and 3 with little loss of control. Other values could be used if required, but experience has shown that the 2 and 3 factors work satisfactorily. There are other points which may require consideration. The material may be manufactured to a specification which lays down the *tolerances* allowable in the product. It is therefore necessary to relate the control limits with these specified tolerances. Two examples are given here, one to show the effect of tolerances which are too tight and the other to show the effect of tolerances which are too wide.

Figure 2.15(a) illustrates what happens when the specification limits are well inside the natural spread of the population characteristic. An excessive number of rejects will be produced. Improving the process so that the variation is reduced is one way of avoiding rejects but it might prove too expensive. An alternative may be to discuss the specification with the person who framed it and to see if

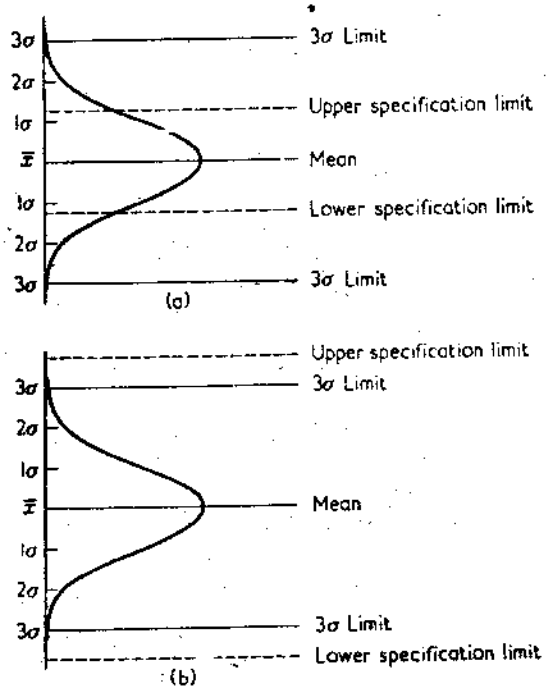


Figure 2.15. Practical limits and specification limits: (a) Specification limits too narrow; (b) Tolerances too wide

the tolerances could be widened and yet still achieve a serviceable product.

Should the specification limits be wider than the natural spread of the process, then even the 3 S.D. limits may still be within the tolerances allowed. It would evidently be a waste of time to issue change instructions when a test result lay outside the 3 S.D. limit but inside the tolerance.

Incidentally, one can be 'change-wheel happy' and do too much machine adjustment, the result being to introduce more variation than is removed. Experience and common sense are indispensable in the implementation of control schemes.

The effect of sample size on the limits

The spread of a sampling distribution changes with the size of the sample. Figure 2.16 shows a comparison between the distributions of individuals and samples of four and nine. The dispersion becomes less as the sample size increases. This effect can be used to modify the spacing of the control chart limits and therefore to modify the degree of control over the process.

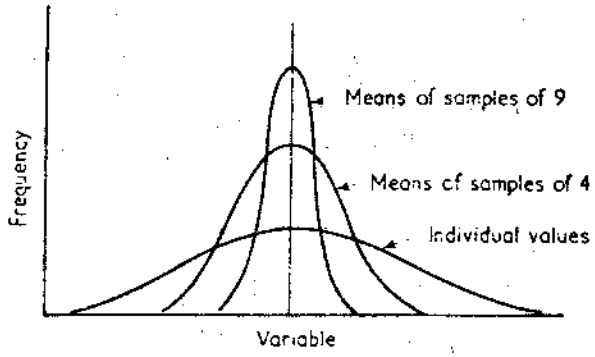


Figure 2.16. Spread of sampling distributions with samples of different sizes

Let $L_{1,000}$ be the action limit,

$$L_{1,000} = 3{\cdot}09 \times \text{S.E.}$$

$$= 3{\cdot}09 \times \frac{\text{S.D. of population}}{\sqrt{n}}$$

Expressing $L_{1,000}$ as a percentage of the mean $\bar{x}$,

$$L = \frac{3{\cdot}09 \times \text{S.D.} \times 100}{\sqrt{n} \times \bar{x}}$$

Rearranging this equation to put n on the left-hand side,

$$n = \frac{100^2 \times 3{\cdot}09^2 \times \text{S.D.}^2}{(L)^2 \times \bar{x}^2} = \frac{90000\ \text{S.D.}^2}{(L)^2 \times \bar{x}^2} \text{ approx.}$$

Hence the degree of control can be increased or decreased by deciding upon the desired value of L and calculating the number of individuals in the sample. For L_{40}, the warning limit,

$$n = \frac{40000\ \text{S.D.}^2}{(L)^2 \times \bar{x}^2} \text{ approx.}$$

Example 1. The standard deviation of a 40s cotton yarn is known to be 1·2 counts. What size of sample is necessary in order that the warning limit is 2 per cent of the mean?

$$n = \frac{40000 \times 1{\cdot}2^2}{2^2 \times 40^2}$$

$$= \frac{144}{16} = 9 \text{ bobbins}$$

If samples of a given size are already in use and the standard error is known, the calculation is simpler.

Example 2. A 40s cotton yarn is tested in samples of 4 bobbins. The standard error is 0·6 counts giving a warning limit of 1·2. How many bobbins must there be in the sample in order that the warning limit is 2 per cent of the mean?

The percentage obtaining with four bobbins in the sample is

$$\frac{1{\cdot}2}{40} \times 100 = 3 \text{ per cent}$$

The standard error corresponding to 2 per cent will be

$$0{\cdot}6 \times \frac{2}{3} = 0{\cdot}4$$

$$\text{Since S.E.} = \frac{\text{S.D. of population}}{\sqrt{n}}$$

$$n = \left(\frac{\text{S.D.}}{\text{S.E.}}\right)^2 = \left(\frac{1{\cdot}2}{0{\cdot}4}\right)^2 = 9 \text{ bobbins}$$

EXAMPLES OF CONTROL CHARTS IN TEXTILE APPLICATIONS

Drawframe control and count control

Some operators of control schemes in spinning mills hold the view that the control of count by testing the spun yarn and changing wheels on the spinning frame is the wrong approach to the problem. The argument put forward is that it is too late to control at the spinning frame because changes made there will probably increase variation in count rather than decrease it. It is considered that by the time the results are known and action can be taken, the cause of wrong count (e.g. too coarse roving) has disappeared and that by changing wheels on the frame to give a finer count the change will operate on roving which has in fact become finer anyway. This will result in over-correction and the count will then be too fine.

The policy of any control system should be to spot trouble as quickly as possible and to put it right before too much faulty material has been passed forward to the following processes. With this in mind the key control point in cotton spinning, for example, is the drawframe. Some people suggest that control could be as far back as the scutcher.

Broadly speaking, the functions of the drawframe are to improve the blending, to reduce irregularity, and to bring the fibres into a parallel condition ready for further drafting. For combed sliver the emphasis is on reduction of irregularity; for carded sliver the main objects are parallelisation and blending.

In most cases four slivers are controlled by a change pinion of the drawframe and each is called a 'delivery'. For control, a certain length from each delivery is measured and weighed, changes being made from the results of the wrapping. Now, if consecutive lengths of sliver from one delivery were tested, then the variation noted would be variation *within* a delivery. However, such a method of testing is not normal practice. There will be differences in sliver weight per test length between the slivers from each delivery, that is, *variation within a machine* or inter-delivery variation. Further, since a number of drawframes supply material to the next process, the latter will also be affected, variation in sliver weight resulting from variation *between* drawframes.

A method of drawframe control is described by Haworth (*Text. Mfr*, p. 407 (Aug., 1958)). The frames are tested twice a day, sliver being taken from deliveries 1 and 3 in the morning and 2 and 4 in the afternoon. Control limits are set so that, if the result falls outside them, a change of one tooth on the change pinion should bring the

sliver weight back within the control limits. Remembering the effect of moisture regain on weight, the samples are checked by an accurate moisture meter and the weighings corrected when necessary. The control chart is illustrated in Figure 2.17. Points to note are:

(1) The recording of the number of teeth in the change pinion.
(2) The deviation from the nominal weight is expressed as a percentage instead of a weight in grains or grams. This is a device which enables the observer to appreciate the fluctuations more readily, especially when a number of sliver weights are processed.

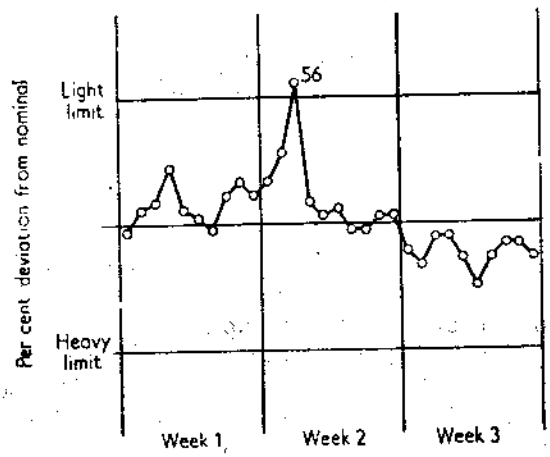


Figure 2.17. Control chart for drawframe sliver

The control limits of a chart of this type are chosen to suit the degree of control which can be exercised by the gearing of the machine. Suppose the finest or minimum correction that the gearing allows is 1 per cent. Let the nominal sliver weight be 80 gr/yd. What length of sliver must be tested to obtain limits which coincide with the minimum change? A series of 1 yd lengths from each delivery could be tested and the data analysed. Referring to Table 2.13, let x_1, x_2, x_3, and x_4 be the weights of 1 yd lengths from the four deliveries, giving a mean of $\bar{x}$. From the four $\bar{x}$ values the range w is obtained. This procedure is repeated a number of times and the mean range $\bar{w}$ determined. The standard deviation is calculated by dividing the mean range by 2·059 (see Table 2.12(a)).

Table 2.13. Drawframe Control (Weights of 1 yd Sliver Lengths from Four Deliveries)

Delivery	*1*	*2*	*3*	*4*	*Mean* $\bar{x}$	*Range* w
Weight of 1 yd lengths	x_1	x_2	x_3	x_4	$\bar{x}$	
	x_1	x_2	x_3	x_4	$\bar{x}$	w_1
	x_1	x_2	x_3	x_4	$\bar{x}$	
	x_1	x_2	x_3	x_4	$\bar{x}$	
	...	...	...	...	...	w_n

$$\text{Mean range } \bar{w} = \frac{w_1 + w_2 + \cdots + w_n}{\text{No. of groups}}$$

$$\text{Standard deviation} = \frac{\bar{w}}{d_n}$$

where d_n is the factor for $n = 4$.

$$\text{Error} = \text{S.D.}\% = \frac{\text{S.D.} \times 100}{\text{mean}}$$

$$= \frac{\text{S.D.} \times 100}{\bar{\bar{x}}} \text{ per cent}$$

where $\bar{\bar{x}}$ is the grand mean. Alternatively the nominal may be used.

Let the mean range in this example be 1·9 gr, giving a standard deviation of 0·92 gr. Expressed as a percentage of the nominal sliver weight of 80 gr the S.D. becomes 1·15 per cent. This percentage has been mentioned earlier in this chapter and referred to as *error*. Thus, the error when 1 yd samples are tested is 1·15 per cent, and so we must now calculate how long the test length must be to reduce the error to 1·0 per cent, the minimum amount of change.

Let n be the number of yards required and assume that the action limits are the 2 S.D. values, i.e. the 1 in 40 limits. Then,

$$\frac{2 \text{ S.D.}}{\sqrt{n}} = 1{\cdot}0 \text{ per cent}$$

$$\frac{2 \times 1{\cdot}15}{\sqrt{n}} = 1$$

$$n = 2{\cdot}3^2 = 5{\cdot}29 \text{ yd}$$

In practice, a 5 yd test length would probably be chosen.

Group control charts for spinning frames

When establishing a scheme of count control, the 'unit of control' must be decided upon. The ring frame is often considered as two separate machines, a left-hand unit and a right-hand unit; so, too, is a mule, each part being capable of independent adjustment. It is not uncommon to find different change pinions on each side even though the count being spun is nominally the same. The following objections to the use of spinning frame bobbins for count control have been put forward:

(1) It is necessary for the final product to be outside the control limits before corrective action is taken; an effective control system should *prevent* the production of incorrect final products.

(2) The essence of a good control system should be the speed at which detection of faulty material is followed by corrective action; when bobbins are tested there is often a delay between collection, testing, issue of notice of action required, and the completion of the necessary changes.

(3) The sample size is limited and the inherent bobbin-to-bobbin count variation is often sufficiently high to require control limits which are spread too widely to be really effective.

Because of these objections some mills are using the drawframe as the point at which count is controlled. Nevertheless, many mills prefer to use the spinning frame as the control point in addition to ordinary drawframe control. A recent development has been the grouping together of a number of similar frames spinning the same count and fed by a common roving supply. The group of frames is then treated as one spinning unit, i.e. the unit of control is a number of frames. Of course, it is necessary to ensure that the frames so grouped are as mechanically identical as possible and a thorough check of gearing and roller sizes, etc., must be carried out first.

With group control only one set of charts is used, and when a change is indicated *all* the frames are changed simultaneously. Experience has shown that the count variation is reduced by using group control and that the frequency of pinion changes is reduced. The method of sampling must be considered. If, say, six frames constituted a group and twenty-four bobbins is the sample size, it would be possible even with perfectly random sampling that a sample could be collected which did not contain one bobbin from a particular frame. To avoid this it is usual to *stratify* the sampling and collect a number of bobbins at random from each frame in the group.

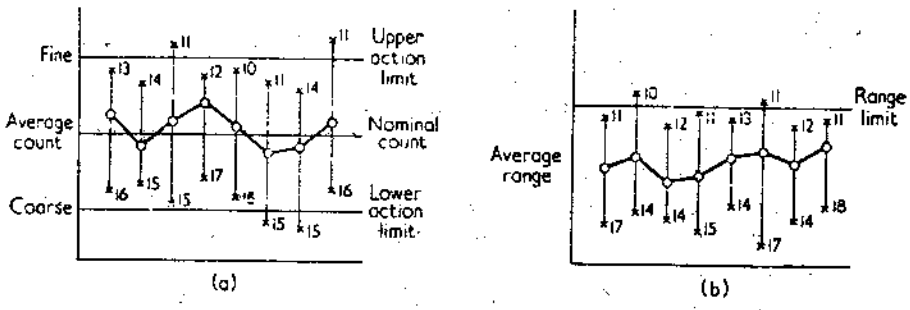


Figure 2.18. Group control charts for yarn count and range

An example of the type of chart used is shown in Figure 2.18. In this example two yarn characteristics are plotted, the count and the count range, measures of average and variability, respectively. If required, the lea count × strength product could be plotted on a third chart. The action limits for count control are related to the average values of the full sample and not to the average values for the individual frames within the group. These latter values are, however, used to provide practical information. The highest and lowest individual frame averages are plotted, so that if a particular frame regularly spins fine or coarse its behaviour is spotted quickly. For example, Frame 11 appears to spin fine and Frame 15 coarse; checks on the two frames would be suggested. Under normal running conditions the frame numbers would appear in the highest and lowest positions at random.

The average range and the individual ranges are plotted in a similar manner. Again an action limit is calculated and the frames showing extreme values are indicated. A frame which regularly appears as the one with the highest range will, of course, be carefully checked, but it is also of interest to know why a particular frame behaves *better* than the others. Examination of such a frame may lead to improvements all round.

THE BINOMIAL AND POISSON DISTRIBUTIONS

Probability

Probability has been mentioned very briefly in an earlier section of this chapter (see page 31).

By tossing a penny many times the number of times heads will result and the number of times tails will result will be equal, i.e. half the total number of times the penny has been tossed. We say, then, that the probability or chance of getting heads is $\frac{1}{2}$.

Similarly, on rolling a die and calling 6 a success, the probability of getting a 6 will be $\frac{1}{6}$. The probability of getting a 4 is also $\frac{1}{6}$.

Generally, if an event can happen in a number of ways and if a certain number of these ways is regarded as a success, then the probability or chance of a success is defined as the ratio of the number of ways favouring a success to the total number, e.g. when two pennies are tossed at the same time the chance of two heads at one time is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$.

The chance of a double six with two dice $= \frac{1}{6} \times \frac{1}{6} = \frac{1}{36}$. Let the odds in favour of a success be $n:m$. Then the probability of a success is

$$\frac{n}{n+m}$$

Conversely, the chance of failure is

$$\frac{m}{n+m}$$

If we let the probability of a success be p and the probability of a failure be q, then

$$p + q = 1$$

The binomial distribution

If N sets of n events are taken, the number of sets having n successes, $(n-1)$ successes, $(n-2)$ successes, etc., will be given by the terms of the binomial expansion:

$$N(p+q)^n$$

Thus, for r successes, the number of sets is given by

$$N {}^nC_r \, p^r \, q^{n-r}$$

where $${}^nC_r = \frac{n(n-1)\,(n-2)\,\ldots\,(n-r+1)}{1 \times 2 \times \ldots r}$$

Statistical theory shows also that the arithmetic mean of the binomial distribution is given by

$$\text{Arithmetic mean} = np$$

Further, the standard deviation is given by

$$\text{S.D.} = \sqrt{(npq)}$$

Example. During an efficiency survey of a weaving shed, sixty-four observations of the six looms of one weaver were made, i.e. sixty-four 'snap readings' in which the number of stopped looms is recorded in

the brief instant of observation. It was found that distribution of the number of stopped looms was as follows:

Number of stopped looms	0	1	2	3	4	5	6
Frequency	30	22	8	2	2	0	0

Can this distribution be represented by the binomial distribution? The number of 'sets of events' in this case is 64, i.e. $N = 64$. The n events are the stoppages of the looms, i.e. $n = 6$. Hence the binomial expansion in this example may be written

$$N(p + q)^n = 64(p + q)^6$$

Now, we have seen that for a binomial distribution np equals the arithmetic mean. In this example the mean is given by

$$\text{Arithmetic mean} = \frac{\text{sum of the frequencies}}{64}$$

$$= \frac{(30\times 0)+(22\times 1)+(8\times 2)+(2\times 3)+(2\times 4)+(0\times 5)+(0\times 6)}{64}$$

$$= 52/64$$

$$\text{Since } n = 6,\ p = \frac{52}{64} \times \frac{1}{6} = 0{\cdot}135$$

and since $p + q = 1$, $q = 0{\cdot}865$, the expansion becomes

$$64(0{\cdot}135 + 0{\cdot}865)^6$$

Rather paradoxically in this instance a 'success' is a stopped loom. The number of times that all six looms were stopped, if the binomial law holds, is given by the first term of the expansion, i.e.

$$64 \times 0{\cdot}135^6 = 0 \text{ (i.e. a very small value)}$$

The number of times that there were no stopped looms is given by the last term, i.e.

$$64 \times 0{\cdot}865^6 = 27 \text{ apprpx.}$$

Working out the intermediate terms we obtain the following distribution:

Number of looms stopped	0	1	2	3	4	5	6
Frequency	27	25	10	2	0·23	0	0

Comparing the calculated and the actual distributions, we observe that there is a reasonable agreement between them. We therefore conclude that the actual distribution follows the binomial distribution.

The conclusion reached above was by inspection only; there are statistical methods of carrying out significance tests and for these the reader is referred to the references given (textbooks).

The Poisson distribution

When the chance of a success is very small but the sample is so large that successes do occur, a special form of distribution arises. In this case p is very small and n is very large. Let $np = m$. Then,

$$(p + q)^n = \exp(-m)\left(1 + m + \frac{m^2}{2!} + \frac{m^3}{3!} + \cdots\right)$$

where exp is the base of Naperian logarithms.

The proportion of 0 successes $= \exp(-m)$
1 success $= \exp(-m)m$
2 successes $= \exp(-m)m^2/2!$
r successes $= \exp(-m)m^r/r!$

Now, the arithmetic mean of a binomial distribution is equal to np, which equals m. Again,

Standard deviation $= \sqrt{(npq)}$.

therefore, Variance $= npq$

Since $q = 1 - p$, the variance $= np(1 - p) = np - np^2$. The limit of $np - np^2$ = limit of $np = m$.

Hence the variance of the Poisson distribution is equal to its mean. Alternatively, the standard deviation is equal to the square root of the mean.

The Poisson distribution is used when randomly occurring events are being studied. In textiles the events are very often end-breakages in spinning and weaving, and faults and defects in yarns and fabrics.

Example. Suppose the number of warp breakages per unit length of 5 yd is studied and the results are as follows:

Breaks per length	*Frequency*	*Breaks × frequency*
0	15	0
1	26	26
2	21	42
3	19	57
4	8	32
5	3	15
6	0	0
7	0	0
8	0	0
Total	92	172

The mean = 172/92 = 1·87
The variance = 1·78

Assuming for the moment that the distribution nearly follows the *Poisson* distribution, let $m = 1{\cdot}87$. Then

$$\exp(-m) = \exp(-1{\cdot}87) = 0{\cdot}154$$

The calculated frequency of

0 breaks: $92[\exp(-m)] = 92 \times 0{\cdot}154$	14·2
1 break: $92[\exp(-m) \times 1{\cdot}87] = 92 \times 0{\cdot}154 \times 1{\cdot}87$	26·6
2 breaks: $92[\exp(-m) \times (1{\cdot}87^2)/(1 \times 2)]$	24·8
3 breaks	15·4
4 breaks	7·2
5 breaks	2·7
6 breaks	0·8
7 breaks	0·2
8 breaks	0·1

The calculated frequency distribution of the breaks to be expected is in reasonable agreement with the actual distribution. If such a good agreement is not obtained the inference is that the breakages are not occurring at random but are being caused by some machine defect. The necessary steps are then taken to locate the cause.

The above discussion on the binomial and Poisson distributions is rather condensed. An excellent account of these distributions and their application to textile problems is given by Tippett (*J. Text. Inst.* **26**, T13–T70 (1935)). The data for the examples given have been taken from Tippett's papers. The Poisson distribution and rates of occurrence are also discussed by Brearley, A. and Cox, D. R., *An Outline of Statistical Methods for use in the Textile Industry*, 5th Edn, p. 53. The counting of neps at the card, using the Poisson distribution, is described by Linnert (*J. Text. Inst.* **52**, P289 (1961)).

RANKING AND SUBJECTIVE ASSESSMENT

Many textile tests provide numerical results, yarn strength in pounds per lea, yarn twist in turns per inch, thread spacing in cloth in terms of cover factor, and so on. There are properties of textiles which although of great importance are difficult to assess numerically. The housewife buying material for curtains may not be interested in the counts of the warp and weft or their respective twist factors and single thread strengths, but she will be in a position to assess the fabric's appearance, handle, and drape, three fabric characteristics which are not easily described by a number. If a

range of fabrics is submitted for examination, the housewife will mentally assess them and rank them in order of merit and then, provided the price is right, she will buy the material which she considers to be the best.

Where laboratory measurement is difficult, a useful device is to submit the range of samples to a number of judges or experts and ask them to rank them in order of preference. In some cases the agreement between the judges can be calculated; in others perhaps the ranking of the team of judges may be compared with the ranking given by a laboratory instrument. The decisions of each judge are, of course, personal decisions and so the method is referred to as *subjective assessment*.

Ranking and rank correlation

Suppose that six fabric samples are to be ranked in order of general uniformity of appearance and that two experts have been asked to make the inspection. All six samples are given to each expert in turn and he ranks them from 1 to 6, No. 1 representing the most uniform fabric. The rankings of both experts are set out as follows:

Sample	*Ranking*		*Difference in ranking*	
	Expert A	*Expert B*	d	d^2
E	2	3	1	1
F	4	5	1	1
G	1	1	0	0
H	3	2	1	1
I	5	4	1	1
J	6	6	0	0
				$4 = \Sigma d^2$

Let the total number of samples be n, $= 6$, and the sum of the squares of the differences, Σd^2, $= 4$. We can now calculate Spearman's coefficient of rank correlation R.

$$R = 1 - \frac{6\Sigma d^2}{n^3 - n}$$

In this example,

$$R = 1 - \frac{6 \times 4}{216 - 6}$$

therefore,

$$R = 0{\cdot}886$$

Spearman's coefficient may take values from -1 to $+1$. If R approaches $+1$, the inference to be drawn is that there is a close agreement between the rankings of the two experts; where R is near 0, little or no agreement is indicated; and if R approaches -1, the two experts disagree strongly—what A considers good, B considers inferior. Close agreement is shown in the example given.

Where the number of items ranked is not less than 10, it is possible to test the significance of the value of R in order to check that the degree of agreement has not arisen purely by chance. The test of significance is made by calculating a value for t and using the t Tables.

Example. Number of items ranked, n, = 10, Spearman's coefficient, R, = 0·78. Then,

$$t = R\sqrt{\left(\frac{n-2}{1-R^2}\right)}$$

therefore, $t = 3{\cdot}54$

This value of t is compared with the value of t corresponding to $n - 2$ degrees of freedom. The 1 per cent level of t for 8 degrees of freedom is 3·36 and the calculated value of t is 3·54; we conclude that the degree of agreement between the two experts is significant.

Ranking by several judges

More than two judges may be asked to rank a number of items. Suppose that five judges were each asked to rank seven fabrics in decreasing order of smoothness, No. 1 representing the smoothest and No. 7 representing the roughest fabric. The rankings could be set out as follows:

Sample		A	B	C	D	E	F	G
Ranking by judge	L	7	3	1	6	2	5	4
	M	5	4	2	7	1	6	3
	N	4	5	1	6	2	7	3
	O	7	1	2	5	3	6	4
	P	7	3	1	6	2	5	4
Rank totals		30	16	7	30	10	29	18

If all the judges were in complete agreement, the rank totals would be in the series 5, 10, 15, 20, 25, 30, and 35, i.e. five 1s, five 2s, etc. The sum of the rank totals is 140: if the judges had shown no ability in ranking the fabrics, the ranking numbers would be at random and therefore the rank totals would be equal and be one-seventh of the total 140, equal to 20. The actual rank totals are now compared with 20:

Sample	*Rank total*	*Difference* d $\lvert 20 - R.T. \rvert$	*(Difference)*^{2} d^2
A	30	10	100
B	16	4	16
C	7	13	169
D	30	10	100
E	10	10	100
F	29	9	81
G	18	2	4
			570 (Sum of $d^2 = S$)

Let S = the sum of the squares of the differences,
m = the number of judges, and
n = the number of samples.

The measure of the degree of agreement among the judges is given by the *coefficient of concordance*, W,

$$W = \frac{S}{[m^2(n^3 - n)]/12}$$

In this example,

$$W = \frac{570}{[25\ (343 - 7)]/12} = 0{\cdot}82 \text{ approx.}$$

The value of W can vary between 0 and +1, values near 0 indicating poor agreement and values approaching 1 indicating close agreement. Thus, the five judges in this case exhibit a high degree of agreement on the ranking of the fabrics for smoothness. The significance of the coefficient of concordance may be tested by reference to the F Tables.

First, the value of W is modified:

(1) Subtract 1 from S.

(2) Add 2 to the divisor $[m^2(n^3 - n)]/12$.

Thus,
$$S = 570 - 1 = 569$$
$$\text{The divisor} = 700 + 2 = 702$$

Hence,
$$W = \frac{569}{702} = 0{\cdot}81 \text{ approx.}$$

The next step is to calculate two estimates of the degrees of freedom:

$$\text{The greater estimate} = (n - 1) - \frac{2}{m} = 6 - \frac{2}{5} = 5{\cdot}6$$

$$\text{The lesser estimate} = (m - 1)\left[(n - 1) - \frac{2}{m}\right] = 4 \times 5{\cdot}6 = 22{\cdot}4$$

The value for F is then calculated:

$$F = \frac{(m - 1)W}{1 - W} = \frac{4 \times 0{\cdot}81}{1 - 0{\cdot}81} = 17{\cdot}1 \text{ approx.}$$

Since the estimates of the degrees of freedom are not whole numbers, it is often necessary to interpolate when consulting the F Tables. In this particular case interpolation is not really necessary because the calculated value of F, 17·1, is well above the 1 per cent level of F, 3·99, for degrees of freedom of 5 and 22.

From our calculations we therefore conclude that the five judges are really in close agreement, a closeness which is not due to chance. The final ranking may now be made by considering the rank totals:

Sample	A	B	C	D	E	F	G
Rank total	30	16	7	30	10	29	18
Final rank	6	3	1	6	2	5	4

Note that samples A and D rank equal sixth.

PAIRED COMPARISONS

In the ranking methods just discussed the complete range of samples is examined at the same time. This has the advantage of being quick, but a more sensitive method is that of *paired comparisons*. The judge is given two samples at a time and rates one of them as the preferred sample. A new pair is then submitted for examination. This procedure is repeated until all possible combinations of pairs have been submitted to the judge and his decisions recorded. It may sometimes happen that the decisions appear illogical. For instance, Sample A may be preferred to B and B preferred to C, but when A and C are paired the judge may rate C better than A. The consistency of the judge is measured by the *coefficient of consistency*.

Suppose five blackboards of yarn are to be judged from the standpoint of regularity. Two people make the test, one acting as judge and the other as recorder. The recorder submits two samples to the judge (identification marks hidden of course) who then indicates the preferred yarn. The preference is recorded in a Table:

Sample	A	B	C	D	E	*Sum* = S	$S - \left(\frac{n-1}{2}\right) = f$	f^2
A	–	1	1	1	0	3	1	1
B	0	–	0	1	1	2	0	0
C	0	1	–	0	1	2	0	0
D	0	0	1	–	1	2	0	0
E	1	0	0	0	–	1	−1	1
$n = 5$			—			—	—	$2 = T$

If the pair A and C were submitted and A is preferred, then a mark 1 is entered in the Table to show that the sample at the left of the horizontal row is preferred to that at the head of the column. A mark 0 is entered at the same time in the corresponding cell of the Table to indicate that the sample at the left of the horizontal row is rejected in favour of the one at the head of the column. This is repeated with all the combinations possible, and with five samples the pairs are as follows:

AB	AC	AD	AE
	BC	BD	BE
		CD	CE
			DE

The sum, T, of the f^2 values is found, in this example $T = 2$. The maximum value of T, T_{max}, is given by

$$\frac{n^3 - n}{12}$$

Hence,

$$T_{max} = \frac{125 - 5}{12} = 10$$

Next, the value $d = (T_{max} - T)/2$ is calculated.

The coefficient of consistency is then given by:

(1) $K = 1 - \dfrac{d \times 24}{n^3 - n}$ when n is an *odd* number

(2) $K = 1 - \dfrac{d \times 24}{n^3 - 4n}$ when n is an *even* number

In our example, therefore,

$$d = \frac{T_{max} - T}{2} = \frac{10 - 2}{2} = 4$$

and since n is 5,

$$K = 1 - \frac{4 \times 24}{125 - 5} = 0{\cdot}2$$

The value d is the number of inconsistent decisions. Therefore, when d equals zero there are no inconsistent decisions and K equals 1. The judge in the example given thus shows a certain measure of consistency in judging yarn blackboards.

Paired comparisons with several judges

In the previous section the paired comparison test with one judge only is discussed. An extension of this principle is to employ several judges, each making the comparisons separately and collecting all the data for analysis. A Table is set out as before, but this time a number j is entered to indicate the number of judges who preferred the sample at the left of the horizontal row to that at the head of the column. If six judges were used and five samples were being examined, the Table might be as follows:

Sample	A	B	C	D	E	*Total*
A	–	5	4	6	4	19
B	1	–	5	4	2	12
C	2	1	–	5	3	11
D	0	2	1	–	0	3
E	2	4	3	6	–	15

Next, for each value of j, calculate the product $j[(j-1)/2]$ and enter it into a second Table:

Sample	A	B	C	D	E	*Total*
A	–	10	6	15	6	37
B	0	–	10	6	1	17
C	1	0	–	10	3	14
D	0	1	0	–	0	1
E	1	6	3	15	–	25
						$94 = \mathcal{J}$

The sum, $\mathcal{J}$, is the number of agreements in the complete test. If all the judges had agreed at every comparison, $\mathcal{J}$ would be a maximum and the first Table would be half filled with the number of judges m, in this case 6, and the other half with 0. The number m would occur $[n(n-1)]/2$ times and would represent $[m(m-1)]/2$ agreements (j being equal to m), and the maximum value of $\mathcal{J}$ thus becomes

$$\frac{m(m-1)}{2} \times \frac{n(n-1)}{2}$$

With six judges and five samples, $\mathcal{J}_{max}$ becomes 150. The measure of agreement between the judges is termed the *coefficient of agreement*, with the symbol A:

$$A = \frac{8\mathcal{J}}{m(m-1) \times n(n-1)} - 1$$

In the example,

$$A = \frac{8 \times 94}{6 \times 5 \times 5 \times 4} - 1$$
$$= 0{\cdot}252$$

The maximum value for A is 1, but the minimum depends on whether m is odd or even.

Where m is even,

$$A_{\min} = \frac{-1}{m - 1}$$

Where m is odd,

$$A_{\min} = \frac{-1}{m}$$

With six judges, therefore, $A_{\min}$ is $-0{\cdot}2$. The coefficient of agreement of 0·252 suggests a measure of agreement between the judges.

The final ranking may now be derived by considering the row totals of the j values in the first Table, high numbers indicating a strong preference for the sample at the left of the row. The ranking is therefore:

A, E, B, C, and D

A fuller treatment of the methods outlined will be found in various textbooks on Statistics. Chapter 18 of Maroney's *Facts from Figures* gives a very readable account of ranking methods. Textile examples of these techniques will be found in papers by Stockbridge and Kenchington (*J. Text. Inst.* **48**, T26 (1957)) and Langhorn and Sondhelm (*J. Text. Inst.* **49**, P617 (1958)). The former deals with roughness of fabrics and the latter with yarn quality assessment by blackboard examination.

CORRELATION

When experiments are made to find out what happens to one property of a material when changes are made to another, we may, if we are lucky, find that the results plotted on a graph lie on a straight line. The two variables, the property studied and the property changed, are then said to be linearly related and the straight line graph can be described by a linear equation of the form

$$y = mx + c$$

where y is the dependent variable, i.e. its value depends upon the value of x, x is the independent variable, m is the slope of the line, and c is a constant, the intercept on the y axis (see Figure 2.19).

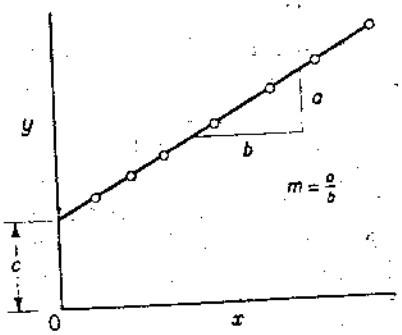


Figure 2.19. Linear relationship between two variables, x *and* y

Very often the plotted points do not lie on a straight line but are scattered. However, in spite of the scatter a trend may be observed. When this happened at school we usually drew in by eye the best straight line through the points, endeavouring to arrange the line so that as many points were above it as below. Where a trend is noted we say that the two quantities x and y are 'correlated'. Figure 7.15 in Chapter 7 shows how the air permeability and the weft twist factor are correlated.

If the value of the dependent variable y increases as the independent variable x increases, the correlation is said to be positive; on the other hand, if y decreases as x increases, the correlation is negative. In the air permeability/twist factor example a positive correlation is noted.

There are special mathematical methods of determining the best straight line to fit the available data. When a method has been established the amount of scatter of the points about this line, or the degree of correlation, is expressed by the correlation coefficient, r. The maximum value of r is $+1$, indicating perfect positive correlation (in other words, all the points lie on the straight line); the minimum value is -1, indicating perfect negative correlation. A value of 0 tells us that there is no correlation between the variables considered. Hence, values of r approaching $+1$ and -1 indicate high correlation, and values approaching zero low correlation.

These few notes on correlation have been included so that the reader will have some idea of the meaning of correlation when he comes across correlation coefficients quoted in the references. The methods of calculation and a more detailed study of correlation, and cause and effect analysis, will be found in most standard textbooks on Statistics.

DATA PROCESSING

Most test results are numerical in character and it is not surprising that more efficient methods of processing data are being investigated. An example of the progress made in this direction is described by Landstreet, Waggoner and Ewald (*Text. Res. J.* **35**, 213 (1965)). Data from the fibre- and yarn-testing machines are collected, printed on paper tape for visual observation and simultaneously punched on to IBM cards for subsequent automatic data processing. The use of a digital fibrograph, which indicates fibre length characteristics in digital form, is clearly a pointer to the type of data required from testing instruments of the future.

FURTHER READING

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MURPHY, T., NORRIS, K. P., and TIPPETT, L. H. C. *Statistical Methods for Textile Technologists* (Textile Institute, 1960)

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DAVIES, O. L. (Ed.) *Statistical Methods in Research and Production* (3rd edn) (Oliver and Boyd, Edinburgh and London, 1957)

FISHER, R. A. *Design of Experiments* (6th edn) (Oliver and Boyd, Edinburgh and London, 1951)

BROWNLEE, K. A. *Industrial Experimentation* (H.M.S.O., 1954)

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YULE, G. U., and KENDALL, M. G. *An Introduction to the Theory of Statistics* (13th edn) (Griffin, London, 1949)

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Statistics applied to textiles

TIPPETT, L. H. C. 'Statistical Methods in Textile Research.' (Pt. 1) *J. Text. Inst.* **21**, T105 (1930)

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GREGORY, G. 'Statistical Quality Control, A Review of Continuous Sampling Plans.' *J. Text. Inst.* **48**, P467 (1957)

BARELLA, A., and VIERTEL, L. 'Quality Control in Cotton Spinning and Weaving. Some Practical Results.' *J. Text. Inst.* **48**, P520 (1957)

VASWANI, S. 'Quality Control in the Blowing Room and its Effect on Production in Subsequent Processes.' *J. Text. Inst.* **45**, P16 (1954)

HOGLEY, B. 'Large Scale Control of Count in Worsted Spinning.' *J. Text. Inst.* **54**, P43 (1963)

LINNERT, A. 'Nep Counting at the Card.' *J. Text. Inst.* **52**, P289 (1962)

LANDSTREET, C. B., WAGGONER, C., EWALD, P. R. 'Automatic Data Acquisition Systems for Fibre and Yarn Testing.' *Text. Res. J.* **35**, 213 (1965)

3

THE SELECTION OF SAMPLES FOR TESTING

WE learned in Chapter 2 that a *sample* is a relatively small fraction which is selected to represent a population. Two important reasons for only testing samples are the time required per test and the destructive nature of many of the tests. Just how small the sample may be in relation to the population can be illustrated by one example. Suppose a bale of cotton weighing about 500 lb is to be tested and the information required is the staple length of the cotton fibre. By using a suitable sampling method the weight of cotton fibre actually tested may be about 20 mg.

$$\text{Bale weight (in mg)} = 500 \times 453{\cdot}6 \times 1{,}000 = 226{,}800{,}000$$

$$\text{Sample weight (in mg)} = 20$$

$$\frac{\text{Sample weight}}{\text{Bale weight}} = \frac{20}{226{,}800{,}000} = \frac{1}{11{,}340{,}000}$$

Thus, less than one eleven millionth of the bulk has to represent the bale.

The sampling methods are governed to a large extent by factors such as the following:

(1) The form of the material.
(2) Amount of material available.
(3) Nature of the test.
(4) Type of testing instrument.
(5) Information required.
(6) Degree of accuracy required.

Within the limitations imposed for particular cases, the underlying principle of most sampling methods is the selection of a *random sample*, free from *bias* and therefore truly representative of the population.

THE RANDOM SAMPLE

In this type of sample every individual in the population has an equal chance of being included in it. The number in the sample must

be sufficiently large to include all the variations of the individuals in the population. A very variable material will require a large number in order to obtain true representation.

In the *British Standards Handbook* No. 11, p. 21 (1963), the *numerical* sample is defined as a sample in which all the fibres in the population have an equal chance of being represented. The expressions 'random' and 'numerical' may thus be interpreted in the same way when considering the selection of a sample of fibre. In a perfect numerical sample the proportion by number of, say, long, medium, and short fibres would be the same in the sample as in the population, e.g. in the bulk, 4 million long, 10 million medium length, 1 million short fibres. Such perfection is well nigh impossible and therefore a random sample with its corresponding random error is the type of sample with which we normally operate.

THE BIASED SAMPLE

Where the selection of an individual is influenced by factors other than chance, a sample ceases to be truly representative of the bulk and a *biased* sample results. The cause of the bias may be the physical characteristics of the individual, its position relative to the person doing the sampling, or perhaps some subconscious bias introduced by that person. For instance, unless special methods are used, the longer fibres have a greater chance of being selected from a strand of material than the shorter fibres, a bias due to the physical characteristics of the longer fibres. Again, a testing-room assistant may pick ten bobbins from the top layer of a case of yarn (whether to save himself the task of digging down into the case or because he has never been told otherwise, we do not know), but the bobbins chosen will be biased due to their position. Subconscious bias is naturally a trickier subject; it may be that the person selecting cones will pick the best looking ones free from ridges, cobwebbed ends, etc., without thinking about it.

The effect of bias on the test results may be negligible or considerable. Where the reaction of a fibre to, say, a chemical treatment is being studied it may not matter much whether the sample is biased in favour of the longer fibres or not. Where the length characteristics of a supply of cotton are to be determined, then a bias in favour of the longer fibres will matter very much indeed. Similarly, if any other property of the fibre is related to length, then the results of the measurement of that property will be affected also. In wool the longer fibres are generally coarser than the short fibres, hence a

determination of fibre fineness based on a length biased sample will contain error.

We will now look at some of the methods used in the sampling of fibres, yarns, and fabrics.

SAMPLING FOR THE DETERMINATION OF FIBRE PROPERTIES*

The sampling method used to select a fibre for testing depends upon the form in which the fibre is available. Thus, fibre in bales, in sliver, card web, yarn, etc., will demand different techniques. The test result of the sample will not necessarily be identical to the result which would have been obtained by testing the bulk. Two sources of error may be present, random error and error due to bias. Random error has been discussed in Chapter 2 in connection with sampling distributions. Bias has been mentioned briefly in the previous section.

A point to note in relation to fibre sampling is the degree to which the fibres have been mixed or blended. Where the bulk to be sampled is well mixed, as in a drawframe sliver, the sample may be selected from one region and the assumption made that fibres from all parts of the original supply are represented. Where mixing has been limited or where it is known that the material may vary from region to region in the bulk, samples should be taken from all parts of the bulk in order to achieve a representative test sample. This is known as *zoning* and is an important step in the preparation of many samples.

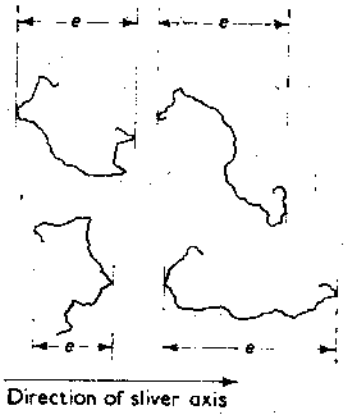


Figure 3.1. The 'extent' of a fibre in a sliver

*See also T.T.S. No. 77 'Methods of Fibre Sampling for Testing' *J. Text. Inst.* **54**, S19 (1963); B.S. Handbook No. 11, p. 20; *Sampling Methods for Fibre Length* B.S. Handbook No. 11, p. 90.

Length and extent biased samples

The *extent* of a fibre in a strand is the distance parallel to the strand axis through which it extends. Figure 3.1 illustrates this point. The chance of a fibre being selected from a strand and included in the sample is proportional to its extent, and unless special sampling techniques are used the sample will be 'extent biased'. By and large, the longer fibres will have the greater extents and, because of this, a badly selected sample will have a bias towards the longer fibres.

A representation of an idealised sliver composed of 6-, 8-, and 10-unit fibres, all parallel to the sliver axis, is shown in Figure 3.2. Suppose we select for our sample all the fibres which cross the line A—A. The sample would consist of six fibres 6 units long, eight fibres 8 units long, and ten fibres 10 units long. This sample would constitute what is termed a 'Wilkinson Tuft', that is, a sample of fibres which traverse a particular cross-sectional area. Wilkinson's paper (*J. Text. Sci.* pp. 76 and 103 (1928)) deals with cotton fibres; a paper by Townend (*J. Text. Inst.* **29**, T55 (1938)) discusses this type of sample for wool. Samples chosen in this way are therefore extent or length biased.

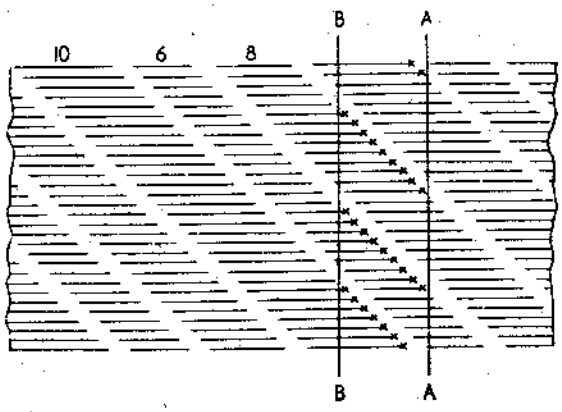


Figure 3.2. Idealised sliver

To obtain an unbiased sample, only those fibres whose ends terminate in a given *volume* should be selected (Townend, *J. Text. Inst.* **26**, T130 (1935)).

Referring again to Figure 3.2, imagine that all the fibres which protrude past AA are combed away and discarded. Let AA be moved back to BB. The fibres now protruding past BB are those whose ends terminate in the *volume* AA/BB. If these fibres are combed

away and classified into length groups, it will be seen that there are nine fibres in each of the 6-, 8-, and 10-unit length groups. Thus, the fibre length has *not* influenced the choice of the fibres included in the sample and therefore an unbiased sample is achieved. This principle is used in several sampling methods where the fibres are more or less in a parallel order.

*The 'squaring' technique**

The sliver is opened out into a web and placed on a black velvet pad. The end of the sliver is then squared off. A glass plate is placed over the fibres to act as a control, and a small fringe is left projecting beyond the edge of the plate. All the protruding fibres are removed and discarded. The plate is moved back a little and a second fringe is removed. Apparently the extent bias has been avoided since all the ends of the fibres have terminated in a given volume. Daniels (*J. Text. Inst.* 33, T137 (1942)) found that it was necessary to repeat the operation until the final position of the plate edge was at least a distance equal to the length of the longest fibre present from its original position. This is necessary because whenever a strand is broken there is a bias of long fibres at each broken fringe.

The cut squaring method†

Where the material is composed of fibres in parallel order, e.g. sliver, roving, and yarn, a modified squaring technique may be used. The twisted forms of material are first untwisted, opened out a little, and laid parallel on a black velvet pad. A glass plate is placed over the fibres with its leading edge at right angles to the strand axis. The fringe is cut across with scissors as near to the glass plate as possible and the fibres whose cut ends project are removed by forceps and discarded. The glass plate is then moved back about 1 mm and again the projecting fringe is removed and discarded. This operation is repeated. Finally, after a third movement of the glass plate, the fringe is removed and used as the sample.

For wool tops and similar forms of material it is recommended that the leading edge of the glass plate be put at an angle of about 60 degrees to the strand axis, and that the cut should be made at a distance from the end greater than the length of the longest fibre present.

*See B.S. Handbook No. 11, p. 24.
†See B.S. Handbook No. 11, p. 90.

Cotton sample for the 'Uster' staple diagram apparatus

The 'Uster' instrument is discussed in Chapter 5 but it is of interest to note at this point that the tuft of cotton fibre on which the measurements are made can be prepared from fibre in sliver form. In place of a velvet pad and glass plate for fibre control, a system of combs is used. The backward movement of the glass plate is replaced by a systematic removal of top and bottom combs.

A zoning technique for raw cotton

If the bulk of the material is not homogeneous, a number of sub-samples must be taken at random from different places in the bulk. The number of sub-samples depends upon the degree of heterogeneity of the bulk and may be found by experiment or known by experience. The method chosen should satisfy the requirement that replicate samples should yield results between which the differences are statistically insignificant. For slivers and yarns the mixing which has taken place during processing has greatly reduced the degree of heterogeneity. It is still present, e.g. in drafting waves (see Chapter 9).

Ideally, when sampling from bulk material, such as a bale of raw cotton, the required number of fibres should be taken one by one at random from different parts of the bale. Since this is impracticable we use a system whose object is still to sample from as many parts of the bulk as possible.

The following procedure is taken from the B.S. Handbook No. 11, p. 33 (1963). Figure 3.3 is a pictorial representation of the method used when preparing a sample for the stapling test by comb sorter.

Step 1. From the bulk, a sample of about 2 oz is prepared by selecting about eighty large tufts chosen, so far as is possible, over the bulk.

Step 2. Divide this sample into four quarters.

Step 3. Take sixteen small tufts at random from each quarter, size approximately 20 mg.

Step 4. Each tuft shall be halved four times, discarded alternately with right and left hands and turning the tuft through a right angle between successive halvings. Sixteen 'wisps' are thus produced from each quarter sample.

Step 5. Combine each set of wisps into a tuft.

Step 6. Mix each tuft in turn by 'doubling and drawing' between the fingers.

Step 7. Divide each tuft into four parts.

Step 8. Obtain four new tufts by combining a part of each of the former tufts.
Step 9. Mix each new tuft again by doubling and drawing.
Step 10. Take a quarter from each tuft to make the final sample.

Note: In Steps 7 and 10 the division of the tufts should be made at right angles to the direction of the fibre length. If the division is made lengthwise the tendency is to produce two parts differing in their length constitution.

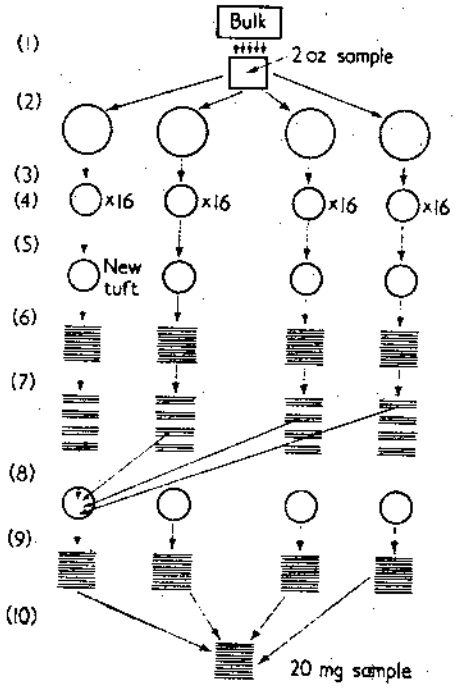
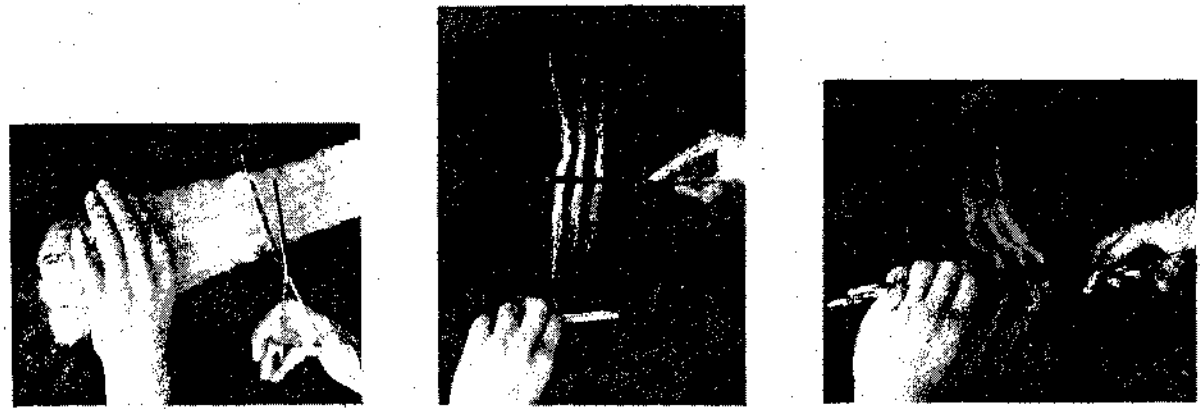


Figure 3.3. Sampling for the cotton stapling test

Dye sampling method for wool to give a random sample
This method is suitable for sampling from slivers and webs in which the fibres are entangled. The merit of the method is the reduction to negligible proportions of the risk of fibre breakage present in the cut squaring method. The material should be capable of being spread into the form of a web without serious disturbance.

The web is stamped over a small rectangular area with a block of brass covered on one face with filter paper soaked with a suitable dye. Fibres passing through the dyed patch and therefore having



(a) (b) (c)

Figure 3.4. Tong sampling: (a) Inserting the tongs; (b) Combing one side of the sample; (c) Preparing to complete the combing

undyed ends are neglected. Those terminating within the patch and thus having one or both ends stained are taken as the sample. Fibres having only one end stained should be given only half the statistical weight in the computations. The size of the patch must be appropriate in area and shape. For example, a small patch and long fibres would produce too many fibres passing right through. A detailed account of this method is given by Palmer (*J. Text. Inst.* **39**, T8 (1948)), and in Chapter 2 of W.I.R.A. Handbook, *Testing and Control*. (See B.S. Handbook No. 11, p. 23.)

The tong sampling method to give an extent biased wool sample

The sampling methods previously described have had as their objective unbiased samples, but in the tong sampling method an extent biased sample is obtained. In effect, the grip of a pair of surgical tongs becomes equivalent to the line AA in Figure 3.2. The material should be in a more or less parallel order, and so slivers, rovings and yarns can be treated in this way. After opening out the material into a thin flat sheet, one pair of tongs is used to clamp about three groups of fibres at right angles to the fibre direction. The clamped fibres are then removed from the rest of the material and carefully combed on one side of the tongs (see Figure 3.4(a) and (b)). After combing, a second pair of tongs clamps the fibres on the combed side of the sample as shown in Figure 3.4(c), care being taken to ensure that the limbs of both pairs of tongs are parallel to each other and in contact. The first pair of tongs is then removed and the uncombed fringe combed. The fully combed sample is then transferred to a velvet pad ready for further testing.

Experience has shown that the best type of tongs to use are surgical forceps. These have a ratchet gripping device and have leather on the face of one limb and longitudinal flutes on the other. At all times the aim is to avoid fibre breakage during clamping and combing (see also the W.I.R.A. Handbook *Testing and Control*, p. 24).

Core sampling of raw wool

In addition to the wool a bale of raw material contains other substances such as grease, vegetable matter, and moisture, and for commercial and technical purposes it is necessary to know the proportions of the various materials. The methods of analysis are given in the chemical testing section of the B.S. Handbook and other standard reference books. For accurate determination of the proportions of wool, etc. a representative sample of the bulk of the material is required. By using the core sampling method it is possible

to obtain samples from a number of unopened bales in a delivery of wool and combine them to form a representative sample of the lot.

In principle a narrow tube about 2 ft long and 0·75 in. in diameter is fitted with a sharp cutting tip at one end. The other end is fitted with a pair of handles where manual 'pressure' coring is used; alternatively an adapter to fit a power drill is favoured in America. A small hole is first cut in the bale covering and the tube either forced in manually or drilled in. As the tube cuts through the bale a plug or core of material is forced up the inside of the tube. A slit along the side of the tube enables the core to be ejected by means of a suitable blade. The ejected cores may be collected in a plastic bag secured to the top end of the coring tube.

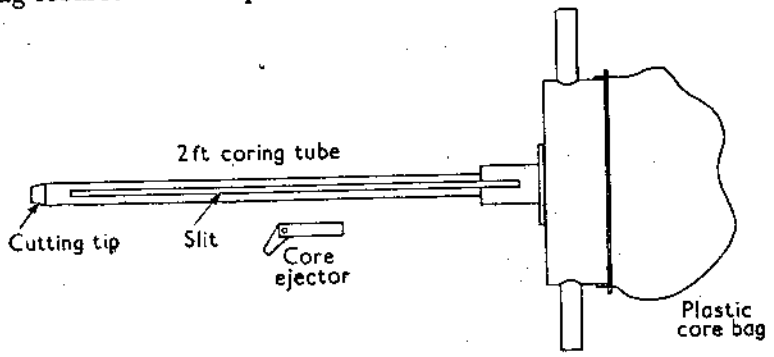


Figure 3.5

The core testing of wool bales for yield is discussed in the W.I.R.A. News Letter of January 1962 from which source the following extract is taken.

'For commercial purposes about 2½ lb wt. of core samples should be taken. This is obtained from about 70 cores using the ⅝" Australian tube, or about 250 cores using the American drill. When a comb test is made on a Merino wool about 100 bales are processed; so with the Australian tube one core per bale is ample. Comparison of results with those of comb tests has shown this procedure to be satisfactory.'

Whichever method of coring is used the following conditions must be complied with.

(1) The weight of the bale at the time of coring must be known.
(2) The tool must be capable of penetrating to any part of the bale.
(3) The tube must be entered in the direction of compression of the bale, so that the cut is perpendicular to the layers of fleeces.

(4) The core in the tube must remain unchanged whilst the tube is being withdrawn from the bale.
(5) The cores must be placed immediately in an air tight container.

The importance of coring at the time of weighing in is obvious, the subsequent yield determination being calculated on the condition of the wool at the time of coring.

The technical problems of cutting tip design and maintenance are discussed in detail by Roberts (*J. Text. Inst.* **52**, T416 (1961)). The American method is given in the *ASTM Handbook:* 'Core Sampling of Raw Wool in Packages for Determination of Clean Wool Fiber Present', *ASTM* D 1060–58. A further reference to core testing is found in the *W.I.R.A. Bulletin* Vol. 24, No. 3 (July 1962). The coring tool described in the notes above was developed by the Commonwealth Scientific and Industrial Research Organisation in Australia.

YARN SAMPLING METHODS

In general, yarn is available as a number of independent packages and the problem of sampling is the selection of a small number of such packages from a large number. The population may be a frame of ring bobbins, a skip of mule cops, a bundle of hanks, or a delivery of yarn on cones. Other forms of yarn will no doubt occur to the reader. Less convenient forms of yarn will be found in fabrics, tape, and braids, etc. From our earlier discussion we know that a random sample is preferred and for mill experiments and research great care is taken to ensure that this type of sample is obtained. In routine mill testing, however, the niceties of randomisation by means of packs of cards and Tables of random numbers are sacrificed in the interests of speed and economy of effort. It must not be inferred that routine mill samples are therefore biased; the randomisation is merely less refined than in research work.

The use of random numbers

In *Cambridge Elementary Statistical Tables*, Table No. 8 is 'Random Sampling Numbers'. A short extract is given in Table 3.1. Suppose that fifty bobbins are available for testing and that ten are to be selected at random. The bobbins could be numbered or perhaps placed in an orderly fashion on the bench in, say, five rows of ten, No. 1 being the first bobbin on the left hand end of the top row.

Consulting Table 3.1, we read the numbers in pairs, starting anywhere. The first pair on the second line is 74, but as this is

greater than 50 we ignore it. The next pair is 49, so into the sample goes bobbin No. 49. 04 follows and so bobbin No. 4 is the second choice. Continuing in this fashion, ignoring numbers higher than 50 and numbers already selected, the final sample consists of bobbins No. 49, 4, 3, 10, 33, 11, 48, 38, 31, and 23.

Table 3.1. Random Sampling Numbers

20 17	42 28	23 17	59 66	38 61	02 10	86 10	51 55	92 52	44 25
74 49	04 49	03 04	10 33	53 70	11 54	48 63	94 60	94 49	57 38
94 70	49 31	38 67	23 42	29 65	40 88	78 71	37 18	48 64	06 57
22 15	78 15	69 84	32 52	32 54	15 12	54 02	01 37	38 37	12 93
93 29	12 18	27 30	30 55	91 87	50 57	58 51	49 36	12 53	96 40
45 04	77 97	36 14	99 45	52 95	69 85	03 83	51 87	85 56	22 37
44 91	99 49	89 39	94 60	48 49	06 77	64 72	59 26	08 51	25 57
16 23	91 02	19 96	47 59	89 65	27 84	30 92	63 37	26 24	23 66
04 50	65 04	65 65	82 42	70 51	55 04	61 47	88 83	99 34	82 37
32 70	17 72	03 61	66 26	24 71	22 77	88 33	17 78	08 92	73 49
03 64	59 07	42 95	81 39	06 41	20 81	92 34	51 90	39 08	21 42
62 49	00 90	67 86	93 48	31 83	19 07	67 68	49 03	27 47	52 03
61 00	95 86	98 36	14 03	48 88	51 07	33 40	06 86	33 76	68 57
89 03	90 49	28 74	21 04	09 96	60 45	22 03	52 80	01 79	33 81
01 72	33 85	52 40	60 07	06 71	89 27	14 29	55 24	85 79	31 96

There are other methods of using the Table of Random Numbers and the reader is again referred to the standard textbooks on statistics.

It will be appreciated that in addition to the numbering of packages for sampling, the principle can be extended to spindles, winding units, and other production points.

EXAMPLES OF SAMPLING METHODS FOR YARNS

The following are extracted from the B.S. Handbook and are included to illustrate how sampling procedures differ according to the test considered.

*The determination of yarn count (B.S. 2010 : 1953)**

Take a unit sample of either sixteen or eight packages as defined below. Unless otherwise required by the materials specification or contract, the number of skeins to be taken from the unit sample for the test is sixteen. Wherever practicable, take these skeins from sixteen separate packages.

*See also B.S. Handbook No. 11, p. 113

For spun yarns from cops, spinning frame bobbins, tubes, or other forms of primary package, take sixteen packages; the skeins should be wound from the top portions of eight of the packages and from about half-way through the remaining eight.

With large packages such as cones and cheeses, take eight packages and wrap two skeins from each; where this is done it is preferable to take one skein from the outer portion and one from near the middle. For continuous filament yarns, one skein only need be taken from the outside of each of sixteen cones or cheeses.

Count of yarn removed from fabric (*Textile Institute Tentative Specification No. 31, 1955*)

Cut from the conditioned fabric at least two rectangular strips containing different warp ends for determining the count of warp yarns, and at least five rectangular strips representing different weft packages for determining the count of weft yarns. All the strips should preferably be the same length and about 20 in. long. Their width should be such as to contain at least fifty lengths of either warp or weft yarn, whichever is under consideration.

Twist in yarn in package form (*B.S. 2085 : 1954*)

Take the test specimens in equal numbers from ten packages, no specimen being taken from within 1 yd of the end of the package. Allow a minimum distance of 1 yd between consecutive specimens.

Lea strength of spun yarns

Take twenty packages, from each of which a complete lea may be withdrawn. If twenty packages are not available a smaller multiple of four packages may be used, provided that in taking twenty leas equal numbers can be taken from each package of a group of four, e.g. eight packages, three leas from each of four packages and two leas from each of the other four packages.

Single thread tensile test (*for C.R.T. Pendulum Tester*)

Specimens may be taken from any type of yarn package, from an unwoven warp, or from a woven or knitted fabric. At least fifty specimens shall be taken for each test on single yarns and two-ply yarns of medium to fine count, but the number may be reduced to thirty for coarse two-ply and for cabled yarns. These shall be selected so as to be representative of the sample.

FABRIC SAMPLING METHODS

Almost every day the problem before the technologist in the testing laboratory is the extraction of the maximum amount of useful information from a minimum amount of material submitted for test. This is often the case where fabric testing is concerned; a sample with pocket handkerchief dimensions or less is accompanied by a request for comprehensive testing. Of course, if a number of patches were taken from random places throughout the whole length of a piece of cloth a good sample would be achieved, but in the process the piece would be left full of randomly distributed holes and of little value commercially. Therefore the expense of testing must be considered and where the fabric is available in the piece it is usual to take samples from the ends.

Some practical details for testing the tensile strength of cloths have been reported by the staff of the Testing Department of the B.C.I.R.A. (*J. Text. Inst.* **36**, S1 (1945)). Included in the article are suggestions regarding the selection of samples which can be usefully applied to tests other than tensile strength determinations. For example, it is pointed out that the region near the selvedges often possesses slightly different properties to the body of the cloth. Therefore fabric within, say, 2 in. of the selvedge should not be used. The reasons for these differences will be appreciated when one watches fabric being woven; the extra strains on the yarns at either side of the cloth are usually noticed and templing will also have its effects.

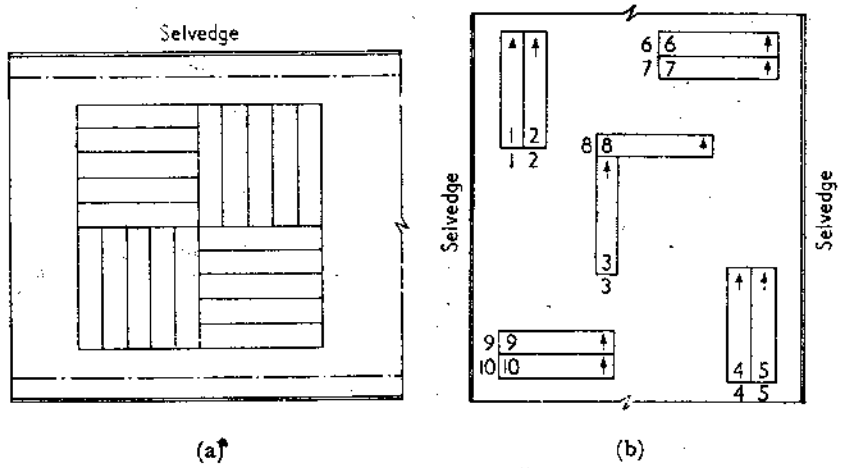


Figure 3.6. Fabric sampling

A second recommendation is that no two samples should contain the same threads; in other words, as many of the component threads as possible should be represented in the samples. Figure 3.6(a) and (b) show how this principle may be applied to the selection of strips of fabric for tensile tests. Incidentally, when weft way strips are selected it is suggested that some of the strips should include fabric woven from two weft packages. This is because the weft tension at the start of a fresh package may be much lower than the tension at the end of the old package, thereby giving rise to a change in the fabric structure and some variation in strength, an effect known as the 'cop end effect'.

In practice, the sampling method will depend upon the form and amount of material available; obviously narrow fabrics such as braids and ribbons will require different methods to those for wide fabrics. Nevertheless, the aim should always be to achieve as representative a sample as possible within the limitations imposed.

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4

MOISTURE RELATIONS AND TESTING

INTRODUCTION

Some of the most important properties of a textile fibre are closely related to its behaviour in various atmospheric conditions. Most fibres are hygroscopic, that is they are able to absorb water vapour from a moist atmosphere and, conversely, desorb or lose water in a dry atmosphere. Many physical properties of a fibre are affected by the amount of water absorbed—dimensions, tensile strength, elastic recovery, electrical resistance, rigidity, and so on. When in fabric form the moisture relationships of a fibre play a major part in deciding whether the fabric is unsuitable for a particular purpose. The importance of this point is appreciated when fabrics for clothing, both outerwear and underwear, are considered. Additional factors arise in these cases since the structural details of the fabric can modify the apparent behaviour of the fibre. For example, fabrics woven from a hydrophobic material such as 'Terylene' can pick up water by a 'wicking' action along the fibre and yarn surfaces.

The mechanism of water absorption is a subject beyond the scope of this present volume, but perhaps one or two points would be useful to bear in mind. In an orderly array of molecules the side chains will be linked, but in a random arrangement a number of free links or 'hooks' will be available, and if they are of a polar character (i.e. possessing an attraction for polar chemical groups such as hydroxyl OH, carboxyl COOH, carbonyl CO, etc.) then water molecules can attach themselves. Orderly arrays of molecules occur in the crystalline regions of the fibre structure and random arrays in the amorphous region. For a first approximation we could conclude that the absorption of water takes place in the amorphous regions. This is, of course, a simplified explanation of the absorption of water by fibres and the literature should be consulted for a detailed discussion.

An entertaining but nevertheless thought-provoking article by Hearle is entitled 'Moisture—Friend or Foe?' (*Skinner's Silk Ray. Rec.*, p. 640 (June, 1955)). In this article the views of numerous workers in this branch of textile science are discussed, some of the apparent contradictions explained, and many confused ideas on fibre/moisture relations clarified. For a fuller treatment of the subject, the reader is

referred to *Moisture in Textiles* (Eds J. W. S. Hearle and R. H. Peters) (Textile Institute; Butterworths, London, 1960); and also *Physical Properties of Textile Fibres* (Eds W. E. Morton and J. W. S. Hearle) (Textile Institute; Butterworths, London, 1962).

REGAIN AND MOISTURE CONTENT

The amount of moisture in a sample of material may be expressed in terms of Regain or Moisture Content.

Regain is defined as the weight of water in a material expressed as a percentage of the oven dry weight (oven dry weight will be defined shortly). Moisture content is the weight of water in a material expressed as a percentage of the total weight.

Let Oven dry weight $= D$
Weight of water $= W$
Regain $= R$
Moisture content $= M$

Then,

$$R = \frac{100W}{D} \quad \text{and} \quad M = \frac{100W}{D + W}$$

Also,

$$R = \frac{M}{1 - (M/100)} \quad \text{and} \quad M = \frac{R}{1 + (R/100)}$$

Atmospheric conditions and relative humidity

Among other things, the regain of a textile material depends upon the amount of moisture present in the surrounding air. The 'dampness' of the atmosphere can be described in terms of 'humidity', either absolute humidity or relative humidity. Both these terms are defined in the B.S. Handbook.

Absolute humidity. The weight of water present in a unit volume of moist air, i.e. grains per cubic foot or grams per cubic metre.

Relative humidity. The ratio of the actual vapour pressure to the saturated vapour pressure at the same temperature, expressed as a percentage.

$$\text{r.h.} = \frac{\text{actual vapour pressure}}{\text{saturated vapour pressure}} \times 100 \text{ (per cent)}$$

An alternative definition for relative humidity is the ratio of the absolute humidity of the air to that of air saturated with water

vapour at the same temperature and pressure. This ratio may then be expressed as a percentage. At ordinary temperatures such as those at which processing and testing are carried out, the two ratios are almost identical. It is convenient to describe a given atmosphere in terms of relative humidity rather than absolute humidity because the regain of textile materials appears to depend upon the relative humidity rather than the actual amount of water vapour present.

Since the relative humidity affects the regain of a textile material, and since the properties of the material are influenced by the regain, it is necessary to specify the atmospheric conditions in which testing should be carried out.

Standard atmosphere. This is defined as an atmosphere at the prevailing barometric pressure with a relative humidity of 65 per cent and a temperature of 20° C (68° F). Certain tolerances are allowed.

Testing atmosphere. An atmosphere for testing is specified as one with a relative humidity of 65 per cent plus or minus 2 per cent and a temperature of 20° ± 2° C (68° ± 4° F).

In tropical and sub-tropical regions the difficulties of achieving a temperature of 20° C are understood and so a higher standard temperature may be used—27° ± 2° C (81° ± 4° F).

THE MEASUREMENT OF ATMOSPHERIC CONDITIONS

The instruments used in the determination of the humidity are known as hygrometers or psychrometers. There are methods such as the gravimetric, chemical, and the dew point methods which may be used, but as they are not commonly used in testing laboratories or mills they are only mentioned here in passing. Details of these methods will be found in standard physics textbooks.

The three main types of instrument are:

(1) Wet-and-dry bulb hygrometer
(2) Hair hygrometer
(3) Electrolytic hygrometer

The wet-and-dry bulb hygrometer

If the bulb of a thermometer is surrounded by a wet sleeve of muslin in an atmosphere which is not saturated, water evaporates into the air at a rate which is proportional to the difference between the actual humidity and 100 per cent humidity, i.e. saturation conditions.

Further, since the evaporation is accompanied by cooling, the temperature indicated by the thermometer will be less than the

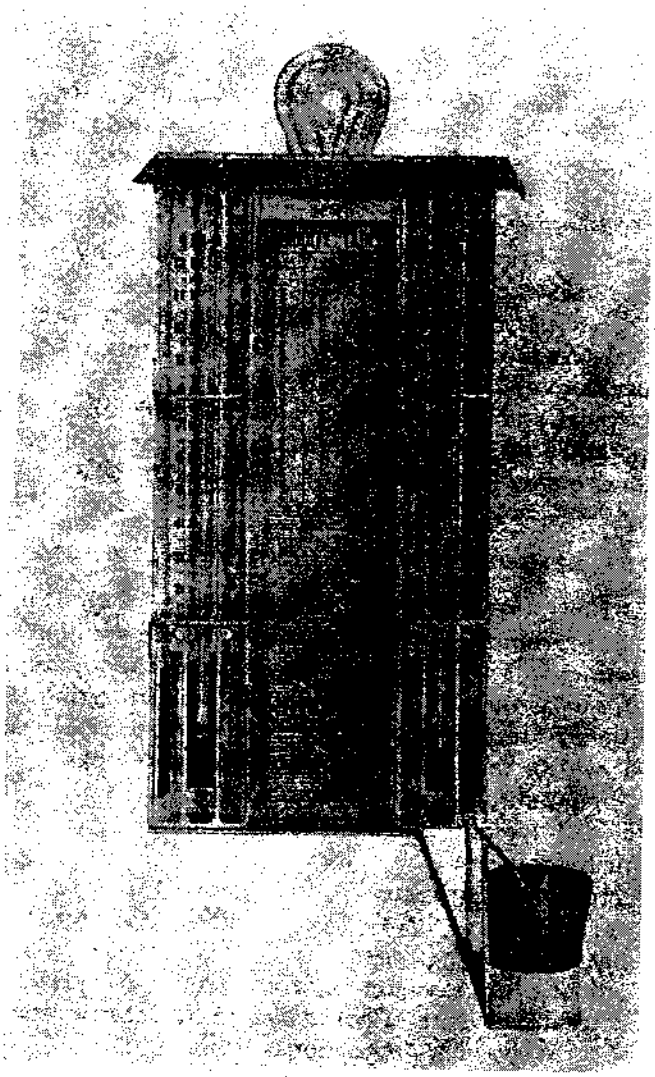


Figure 4.1. Wet-and-dry bulb hygrometer, wall mounting (10 in. tubes)

room temperature. By mounting identical thermometers in a frame and arranging one of them to have a wet muslin sleeve over its bulb, two temperatures can be read directly, the dry bulb and the wet bulb. The difference is noted and Tables consulted from which the percentage r.h. is derived. For example,

Dry bulb reading	= 68° F
Wet bulb reading	= 61° F
Difference	= 7° F
R.H. per cent from Tables	= 67

A typical instrument of this type is shown in Figure 4.1. The muslin sleeve, or wick, dips into a reservoir of distilled water. A Table is printed between the two thermometers. For factory use this type of hygrometer serves its purpose, but, due to radiation effects and lack of suitable air movement around the instrument, the results are not sufficiently accurate for use in testing laboratories.

Alternative designs of wet and dry bulb are available, such as the sling or whirling hygrometer and the Assmann hygrometer. In the sling hygrometer the thermometers are mounted in a frame pivoted on a handle. This enables them to be whirled round at 2 or 3 rev/sec so that the air speed past the wet bulb is at least 15 ft/sec. After about ½ min the whirling is stopped and the wet bulb thermometer read immediately. This procedure is repeated three or

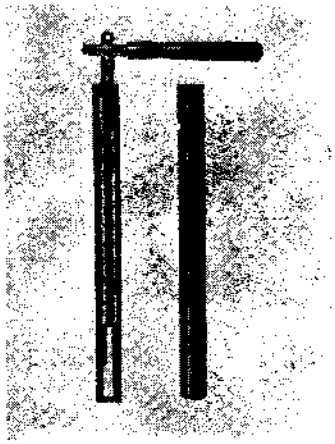


Figure 4.2. Wet-and-dry bulb hygrometer, Sling type (11 in. tubes)

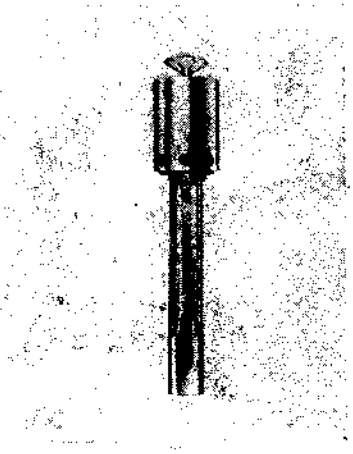


Figure 4.3. Assmann-type hygrometer (11 in. tubes)

four times until a minimum reading is obtained. As before, the difference between the wet and dry bulb temperatures is noted and Tables consulted for the percentage r.h.

The Assmann hygrometer is a more refined instrument. Two very accurate thermometers are mounted inside a perspex case with their bulbs in separate air ducts. One bulb has a closely fitting muslin sleeve which is wet out with distilled water. A clockwork or electrically driven fan draws air through the ducts and past the bulbs. When the wet bulb thermometer indicates a steady value both thermometer readings are taken and the percentage r.h. calculated from the Tables. Figures 4.2 and 4.3 show Sling and Assmann types of hygrometer.

Mercury-in-steel instruments

Hygrometers are available in which the mercury of the thermometers is contained in cylindrical steel bulbs, the dry bulb copper-plated and the wet bulb covered in tin. The bulbs can be mounted some distance away from an indicating dial on which two pens trace out the temperature changes on a circular chart which rotates either once per day or once per week.

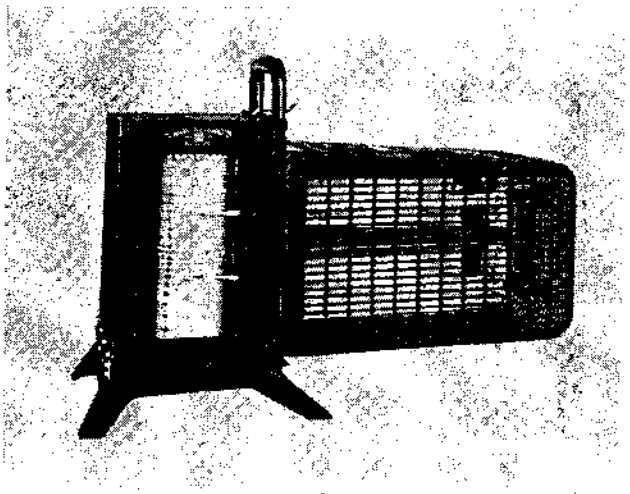


Figure 4.4. Thermo-hygrograph (total height of chart is 7 in.)

The hair hygrometer

Human hair has the property of lengthening or shortening as the humidity of the surrounding air increases or decreases. By anchoring a band of hairs to a suitable lever system, the relative humidity may be indicated directly and, if required, recorded on a chart. Great accuracy is not claimed with this type of instrument; for example, to within 3 or 4 per cent for the range of humidity 30 to 80 per cent and temperature 50° to 70° F. A combined temperature and humidity recording instrument, called a 'thermo-hygrograph', is shown in Figure 4.4. This uses a bimetallic helical coil for the temperature measurement and a band of human hair for the percentage r.h. measurement.

The main advantages of the hair type of hygrometer are the direct readings and the elimination of the need for distilled water. Disadvantages are present, however, such as the frequent calibration against a more precise instrument and the rather slow response to changes in atmospheric conditions.

The electrolytic hygrometer

The heart of this type of instrument is an element consisting of a plastic frame carrying platinum-clad electrodes. Round these electrodes is wound a skein of very fine fibres impregnated with a chemical, such as lithium chloride, which has the property of very rapidly attaining equilibrium with the surrounding atmosphere. The electrical resistance of the chemical is governed by its moisture content and so, if a constant voltage is applied to the element, the current flowing will vary with changes in the percentage r.h. of the atmosphere. The variation in current is translated into pointer movement over a scale or dial graduated in per cent r.h.

The advantage of this type of instrument is its rapid response to changes in the humidity of the surrounding air, only about ½ min being required before the direct reading can be taken. In addition, only low air currents are needed, therefore forced air circulation is unnecessary. Where required, of course, the instrument may be modified to produce a permanent record of the changes in the percentage r.h.

THE CONTROL OF THE TESTING ROOM ATMOSPHERE

In the previous sections the instruments described are those used in the *measurement* of the percentage r.h., but it is often necessary to *control* the atmospheric conditions of a work room or testing labora-

tory. Some of the instruments described can be modified so that an air conditioning plant is controlled by them. Such control instruments are referred to by the makers as 'hygrostats' or 'humidostats'.

One controlled system is shown in a simplified form in Figure 4.5, which represents the system used in the testing laboratory of the Bolton Technical College. The thermostats and hygrometer control valves operate by compressed air. The air input to the conditioning plant may come from outside or be recirculated air, or a mixture of both. In all instances it is filtered before heating and conditioning. A fan blows the conditioned air into the laboratory through special ducts with louvred outlets in the ceiling. All the windows are double glazed to prevent condensation in cold weather, and double doors are used to prevent unwanted air coming in from the corridor when people pass in and out of the laboratory.

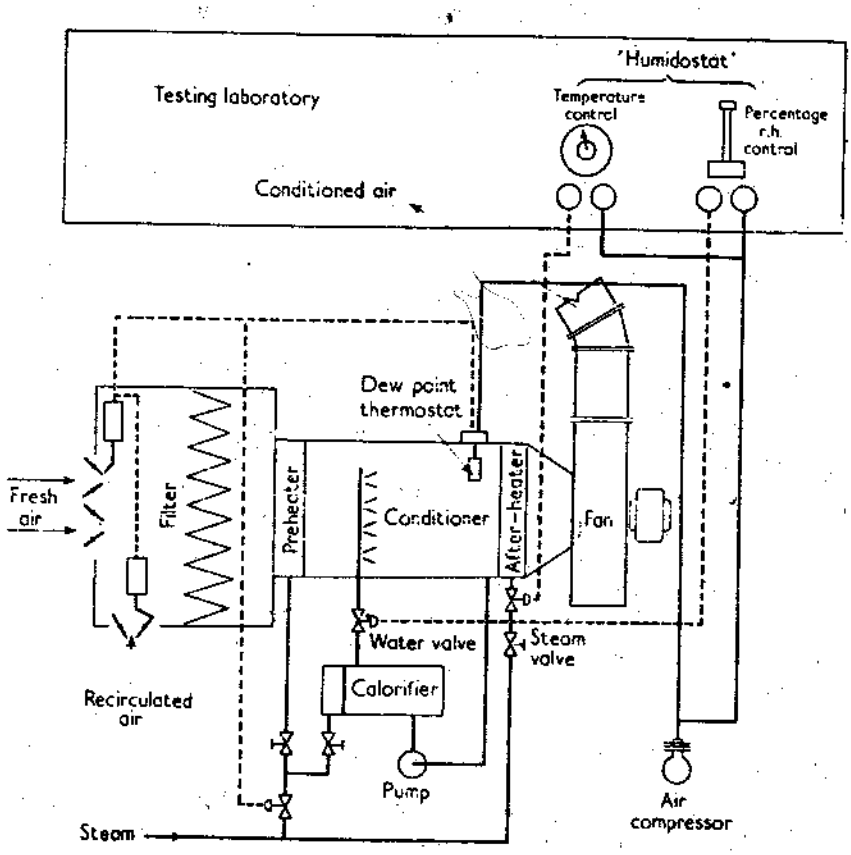


Figure 4.5. Air conditioning system for the textile testing laboratory at Bolton Technical College

Where a large air conditioning plant is not justified a self-contained unit can be installed. In the Reynolds and Branson automatic unit two 'towers' are used, one for adding moisture and one for subtracting moisture from the air. Each tower draws in air from near floor level by an exhaust fan and discharges the air in an upwards direction. The wetting unit consists of a double walled cylinder which is packed with either fine washed coke, pumice, or high contact porcelain rings. A sprinkler fed from an automatic siphoning tank keeps the unit saturated with water. The drying unit contains silica gel for the drying agent.

Table 4.1

Solid phase	t (*deg. C*)	*Relative humidity* %
$H_3PO_4.\frac{1}{2}H_2O$	24	9
$LiCl.H_2O$	20	15
$KC_2H_3O_2$	20	20
$CaCl_2.6H_2O$	24·5	31
$CaCl_2.6H_2O$	18·5	35
$Zn(NO_3)_2.6H_2O$	20	42
KnO_3	20	45
$Ca(NO_3)_2.4H_2O$	24·5	51
$Ca(NO_3)_2.4H_2O$	18·5	56
$NaBr.2H_2O$	20	58
$Mg(C_2H_3O_2)_2.4H_2O$	20	65
$NH_4Cl + KNO_3$	25	71·2
$NaClO_3$	20	75
NH_4Cl	20	79·5
$KHSO_4$	20	86
$ZnSO_4.7H_2O$	20	90
$NaSO_3.7H_2O$	20	95
$Pb(NO_3)_2$	20	98

(The Table shows the relative humidity percentages at the given temperature within a closed space when an excess of the substance indicated is in contact with a saturated aqueous solution of the given solid phase. (N.B.—This Table is a condensed version from the *Handbook of Chemistry and Physics* and is reproduced by kind permission of the Department of Chemistry at the Case Institute of Technology, Cleveland, Ohio.))

Constant humidity may be achieved by using solutions of sulphuric acid at different densities (see *Handbook of Chemistry and Physics* (35th Edn.), p. 2310).

The automatic control of the humidity is accomplished by means of a sensitive hair suspension which, in conjunction with vacuum relays, operates the wetting and drying fans. Temperature control is

provided by a thermostatically controlled heater of 1 kW. The room temperature is brought to within a few degrees of the desired controlled temperature, preferably by a space heating system which will ensure a reasonably constant temperature. The 1 kW heater will then raise the temperature to, and maintain it at, the desired level. As in the case of the large scale system, it is desirable to have double glazing and double doors. On an even smaller scale, a cabinet can be given automatically controlled humidity and temperature.

To obtain various percentages of r.h. in a small cabinet a simple method is to use solutions of different acids and salts. When left to reach equilibrium in a given space these solutions produce certain steady relative humidities. These solutions and the corresponding r.h. percentages are given in Table 4.1.

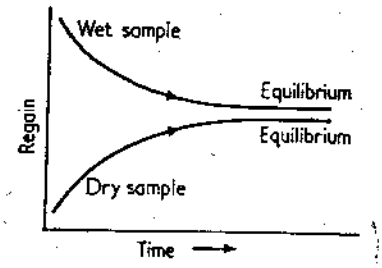


Figure 4.6. Regain–time curves and hysteresis

REGAIN–HUMIDITY RELATIONS OF TEXTILES

Suppose two samples of the same material were taken into a given atmosphere, one completely wet and the other dry, and at intervals of time the regain values for each were determined. By plotting the regain against time for both samples two curves would be obtained something like those in Figure 4.6. The regain changes fairly quickly at first and then more slowly as equilibrium conditions are approached. One might expect that the two curves would meet, but curiously enough the equilibrium regain values differ. The sample which was originally wet has a higher regain value than the other, an effect known as 'hysteresis' (look up the hysteresis effect in magnetism for comparison). The behaviour of textile materials can be studied from the curves produced by plotting regain against relative humidity (see Figure 4.7). Curve A is the absorption curve, that is, the regain–r.h. percentage relation as a material takes up moisture. Curve D is the desorption curve. These curves have a

characteristic sigmoid or 'S' shape. It should be noted that the desorption curve does not follow back the absorption curve. For instance, point b is the equilibrium condition at 65 per cent r.h. when approached from the wet side, and point a is the equilibrium regain when approached from the dry side; this is the hysteresis effect mentioned earlier. A sample which absorbed moisture up to point c would, if the atmosphere became drier, follow an intermediate course from curve A to curve D. Similarly, a whole family of curves could be drawn to illustrate varying conditions.

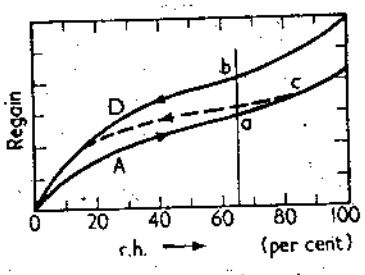


Figure 4.7. Absorption–desorption curves

Absorption curves of various materials (*see Figure 4.8*)

The following should be noted with regard to absorption curves:

(1) The similarity of the general shape of the curves, S-shaped except for acetate rayon. In the acetate molecule the OH groups of cellulose which attract water are replaced by the acetate groups which are relatively inert and do not attract water rapidly; there is no sharp increase at the lower end of the curve.

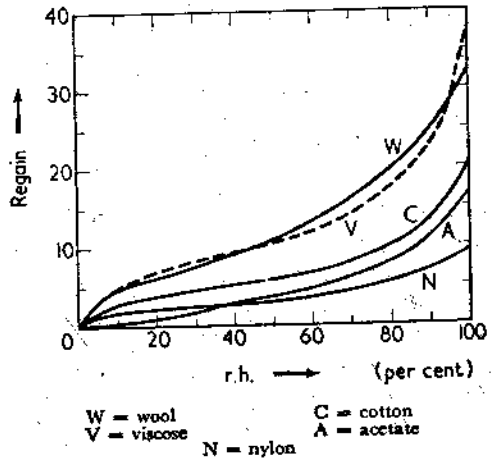


Figure 4.8. Absorption curves for various materials

(2) Wool and viscose rayon exhibit similar absorption curves. Different results appear for various wools, depending on the previous history of the material tested.
(3) The low absorption properties of the synthetic fibre nylon is one of the reasons for the difficulties of dyeing and finishing such material.
(4) The intermediate position of cotton between wool and viscose, and the synthetics.

Some factors affecting the regain of textile materials

Relative humidity. This has just been discussed.

Time. A material placed in a given atmosphere takes a certain amount of time to reach equilibrium. The 'rate of conditioning' depends on several factors, such as the size and form of the sample, the material, external conditions, etc. The rate of change of moisture content is discussed by J. Crank in Chapters 7, 8, and 9 of the textbook *Moisture in Textiles.*

This time element is reflected in the procedures for testing set out in the B.S. Handbook. For example, in testing yarn for count it is recommended that: 'Prior to reeling condition the samples in the atmosphere for testing . . . for not less than one hour for yarn in hank, and for not less than three hours of yarn in all other types of package, and reel them in that atmosphere.'

Temperature. For practical purposes the effect of temperature on regain is not important, it is the relative humidity which plays the major role. A change of 10° C will give a change in the regain of cotton of about 0·3 per cent, but since it is unlikely that the testing room temperature will ever be 10° or 30° C this effect can be ignored.

The previous history of the sample. It has already been seen how the previous history of the sample can affect the equilibrium regain. The hysteresis effect is a good example. Processing can also change the regain. When oils, waxes, and other impurities are removed the regain may change. The official regain for scoured wool is 16 per cent and for oil-combed tops 19 per cent (see Table 4.2). In the study of regain values the physical and chemical history of the materials must therefore be taken into account.

The interpretation of regain values, absorption and desorption curves

A word of caution is necessary here to prevent false conclusions being drawn from Tables of regain and the graphs of the r.h.–regain relationships. The moisture relations of the *fibre* may not be directly related to the moisture relations of the *yarn* or *fabric.* For example,

Table 4.2. Allowances Based on the Dry Weight of the Sample Without Cleaning

Material	*Percentage addition to dry weight R*
Acrylic hand-knitting yarns	1½
Cellulose acetate staple tops and yarns produced by the wool textile industry	6
Cotton	8½
Flax and hemp	12
Polyamide 6 (nylon 6)	4
Polyamide 6·6 (nylon 6·6)	4
Silk	11
Sisal and manilla	12
Viscose rayon staple tops and yarns produced by the wool textile industry	11
Wool:	
Carbonised burrs	17
Carbonised card waste	17
Carbonised noils	17
Carbonised wool	17
Laps	18¼
Noils (Noble, Lister, or Holden combed)	14
Noils (Schlumberger)	16
Scoured wool	16
Thread waste (garnetted or mechanically pulled)	18¼
Thread waste (not garnetted or mechanically pulled)	16
Tops (dry combed)	18¼
Tops (oil combed)	19
Yarn (woollen and worsted)	18¼
Cloth (woollen and worsted)	16

fabrics produced from hydrophobic fibre such as 'Terylene' can hold large amounts of water, not *in* the fibre but *on* the fibre and yarn surfaces. Bulked yarns with large surface areas available can retain surprising quantities of free water. The problems confronting the technologist when designing a fabric for a specific purpose are obviously made even more complex by the changes in fibre behaviour when assembled in particular structural forms. The wetting and drying properties of fabrics is a subject on its own and the reader is referred to the literature cited.

Examples to illustrate some effects of regain on fibre properties

Dimensions. Absorption of moisture is accompanied by changes in the dimensions of fibres. Swelling is mostly transversal since the

water molecules penetrate between the more or less parallel molecular chains and exert their forces outwards (see Table 4.3). Although the Table shows that the length of the fibre increases due to absorbed moisture, the net result of absorbed moisture in fabrics is a decrease in length (i.e. shrinkage), again a function of the structure of the fibre assembly rather than the inherent fibre behaviour. Dimensional changes in the fabric as it passes from one atmosphere to another may result in the wrinkled appearance of suits tailored in one atmosphere and worn in others, especially in climates where high humidities are found.

Table 4.3. Dimensional Changes Due to Absorption of Moisture

Fibre	*Transverse or area swelling* (%)	*Axial or longitudinal swelling* (%)
Cotton	21[1]	1·1[2]
Wool	25[1]	1·2[2]
Viscose	60[1]	4·0–7·0[2]
Acetate	8[1]	0·3[1]
Nylon	3·2[1]	1·5[3]
Silk	19[1]	1·3–1·7[2]

Note: $\text{Swelling} = \dfrac{\text{swollen dimension} - \text{dry dimension}}{\text{dry dimension}} \times 100$ (per cent)

(1) Morehead. *Text. Res. J.* **17**, 96 (1947)
(2) Valko and Ott. 'Cellulose and Cellulose Derivatives.' *High Polymers*, Vol. V, p. 412 (Interscience, New York, 1943)
(3) Abbott and Goodings. *J. Text. Inst.* **40**, T232 (1949)
See also Preston and Nimkar. *J. Text. Inst.* **40**, P674 (1949)

Advantage of swelling is taken in the design of waterproofs. A close weave can be used which becomes even closer as the component yarns swell, thus preventing the penetration of water.

Mechanical properties. The general effect of water molecules in the fibre is to reduce the size of the forces holding the molecular chains together, thereby weakening the fibre. (Important exceptions to this are found when the vegetable fibres such as cotton and flax are considered—an increase in strength is noted.) Not only is the maximum strength reduced but the stress–strain curve assumes a different form. The yield point may be shifted, and applied loads, which on dry fibres would not cause damage, may stress the fibres beyond the lowered yield point.

Other mechanical properties affected by regain include extensibility, crease recovery, flexibility, and ability to be 'set' by finishing processes.

Electrical properties. The 'before and after' effect of moisture on the electrical resistance of textile materials is most striking. The ratio of the resistance at low regain and at high regain can be of the order of hundreds of thousands to one, a circumstance which has led to the design of moisture meters based on the measurement of resistance values of textiles.

Other electrical properties affected by the amount of moisture in the material are the dielectric characteristics and the susceptibility to static troubles. Changes in dielectric characteristics are a source of error in the measurement of the irregularity of slivers, rovings, and yarns on capacity type testers (see Chapter 8).

In processes where the regain of the product is required to be reasonably constant, e.g. in warp sizing and cloth finishing, both the resistance and the dielectric effects are utilised in the design of control systems; the Shirley Electrical Hygrometer uses the resistance principle and the Fielden Drimeter takes advantage of the dielectric effect (see Moncrieff, *Fibres* (Sept. and Dec., 1949)).

Thermal effects. When moisture is absorbed by textile materials heat is generated. This heat is referred to as the 'heat of absorption'. Suppose the dry weight of a sample is 1 g and it is then completely wetted, the heat evolved, expressed in calories per gram of dry material, is termed the 'heat of wetting'. A practical example of the importance of this effect is seen when clothing is considered. In winter, a person passing from indoors to outdoors usually goes from a warm room with a low percentage r.h. into a cold environment with a higher percentage r.h. The regain, particularly of the outer garments, increases and heat is generated, so acting as a buffer to the sudden shock of a change in temperature which the body would otherwise suffer. Meredith, in *Fibre Science*, Chapter 12, gives some figures for illustration: 'In passing from a room at 18° C and 45 per cent r.h. into an outside atmosphere at 5° C and 95 per cent r.h., a man's woollen jacket weighing 1 kg will produce 100,000 cal of heat, i.e. as much heat as normal body metabolism will produce in 1 hr.'

The direct application of such theoretical facts in the design of clothing is not as simple as it might appear at first glance. A recent study is reported by Rodwell and associates in which they discuss the physiological value of sorption in clothing assemblies (*J. Text. Inst.* **56**, T624 (1965)).

THE MEASUREMENT OF REGAIN

The methods employed in the determination of regain vary in refinement and accuracy, and the method chosen may be directly related to the object of the test. In research work great accuracy is usually demanded and a period of several months may be required to complete the measurement. For many mill purposes speed of test is essential, and one of several rapid but less accurate methods may be used. For commercial purposes where goods and materials are bought on a weight basis, certain official allowances have been agreed upon for the various types of materials (see Table 4.2). These values are only *approximately* the regains which the materials would exhibit when in equilibrium with a standard atmosphere. These allowances are used in the calculation of invoice weights.

From the definition of regain, i.e. the weight of moisture in a material expressed as a percentage of the oven dry weight, it follows that the basic method of measuring regain must be to weigh the sample in its original condition, to dry it, and then to weigh it again. The 'oven dry weight' is defined as 'the constant weight obtained by drying at a temperature of 105 ± 3° C'. In B.S. 1051: 1964 the drying conditions specified include a recommendation to use a ventilated drying oven with a positively induced air current. When successive weighings at intervals of 20 min differ by less than 0·05 per cent, it may be assumed that a constant weight has been reached.

An adequate sampling scheme should always be used where possible so that the samples on which the tests are made are representative of the bulk. Sometimes the samples contain oils, sizes, and other types of added substances which should be removed before oven drying. Recommended methods of doing this are given in Appendix C of B.S. 1051:1964. Since an accuracy of one part in 2,000 is demanded in the weighing, it is obvious that a larger sample permits the weighings to be less precise than if a small sample is tested. For example, a 200 g sample requires weighing to 0·1 g, whereas a 20 g sample would need weighing to 0·01 g. To prevent moisture absorption during the transfer from the drying oven to the balance, the weighings should be made with samples remaining in the oven; alternatively the material is weighed in tared stoppered containers.

Correct invoice weight

In commercial transactions where textile materials are paid for by weight it is clearly necessary to have agreement between buyer and

seller on the exact weight to be paid for. The buyer certainly does not wish to pay for excess water at the price per lb of the textile material. A 'correct invoice weight' is therefore determined. When a consignment is delivered and weighed a sample is taken and tests made to enable the correct invoice weight to be calculated. The first step is to determine the oven dry weight of the sample. This may be found either with or without cleaning the sample before taking it to constant weight in the drying oven.

Let W = the weight of the consignment at the time of sampling
d = the oven dry weight of the sample (either with or without cleaning)
S = the original weight of the sample
C = the oven dry weight of the consignment.

Then $C = W \times \frac{d}{S}$

For samples dried out without cleaning,

$$\text{Correct invoice weight} = C \times \left(\frac{100 + R_1}{100}\right)$$

where R_1 is the official allowance (see Table 4.2).

For samples dried out after cleaning,

$$\text{Correct invoice weight} = C \times \left(\frac{100 + R_2 + A_2 + B_2}{100}\right)$$

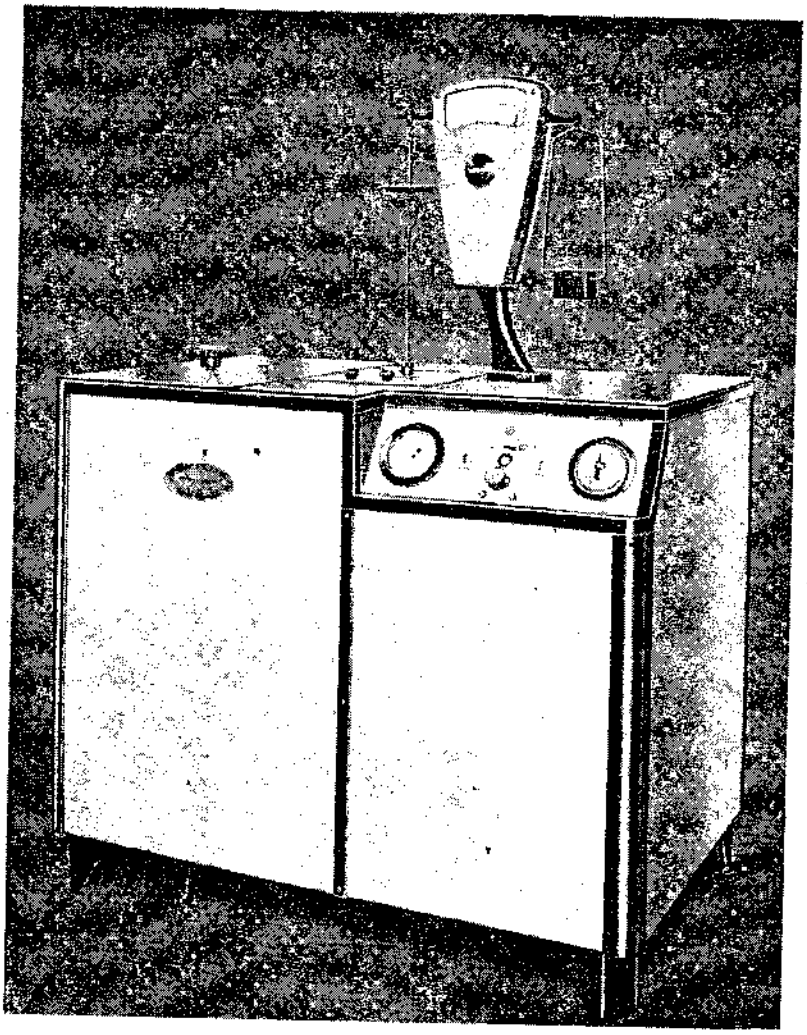
where $(R_2 + A_2 + B_2)$ is the total allowance for moisture regain, natural grease, wax, fatty matter, added oil, dressing, etc.

In B.S. 1051:1964 a special table provides the R_2, A_2, and B_2 values. If a blended sample is considered and the relative proportions of each component is known, the allowance can be calculated. For example, if the blend is an 80/20, cotton/nylon mixture, the allowance is calculated:

$$\left(\frac{80}{100} \times 8{\cdot}5\right) + \left(\frac{20}{100} \times 4\right)$$
$$= 6{\cdot}8 + 0{\cdot}8 = 7{\cdot}6\%$$

Moisture testing ovens

The manufacturers of testing instruments offer moisture testing ovens which conform to the standards set out in B.S. 1051:1964 and at the same time simplify the work. One example is that made by Heal, shown in Figure 4.9. Features of the oven include:



(*By courtesy of James H. Heal & Co. Ltd*)

Figure 4.9. Moisture testing oven

(1) Forced hot air draught thermostatically controlled.
(2) An automatic balance to eliminate the need to use small loose weights.
(3) Weighing is carried out with the sample inside the heated compartment with the lids closed.
(4) A preheater in which samples weighed in their original condition can be partly dried before transfer to the main oven, thus saving time.

The determination of the regain by the use of this type of tester is direct and follows the recommended procedure. Methods which are indirect, using one or another of the effects of regain, are checked against the drying oven method for accuracy.

The W.I.R.A. rapid drying oven

The Wool Industries Research Association have developed a new drying oven which can bring a 1 lb sample of textile material from normal regain to dry weight at an accuracy of 0·02 g in from 4 to 6 min. Apart from the heating system, this new oven features a Sartorius direct-reading balance, capable of weighing to an accuracy of 0·02 g, sited over the oven. The balance has provision for attaching the pan to its underside. External means have been devised for connecting the pan to the balance without opening the oven door, and a safety device to preclude overloading the balance is incorporated. For ½ lb and core samples a smaller sample holder is used to maintain the correct packing density and minimum drying times.

THE OVEN DRY WEIGHT OF WOOL

When samples of textile materials are taken to oven dry weight in a ventilated drying oven constant weight is assumed to have been attained when successive weighings at intervals of 20 min differ by less than 0·05 per cent. In the case of wool a correction is made for the moisture present in the hot air used for drying.

$$\text{Percentage correction} = 0{\cdot}053\left(9{\cdot}470 - \frac{622er}{760 - er}\right)$$

where r is the relative humidity $\frac{\text{per cent}}{100}$, and e is the saturation vapour pressure in mm Hg.

Errors due to buoyancy and convection effects

When a sample is weighed whilst still in the hot drying container, buoyancy and convection effects can lead to errors in the dry weight

of the sample. Such errors may exceed 1 per cent in some cases. Mackay and O'Donnell have studied this problem (*J. Text. Inst.* **55**, T333 (1965)). They suggest that by using steel wool as a sample, i.e. a non-hygroscopic material, the mill laboratory may experiment and determine the value of the correction weight needed to compensate the buoyancy and convection effects. It is suggested that the error due to hot weighing can be kept below 0·1 per cent of regain.

Drying by means of a chemical oven

Where a special drying oven is not available, an ordinary chemical drying oven may be used in conjunction with glass weighing bottles fitted with ground-glass stoppers and an analytical balance. It is convenient to number the weighing bottles and to record their weights if moisture determinations are to be fairly frequent. The testing procedure is straightforward but a point to watch is that the weighing bottle must be placed in the oven with its stopper across the mouth, and in transfer from oven to balance the stopper must be fitted so that moisture is not picked up. Cooling in a desiccator before weighing is recommended. The drying and weighing should be repeated to check that all the moisture has been removed, or at least the oven dry weight has been reached and is constant.

Calculation of the regain

Weight of bottle + stopper = W_1

Weight of bottle + stopper + sample (moist) = W_2

Weight of bottle + stopper + sample (dry) = W_3

Therefore,

$$\text{Weight of moisture} = W_2 - W_3$$

$$\text{Regain} = \frac{\text{weight of moisture}}{\text{oven dry weight}} \times 100$$

$$= \frac{W_2 - W_3}{W_3 - W_1} \times 100 \text{ (per cent)}$$

Drying by means of a concentrated hot air current

This method still uses the basic principle of weighing the sample in its original condition, driving off the moisture, re-weighing, and calculating the regain from the weighings. The samples are weighed in tared containers fitted with caps over each end. When the weighing is carried out solid caps are used, but when the container is

pushed into the drying unit one cap is removed and the other replaced by a perforated cap to prevent loss of material and to allow the passage of air. A thermostatically controlled current of hot air is blown through the sample for about 15 min, after which the solid caps are replaced and the container weighed. The process is repeated, this time drying for about 5 min. When successive weighings indicate that a constant weight has been reached, the regain is then calculated. An example of this type of instrument is the Reynolds and Branson 'Rapid Regain' apparatus (see Figure 4.10).

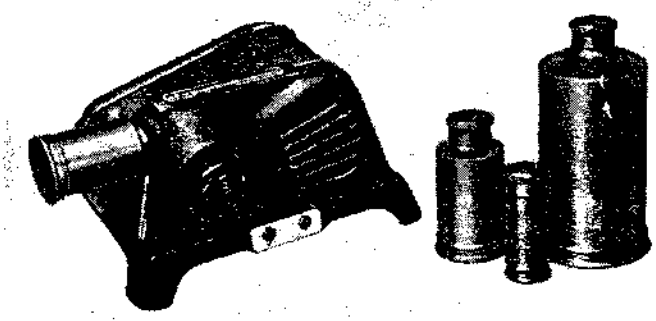


Figure 4.10. The Reynolds and Branson 'Rapid Regain' tester. Note the tared metal containers and thermostat control

THE C.S.I.R.O.* DIRECT READING REGAIN TESTER

The determination of regain by using hot air for drying the material normally requires a certain amount of calculation based on the weights of containers and the sample weight before and after drying. Time is required for the laboratory staff to collect the sample, to carry out the test, and to report the results to the interested parties. The need for a regain tester which can be operated by mill opera-

*Commonwealth Scientific and Industrial Research Organisation.

tives for purposes of mill process control, and which will give quick, but accurate results, has led to the development of the C.S.I.R.O. Direct Regain Tester.

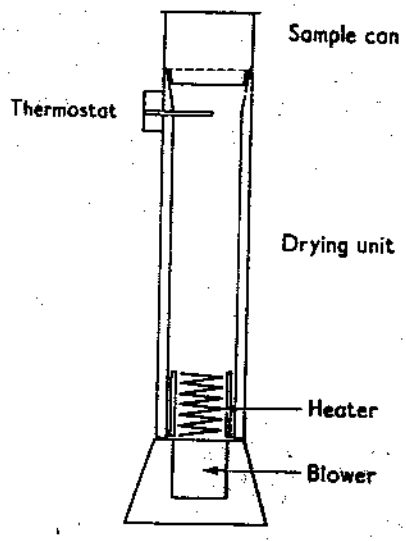


Figure 4.11. Sketch of C.S.I.R.O. Direct Regain Tester

The rapid drying device is a vertical free-standing unit about three feet. It consists of a heater, a thermostat control, and an air blower. An aluminium sample can which fits in the top of the dryer has perforations both in the base and the lid to allow the passage of air but small enough to prevent the loss of any of the sample.

A proportional balance is used and this gives a pointer deflection which depends upon the ratio of the undried weight W_2 to the dried weight W_1 but is independent of the actual values. This eliminates the necessity for calculation.

$$\text{Percentage regain} = 100 \times \frac{\text{Weight of moisture}}{\text{Dry weight of sample}}$$

$$= 100 \times \frac{W_1 - W_2}{W_2}$$

$$= 100 \times \left(\frac{W_1}{W_2} - 1\right)$$

The lever-type proportional balance indicates the ratio W_1/W_2 and thus the scale may be calibrated directly in percentage regain.

To make a test the wool is packed firmly into the can so that channelling of the hot air is minimised. The cold can and sample are placed on the balance and the instrument is adjusted to read zero. The can is then clamped in the dryer and hot air blown through for about six minutes. The hot can and dried sample are replaced on the balance and the pointer indicates regain directly. If required, the scale can be calibrated to read moisture content. The range of the apparatus is from 1·5 per cent to 30 per cent regain. A small correction weight is incorporated in the weighing system to compensate for buoyancy and convection errors when the hot can is weighed. It is stated that the accuracy of this instrument is within $\pm 0{\cdot}5$ per cent and if a further correction is made for the moisture content of the air the accuracy can be $\pm \frac{1}{3}$ per cent.

Drying by infra-red radiation

The accent on speed of testing is illustrated by the Townson and Mercer instrument which employs an infra-red lamp to dry out the sample. A 5 g sample is used, a constant original weight which enables the balance incorporated in the instrument to be graduated in percentages of moisture instead of grams. Times quoted for the test include 3 min for viscose fibre and 8 min for cotton. The accuracy claimed is that the results are reproducible to within 0·2 per cent with unskilled operators.

Drying by desiccator

For routine mill testing the time required for drying by desiccator is too great, but for research a desiccator may be necessary.

The W.I.R.A. electrical hygrometer

This instrument has been designed to determine the regain of material in the interior of a wool bale or a roll of textile material. Figure 4.12 shows the general design of the instrument. Before describing the operation of this device it would be useful to explain that a thermistor is a semiconductor whose electrical resistance varies greatly with variation in temperature. It is very small and therefore requires an air flow of much lower velocity, for obtaining the true wet bulb temperature, than a standard thermometer. An additional advantage of the small size, and small heat capacity, is that equi-

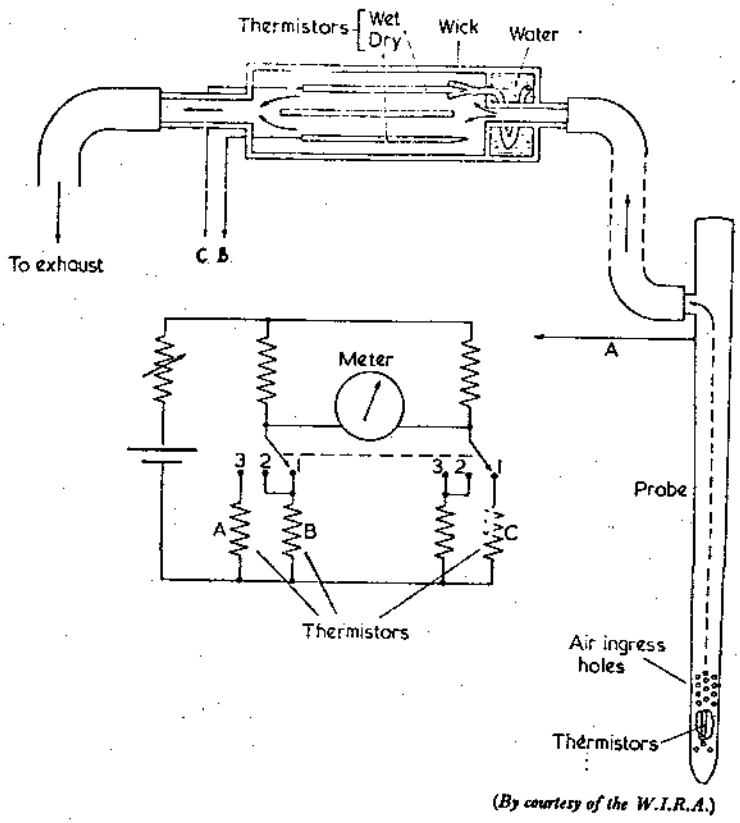


Figure 4.12. The W.I.R.A. electrical hygrometer

librium reading is reached very quickly. Furthermore, electrical instruments are much easier to read accurately because the reading is given on a dial.

The probe, containing a thermistor in the end, is inserted in the material. Air is drawn from the interior of the material over the thermistor (measuring the internal temperature) and then out and through an external chamber containing wet and dry thermistors. Thermistors A and B form one arm of a bridge of which C forms an opposing arm. With the switch in position 1 the meter reads the difference between wet and dry bulb temperatures in the external chamber. In position 2 the meter reads dry bulb-temperature in the external chamber and in position 3 the temperature in the interior of the material (probe temperature). From these three readings the regain of the material can be derived.

Three points must be appreciated:

(1) Relative humidity is the ratio, expressed as a percentage, of the water vapour in the atmosphere to the saturation water vapour pressure.

(2) The saturation water vapour pressure is known accurately for any temperature and can be read off from published Tables; consequently, if the water vapour pressure can be measured, relative humidity can be immediately determined at any temperature.

(3) The water vapour pressure in the atmosphere does not change when the atmospheric temperature changes, provided that no water is added or subtracted.

The W.I.R.A. electrical hygrometer makes use of the above relations in the following way. The probe is inserted deep into the material and air is sucked through the probe past the thermistor in its end (the interior temperature is measured). The air is continually being moved past the fibres in the interior, so the water vapour pressure is that of the interior when in equilibrium. Now, when the air emerges from the probe and reaches the instrument its temperature will have changed; it will approach room temperature owing to the conduction of heat through the walls of the piping. But the water vapour pressure will be unaltered, see (3) above, because no air will have leaked in or out.

By using appropriate switching the dry bulb temperature and difference between dry and wet bulb temperatures are observed and the water vapour pressure can be read from Tables—see (2) above. This vapour pressure will also be that of the interior, so that dividing it by the saturation vapour pressure corresponding to the probe temperature we obtain the relative humidity at the probe. From Tables or graphs giving the relationship between relative humidity and regain for the material being tested, the regain of the material is determined.

Note: due to hysteresis, there is a difference between the regain of materials approaching equilibrium from the dry side and those approaching it from the wet side. If this is not taken into account there may be an error of up to about 1·0 unit of regain. However, in practice it is usually known whether the material is approaching equilibrium from the dry or wet side, and the error can thus be much less, probably about 0·3 unit of regain. (The description of this instrument has been taken from the literature of the Wool Industries Research Association.)

INSTRUMENTS USING EFFECTS OF REGAIN ON ELECTRICAL PROPERTIES OF TEXTILE MATERIALS

Resistance methods

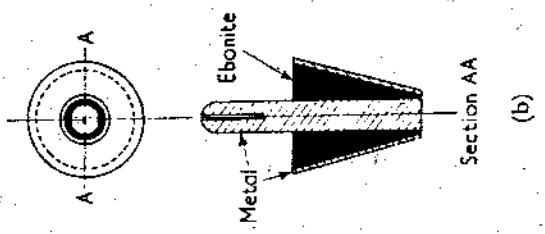
The enormous difference in the electrical resistance of a textile material at various regain values offers a method of estimating the regain indirectly by resistance measurement. Two examples of instruments based on this effect are the Shirley moisture meter and the Hart moisture meter.

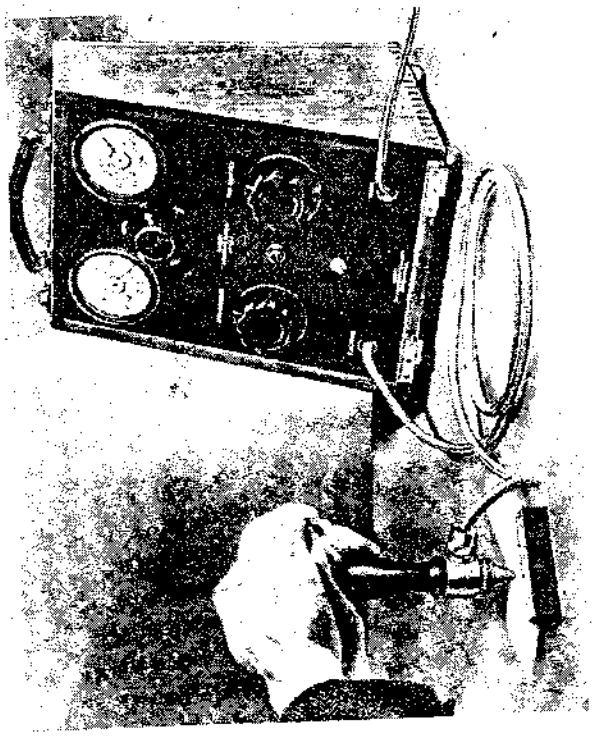
The Shirley moisture meter. This instrument, see Figure 4.13, is manufactured by the Record Electrical Co. Ltd, and was specifically designed for the measurement of the regain of raw cotton and grey cotton yarns. However, Tables are available which enable the operator to test other materials and convert the indicated regain to corrected values. The electrodes consist of a central conductor insulated from an outer circular sheath. When pressed into the cotton, the fibres bridge the insulation and their resistance is measured. Two electrodes are used, one for raw cotton and the other for yarns, the difference being that for yarns the spacing between the conducting elements is increased. This counteracts the increased conductivity of yarns due to the more or less parallel arrangement of the fibres compared with the random arrangement of the fibres in loose cotton. The indicating unit translates the resistance value into a regain reading on one of two dials. One dial covers the normal range of regain values from about 7 to 11 per cent and the other caters for two ranges, 'Damp' from 9 to 15 per cent and 'Dry' from 5 to 9 per cent.

To make a test the correct electrode is fitted into a holder and the instrument adjusted to 'Zero' and 'Maximum' readings for checking the pointer indication. A firm pressure is then used to bring the electrode and the fibre into close contact and the regain is read off directly. To save tiring the operator by repeated testing, a constant pressure device is available which spring loads the electrode holder to a 45 lb/in^2 pressure. A range of other types of electrodes are available to enable tests to be made on wool yarns, viscose cakes, wood pulp, powders, etc.

In a series of comparative tests against the oven method it was found that for 84 per cent of the results the differences between the oven and the Shirley moisture meter regain values were 0·3 per cent or less. Reasons for the differences include variation (within samples), errors in the oven test, and differences in the electrical properties of various cottons.

The speed of the test enables a number of values to be obtained from various parts of the material and an average value to be calculated. A particular point to note is that dyeing and other chemical treatments alter the electrical properties of the material and it is not always possible to calibrate and draw up conversion tables with a sufficient degree of accuracy. It should be noted that caution must be used in testing materials so treated.





(a)

Figure 4.13. The Shirley moisture meter: (a) Indicating unit; (b) Electrode

The Hart moisture meter. In this instrument, manufactured by Geoff. E. Macpherson Ltd, the regain is not indicated on the meter scale. Instead, the resistance of the material, clamped firmly between flat, circular electrodes, is balanced to give a zero meter reading by a variable resistor. After removal of the sample, the resistance of the variable resistor is itself balanced by pressing a range of buttons successively until once again the meter reads zero. Depression of the buttons brings into circuit different standard values which are calibrated against the resistance of the material at known regains. A system of this type eliminates variation in meter readings caused by changes in the electrical characteristics of the circuits used, e.g. ageing valves, decreased battery voltages, etc.

The range extends from 2 per cent in the case of cotton and linen (5 per cent for wool) up to 20 per cent. An accuracy of 0·25 per cent is claimed in the dry range from 2 to 18 per cent. An additional feature of this meter is a static suppressor which ensures that a steady meter needle is obtained when testing fabrics in spite of atmospheric conditions or stray electrical fields. An account of this instrument is given by Toner, Bowen, and Whitewell in *Text. Res. J.* **18**, p. 526 (1948); and **19**, p. 1 (1949).

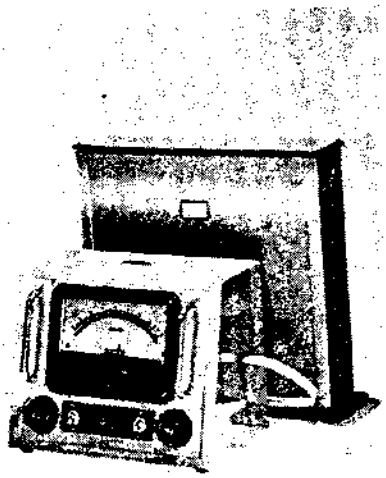
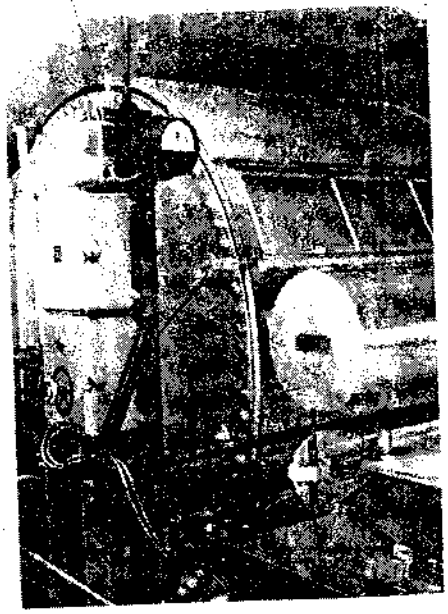


Figure 4.14. The Shaw Type 2 moisture meter. Note the plastic container

Capacity methods

The Shaw moisture meter Type 2. This instrument, see Figure 4.14, is designed for the measurement of moisture in wool and is unaffected by temperature changes or the oil content in the tops. A $\frac{1}{2}$ lb sample is placed in a tall plastic container and compressed by a specially shaped lid to a constant pressure (the lid weight) and the tester switched on. Moisture affects the dielectric properties of the wool, the change being dependent on the regain. The measuring circuit, therefore, estimates the regain by measurement of the dielectric characteristic of the sample and the scale of the meter is therefore graduated in regain value. The makers state that over 95 per cent of wool combers in Great Britain use this type of meter with satisfactory results.

The Fielden Drimeter. A brief outline of this device, which is manufactured by Fielden (Electronics) Ltd, is included here to illustrate the importance of the control of regain in processing and how a measuring principle can be used as a basis of a control system. Figure 4.15 shows the electrode unit on a warp sizing frame. The material



(By courtesy of Fielden (Electronics) Ltd)

Figure 4.15. Processing application of capacitance principle

passes between the two plates which form an air spaced condenser. Variation in regain produces variation in the dielectric constant of this condenser and this change in the capacitance is measured electronically and indicated on a meter in terms of regain. Suitable circuits can be designed to control the speed of the machine so that the delivered yarn has a uniform regain.

The Forté electronic moisture content analyser. One of the problems associated with the measurement of moisture in wool is the difficulty of obtaining truly representative samples from balls of top. The moisture is not uniformly distributed and variation is observed when testing wool samples drawn from the outside and inside of a ball of top. To avoid the sampling problem the Forté electronic moisture content analyser tests the complete ball using the capacity method on a large scale. In an article on this instrument (*Text. Inst. Ind.*, p. 256 (Nov. 1964)) Breen points out the advantages of this method:

(1) No physical or electrical contact need be made with the sample being tested.

(2) The electrical field which passes through the entire sample produces a scale deflection proportional to the average moisture content.

(3) The capacitance method is quick, the time constant of the Forté analyser being a few milliseconds, and an actual measurement including handling of the ball of top requires only 30 sec.

(4) The capacitance test is completely passive and harmless to the wool and no waste is generated.

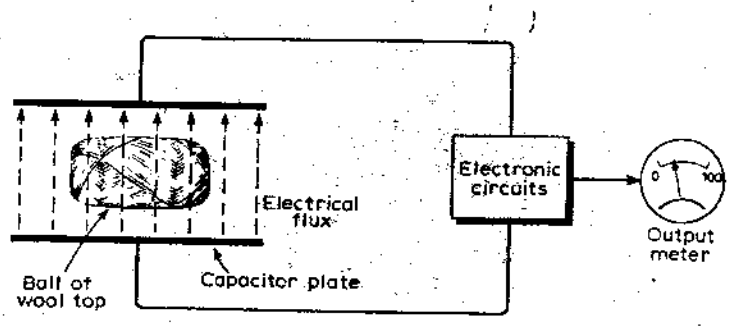


Figure 4.16. Principles of the Forté electronic moisture content analyser

(5) The capacitance test is not substantially influenced by most oils and waxes or extraneous vegetable matter.
(6) It has been verified that the capacitance measurement is not influenced by variations in pH between 6·6 and 8·9.

The general principle of the instrument is shown in Figure 4.16. The readings on the output meter, which is scaled from 0 to 100, are calibrated by first testing sample balls of top in the analyser and then in the usual drying oven. Other models of the instrument are designed to test cones of yarn, samples of bulk fibre and even entire bales of fibre. A comparison of the Forté method for measuring moisture in wool tops with standard conditioning house practice is reported by Hullah (*J. Text. Inst.* **56**, T287 (1965)).

A NOTE ON ELECTRICAL REGAIN TESTERS

The use of electric meters for the measurement of regain has been considered by several authorities and a word of caution is required on the use of these instruments. It is pointed out by Mackay (*Text. Inst. and Ind.*, p.13 (1963)) that, 'Electrical meters owe their popularity mainly to their measuring speed, a few seconds is typical, their cheapness and their relative simplicity of operation. Their chief drawback is that the readings can be affected by factors other than the regain of the textile. For example, the presence of dyes or antistatic agents, the packing density, and the fibre quality. For this reason, an electrical meter usually requires a separate calibration against the drying method for every material on which it is used and for different forms of the same material. When calibrated this way, the results of tests by the Wool Industries Research Association at Leeds indicate that the accuracy of the best of these meters operating on a uniform material is probably about ± 1 per cent regain over a limited range.'

Morton and Hearle (*Physical Properties of Textile Fibres*, p. 159) note that the accuracy of the Shirley Moisture Meter, an instrument based on the variation of the textile's resistance with change in regain, has an accuracy as good as that of the drying oven method, provided that it has been calibrated. However they point out that, 'Instruments based on the variation of dielectric constant are also available, but they suffer from the disadvantages that the weight and distribution of the material between the plates of the condenser must be controlled, and that the variation of dielectric constant with moisture content is much less than the variation of resistance. Where it can be applied, a resistance method is better.'

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5

FIBRE DIMENSIONS AND QUALITY

THE unit from which the many complicated textile structures are assembled is the single fibre, a very small beam characterised by great length relative to its cross-section. This unit is itself a complex structure built from atoms and molecules. In this chapter we shall consider the measurement of the dimensions of fibres and the assessment of other fibre properties which are of importance in the evaluation of the raw materials available to the spinner.

Two important dimensions are fibre length and fineness, and as we shall see shortly there is sometimes a relationship between these two quantities when natural fibres are considered. With man-made fibres both the fibre length and fineness can be controlled independently, although even here the influence of natural fibres may still be felt because man-made fibres may have to be processed on machines designed to suit the dimensions of natural fibres. Further, when natural and man-made fibres are blended, their dimensions must be compatible. The measurement of natural fibres is a task which is not made any easier by the fact that variation exists not only between different types of the same material but also within the same type. Thus, the Sea Island cottons are longer than American cottons, but within a sample of Sea Island or American cotton there is variation in length between fibres. Because of this variation it is necessary not only to derive a single length value to characterise a given sample but also to obtain an index of the variation present. In the sections which follow we shall see how these quantities are determined and how the problems presented by different materials are overcome.

FIBRE LENGTH MEASUREMENT—GENERAL

Frequency, weight and length distributions

A logical approach to the problem would be something like this: A representative sample of fibres is taken and the length of each individual fibre measured over a suitable scale. The values are then classified and the necessary statistical calculations carried out to produce the *arithmetic mean* and the *coefficient of variation.* In addition to this, some graphical representation of the results may be desirable

and could be in the form of a histogram or frequency polygon. This basic method is used in certain instances but in others the arithmetic mean is not the most convenient quantity from the point of view of the mill technician who had to decide on the settings of his machinery. We shall see that in the measurement of the length of cotton an alternative quantity is used. For the moment, however, we will continue to discuss the original approach. The cumulative frequency diagram or distribution curve is another way of presenting the length values in a graphical form and is often preferred to the usual frequency distribution curve. Its construction is fairly straightforward and is illustrated by the following example.

Table 5.1. Length Measurements of a Sample of 500 Cotton Fibres

1	*2*	*3*	*4*	*5*
Class length ($\times \frac{1}{32}$ in.)	*Class frequency*	*Cumulative class frequency*	*Class frequency percentage*	*Cumulative class frequency percentage*
50	5	5	1·0	1·0
46	15	20	3·0	4·0
42	35	55	7·0	11·0
38	56	111	11·2	22·2
34	76	187	15·2	37·4
30	64	251	12·8	50·2
26	56	307	11·2	61·4
22	52	359	10·4	71·8
18	47	406	9·4	81·2
14	36	442	7·2	88·4
10	30	472	6·0	94·4
6	20	492	4·0	98·4
2	8	500	1·6	100·0

Suppose we measured the length of each of 500 fibres and grouped the values in classes as shown in Table 5.1. A histogram of the frequency distribution is given in Figure 5.1; in this case it can be seen that it is an asymmetrical distribution. To enable frequency distributions to be compared it is convenient to express the frequencies in percentages, as shown in column 4 of Table 5.1. The cumulative class frequencies in column 3 are obtained by successively adding the class frequencies in column 2, e.g. $5 + 15 = 20$, $20 + 35 = 55$, and so on. Figure 5.2 shows the cumulative class frequencies plotted against the class length values, the former on the horizontal axis,

the latter as ordinates. Here, again, the frequencies are easily transformed into percentages if required. It will be noticed that the cumulative frequency diagram has a rather smoother appearance than the histogram.

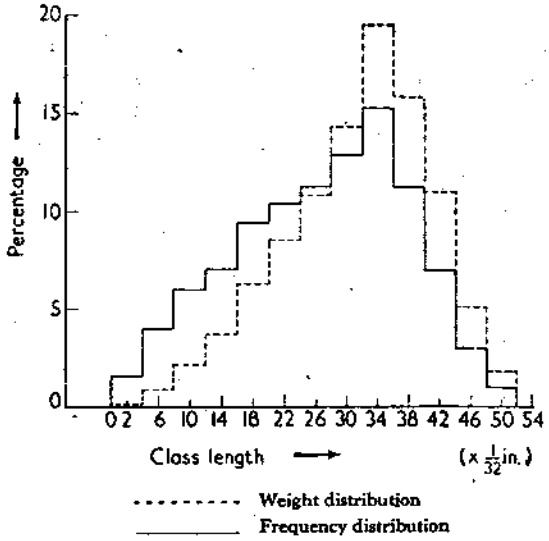


Figure 5.1. Histogram of cotton fibre length distribution

The distribution presented in this form is a *frequency distribution*, i.e. the *numbers* of fibres in each class have been considered. In some cases the *weight* of fibres in each class is considered and a *weight distribution* derived.

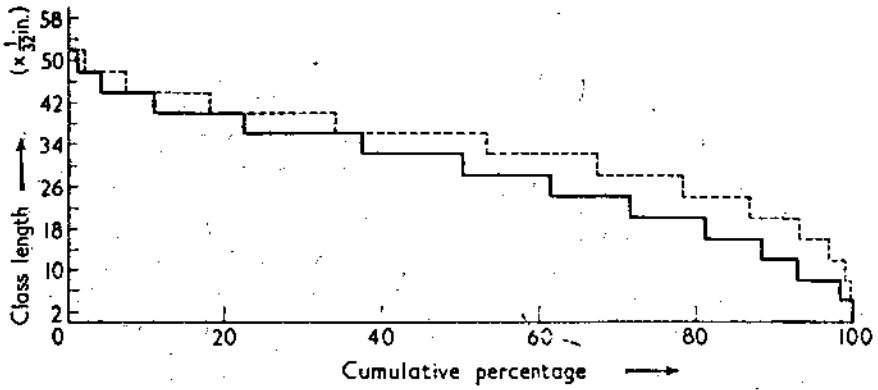


Figure 5.2. Cumulative frequency diagrams derived from Figure 5.1

If it is known that the weight per unit length of the fibre is the same for all fibre lengths, the weight distribution can be derived from the data in Table 5.1. Let the weight per unit length of fibre be *h*. Then the weight of a class will be given by: Class length × class frequency × *h*. Table 5.1 can now be recast into Table 5.2. The value of *h* in this example is taken as 4 μg/in. The corresponding histogram and the cumulative weight distribution are shown dotted in Figures 5.1 and 5.2. In Figure 5.3 the two cumulative diagrams are shown as smooth curves to emphasise the difference in their shapes.

Table 5.2. Weight Distribution of the Sample in Table 5.1

1	*2*	*3*	*4*	*5*	*6*
Class length (× $\frac{1}{32}$ in.) (l)	*Class frequency* (f)	*Class weight* (l × f × h ÷ 32)*	*Cumulative column* 3	*Column* 3 *in per cent*	*Cumulative column* 5
50	5	31	31	1·85	1·85
46	15	86	117	5·12	6·97
42	35	184	301	11·0	17·97
38	56	266	567	15·8	33·77
34	76	323	890	19·3	53·07
30	64	240	1130	14·3	67·37
26	56	182	1310	10·8	78·17
22	52	143	1455	8·5	86·67
18	47	106	1561	6·3	92·97
14	36	63	1624	3·7	96·67
10	30	37	1661	2·2	98·87
6	20	15	1676	0·9	99·77
2	8	2	1678	0·12	99·89

* h = fibre hair weight in μg/in.

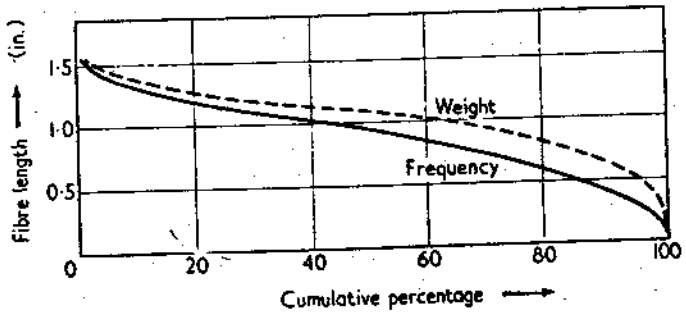


Figure 5.3. Smoothed-out cumulative frequency diagram of Figure 5.2

Sometimes the fibre weight per unit length is not constant but varies with the fibre length, e.g. wool. Here the class weight would be calculated by multiplying the class length–class frequency product by the value of h for the class length. The rest of the arithmetic would be as before.

A *length* distribution is sometimes called for. In this case the total length of fibre in each class is calculated. Thus, the fibre length in each class is the class length multiplied by the class frequency. A Table is set out and the results examined as before. If the fibre weight per unit length is constant, then the length distribution and the weight distribution curves will coincide.

Up to now we have discussed the distribution of fibre length in general terms without reference to specific methods for measuring the length characteristics of the different fibres. For convenience the various types of fibre will be treated separately. It is assumed, of course, that the samples tested have been properly sampled. Another point to bear in mind is that although the measurement of fibre length is mainly used for the assessment of the raw materials, it can also be used to see what effect processing has on the fibre, e.g. calculating the amount of fibre breakage, determining the efficiency of the combing process, etc.

COTTON FIBRE LENGTH MEASUREMENT

Cotton is grown in different parts of the world. After picking and ginning, the bales have to be assessed for quality. One of the attributes of cotton which requires measurement is the 'staple length'. A definition of staple length could be as follows: 'A quantity estimated by personal judgement by which a sample of fibrous raw material is characterised as regards its technically most important fibre length'. The first determination of the length characteristics of the cotton is carried out by classers who use the hand stapling method. In essence, this consists of selecting a sample and preparing the fibres by hand doubling and drawing to give a fairly well straightened tuft about $\frac{1}{2}$ in. wide. This is laid on a flat black background and the staple length measured. The extreme tips of the tuft will not be the limits used for measurement since they represent only the longer fibres present. The shorter fibres will lie in the body of the tuft. The classer chooses limits where there are reasonably well-defined edges, that is, where the density of the tuft changes most rapidly. Since the measurement is of such a subjective nature, it is not surprising to find that differences exist between classers. The

geographical spread of the centres of the markets is also a cause of differences in the basis of staple length measurement. An added complication is that the different types of cottons may be classified by different standards even in the same markets.

Because the staple length is given on a personal judgement, it is obvious that there is the possibility for the shifting of the basis of judgement over a number of years. To counteract this tendency, the U.S. Department of Agriculture has a range of official standards for staple length; sets of these are obtainable. A given tuft can then be compared directly; alternatively, the classer can check his standards of judgement from time to time. From the foregoing notes it must not be inferred that the accuracy of the staple length as determined by the classer is not of a very high order. The classer is an expert at his job and he brings a fund of experience to the task, and his methods are still the fastest. The staple length determined by the classer may be given to the nearest sixteenth of an inch, although the U.S. Department of Agriculture recognises differences of a thirty-second of an inch.

A study of the consistency of staple length classification has been made by Lord (*J. Text. Inst.* **51**, T375 (1960)). The following extract gives the summary and conclusions of this study.

'The cotton crop of the United States is sold partly on the basis of staple length. It is therefore essential that assessment of staple length shall be made accurately by different classers in the same season, and on the same basis from year to year. There is a range of sixteen staple-length standards of American Upland cotton and type samples of these are prepared by the United States Department of Agriculture, by matching bales of potentially suitable cotton with permanent standard cottons of agreed nominal staple length. The purpose is to provide classers with types of known staple, for use in maintaining or adjusting individual levels of classification to a common basis.

Comb sorter diagrams have been made on four series of standard types, obtained in the period 1935 to 1958. Statistical analysis of the values obtained for the effective lengths determined from comb-sorter diagrams of the types shows that (i) no detectable gross change has occurred in the level of staple length classification represented by the type samples during this period and (ii) individual type samples may sometimes be in error by $\frac{1}{32}$ inch, but a divergence of $\frac{1}{16}$ inch between actual and nominal staple length is uncommon.

The form of the relation between effective length and staple

length has been investigated, and is summarised both by an equation and in the form of a derived transformation table. A rough working rule to obtain the staple length is to subtract $\frac{3}{32}$ inch from effective lengths between 34/32 inch and 39/32 inch, $\frac{1}{8}$ inch for longer cottons and $\frac{1}{16}$ inch for shorter cottons.

A small range of standard types is available for American-Egyptian cotton of the United States. The limited data suggest that the staple length is nearly $\frac{1}{32}$ inch shorter than the effective length for cotton between $1\frac{3}{8}$ inch and $1\frac{5}{8}$ inch staple; an anomaly is noted for the longest, $1\frac{3}{4}$ inch, type. This compares with a tendency in the United Kingdom to assess long staple Egyptian-type cotton about $\frac{1}{32}$ inch longer than the corresponding effective length.'

The equation referred to in the summary is given below.

$$L-S = 2{\cdot}1 + 1{\cdot}13(L-26)^{4}(51-L)^{3/2} \times 10^{-6}$$

where L is the effective length and S is the American staple.

Table 5.3. Transformation Table. Prediction of American Staple S *from Effective Length* L (*By Courtesy of the Textile Institute*) (*Units: 1/32 in.*)

L	*S*	*L*	*S*
28	25·9	38	34·8
29	26·9	39	35·6
30	27·9	40	36·3
31	28·8	41	37·1
32	29·8	42	37·9
33	30·7	43	38·8
34	31·6	44	39·7
35	32·4	45	40·7
36	33·2	46	41·9
37	34·0	47	43·1

Single fibre measurement

It is possible, with patience, good lighting, a microscope slide over a scale, and medicinal paraffin to control the fibres, to measure the individual length of cotton fibres. Each fibre is taken and gently straightened over the slide with the tips of the little fingers; the length is then recorded. This method is obviously tedious and time consuming and not used in the mill laboratory. (See B.S. Handbook No. 11, p. 29.)

Fibre sorter methods

As single fibre measurement takes time and hand stapling requires experience (although even then this is a subjective test), alternative methods have been developed. One of the most popular is the use of the fibre sorter, examples of which are the Baer, the Shirley, and the Suter Webb. The fibre sorter is an instrument which enables the sample to be fractionalised into length groups. Basically, the operation involves four main steps:

(1) The preparation of a fringe or tuft with all the fibres aligned at one end.

(2) The separation or withdrawal of fibres in order of decreasing length.

(3) The preparation of a sorter diagram by laying the fibres on a black velvet pad in decreasing order of length, the fibres parallel and their lower ends aligned along a horizontal base line (see Figure 5.5).

(4) The analysis of the diagram.

English and American methods differ in detail. The English system will be described here and a note on the American method will be given later.

The Shirley comb sorter

This instrument consists of a bed of combs which control the fibres and enable the sample to be fractionalised into length groups. Nine bottom combs and eight top combs are used, each set spaced $\frac{1}{4}$ in. apart except the first two bottom combs which are $\frac{3}{16}$ in. apart. Thus, the distance from a row of bottom needles to a row of top needles is $\frac{1}{8}$ in. Manipulation of the fibres is by a grip, an aluminium depressor, and a blunt needle. The procedure is given in the B.S. Handbook but for convenience it is included here (the sample is taken in the way described in Chapter 3, the weight of the sample being about 20 mg).

'The sample shall be carefully drawn and doubled several times until the fibres are straightened and parallelised. It is advisable to keep the bundle as narrow as possible throughout the whole process. The method of sorting is as follows:

(1) The sorter shall be placed with the back towards the operator and the top combs shall be lifted. The prepared sample shall be slightly twisted and placed in the lower combs, at the right-hand side of the sorter as it faces the operator, with a small tuft protruding (see Figure 5.4).

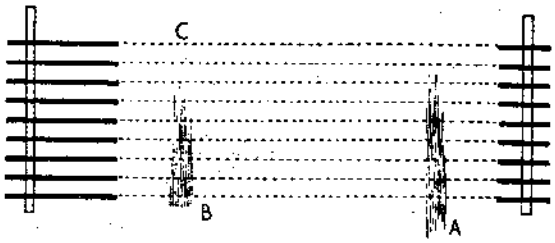


Figure 5.4. Comb sorter technique for cotton fibre length

(2) By means of the grip all the loose fibres shall be removed from the protruding end until there is a straight edge A, the loose fibres pulled out being placed between two glass slides. Later these shall be re-incorporated in the original sample.
(3) A tuft shall now be pulled from the sample, care being taken to grip the fibres as near the ends as possible. This tuft shall be combed several times (combings being preserved) and transferred to the left-hand side of the sorter, so that the co-terminous ends of the fibres are almost flush with the nearest comb B and the tuft is straight and at right angles to the combs. This tuft shall now be pressed into the combs by means of the depressor.
(4) This process shall be repeated until all the sample of lint is transferred to the left-hand side of the sorter, all combings, etc., having been re-incorporated in the original sample.
(5) The sorter shall now be turned round so that the front faces the operator and the longest hairs project towards him (C).
(6) The top combs shall be lowered and fitted in the rack so as to grip the tuft and prevent uncontrolled slipping of the fibres.
(7) The lower combs shall be dropped successively until the tips of the longest fibres are seen.
(8) The fibres shall be pulled out in tufts of successively shorter lengths by means of the grip, the longest first, the combs being successively dropped as required. The fibres shall be combed, straightened, and laid down on the velvet pad with the straight edge against the marked line.'

Examples of sorter diagrams or fibre arrays are shown in Figure 5.5. It will be seen at once that the outline produced by the upper ends of the fibres is very similar to the curve of a cumulative frequency diagram which, in fact, it is. Provided that the fibres are evenly spaced on the velvet pad, distances along the base line are proportional to the number of fibres. Even without further operations the visual examination of the fibre array will provide informa-

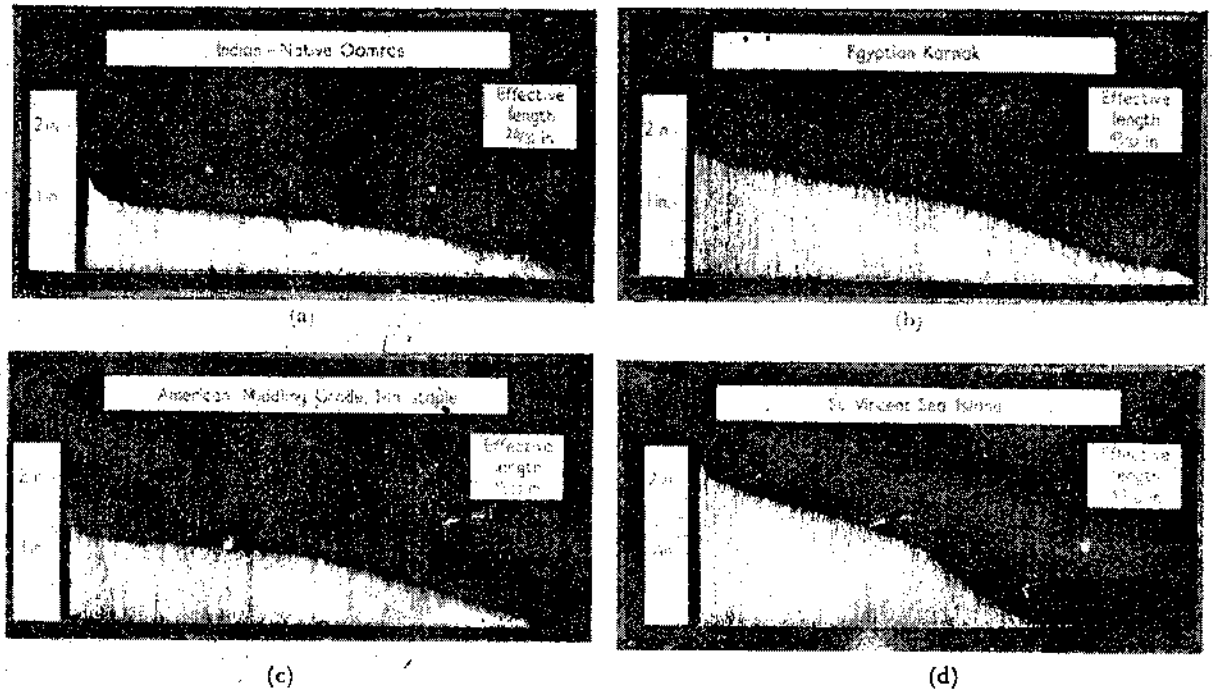
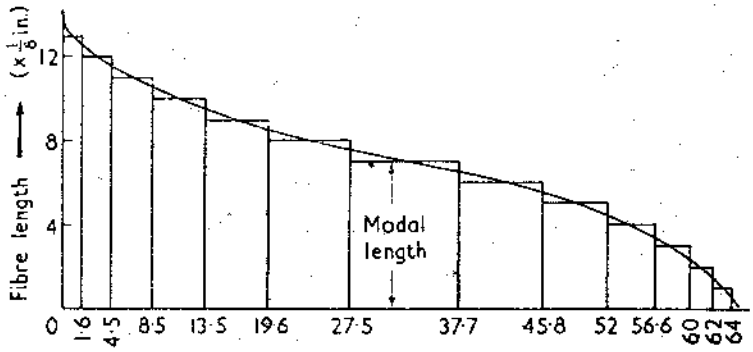


Figure 5.5. Fibre arrays of four types of cotton: (a) Indian—Native Oomras (effective length 28/32 in.); (b) Egyptian Karnak (effective length 47/32 in.); (c) American, middle grade, 1 in. staple (effective length 35/32 in.); (d) St. Vincent Sea Island (effective length 60/32 in.)

tion regarding the general length characteristics of the cotton, its variability, and the amount of short fibre. For a more detailed analysis of the diagram it is necessary to take a tracing of it because this is more convenient to deal with than the actual diagram on the pad.



$$\text{Mean length } (\times \tfrac{1}{8} \text{ in.}) = \frac{\text{Sum of base line readings}}{\text{Base line length}} = \frac{453{\cdot}2}{64} = 7{\cdot}1$$

$$\text{Mean length } (\times \tfrac{1}{32} \text{ in.}) = 4 \times 7{\cdot}1 = 28{\cdot}4$$

Figure 5.6. Comb sorter diagram analysis

Analysis of the sorter diagram

In the construction of the cumulative frequency diagram the frequency of the fibres in each length class was known and the diagram derived from this information. In the analysis of the sorter diagram we more or less work the opposite way round, the curve is known but the distribution over the classes is required to be found. By placing the tracing over graph paper ruled in sixteenths of an inch, the diagram can be readily divided into $\frac{1}{8}$ in. classes. Figure 5.6 shows a curve divided into $\frac{1}{8}$ in. (or $\frac{4}{32}$ in.) classes by erecting the limit ordinates at $\frac{1}{16}$ in., $\frac{3}{16}$ in., $\frac{5}{16}$ in., and so on. In practice, the construction of the ordinates is really unnecessary since the ruled lines of the graph paper enable the base line readings of the limits to be taken directly and recorded.

Average or mean length. The sum of the base line readings divided by the base line length gives the mean length in units of $\frac{1}{8}$ in., the class interval. Multiplying by 4 expresses the mean length in $\frac{1}{32}$ in. units. We are actually finding the mean height of the curve by dividing the total area under the curve by the base length. A study of Figure 5.6 should show how the arithmetic works.

Maximum length. This is read directly from the diagram.

Modal length. The mode of a frequency distribution is the class value of the class with the highest frequency; in other words, the most 'fashionable' value. Since distances along the base line are assumed to be proportional to frequency, the modal length will be given by the class which has the greatest base length. In Figure 5.6 the modal length is therefore $\frac{7}{8}$ in. We will meet this term 'modal length' again when the Shirley photoelectric modal stapler is described.

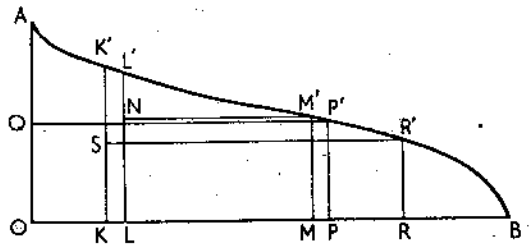


Figure 5.7. Geometrical analysis of comb sorter diagram

Effective length. This value has been defined as the length of the main bulk of the longer fibres. It is obtained by a geometrical construction on the sorter diagram, a construction which also produces several other useful quantities. Figure 5.7 illustrates this operation:

(1) Q is the mid-point of OA, i.e. OQ = $\frac{1}{2}$OA.
(2) From Q draw QP' parallel to OB to cut the curve at P'.
(3) Drop the perpendicular P'P.
(4) Mark off OK equal to $\frac{1}{4}$OP and erect the perpendicular K'K. This is a first approximation to the effective length.
(5) S is the mid-point of K'K.
(6) From S draw SR' parallel to OB to cut the curve at R'.
(7) Drop the perpendicular R'R.
(8) Mark off OL equal to $\frac{1}{4}$OR.
(9) Erect the perpendicular L'L. This is the effective length.

There are one or two points to note about this construction. The short fibres are, in the main, ignored; this action is justified since the classers deliberately reject the short fibre when hand stapling. Further, the effect of the initial rapid change in length from the maximum is reduced, therefore the effective length is a characteristic of the bulk of the longer fibres. The term 'effective' is used because it is to this length value that many machinery settings are related, in particular the distances between the nips of successive pairs of drafting rollers.

The full geometric construction is not always necessary in practice since the tracing can be placed over graph paper and the analysis made mentally. With a reasonable degree of skill on the part of the operator in the preparation of the sample, the diagram, and the tracing, the subjective element of the measurement is largely eliminated.

The relation between effective length and staple length

We have seen earlier that basis of judgement of staple differs between markets and types of cotton. These differences can be accommodated by making certain corrections to the effective length. Lord and Underwood report that, 'For American Upland cottons, from about $\frac{3}{4}$ in. to $1\frac{1}{4}$ in. staple and classed on the basis of American Staple Length Standards, a simple conversion formula is

$$\text{American staple} = 0{\cdot}91 \times \text{effective length}$$

For Egyptian-type cottons no staple length standards are in universal use, but on the average it is found that the staple length is equal to the effective length.'

Incidentally, in the same article (*Emp. Cott. Gr. Rev.* **35**, No. 1 (1958)) a neat definition of the effective length is given: 'The effective length may be defined statistically as the upper quartile of the fibre length distribution curtailed below the value equal to half the effective length.'

Percentage short fibre

This is the percentage of fibres less than half the effective length. In Figure 5.7 the percentage short fibre is therefore given by:

$$\frac{\text{RB}}{\text{OB}} \times 100 \text{ (per cent)}$$

Dispersion

The uniformity, or perhaps more aptly the variability of the cotton, can be expressed as the 'inter-quartile range'. In Figure 5.7 L'L is the *upper quartile* and M'M is the *lower quartile*, where $\text{OM}' = \frac{3}{4}\text{OR}$. The difference between L'L and M'M, NL' is the inter-quartile range. This measure of the dispersion may now be expressed as a percentage of the effective length:

$$\text{Dispersion} = \frac{\text{NL}'}{\text{L}'\text{L}} \times 100 \text{ (per cent)}$$

Here again the influence of the longest and shortest fibres is minimised. Simply stated, the flatter the middle section of the sorter diagram outline the lower the dispersion.

A note on the American method of the analysis of the fibre length distribution
A larger sample is used, 75 mg as against about 20 mg. Separation into classes is accomplished by means of two sets of combs, but the groups of fibres are placed on the velvet pad separately and later raked into groups so that the range of fibre length in each group is $\frac{1}{8}$ in. These groups are then weighed on a sensitive torsion balance. A weight distribution is obtained and, by calculation, the 25 percentile (i.e. 1st quartile) is determined in order to give a measure of the staple length.

Additional calculations are made to determine the mean length, the variance, the standard deviation, and the coefficient of variation. The details of these operations are found in *A.S.T.M. Handbook for Textile Materials* (D 1440–1455). (See Morton, W. E., and Hearle, J. W. S., *Physical Properties of Textile Fibres*, p. 94 (Textile Institute; Butterworths, London, 1962).)

The 'Uster' staple diagram apparatus
This instrument is made by the Swiss firm Zellweger Ltd. It is designed to reduce the time taken to produce a sorter diagram and, at the same time, eliminate some operator errors by the use of mechanised fibre control systems. As with other methods, the sampling must be unbiased. Drawframe sliver may be used and has the advantage of well mixed fibres. Where raw cotton is tested, a sample between 10 and 30 mg is prepared as described in Chapter 3. Replicate samples are recommended, two for drawframe slivers and three or even four for raw cotton.

The apparatus consists of three main units:
(1) The mechanical comb sorter and transport comb (see Figure 5.8).
(2) The tuft forming unit.
(3) The gauging unit.

The sliver or sample is placed on the bed of combs and the top combs lowered into position. A sliding grip handles the fibres and is first used to remove any protruding fibres. Fibre removal can be continued after one or two combs have been dropped; in this way a form of fibre sampling by the 'squaring' method is achieved. A raw cotton sample should be laid inside the front combs, therefore one or two combs must be dropped and lifted before fibres can be transferred from the comb bed to the transport comb.

The sliding grip is used to transfer the fibres from the combs to the transport comb, thus resulting in a build-up of a fringe of fibres whose right-hand ends are nominally aligned (nominally because

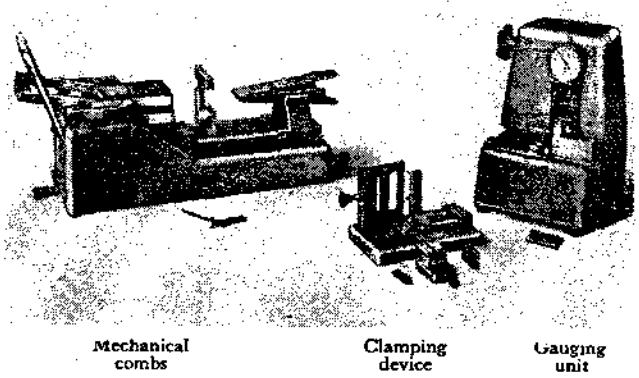


Figure 5.8. The 'Uster' stapler

the combs are set at 2mm intervals and, therefore, there will be a spread of ± 1 mm about a mean line). This spread compares favourably with the spread of the aligned ends of a fibre array on a velvet pad.

With sliver a random sample has been selected because the right-hand ends of the fibres have all terminated in a given sliver volume. With raw cotton the whole sample itself should be unbiased if correctly selected.

The fringe of cotton is transformed into a tuft by means of a tuft forming device which produces the tuft clamped in a holder. The right-hand ends of the fibres are thus gripped for a distance of $\frac{3}{16}$ in. along their length.

The next operation is to measure the thickness of the tuft at intervals between the point of grip and the tip of the tuft. This is done by the gauging unit. The tuft is placed into a narrow slot and a feeler lowered on to it. A constant pressure is exerted because the feeler is spring loaded; in order to reduce friction effects and, at the same time, pack the fibres, an electrical vibrator maintains the feeler in vibration for about 30 sec. At the end of this time the pointer of the gauge dial will have reached a constant position, thus allowing a reading to be taken. Since the tuft is gripped for $\frac{3}{16}$ in., the first reading will be the thickness of the tuft at $\frac{3}{16}$ in. from the aligned ends. Successive readings are taken at $\frac{1}{16}$ in. intervals by lifting the feeler, moving the holder along $\frac{1}{16}$ in., and lowering the feeler again. A series of readings is taken until the tuft tips have

been reached and the slot is empty. From the readings a staple diagram is derived.

The underlying theory of the measurement is fairly straightforward. The gauge reading is proportional to the thickness or cross-section of the tuft. The thickness will depend, in turn, on the number of fibres in the cross-section and the cross-section of the individual fibres. If the latter is uniform, then the gauge reading will be directly proportional to the number of fibres in the tuft cross-section at each point of measurement. This will be the case when, say, rayon staple is being examined. The highest reading will therefore be the first one. Table 5.4 gives the readings obtained on a sample of viscose rayon roving. To construct the fibre diagram all the readings are converted to percentage values relative to the highest reading. The percentage values are then plotted against the length and the curve drawn (see Figure 5.9).

Table 5.4. 'Uster' Staple Diagram Apparatus Readings
(Material: Viscose rayon staple taken from roving. $1\frac{1}{2}$ denier, $1\frac{7}{16}$ in.)

Distance from end of tuft ($\times \frac{1}{16}$ in.)	*Dial reading*	*Percentage of highest reading*
3	590	100
4	568	98
5	562	97
6	556	94
7	536	91
8	520	88
9	503	85
10	490	83
11	478	81
12	476	80
13	466	79
14	459	78
15	458	78
16	455	77
17	455	77
18	443	75
19	418	71
20	407	69
21	394	67
22	256	43
23	158	27
24	82	14
25	28	5
26	10	1·7
27	3	0·5

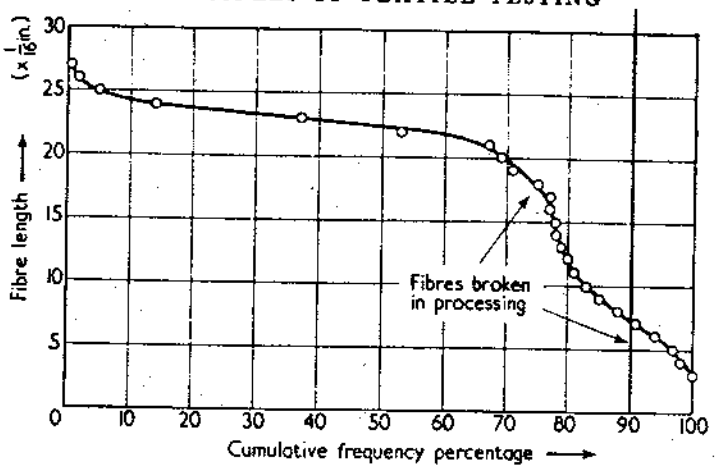


Figure 5.9. Fibre diagram determined by the 'Uster' apparatus. Viscose rayon staple 1 7/16 in. taken from roving

With cotton fibres a complication arises. It is known that the cross-section of a cotton fibre is not uniform from root end to the tip. The thickest part of the fibre varies from about 4 mm to 14 mm from the root end and hence the fibre tapers towards both the root and the tip. In the prepared tuft of cotton some of the fibres will be clamped at their root ends and some by their tips. The net effect is that when measuring the thickness of the tuft the maximum gauge reading may not be the first reading but a later one. Nevertheless, it is still the *highest* reading which is taken as 100 per cent, irrespective of its position along the tuft, and all the other readings are converted to percentage values accordingly. Table 5.5 gives the readings obtained for a cotton sample and Figure 5.10 shows the resultant fibre diagram. The analysis of the diagram is carried out in the normal way. An account of this apparatus is given by Honnegger (*J. Text. Inst.* **42**, P57 (1951)).

Experience with this instrument has shown that it is necessary to use certain corrections to the effective length determined by the geometrical analysis of the 'Uster' fibre diagram, e.g. for cottons add $\frac{3}{32}$ in., and for rayons add $\frac{1}{32}$ in.

The 'Shirley' photoelectric stapler

The use of the comb sorter enables the effective length and other useful information to be extracted from a sample, but often only the staple length is really required and the time taken by the comb

Table 5.5 (Material: American cotton)

Distance from end of tuft ($\times \frac{1}{16}$ *in.*)	*Dial reading*	*Percentage of highest reading*
3	920	100
4	900	98
5	882	96
6	855	93
7	836	91
8	810	88
9	781	85
10	745	81
11	700	76
12	652	71
13	598	65
14	532	58
15	468	51
16	395	43
17	322	35
18	248	27
19	165	18
20	92	10
21	55	6
22	32	3·5
23	14	1·5
24	5	0·5

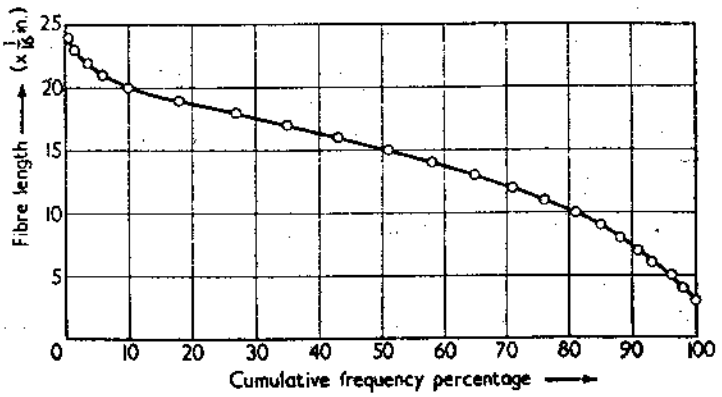


Figure 5.10. Fibre diagram determined by the 'Uster' apparatus. American cotton; corrected effective staple length 40/32 in.

sorter method is in many cases too great. The photoelectric stapler has been developed for use when quicker measurements of staple length are wanted. When hand stapling was discussed two points were made: first, that the short fibres are deliberately discounted, and second, that the length measured is the distance between two 'lines' near the edges of the hand-prepared tuft where the density of the tuft changes most rapidly. The density of the tuft is related to the number of fibres. Starting at the extreme edge of a fringe, the density will be low at first and then increase as the main body of the tuft is approached. The 'density gradient' can be regarded as the rate at which the tuft density changes along the tuft length. At a certain distance from the extreme edge the density gradient will be a maximum, and similarly at the other end. The photoelectric stapler detects these two points and automatically records the distance between them, i.e. the staple length as estimated by eye by the cotton classer.

A sample of cotton is taken and fibre fringes prepared by hand. In the preparation of a fringe the short fibres are combed away and the remaining fibres manipulated into a thin orderly fringe and laid carefully on to a small pad covered with black velvet. It is recommended that the thickness of the fringe should be such that traces of the black velvet can be seen through the central part where the density is greatest; this prevents measurements of staple length erring on the high side.

The instrument (see Figure 5.11). The pads are placed in turn on an endless belt inside the stapler. The belt is moved by rotating a knob and a fringe is brought into position where two strips of light fall across its width. Light reflected from each illuminated strip of fibres falls on to one of two photoelectric cells connected in opposition to each other. The opposed cells pass a current which is proportional to the difference in the intensity of the light reflected from the two illuminated strips of fibres and hence is substantially proportional to the density gradient midway between the strips. Variations in current are shown on a sensitive galvanometer. As the fringe is advanced inside the instrument the galvanometer deflection steadily increases to a maximum value, indicating the maximum density gradient. This occurs when the two strips of light straddle a line across the fringe which is equivalent to the line which the cotton classer judges by eye and uses as one of the limits for measurement.

At this point the scale of the instrument reads zero. A switch is now set so that subsequent displacements of the fringe are recorded in thirty-seconds of an inch. The fringe is advanced further and the

galvanometer deflection falls from its first maximum value to zero as the two strips of light illuminate the uniform central part of the fringe.

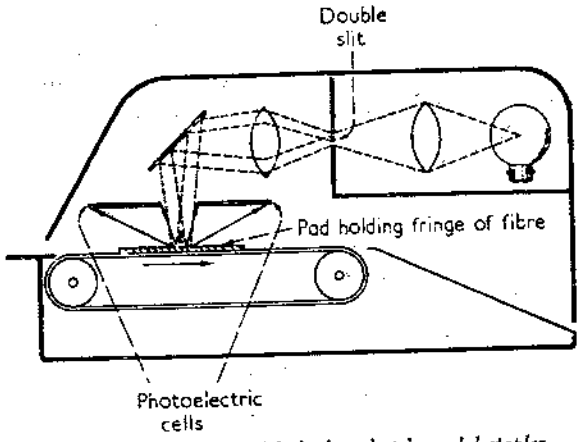


Figure 5.11. The 'Shirley' photoelectric modal stapler

Continuing to move the fringe, the galvanometer deflection again moves away from zero in the opposite direction, and attains a maximum value when the tail end of the fringe is straddled by the strips of light. The distance moved between the two positions of maximum density gradient may be termed the 'P.E. staple' and the value of it is read directly from the scale.

Experience with the instrument has shown that for the main range of American-type cotton, the results from the P.E. stapler are close measures of staple length based on American standards. An estimate of the effective length is given by

$$\text{Effective length} = \text{P.E. staple} \times 1{\cdot}10$$

When the fringes are prepared by an experienced operator, the difference between the highest and the lowest values will be less than 10 per cent of the mean value and the length estimates will usually be correct to $\pm \frac{1}{32}$ in. on medium staple American-type cottons. Control samples can be used to correct any small drift in the operator's technique and to judge the results against standards. For example, suppose the control sample value of the staple length is 28·6 and an operator obtains a value of 27·7. His values for the cottons being tested can then be corrected by multiplying them by the factor 28·6/27·7, i.e. 1·03.

The time taken to prepare and test one fringe is only about 3 min; therefore a mean staple length estimate can be produced from five fringes in a comparatively short time.

*The 'Fibrograph'**

Photoelectric cells are used in this American instrument for measuring the length characteristics of cotton but in a different manner to those in the 'Shirley' P.E. stapler. A fringe of cotton is prepared by taking about $\frac{1}{2}$ oz of cotton and combing it by means of two hand combs. The prepared sample is in a straightened condition with the fibres divided between the two combs; those longer than $\frac{1}{4}$ in. are caught in the teeth in a random position along their length. The fibre fringes are placed on the measuring unit in such a way that they lie over a long narrow slot behind which are mounted the photoelectric cells. A light source illuminates the fringes and the amount of light penetrating through the fringes is measured electronically. At the start of the measurement the fringes are scanned across the densest region, i.e. near the comb teeth, and the light which penetrates will be a minimum. As the sample is traversed towards the fibre ends, more and more light will fall on to the photoelectric cells.

The new 'Servo-Fibrograph' automatically records the change in the amount of light reaching the cells, not in terms of intensity of illumination but as a special form of frequency distribution. This curve is traced out on a card which is then removed from the instrument and analysed.

Figure 5.12(a) shows the type of curve produced and the way in which it is used to provide the required information. Let X be a point on the curve $\frac{1}{4}$ in. from the horizontal axis.

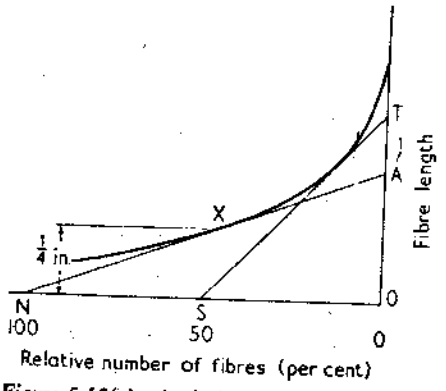


Figure 5.12(a). Analysis of the Fibrograph curve

*The Fibrograph is discussed by Morton, W. E., and Hearle, J. W. S. *Physical Properties of Textile Fibres*, p. 104 (Textile Institute; Butterworths, London, 1962). (The Digital Fibrograph, a development of this instrument, dispenses with the curve, a computer presenting the results automatically.)

Construct the tangent to the curve to cut the horizontal at N and the vertical axis at A. OA is then the average length of fibres longer than $\frac{1}{4}$ in. Distances along ON represent the frequency percentage of fibres longer than $\frac{1}{4}$ in.

From S, the 50 per cent mark, construct the tangent ST to cut the vertical axis at T. OT is then the *upper half mean length* of fibres longer than $\frac{1}{4}$ in., based on a weight distribution. The ratio OA/OT $\times$ 100 per cent gives the length *uniformity ratio* of the fibres. The upper half mean length approximates to the staple length obtained by the cotton classers.

The Digital Fibrograph

As its name implies, the Digital Fibrograph presents the test results in digital or numerical form. Preferably, a special fibre sampler, a 'Fibrosampler', is used to prepare the beards or fringes of cotton. The principle of scanning the beards by a light source is similar to that used in the earlier fibrograph but the signals from the measuring console are fed into a separate transistorised unit. The signals are electronically processed and the results fed back to the measuring unit which has two four-digit counters facing the operator. One counter is labelled 'Amount', the other, 'Length'. A servo-follower system connected to the photoelectric cells indicates on the 'Amount' counter the relative number of fibres in the sample beards at the point where the light beam passes through them. A servo-computer 'remembers' the number of fibres at the 0·15 in. distance from the centre of the comb teeth and computes the number of fibres corresponding to the different Span Lengths. When a span length is selected, the comb carrier moves until the number of fibres under the lighthouse is equal to the number of fibres corresponding to that span length. The span length is then indicated by the 'Length' counter, which indicates, in inches, the movement of the comb carrier.

Suppose that the instrument has been properly checked and calibrated and that a sample has been placed in the lighthouse. The 0·15 in. button on the console is depressed and the 'Amount' counter reads 1500. By depressing the 50 per cent span length button the 'Amount' counter should now read 750 and the 'Length' counter will indicate the 50 per cent span length value in inches. Other preset span length buttons are for 2·5 per cent S.L. and 67·7 per cent S.L. A second set of fixed-length push buttons for 0·15 in., 0·45 in. and 0·55 in. enable the percentage of fibres shorter than 0·5 in. to be calculated.

Span Length. The term 'span length' is not used when analysing the comb sorter diagram and requires some explanation. Figure 5.12(b) represents a strand of fibres caught by a clamp. All loose fibres to the right of the clamp are removed. The number of fibres are counted, say 12,000. We now imagine the clamp line to move to the right until only 300, i.e. 2·5 per cent of 12,000, fibres are counted. The distance D is the 2·5 per cent S.L. Similarly, the 67·7 per cent S.L. and 50 per cent S.L. values can be visualised. It has been pointed out that this approach to obtaining a measure of fibre length is more realistic than the array or sorter technique since it is a measure derived from fibres oriented in a similar fashion to fibres in process, i.e. randomly arranged rather than the fibre ends co-terminus along a base line.

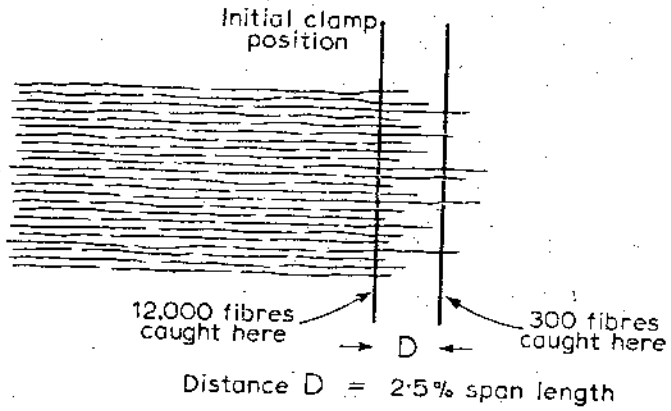


Figure 5.12(b). Explanation of the term 'span length'

If the 2·5 per cent S.L. were 1·06 in. then 2·5 per cent of the fibres clamped would be 1·06 in. or longer; if the 50 per cent S.L. were 0·44 in. then 50 per cent of them would be 0·44 in. or longer. A uniformity ratio may be calculated:

$$\text{U.R.} = \frac{S_{50\%}}{S_{2{\cdot}5\%}} \times 100$$

In drafting systems the floating fibres between the drafting roller nips are of importance and an index of such fibres may be calculated from the fibrograph data.

The floating fibre percentage is defined as the number of fibres that are at any instant between the drafting rollers, expressed as a percentage of the total number of fibres in the cross-section.

At a 1:1 draft this has been shown to be given by:

$$\text{Floating fibre percentage} = \left[\frac{S_{2\cdot5}}{L} - 0{\cdot}975\right] \times 100$$

where L is the average fibre length.

If required, the Digital Fibrograph can provide data from which a fibrogram curve may be plotted and then analysed in the same way as when the curve is produced with a manual fibrograph. Thus mean length and upper half mean length can be derived.

As with all electronic equipment checking, calibration and efficient maintenance is necessary in order to get the best out of the instrument. In addition, the possibility of operative errors must be recognised and at all stages sampling methods and preparation technique examined critically. Prakash has published papers dealing with the Digital Fibrograph and the reader is referred to them (see Further Reading).

*The sledge sorter**

This sorting instrument is in two units, a miniature drawframe which prepares a small sliver from the cotton sample, and a 'sledge' which holds the prepared sliver and deposits the fibre in ascending order of length as it is traversed over a long length of plush. After a number of sledge traverses has been made, a narrow web of fibre is formed on the plush. A scale along the edge of the plush enables the fibres to be grouped into length classes and the groups are then weighed. A weight distribution of the fibre is obtained.

The original device was described in detail by W. L. Balls as long ago as 1921 in 'A Method of Measuring the Length of Cotton Hairs', *Handbook of the Sledge Sorter*, published by Macmillan. (He also gives a briefer description on p. 361 et seq. of *Studies of Quality in Cotton*, published by Macmillan in 1928.) A commercial model is available today, manufactured by Metrimpex of Budapest. This firm has also developed an automatic version of the sledge sorter. The web is deposited on a drum surface and scanned by a photoelectric system. The intensity of a reflected beam of light is proportional to the number of fibres scanned at a particular part of the web. Variation in intensity is recorded on a chart which represents the frequency diagram of the fibre length. Analysis of the diagram produces estimates of staple length, modal length, etc.

*See also Morton, W. E., and Hearle, J. W. S. *Physical Properties of Textile Fibres*, p. 96 (Textile Institute; Butterworths, London, 1962).

Data from sledge sorter tests is compared with the results obtained from the digital fibrograph in a study by Prakash (*Text. Res. J.* **34**, 857 (1964)).

WOOL FIBRE LENGTH MEASUREMENT

The two main methods of determination of wool length characteristics are the single fibre and the tuft methods. For research purposes, or in cases where the time element is of minor importance, the single fibre methods have particular merit and, as we shall see shortly, even single fibre measurement has been speeded up by the introduction of semi-automatic instruments which both reduce operator fatigue and the time per test. The term 'wool fibre length' is really an indeterminate expression somewhat akin to the 'length of a piece of elastic'. A wool fibre has a naturally wavy configuration when free from applied tension and the crimp is multi-planar, i.e. the kinks jut out in all directions. If a fibre were gripped at one end and an increasing force applied at the other, it would gradually straighten out until all the crimp was removed—its length at any instant would depend on the load at the moment. It is therefore necessary to define the following terms used in connection with wool:

Crimped length: The distance separating the ends of the fibre when it is not constrained.

Fibre length: The estimate of the distance between the fibre ends when a tension just sufficient to remove the crimp has been applied.

Even the latter definition is not too precise since different operators may have different conceptions of the point when the crimp is 'just removed'.

*Single fibre methods**

The two forceps method. This is a basic method requiring a minimum amount of apparatus but much time and patience on the part of the operator. From the sample, fibres are removed one at a time and gripped at each end by pointed forceps. The measurement is made by putting the tips of one pair of forceps over the zero line of a scale and gently stretching the fibre until the crimp is just removed; the position of the tips of the second pair of forceps is noted and recorded

*See also *Length of Man-Made Staple Fibre (By Measurement of Single Fibres)*. B.S. Handbook No. 11, p. 29.

in the relevant length class. In many cases the measurement may be to the nearest centimetre or half centimetre. The data obtained are analysed statistically to determine the mean length, coefficient of variation, and so on. Assuming a coefficient of variation of 50 per cent for the fibre length in a wool top, and the limits of error to be 3 per cent of the mean, 1,112 fibres must be measured (see B.S. Handbook, p. 27). Experienced operators are capable of measuring about 150 fibres per hour. Therefore, with four assistants available, 2 hr or so is required for the test (see Daniels, H. E. *J. Text. Inst.* **33**, T137 (1942)).

If errors due to different operators using different tensions in stretching the fibres are to be avoided, standardised tensioning clips may be put on to the ends of the fibres in place of the second pair of forceps and the fibre measured in a vertical position. The increase in accuracy is, however, accompanied by an increase in the time taken (see Palmer, R. C. *J. Text. Inst.* **42**, P23 (1951)).

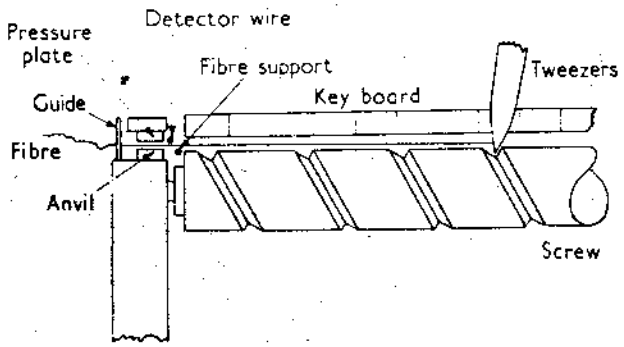


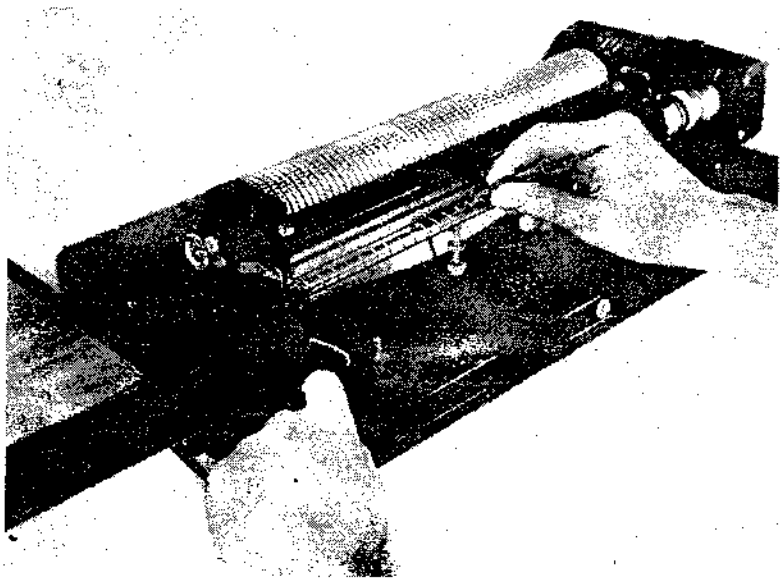
Figure 5.13. Diagram of the W.I.R.A. fibre length machine

*The W.I.R.A. fibre length machine.** The Wool Industries Research Association developed the automatic fibre length machine to retain the advantages to be gained from single fibre measurement and at the same time to eliminate some of the disadvantages, i.e. the indeterminate point of crimp removal, operator fatigue, and the time required to measure a sufficiently high number of fibres. A sample is prepared on a pad covered with black velvet with a short fringe of fibres protruding from beneath a glass plate. The essential features of the instrument are shown in Figures 5.13 and 5.14. Each

*See also B.S. Handbook No. 11, p. 87.

fibre is picked from the velvet board by a pair of pointed tweezers, led through the fibre guide, and over the anvil and the fibre support. Depression of a lever with the left hand brings down the pressure plate to tension the fibre and, at the same time, a fine detector wire. The nose of the tweezers is put into the thread of the revolving screw, in this way drawing the fibre sideways to the right. When the tail end of the fibre comes away from the control exercised by the pressure plate, the detector wire drops, thereby contacting a mercury switch which stops the screw. The nose of the tweezers is then flicked upwards to lift a key of the counter. This registers one more unit on the corresponding drum of a bank of counters. The keys are 0·5 cm wide. The fibre is measured automatically, under a controlled tension independent of the operator, to the nearest half centimetre. Up to about 500 fibres may be measured in 1 hr.

On completion of the measurements the bank of counters has the store of information required for statistical analysis, i.e. the distribution of the frequencies in half-centimetre class intervals.



(By courtesy of W.I.R.A.)

Figure 5.14. The W.I.R.A. fibre length machine

Tuft methods

The comb sorter. The simplest form of comb sorter for wool fibres is a bed of about thirty combs spaced at centimetre or half-inch intervals—in fact, a cotton comb sorter on a larger scale but minus top combs. A diagram of the plan view is shown in Figure 5.15. For untwisted materials, such as slivers and tops, a length longer than the longest fibre is cut and pressed into the comb bed with one end projecting from the first comb (A). With twisted materials, such as rovings and yarns, the sample is prepared by untwisting a number of strands and combining them to form a sliver. This is then pressed into the comb bed with a fringe projecting from the first comb and the fringe cut off square. With loose wool a sliver is prepared by hand by extracting tufts of fibres from different parts of the bulk ('zoning') and hand-drawing them into a more or less parallel sliver. In all cases it is desirable that fibre breakage due to entanglement be kept to a minimum.

The next step is to remove and discard the cut fibres from the short projecting fringe and at the same time to square-off the sliver end. A special grip which can be opened and closed by hand is used when handling the fibres.

From the squared-off fringe, groups of fibres are gripped near their ends, drawn carefully forwards out of the combs at A, and placed on to the combs at B with their trailing ends toward the front

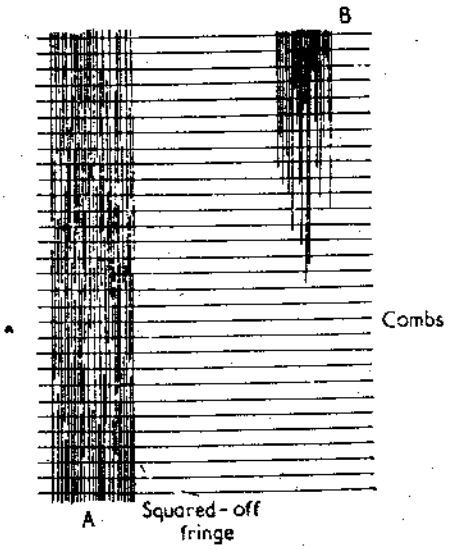


Figure 5.15. Plan view of wool comb sorter

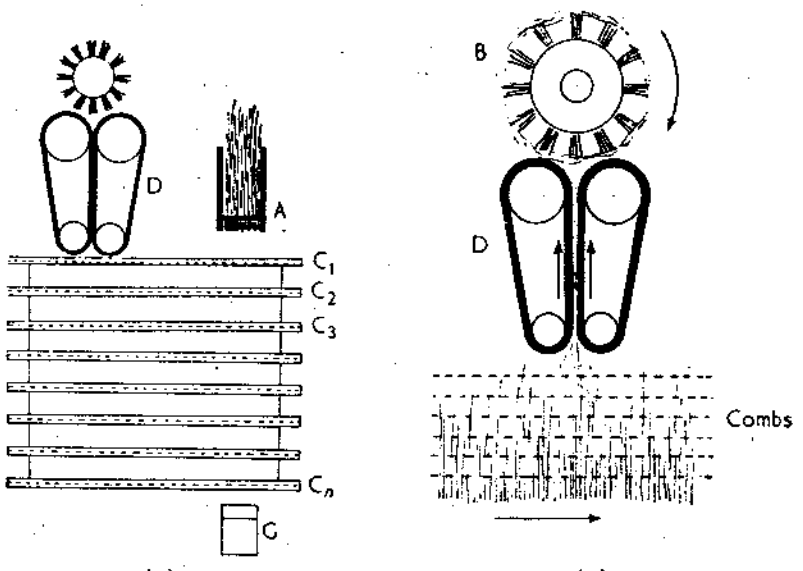
comb and their gripped ends aligned at the back. A wire fork is used to press the fibres home into the comb needles. This process is repeated until a sufficiently large sample has been collected at B. The remaining portion of the sliver is removed from the sorter.

At this point it would be useful to see what has happened. In the case of slivers, tops, rovings, and yarns, an unbiased sample of fibres has been prepared by the 'cut squaring' method. With loose wool the zoning technique has been used and, incidentally, the whole of the loose wool sample is transferred to position B, an operation which usually means that a few combs are dropped initially to expose the fibre ends.

It is now necessary to sort the fibres into length classes. The combs are dropped successively until the tips of the longest fibres are showing. These are removed and weighed on a suitable sensitive balance. The class interval for the length is derived from the number of combs remaining in the 'up' position and the comb spacing. Thus, if nine combs remain up and the spacing is $\frac{1}{2}$ in., then the class length value is $(9 - \frac{1}{2}) \times \frac{1}{2}$ in., i.e. $4\frac{1}{4}$ in. In general terms the class length is given by $(n - \frac{1}{2}) \times d$, where n is the number of combs in the 'up' position and d is the comb spacing.

The various classes are sorted by dropping the combs one by one and removing the exposed fibres and weighing them. The data is then used to plot a histogram or a cumulative fibre diagram; the various length characteristics can then be calculated. Note that the results so derived are based on a *weight* distribution. If a frequency distribution were required it would be necessary to determine the fibre weight per unit length and convert the weight of each class into a frequency.

The Schlumberger comb sorter. This instrument (see Figure 5.16(a) and (b)) is an automatic version of the comb sorter. An account of it is given in *Wool Sci. Rev.* No. 9 (1952) as follows: 'The combs C_1, C_2, C_3, etc., can be moved towards A and dropped in turn as in a gill box. The sequence of movements carried out by turning a handle (or in later models electrically) results in the grip G moving repeatedly over the combs towards and then away from the squared end of the top A and building up a tuft of fibres with ends aligned on comb C_n. The whole frame of combs is then traversed leftwards. The moving leather belts D draw off the fibres projecting beyond C_1 and deposit them on the brush B, from which they are removed and weighed. The comb C_1 then drops and the remaining combs move forward so that C_2 takes the place of C_1, the comb bed is again traversed and the next group of fibres deposited on B.'



(By courtesy of W.I.R.A.)

Figure 5.16. Schlumberger comb sorter

The clamped tuft method

Known also as the 'combed tuft' method, this technique enables the operator to obtain a weight biased estimate of the mean fibre length from slivers in which the fibres are well ordered and parallel. The apparatus required is simple. A brief account of the method is given in *Wool Sci. Rev.* No. 9 (Dec., 1952) as follows: 'The metal clamp A (Figure 5.17) consists of two halves which can be screwed together, the bottom half being slightly wider than the top half to provide a cutting block. It is supported vertically and a length of sliver, several times the length of the longest fibre which it is likely to contain, is opened out and hung from a convenient clip (not shown) so that it drapes over the base of the open clamp. The clamp is tensioned uniformly by a clip B which is put on its lower end; and the top half is then put on (as in the illustration). The sliver is combed at each side of the clamp in turn so that all fibres not gripped by it at some point are removed. The two combed tufts remaining in the clamps are then cut off and weighed together, the clamp is opened, and the length of sliver gripped by it also weighed. If the width of the clamp is W, then the mean fibre length is given by

$$\text{Mean fibre length} = W \times \frac{\text{total weight of combed tufts}}{\text{weight of clamped sliver}}$$

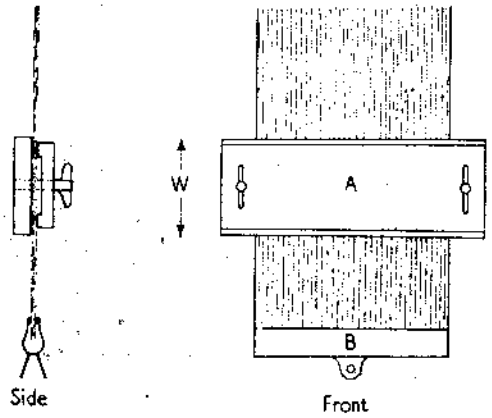


Figure 5.17. The clamp tuft method

The estimate of mean length is a weight-biased one, the same as that usually obtained from the comb sorter. This method, since it involves a combing procedure, may involve a certain amount of fibre breakage. According to Anderson (*Tech. Comm. Proc.* **2**, p. 19 (I.W.T.O., 1948)) the results are reasonably reproducible within a laboratory, and with one measurer the mean of three results will give about 3½ per cent accuracy. It appears to be in use in a number of works laboratories as a control method.'

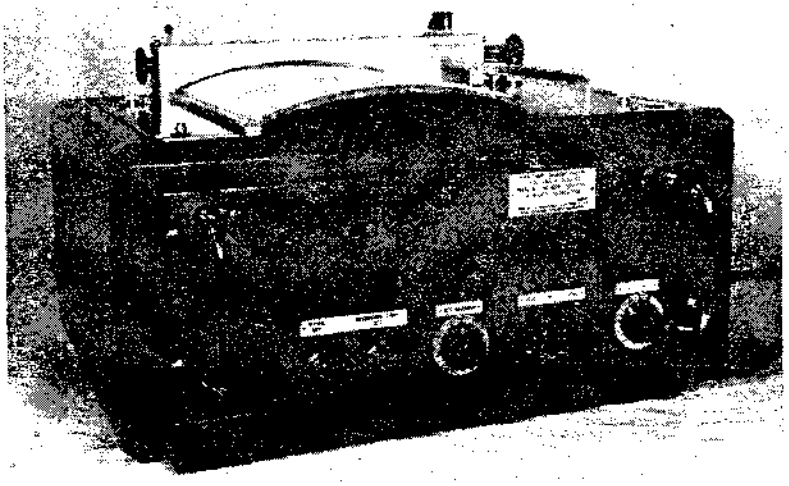
A further account of this method will be found in *Wool Research* Vol. 3, and *Testing and Control*, Chapt. 3. (See also Morton, W. E., and Hearle, J. W. S. *Physical Properties of Fibres*, p. 109 (Textile Institute; Butterworths, London, 1962).)

The W.I.R.A. fibre diagram machine

The W.I.R.A. fibre length machine described earlier in this chapter measures the lengths of single fibres, but the fibre diagram machine operates on a draw of fibres. A separate unit prepares a draw of fibres aligned at one end and sealed with a thin strip of polyvinyl chloride, Figures 5.18 and 5.19. The draw of fibres is traversed in successive ½ cm intervals through a special electrode system which 'observes' the number of fibres at the ½ cm points. The observations are translated into the movement of a spot of light thrown on to a sheet of graph paper which moves forward in sympathy with the draw of fibres. At each ½ cm interval the position of the spot of light is recorded on the graph paper by a pencil mark. When the ends of the longest fibres have passed through the electrodes the graph paper is removed and the points joined up to produce the fibre

(*By courtesy of W.I.R.A.*)

Figure 5.18. Draw of fibres for the W.I.R.A. fibre diagram machine



(*By courtesy of W.I.R.A.*)

Figure 5.19. The measuring unit of the W.I.R.A. fibre diagram machine

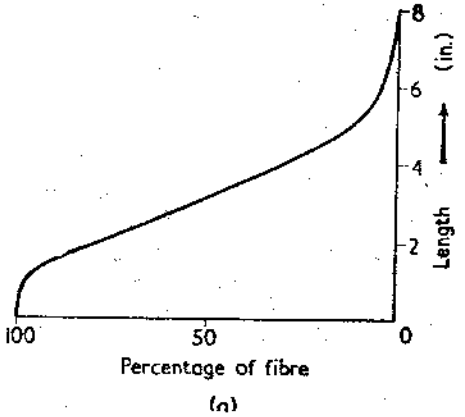
diagram. Figure 5.20 shows that the ordinate gives the fibre length and the horizontal axis gives the percentage of fibre. The lowest fibre length is about 1·3 cm since measurements must start clear of the sealed ends. In practice this has not proved a severe drawback to the method. (Compare the 'Uster' cotton fibre diagram in which measurement starts at $\frac{3}{16}$ in.)

We have suggested in the last paragraph that the electrodes measure the number of fibres, but this is not strictly true because it is really the mass of fibres which is measured by the electrode system. However, tests have shown that the difference between a true cumulative frequency distribution and the cumulative 'fre-

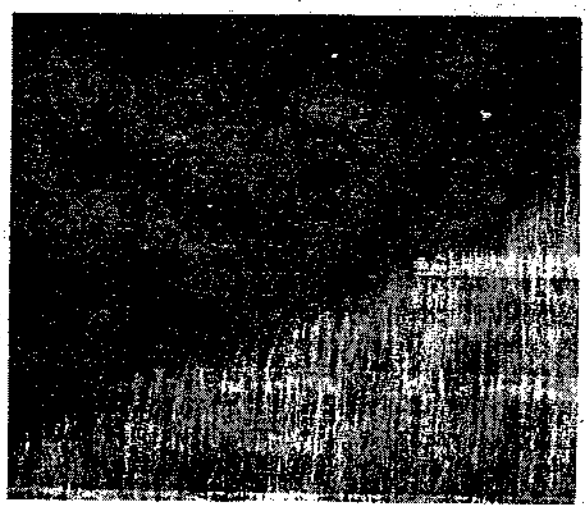
quency' distribution produced by this method are quite small. Compare the distribution produced by the W.I.R.A. fibre diagram machine and the staple diagram prepared by hand (Figure 5.20).

To calculate the average fibre length from the diagram, the fibre lengths corresponding to 5, 15, 25, . . . 95 per cent are recorded, the ten values totalled and divided by 10.

The machine may also be used to investigate the length characteristics of tops of man-made fibres such as Orlon and Acrilan.



(a)



(b) (*By courtesy of W.I.R.A.*)

Figure 5.20. Comparison of (a) diagram from the W.I.R.A. fibre diagram machine with (b) staple diagram prepared by hand—56s wool top

FLAX FIBRE LENGTH MEASUREMENT

A sorting machine designed by the Linen Industry Research Association is described in B.S. Handbook, p. 37.

ASBESTOS FIBRE LENGTH MEASUREMENT

The length properties of asbestos fibres may be assessed with the aid of a comb sorter using appropriate techniques.

Matthews (*Textile Fibres*) mentions the Quebec Standard Testing Machine used in the grading of milled asbestos fibres. Briefly, four screens or trays are superimposed one above the other and a sample of asbestos placed in the top tray. The tray bottoms are brass mesh of varying openness, the top tray having a screen opening of 0·5 in., the next 0·187 in., and the third 0·053 in.; the bottom tray collects material which drops through the upper three trays. A reciprocating shaker mechanism shakes the whole assembly. Thus, long fibres will remain in the top tray and the shorter fibres collect in the lower trays according to their lengths. The weight of material in each tray is noted and used to grade the asbestos. The more material in the top tray the higher the grade, of course.

THE MEASUREMENT OF FIBRE FINENESS

The importance of fibre fineness

In the determination of the merit of a material for spinning, the fibre length is often taken as the criterion, whereas for many purposes the fineness of the fibre is of equal and sometimes of greater importance. When irregularity is considered in Chapter 9 it will be shown that even with perfect machines the best yarn that can be produced is one in which the fibres are distributed along the strand in a random order. Martindale (*J. Text. Inst.* **36**, T35 (1945)) shows that the irregularity in the strand is dependent upon the average number of fibres in a cross-section. With a greater number of fibres in the cross-section the basic irregularity is reduced. For a given count the average number of fibres in the cross-section will depend on the fibre fineness; the finer the fibre the higher the number and the lower the irregularity.

Another way of looking at this effect is to consider what happens when we start with a given material and try to spin finer and finer yarns. As the yarn becomes finer the number of fibres in the cross-section diminishes and the irregularity increases until a point is reached when spinning any finer becomes impracticable and the spinning limit has been reached. Starting with a coarse fibre the

spinning limit is reached fairly soon. Summarising these ideas, two points emerge:

(1) If a given count is spun from a fine and a coarse fibre, a more uniform and a stronger yarn will result from the fine fibre.
(2) A fine fibre can be spun to finer counts than a coarse fibre.

Broadly speaking, the finer the fibre the greater the total surface area available for inter-fibre contact and, consequently, less twist is needed to provide the necessary cohesion. This is reflected in the twist factors used for different types of material.

The fineness of the fibre also affects several mechanical properties and therefore influences the behaviour of the fibre during processing and the properties of the resultant yarns and fabrics. Two fibre properties of importance are the torsional rigidity (resistance to twisting) and stiffness (resistance to bending). Without going into the theoretical aspects of these two characteristics, it may be noted that a fibre which is difficult to twist will probably be difficult to spin because spinning necessarily involves the twisting of the fibre. A stiff fibre will affect the ability of the fabric to drape and hang gracefully. The fineness of the fibre can often play a more important role in the behaviour of the material than its inherent properties. For example, if the diameter is doubled its rigidity is quadrupled, if increased ten-fold its rigidity is increased a hundred-fold. Even materials which are basically brittle, e.g. glass, can be quite flexible if made sufficiently fine.

The definition of fineness

If all fibres had perfectly circular cross-sections it would be a relatively simple matter to measure the diameter by means of a microscope. The task would be even simpler if it were known that the cross-section was uniform along the fibre length and from fibre to fibre. However, fibres exhibit a variety of cross-sectional shapes and they also vary in section along their length and vary from fibre to fibre. It is necessary, therefore, to derive some index of fineness which can overcome these difficulties and at the same time be comparatively easy to determine.

The mass of a cylinder or prism is given by

$$\begin{aligned}\text{Mass} &= \text{volume} \times \text{density} \\ &= \text{cross-sectional area} \times \text{length} \times \text{density}\end{aligned}$$

From this we see that mass is directly proportional to the cross-section. Further, the mass of a known length of material will be directly related to the cross-section. By measuring the *weight* of a

known length of fibre we obtain a quantity called the *linear density*,* and this can be expressed in terms of *weight per unit length*. In England the linear density is called either the fibre weight per centimetre or the hair weight per centimetre, H. The unit of weight is the milligram $\times 10^{-5}$. Thus, the fibre weight per centimetre for an American Upland cotton may be 192, i.e. 192 mg $\times 10^{-5}$/cm.

In America the weight unit is the microgram (g $\times 10^{-6}$) and the length unit is the inch. The linear density of the American Upland cotton would be 4·9 μg/in.

Since H = fibre weight in g $\times 10^{-6}$/cm, and the American linear density = fibre weight in g $\times 10^{-6}$/in.,

$$\text{American linear density} = H \times 2{\cdot}54 \times 10^{-2}$$

For example, $H = 192$. Therefore,

$$\text{American linear density} = 192 \times 2{\cdot}54 \times 10^{-2} = 4{\cdot}9 \text{ μg/in.}$$

(The denier of a filament is the linear density expressed as the mass in grams of 9,000 metres.)

It should be noted that it is quite possible to have fibres with identical linear densities but different cross-sectional areas. For example, a fibre with a high density will have a smaller cross-sectional area than a fibre of low density.

PRINCIPLES OF FINENESS MEASUREMENT

Gravimetric methods

Cotton. A convenient time to carry out the measurement of the fibre weight per centimetre occurs when a comb sorter diagram has been made. The full procedure is given in B.S. Handbook (p. 40 in the 1963 edition). Five tufts of fibre are taken at intervals down the diagram and from each tuft a section is sliced out by means of two razor blades set in a holder at a spacing of 1 cm. Using a large lens and good lighting (and patience too), 100 fibres are counted from each of the tufts. Each group of 100 fibres is collected and weighed on a sensitive microbalance. From the weighings the mean fibre weight per centimetre is calculated. This result may then be corrected to give the standard fibre weight per centimetre, H_s, after the maturity of the cotton has been determined (maturity will be discussed later in this present chapter).

A variation of this method is to place the tufts of fibres from the staple diagram on a microscope slide and cover them with a cover

*B.S. Handbook, B.S. 2016:1961; Linear density is the mass per unit length of a fibre or filament expressed in millitex (milligrams per kilometre). N.B. The numerical value of millitex will be the same as the H.W.P.C.

slip. An accurate count is then made using a projection microscope. After the count the fibres are bundled together, and from the middle a section of known length is cut and weighed. Five tufts are treated in this way and the mean fibre weight per centimetre calculated.

*Bast fibres.** Five tufts from the staple diagram are taken, combed straight, and a known length cut from the middle of each tuft. All the fibres are weighed to an accuracy of 1 in 100 and the number of fibres counted. The mean fibre weight per unit length is then calculated.

Man-made staple fibres.† With individual complete fibres the length of each fibre is measured against a scale on a velvet pad. Two pairs of tweezers are used to remove the crimp. Each fibre is weighed on a microbalance and the results used to calculate the fibre weight per unit length.

Wool.‡ Methods other than gravimetric are usually used for wool but the following method can be used. After completing a fibre length test the fibres are collected and thoroughly cleared of oil, allowed to condition, and then weighed on a microbalance. The total fibre length is calculated and knowing the number of fibres the fibre weight per unit can be derived.

Let h = the class length,
n = the number of fibres in each class, and
W = the total weight of all the classes.
Then,

$$\text{Mean weight per unit length} = \frac{W}{\Sigma hn}$$

For a given density the weight per unit length and the fibre diameter are related. Assuming a circular cross-section and taking the density of wool to be 1·31, the diameter is given by

$$d_{\text{grav}} = \sqrt{\left(\frac{97190\ W}{\Sigma hn}\right)}\ (\mu)$$

where W is the total weight of the fibres, in milligrams,
n is the number of fibres in each length class of h centimetres, and
d_{grav} is the diameter, in microns (determined gravimetrically).

*B.S. Handbook, B.S. 2016:1961, p. 40.
†B.S. Handbook, B.S. 2016:1961, p. 40.
‡*Wool Sci. Rev.* No. 8 (May, 1952); Palmer, R. C. *Proc. Int. Wool Text. Org.* **2**, p. 13; Palmer, R. C. *J. Text. Inst.* **42**, p. 23.

General remarks

(1) Since regain affects the weight, it is essential that the tests are carried out with the fibres in equilibrium with a standard testing atmosphere.
(2) The balances must be accurate to 1 part in 100 and checked or calibrated before use.
(3) The apparatus used for cutting the known lengths should be accurate and checked from time to time. Where razor blades in a brass holder are used, too much pressure may splay the blades out and cause the length to err on the long side. Fibres should be combed straight before cutting.
(4) Random samples should be tested.

*Optical methods**

The techniques of micrometry are fully described in the standard textbooks on textile microscopy, listed at the end of this chapter. It should be remembered that with natural fibres the shapes and 'diameter' of the cross-sections are subject to a greater degree of variation than those of man-made fibres. To obtain reliable results it is therefore necessary to measure a large number of fibres, the more variable the measured dimension the higher the number will have to be to give results to a desired accuracy.

For the measurement of diameter, Heyn (*Fibre Microscopy*, p. 95) recommends the use of a special micrometer in which the entire micrometer scale is moved and the readings taken from the micrometer screw.

In *Fibre Microscopy* (p. 257), Stoves gives the following method by which the denier of a fibre can be calculated if the density is known: 'Cross-sectional area is measured by projecting on to graph paper ten or more images of sections. The scale is calibrated in microns by means of a stage micrometer and the number of squares covered by the fibre sections counted. From the average cross-sectional area the denier is calculated by substituting in the formula (see below), care being taken to convert the value for the area from square microns to square centimetres (1 μ = 1/1,000 mm).'

Since the denier, D, is the weight in grams of 9,000 m of filament,

$$D = a \times 900000 \times \Delta$$

where a is the cross-sectional area in square centimetres and Δ is the density in grams per cubic centimetre.

*Morton, W. E., and Hearle, J. W. S. point out that considerable skill in section cutting and subsequent measurement is necessary. Misleading results may be obtained by inexperienced operators. (*Physical Properties of Textile Fibres*, p. 126 (Textile Institute; Butterworths, London, 1962).)

The densities of a number of fibres are given below:

Nylon	1·14	'Terylene'	1·38
Orlon	1·17	Acetate	1·31
Vicara	1·25	Acetate (TiO_2 delustred)	1·33
Dynel	1·28	Cuprammonium	1·52
Silk	1·34	Viscose	1·52

Note. Where the fineness is required in millitex units the formula is modified slightly:

$$\text{Fibre fineness in millitex units} = a \times 10^6 \times \Delta$$

(A millitex unit is the weight in milligrams of 1 km of material)

The profile method for wool. The recommended method of using a projection microscope to measure the fineness of wool is described in detail in Chapter 3 of the W.I.R.A. handbook *Testing and Control.* The standard procedure is given on p. 57 of B.S. Handbook.* (See also *Wool Sci. Rev.* No. 8 (May, 1952)).

Essentially, the method is to mount a sample of very short cut lengths of fibre in a suitable mountant and to project their images on to a screen carrying a movable transparent scale. The lengths of the pieces are 1 mm or less and under the microscope they look like little cylinders; it is the width of these cylinders which is measured and recorded. The choice of the mountant is important since it must not absorb water (to prevent fibre swelling), it must have a refractive index of between 1·53 and 1·43 (to give a well defined image), and it must be capable of dispersing the tiny cylinders of wool. Cedar wood oil and liquid paraffin have been found suitable.

The measuring technique given in the B.S. Handbook almost eliminates the chance of the same piece of fibre being measured twice. When the results are complete the calculation of the mean diameter and the coefficient of variation is carried out. It has been found that for unblended wool tops and worsted yarns the coefficient of variation lies between 20 and 28 per cent. This determines how many fibres must be measured to give a result to a desired degree of accuracy. Thus, for the result to be within 5 per cent of the population mean at the 95 per cent confidence interval, at least 100 fibres must be measured. To be within 1 per cent, the number rises to 2,500. Where the coefficient of variation is higher, e.g. in blends, different limits will apply and the number of measurements to give the same percentage accuracy will consequently be higher.

Because the actual cross-section, i.e. a section at right-angles to

*B.S. Handbook, B.S. 2043:1953.

the fibre axis, is not measured, this method is called the 'profile method'. Examination of the wool fibre cross-section is made when a study of the ovality or ellipticity of the fibre is the object of the test.

The 'rapid comparator' for wool. There are times when it is essential that an estimate of the fineness of a wool sample must be obtained with the utmost speed as, for instance, when checking deliveries of tops. An account of the rapid comparator method is given in *Wool Science Review* (No. 8, May, 1952) from which the notes which follow have been taken. Cross-sections of the wool are prepared by a Hardy-type microtome. 'An image of the cross-section of the fibres is then projected at a magnification of 500 times through a projection microscope. The mean diameter and standard deviation are then estimated from the projected image by comparison with a set of photographs of standard cross-sections giving various combinations of mean fibre diameters and standard deviation of diameter. It is more convenient to have the standards available as a 35 mm film strip. This can be projected at a magnification of 500 times and side by side for easy comparison. Pohle (*Text Ind.* Vol. 114) has prepared such a film strip which comprises sixty-five standard cross-sections covering thirteen grades of wool top (ranging from 80s to 36s) and with five different standard deviations of fibre diameter for each grade of top.'

The accuracy of this method is discussed in this article. It is pointed out that in order to achieve an accuracy of about 2½ per cent, i.e. the degree of accuracy required to place a top in its correct quality grade, the mean of at least seven comparisons would be required for the finer wools and even more for the coarser types. Nevertheless, it is a quick test which gives a measure of variability in addition to average fibre diameter.

Measurement of fineness by vibroscope. The accuracy of the estimate of fibre 'diameter' by projection microscope is not of a high order when the fibre has an irregularly shaped cross-section. Airflow methods may be used, and although for some purposes they are extremely useful, the results give no measure of the variability within the sample and there are certain factors which can affect the result and perhaps give misleading information (see Lord, E. *J. Text. Inst.* **46**, T191 (1955)). We have noted already that a fundamental method of determining fibre fineness is to measure the fibre weight per unit length, a gravimetric method using a direct weighing of cut lengths. An indirect method of estimating the mass per unit length of a fibre or yarn has been developed and is based on the theory of vibrating strings.

When a violinist tunes his instrument he adjusts the tension in each string until the pitch of the note produced by bowing or plucking the string is correct. In other words, the string is vibrating at the right frequency. The violin has four strings tuned to E, A, D, and G, respectively, the E string being the highest in pitch. The 'count' or 'denier' of the strings varies too, the finest being the E string and the coarsest the G. From this preamble it may be inferred that frequency, tension, and fineness are related quantities.

Let M = the mass per unit length of a perfectly flexible string,
l = the length,
f = the natural fundamental frequency of vibration (c/s), and
T = the tension in the string

Then,
$$f = \frac{1}{2l}\sqrt{\left(\frac{T}{M}\right)}$$

From which
$$M = T\left(\frac{1}{2lf}\right)^2 \quad \ldots (5.1)$$

Consider the system in Figure 5.21. A string (or fibre) of length l is clamped at one end, led over a knife-edge support, loaded by a weight W, and is induced to vibrate at its natural fundamental frequency f.

Substituting in equation (5.1).
$$M = \frac{Wg}{(2lf)^2} \quad \ldots (5.2)$$

The wavelength of the oscillation, λ, is $2l$, and equation (5.2) may be written
$$M = \frac{Wg}{\lambda^2 f^2} \quad \ldots (5.3)$$

To express M in terms of denier, equation (5.3) can be written
$$M = \frac{Wg}{\lambda^2 f^2} \times 9 \times 10^5 \text{ denier} \quad \ldots (5.4)$$

Several instruments, known as vibroscopes, have been designed to measure the linear density of fibres and have been described in various journals (see the references at the end of this chapter). An outline of the 'Vibrascope' developed by the British Rayon Research Association and manufactured commercially by Louis New-

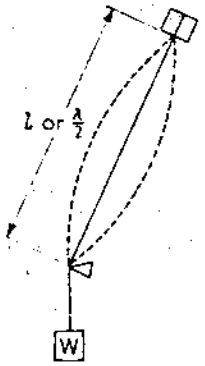


Figure 5.21. The vibrating string

mark Ltd is given here. (The notes have been taken from a description of the instrument by Butler, K., in *Skinners Silk Ray. Rec.*, Jan., 1958; also in *B.R.R.A. Tech. Reprint* No. 25.)

A schematic diagram of the instrument is shown in Figure 5.22. The weighted specimen is clamped to the vibrator at A and passes over the knife edge K. The clamp and knife edge are connected to a 150 V source so that the specimen is electrically charged. Transverse vibrations of the specimen will therefore induce a charge in a brass screw S situated midway between the clamp and the knife edge and spaced 1 mm from the specimen. The screw thus acts as a transducer; if the signal from it is amplified suitably and fed back to the vibrator, an oscillatory loop is formed, thus causing the specimen to vibrate at its resonant frequency. The voltage across the vibrator can then be fed into the frequency measuring circuit and the frequency of the oscillation indicated on the meter.

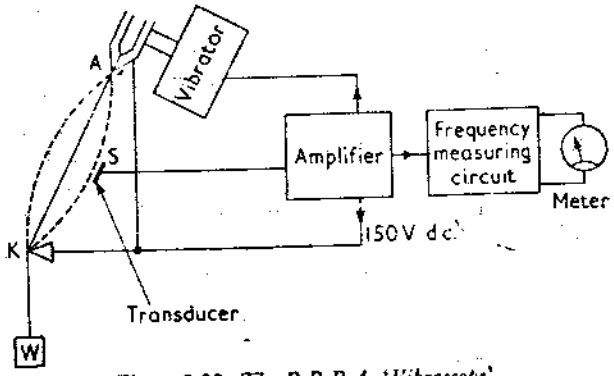


Figure 5.22. The B.R.R.A. 'Vibrascope'

Hence, in equation (5.4), Wg is known, λ is known ($2l$), and f has been accurately measured; the mass per unit length may then be calculated. It would be possible to calibrate the meter directly in denier instead of frequency, but to do so would restrict the range of the instrument. To ensure that a range from 0·4 to 450 denier can be accommodated, several weights are used, the meter scaled from 0 to 100, and a calibration chart prepared for each weight, the curves being plotted from equation (5.4).

A refinement to the estimation of the denier is possible by correcting the result to allow for the stiffness of the specimen. Since various fibres have different values for Young's modulus, the effect is allowed for by using equation (5.5)

$$M = \frac{Wg}{\lambda^2 f^2} \times 9 \times 10^5 \left[1 + \frac{R}{l}\sqrt{\left(\frac{E\pi}{T}\right)}\right]^2 \quad \ldots (5.5)$$

where R = the radius of the specimen,
l = the length, and
E = Young's modulus

Experience with the vibroscope has proved that reproducible and accurate results can be obtained even by unskilled operators since it is only necessary to mount the specimen on the instrument, close the draught excluding cover, and read the meter—no delicate manipulation of sensitive apparatus is required. An instrument of the vibroscope type (but not the B.R.R.A. model) was used by Morton in his investigation into the variability of fineness within samples of various staple fibres (*J. Text. Inst.* **47**, T422 (1956)).*

Air flow methods

The measurement of fibre fineness by gravimetric and most optical methods is not well suited for mill routine testing in which speed of testing is of major importance, not even when some accuracy is sacrificed in order to obtain quick results. In recent years, testing instruments have been developed which cut the testing time to a fraction, offering the mill laboratories the opportunity of quickly assessing the qualities of raw materials and of using the information in the selection of suitable varieties, and also to check the deliveries. By judicious mixing, variations between bales can be smoothed out and reasonably uniform blends put through the processing machinery.

*See *A.S.T.M.* D1577–60T.

These modern instruments are based on air flow principles. Generalising somewhat, a sample of a known weight is compressed in a cylinder to a known volume and subjected to an air current at a known pressure. The rate of air flow through this porous plug of fibre is measured, the flow meter often being calibrated in terms of fineness instead of volume per unit time, e.g. microns for wool, micrograms per inch for cotton.

The theory of fluid flow through porous media is outside the scope of this present volume but the reader wishing to possess more detailed information is referred to the references given at the end of this chapter. Nevertheless, the underlying principles may be appreciated by considering a simplified explanation of the relationship between air flow and fibre fineness. Suppose two cylinders of similar dimensions were filled with (1) a few circular rods of large diameter, or (2) many rods of small diameter, the numbers and dimensions being chosen so that the total cross-sectional areas are equal (see Figure 5.23). If air were blown through the two cylinders at the same pressure, it would be found that the rate of air flow through (b) was less than through (a), even though the space through which the air passes is the same for both cylinders. The reason is that the air flowing through (b) has more rod surface to flow past. This surface acts as a drag on the air in a manner similar to the drag on the water by river banks.

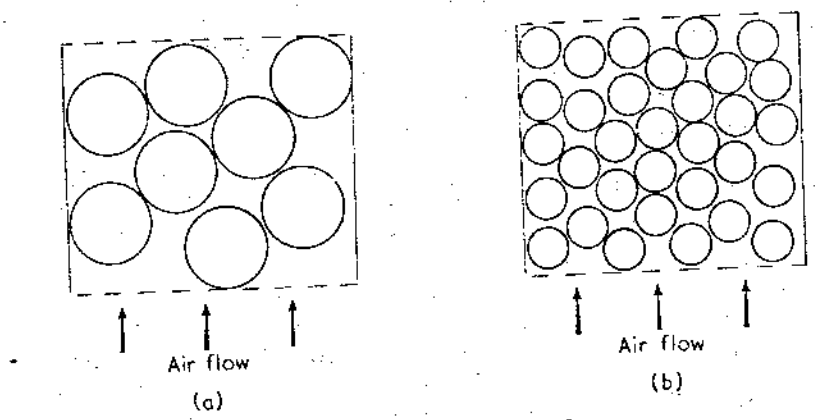


Figure 5.23. Air flow and fibre fineness

Hence, a difference in the rate of air flow is a measure of the difference in the surface area of the large diameter and small diameter rods. This leads us to consider the term *specific surface.*

Specific surface is defined as the ratio of surface area to volume, e.g. the specific surface of a cylinder.

Let the volume V = cross-sectional area A × length L

$$= \pi \left(\frac{d}{2}\right)^2 L$$

where d = the diameter of the cylinder.

The surface area (ignoring the ends) = πdL

Therefore,

$$\text{Specific surface } S = \pi dL \div \pi\left(\frac{d}{2}\right)^2 L = \frac{4}{d}$$

This ratio also equals the ratio

$$\frac{\text{Perimeter of cross-section}}{\text{Area of cross-section}} = \frac{\pi d}{\pi(d/2)^2} = \frac{4}{d}$$

Thus,

$$S \propto \frac{1}{d}$$

It follows from this reasoning that, for fibres of circular cross-section, specific surface is inversely proportional to the fibre diameter. Therefore, by measuring the rate of air flow under controlled conditions, the specific surface of the fibre can be determined and consequently the fibre diameter. Then, by using a value for the density of the material, the fibre weight per unit length could be derived. Referring again to the rods in Figure 5.23, it will be noted that since the total cross-sectional areas of the large and small diameter rods are equal their weights will also be equal. Speaking of fibres instead of rods, we might now conclude that for *equal weights* of fibre sample the rate of air flow will be less for fine fibres than for coarse fibres.

In the discussion so far we have considered circular cross-sections. Wool fibres are not quite circular in cross-section but have an elliptical shape with a contour ratio (ratio of major to minor axes) of between 1·1 and 1·2. By assuming uniformity of shape, the specific surface will depend upon the mean fibre diameter, therefore the air flow instrument for wool may be graduated to read mean fibre diameter instead of either specific surface or rate of air flow.

Before describing some of the instruments it is important to note that any factors which may affect the rate of air flow, fibre dimen-

sions, or weight, will also affect the reliability of the results. It is therefore necessary to test the materials in a standard testing atmosphere after conditioning. In this way the air viscosity will be constant, the weights of the samples will be measured at constant regain values, and any swelling due to regain will be the same for samples of similar fibres.

The W.I.R.A. fineness meter for wool. The development of this instrument can be followed in part by the study of the following references:

Anderson, S. L. *J. Text. Inst.* **45**, P312 (1954)
Richards, N. *J. Text. Inst.* **45**, P661 (1954)
Anon. *J. Text. Inst.* **47**, P960 (1956).
Anon. *J. Text. Inst.* **49**, P326 (1958).*

The last reference is, in fact, the Tentative Textile Standard No. 51, 1958. It is mainly from these sources that the notes which follow have been derived.

The general arrangement of the apparatus is shown in Figure 5.24. A is a cylindrical chamber, with a perforated false bottom, in which a sample of wool of a fixed weight is compressed to a fixed volume by the piston P, which also has a perforated bottom. Air is drawn through the plug of wool by an exhaust pump and the rate of air flow indicated by the flowmeter F. This meter is a special glass tube in which a light float rises to a height depending upon the rate of air flow, the rate then being read off from the top of the float against a scale marked on the glass tube.

The pressure drop across the plug of wool is measured by the manometer M, which consists of a reservoir and the U-shaped tube. Control of air flow is by means of the valve V.

Two methods of carrying out a test are possible:

(1) At a constant rate of air flow (using a sample of 1·5 g).
(2) At a constant pressure difference (sample weight 2·5 g).

It is suggested in the Tentative Textile Standard that Method (2) is more suitable for mill use since the larger sample needs less accuracy in weighing and has an almost linear scale. To make a test by Method (2) a sample of 2·5 g is prepared and packed evenly into the constant volume chamber A, the piston P pushed home and secured by a retaining cap. The exhaust pump is switched on and the valve V adjusted until the pressure difference across the plug of wool is equal to 18 cm of water. The height of the float in the flowmeter is read and the indicated average fibre diameter

*See B.S. Handbook No. 11, p. 51. B.S. 3183:1959.

read to the nearest 0·1μ. Three specimens are tested for wool above 30μ, and two for wool below 30μ.

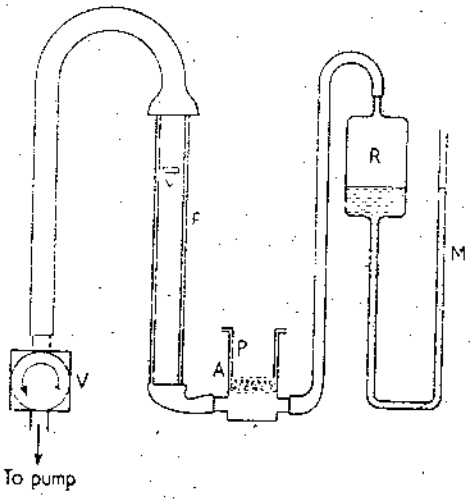


Figure 5.24. Schematic diagram of the W.I.R.A. fineness meter for wool

Calibration of the flowmeter. The flowmeter is calibrated against wool samples whose diameters have been measured by the projection microscope method set out in B.S. 2043. A scale is prepared, graduated in microns, and fixed behind the flowmeter.

Effects of oil. Oil on the fibres results in higher rates of air flow (see Richards' paper). The Standard* recommends that where oil is present the sample should be cleared by two rinsings in light petroleum or carbon tetrachloride. If oil combed tops are regularly tested, however, the time taken to degrease and condition the samples may be eliminated by preparing a separate scale for oil combed tops only.

Testing by Method (1). Briefly, the 1·5 g sample is prepared, packed into the constant-volume chamber, and the air flow adjusted to a fixed value. The height of the meniscus in the right-hand limb of the manometer is then read off against a scale calibrated against known samples and graduated in microns.

The apparatus for Methods (1) and (2). Constructional details and the full procedures for sampling, testing, and calibrating the instrument will be found in the Tentative Textile Standard No. 51, 1958.

*British Standard B.S. 3183:1959.

*Air flow instruments for cotton.** The rate of air flow through a plug of cotton of a given weight is governed both by instrinsic fineness and maturity. The maturity of a cotton is discussed later in this present chapter. For the reader who is unfamiliar with this aspect of cotton quality it is suggested that he should study the section devoted to maturity and its measurement before going further into air flow instruments for cotton.

The perimeter of a cotton fibre is a characteristic of the growth considered. For example, the perimeter of a Sea Island cotton, a 'fine' growth, is less than that of, say, an Indian cotton. Within a particular growth the perimeter is fairly constant and is governed by heredity. If two samples of equal weight were taken, one from a fine and one from a coarse cotton, there would be a greater number of fibres in the sample of fine cotton, other things being equal, and therefore the total surface area would be greater. If both were tested in an air flow instrument the fine cotton sample would exhibit a greater resistance to the flow of air. Thus, the rate of air flow would be used to obtain a measure of the fineness of the cotton. A complication arises, however, with cotton in that the maturity of the material influences the indicated rate of air flow.

Since maturity is concerned with the development of the cell wall, and the cell wall thickness of a mature fibre is greater than that of an immature fibre, a given weight of mature fibres of a particular growth will contain fewer fibres than a similar weight of immature fibres. Hence, for the mature sample the rate of air flow will be higher.

The relationship between specific surface S, the maturity ratio M, and the fibre weight per centimetre H, has been shown to be

$$S = \text{constant} \times \frac{1}{\sqrt{(MH)}}$$

The specific surface is inversely proportional to the root of the product of fibre weight per centimetre and maturity ratio.

Accepting the fact that with cotton the rate of air flow through a plug of given weight depends on both fibre fineness and maturity, the following question arises: 'How are the results obtained from air flow instruments interpreted'? It has been pointed out earlier that within a particular growth of cotton the perimeter is fairly constant. From this fact we can argue that, for a particular growth, *variations in air flow will indicate variations in maturity*. Generally speak-

*See B.S. Handbook No. 11, p. 44. B.S. 3181:1959.

ing, spinning mills use a limited range of growths, therefore deliveries can be checked against standards set up in the light of experience. The term 'micronaire value' is now a widely used expression and whereas originally the figure meant fibre weight in micrograms per inch, the units are commonly ignored and the micronaire value regarded as an indication of maturity.

The notes which follow are taken from the Shirley Developments Ltd publication *The Maturity of Cotton—Micronaire Value and Nep.*

'It should be carefully noted that micronaire value in itself is not a measure of maturity. The growth must be taken into account. Remember, micronaire value is a combination of fineness and maturity, e.g. coarse Indian cottons generally have higher micronaire values than American growths, irrespective of maturity. If American cotton is very immature it will give a lower micronaire value than a much finer but mature Egyptian cotton. Bales of lower micronaire value than average for the growth are usually lower in maturity, and the further their value falls below the average for the growth the lower is likely to be their maturity and the greater the chance of nepping and bad dyeing.

Using the micronaire value

Two courses are open to the spinner:

(1) He can buy many cottons, particularly American, on grade and staple and on an agreed micronaire value—his broker will supply him with a list showing the micronaire value of each bale in the lot.

(2) He can test samples from each delivery on his own air flow instrument and establish the micronaire value of each bale. Even if the cotton is bought on micronaire value, most spinners will wish to have their own instrument which they can use to check the consignments.

Having established the micronaire value of each bale in a consignment we may now have a list as follows:

	Number of bales	*Micronaire value*
B	10	4·8
	15	4·3
	10	4·1
	40	4·0
	10	3·9
A	10	3·2
	5	3·1

The fifteen bales, Group A, of 3·2 and 3·1 are likely to cause serious trouble should a number of them occur in the same mix. Forearmed with this valuable information the spinner can arrange that when these

bales are processed their low value can be partly counterbalanced by making sure that the bales from Group B, the high value group, are included in the same mix, thus avoiding the incidence of a high proportion of low maturity cotton in the same mix and a resultant neppy yarn.

A mill could adopt a fairly simple procedure in that instead of referring to the numerical micronaire values of individual bales, having tested a lot, bales could be marked either high, low, or average, possibly using coloured signals, e.g.:
Low values: A red paint mark on the bale band.
Average values: A yellow paint mark on the bale band.
High values: A green paint mark on the bale band.
When a mix is set down, a red bale could be offset by the inclusion of a green bale.

It is fairly simple to use this information where a mix consists of only one growth of cotton, but complications are introduced where a number of different growths are used in the same mix. However, this can be overcome by considering each growth separately and evaluating the micronaire values of each bale as high, low, or average for the particular growth in question.

Experience has proved that the use of micronaire values when buying or mixing cotton is of very real help in the production of a better and more regular yarn.'

The W.I.R.A. cotton fineness meter. This instrument is a modified version of the wool fineness meter and is manufactured by Shirley Developments Ltd. Two models of the instrument are now in existence, an earlier model which had to be calibrated in micronaire units by the user, and a new model in which this calibration is

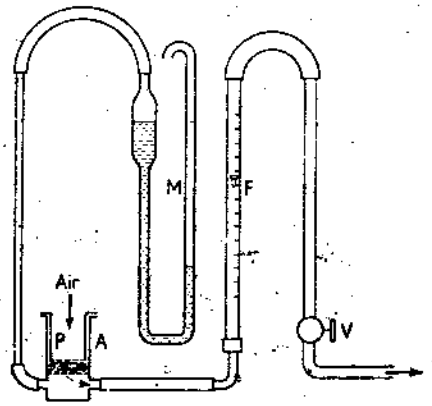
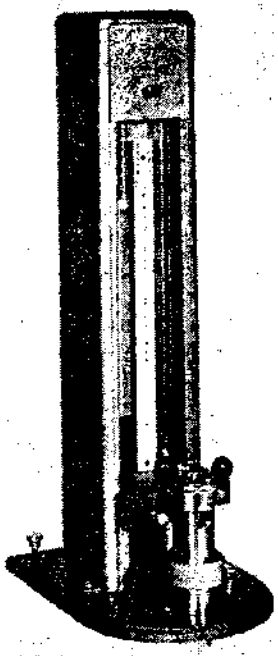


Figure 5.25. Schematic diagram of the W.I.R.A. fineness meter for cotton

incorporated in the instrument. A diagram of the general arrangement of the apparatus is shown in Figure 5.25, and a photograph of the new model of the instrument is shown in Figure 5.26.



(By courtesy of Shirley Developments Ltd)

Figure 5.26. The W.I.R.A. fineness meter for cotton

For the earlier model a 6 g sample weighed to an accuracy of ±0·05 g is fluffed up to eliminate any tangled parts (if a Shirley Analyser is available the raw cotton can be cleaned, opened, and blended at the same time). The sample is then packed into the cylindrical holder and compressed to a constant volume by the perforated plunger. With the flow control valve shut, the exhaust pump is switched on. The air flow is then regulated by the control valve until the manometer indicates that a pressure difference of 18 cm of water exists across the ends of the plug of cotton.

The flowmeter tube is graduated in litres per minute and the reading of the top of the indicator float is recorded. A repeat observation is made after removing the sample and repacking it into the holder. A third observation may be made if greater accuracy is required. For many routine testing purposes it is recommended that tests should be made on two independent test specimens, with two flow determinations on each, taking the mean of the four readings.

The flowmeter readings and their interpretation. Where the results are being used internally for routine mill checks the air flow values in litres per minute may be used, the higher the readings the higher the maturity. Standards may then be set out to suit the spinning conditions which apply. It may be preferable to express the results in terms of micronaire values. This can be done because the W.I.R.A. instrument and the Sheffield Micronaire operate on similar principles.

The rate of air flow and the product of maturity ratio and fibre weight are related (see Lord E., *J. Text. Inst.* **47**, T16 (1956)). In addition, experiments produced a relationship between this product and the micronaire value.

Let M = maturity ratio
H = hair weight
H_s = intrinsic fibre fineness (i.e. the standard fibre weight per centimetre), and
X = micronaire value

(1) Rate of air flow $\propto MH$
By definition, $H_s = H/M$ and, therefore, $H = H_sM$.
Thus, $MH = M \times H_sM = M^2H_s$
We can now rewrite the first line,
Rate of air flow $\propto M^2H_s$

(2) $MH = M^2H_s = 3{\cdot}862X^2 + 18{\cdot}16X + 13{\cdot}0$

Hence, the rate of air flow and the micronaire value X are related and it is possible to calibrate the flowmeter by means of samples of cotton of known micronaire values.

Sets of six standard blended samples of cotton are available from standard blended bulks of these cottons at the Shirley Institute. The values of the quantity MH and the corresponding micronaire values have been determined at the Institute. From each of the six samples three test specimens are taken and three air flow determinations are made on each specimen, giving nine tests all told for each sample, and the mean values obtained. The six mean values can then be used in the following two ways to give an approximate calibration:

(1) Plot a graph of air flow against corresponding values of *MH*, drawing a *straight line* to pass evenly through the six points. From this graph a Table may be prepared to give values of *MH* for a range of suitably spaced air flow values.

(2) Plot a graph of air flow values against the corresponding micronaire values, drawing a *smooth curve* to pass evenly through the six points. From this graph a Table may be prepared to give the micronaire values corresponding to a range of suitably spaced air flow values. For quick readings a chart may be drawn, graduated in micronaire values and mounted behind the flowmeter tube. Micronaire values can then be read off directly.

These approximate methods should be quite suitable for mill use, but where inter-laboratory comparisons are to be made a more accurate calibration may be obtained by calculated conversion tables.

The new version of the W.I.R.A. Cotton Fineness Meter is supplied with a scale engraved in micronaire units. It is used in the same way as the earlier model except that a 5 g sample is used rather than a 6 g sample.

*The Sheffield Micronaire—for cotton and wool.** This is an American instrument originally designed to estimate the fibre fineness in terms of micrograms per inch for cotton by air flow methods. The values so determined became known as 'micronaire values' and this term has remained in usage although the values have since become associated with maturity. When wool is tested the scale of the instrument is graduated in microns, the units used for fibre diameter.

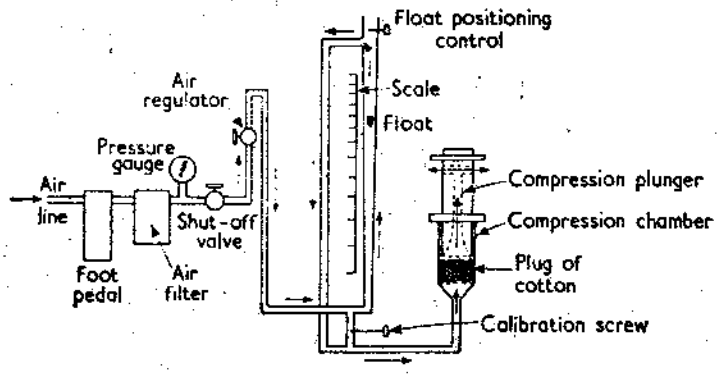


Figure 5.27. Air circuit for Sheffield Micronaire

*See also *A.S.T.M.* D1448–59.

The air circuit diagram is given in Figure 5.27. An air compressor supplies air to the instrument via the foot-operated valve, the air filter, the shut-off valve, and the air regulator. This air regulator controls the air pressure difference across the plug of fibre, reducing the input pressure of over 40 lb/in^2 to 4·75 lb/in^2, a value measured by a mercury manometer built into the instrument.

A special master plug is pushed home into the fibre compression chamber. The instrument is then adjusted so that the float in the flowmeter tube rises to an upper limit, with air flowing through the plug, and to a lower limit, when the flow of air is restricted by placing the thumb over a hole in the top face of the plug. The adjustments are made by the float positioning knob and the calibration screw. When this initial adjustment is completed the master plug is removed and the instrument is ready to test the samples.

Test procedure for cotton (condensed from *Micronaire Manual*)

(1) Very carefully weigh the sample of 50 gr (3.24 g) with a good quality balance. An accuracy of ± 0·1 gr (6 mg) is permissible. Use a balance shielded against air currents, as they can cause erroneous sample weights.
(2) Work the sample into a fluffy mass with the fingers to thoroughly randomise the fibres, eliminating all knotty balls and stringy sections of fibre.
(3) Place the sample in the fibre compression chamber.
(4) Insert the fibre compression plunger and lock into place by twisting. This compresses the sample into a porous fibre plug of 1 in. diameter and 1 in. length.
(5) Step on the foot pedal to turn on the air and take the scale reading to the nearest 0·1 scale unit at the point level with the top of the float.
(6) Step on the foot pedal to shut off the air, remove the fibre compression plunger and again step on the foot pedal. The sample will be blown out of the compression chamber.
(7) Before inserting another sample, operate the foot pedal to shut off the air supply.
(8) It is recommended that at least two samples be chosen and weighed from each test lot.

Interpretation of the results. The use of micronaire values for the indication of variation in maturity within a particular growth has been discussed earlier. A report on the micronaire test is given by Lord (*J. Text. Inst.* **47**, T16 (1956)). Lord points out that 'the micronaire test for raw cotton may be used in conjunction with (1)

the fibre weight per centimetre to assess fibre maturity, and (2) the routine maturity test to estimate intrinsic fibre fineness.

(1) Suppose the average fibre weight per centimetre, H, has been determined by the usual routine method, and a micronaire test is made on the same sample. The maturity ratio, M, of the cotton can be calculated using the equation

$$\text{Estimate of } M = \frac{\text{Micronaire estimate of } MH}{\text{Test value of } H}$$

Knowing H and M, the standard fibre weight per centimetre can then be calculated from $H_s = H/M$.

(2) From immaturity test figures for percentages of normal and dead fibres, the maturity ratio M may be calculated and then combined with the information derived from the micronaire test to give the average fibre weight per centimetre. Thus,

$$\text{Estimate of } H = \frac{\text{Micronaire estimate of } MH}{\text{Test value of } M}$$

As before, the standard fibre weight per centimetre may be calculated from $H_s = H/M$.'

The data from a range of cottons tested by Lord were examined and estimates of M calculated as in (1) above and compared with the maturity ratio derived from the standard caustic soda method. The accuracy of the estimate appeared to be rather low.

The 'Causticaire' test. Remembering that air flow methods are really measuring specific surface and that the standard maturity test involves the swelling of the fibres by a solution of caustic soda, it would seem that the testing of a sample of cotton before and after swelling would offer a convenient method of estimating maturity. This extension of the use of the micronaire is discussed fully by Lord (*J. Text. Inst.* **47**, T635 (1956)), but it would appear from his conclusions that errors present in the method make this technique unsuitable for practical use.

The micronaire test for wool. Essentially, the micronaire test for wool fineness is similar to the test for cotton, the differences arise in regard to size of sample (5·9 g), pre-treatment (the wool must be degreased and then conditioned), and in the interpretation of the results. The fibre diameter is read from the scale and there are no maturity complications as in the case for cotton. There are some possible sources of error, however; they have been mentioned in an article in *Wool Science Review* (May, 1952) and are repeated below:

(1) The degree of random orientation of the fibres in the plug.

(2) Regain. Although the sample is conditioned before being compressed into the compression chamber, the r.h. of the compressed air supply will probably differ from the laboratory air.
(3) Medullation. The medulla, or hollow canal, which is present in some wool fibres will affect the reading. Where high medullation is present, there will be more fibres in a given weight. There will thus be a greater resistance to air flow and the float will not rise as high as it would for a sample of the same mean diameter but free from medullation. Hence, the mean diameter readings for heavily medullated wools will give too low a figure for the mean fibre diameter.

NOTES ON OTHER TYPES OF AIR FLOW INSTRUMENTS

*The Arealometer**

A sample of raw cotton is prepared in the form of a cylindrical plug and its resistance to air flow is determined at two degrees of compression. Two measures of specific surface are obtained, and from them estimates of mean specific surface, mean fibre weight, and maturity are derived. Morton and Radhakrishnan investigated the performance of the Arealometer (*J. Text. Inst.* **45**, T774 (1954)) and their conclusions were as follows:

(1) The Arealometer is a portable and self-contained instrument with which it is possible, in about 15 min, to measure the specific surface, the hair weight, and the maturity of a sample of raw cotton.
(2) For reasons which remain to be more fully investigated, it is not suitable for maturity tests on material that has been processed or mechanically handled.
(3) Mean specific surface and mean hair weight are determined with an accuracy that is probably not exceeded by any other method, however laborious.
(4) A geometric measure of maturity is obtained which, though not claimed to be as accurately determined as hair weight and specific surface, seems to be no less reliable than that obtained by the much more subjective method of deconvolution counts.

The Speedar

This is another American instrument and is designed to measure specific surface quickly. Any weight of sample between 5 and 10 g may be tested. Adjustment to a fixed weight is not required, there-

*See also *A.S.T.M.* D1449-58.

fore an increase in the speed of testing is achieved. The information produced by the Speedar is similar to that furnished by the W.I.R.A. and Micronaire (see Hertel and Craven, *Text. Res. J.* **25**, No. 5 (1955)).

The Port-Ar

A portable instrument testing an 8 g sample and producing (1) micronaire value, and (2) 'equivalent fibre thickness'. The latter is defined as

$$H = 2000/A$$

where H = equivalent fibre thickness, and
A = specific surface in square millimetres per cubic millimetre.

A review of air flow instruments, which includes descriptions of the W.I.R.A., Micronaire, Arealometer, Speedar, and Port-Ar, is contributed by Robinson in *Texture*, June, 1957.

THE MATURITY OF COTTON

Maturity ratio, maturity count, standard fibre weight per centimetre

The maturity ratio concerns the development of the cell wall. The perimeter of the cotton fibre is least affected by environment and most by heredity, but cell wall thickening is highly sensitive to growing conditions. Even when cotton is grown under favourable conditions a small proportion of the fibres will be under-developed or immature, but adverse weather, poor soil, plant disease, and pests, etc., will increase the proportion of immature fibre and lead to trouble in processing. Immaturity in the tufts tends to remain in patches and immature fibres tend to associate even through to the yarn stage. Small patches of crops can be affected and the chances of maturity variation are great in any sample or bale of cotton.

One of the main troubles caused by the presence of these thin-walled immature fibres is nepping. Apart from natural causes like fragments of seed pod attached to a fibre, nepping is *created* during processing, starting at the gin. Where rubbing between surfaces occurs, e.g. during carding, minute knots of tangled fibre are caused and the flabby immature fibres are most prone to this nepping effect. When fine cottons are being processed the danger of nepping is even more acute, since even mature fine cottons can be nepped by faulty processing. In addition, the neps so formed are usually more prominent because of their size relative to the diameter of the finer yarn.

Immaturity also affects the shade after dyeing. As the response of the primary wall to certain classes of dyes is less intense, the thinner the secondary wall the lighter the shade. Fine cotton tends to be lighter in shade than coarse cotton. This is only a partial explanation of shade difference. The colour component reaching the eye from dyed fibre is mainly composed of rays of light reflected from internal surfaces. In Figure 5.28 we note that light reflected from A will be the colour of the dye in B, and the colour we see will be the remnants of the incident light which has not been absorbed by the fibre. The greater the depth of B the deeper the shade. If the walls are thinner there will be a greater possible number of reflecting surfaces per unit mass of cellulose and, consequently, a greater amount of light emerging after passing through only a small amount of stained material. The apparent shade is therefore lighter.

With two deliveries of weft spun from cotton of different maturity, weft bars are a possibility. Neps will show up as specks in the dyed cloth.

In order to assess the quality of cotton with respect to maturity and its effect on ends down, yarn strength, dyeing troubles, and so on, some method of measurement is required. The degree of cell wall thickening may be expressed as the ratio of the actual cross-sectional area of the wall to the area of the circle with the same perimeter (see Figure 5.29).

The 'degree of thickening', θ, $= A/A'$

$$A' = \pi r^2 = \frac{4\pi^2 r^2}{4\pi}$$

multiplying by 4π,

$$= \frac{p^2}{4\pi}$$

because $p^2 = \text{perimeter}^2 = (2\pi r)^2$

Therefore,

$$\theta = \frac{A}{A'} = \frac{4\pi A}{p^2}$$

Direct measurement of this ratio is not a practicable routine test and is not normally done. An indirect method which has been in use for a number of years is the cotton fibre immaturity count* (B.S. Handbook, p. 69). A convenient time at which to make this

*B.S. 3085:1959 *Cotton Fibre Immaturity.*

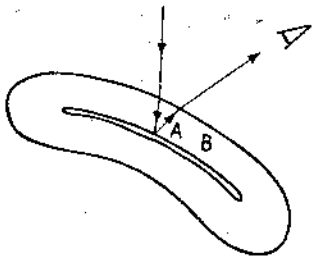


Figure 5.28. Reflection of light from the internal surface of a cotton fibre

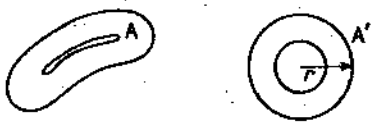


Figure 5.29. 'Degree of thickening' of a cotton fibre

test is after a sorter diagram has been prepared for the measurement of the fibre length characteristics and fibre weight per centimetre. After the fibre weight has been determined, five tufts of cotton are left on the velvet pad. Each tuft is laid on a microscope slide, the fibres parallel but separated, and a cover slip put over the middle.

The fibres are then irrigated with a small amount of 18 per cent caustic soda solution which has the effect of swelling them. The presence or absence of convolutions is then observed, preferably by means of a projection microscope. This enables the fibres to be classified into three groups:

(1) Normal fibres.
(2) Thin-walled fibres.
(3) Dead fibres.

Mature fibres with a well-developed cell wall and pronounced convolutions in the raw state become rod-like after swelling. These rod-like fibres are classed as 'normal'. Dead fibres appear ribbon-like even after swelling. Thin-walled fibres are those lying between the other two classes. Borderline cases may be judged from the thickness of the cell wall relative to the total width of the 'ribbon'. If the wall is less than one-fifth of the total width the fibre is classed as dead (see Figure 5.30).

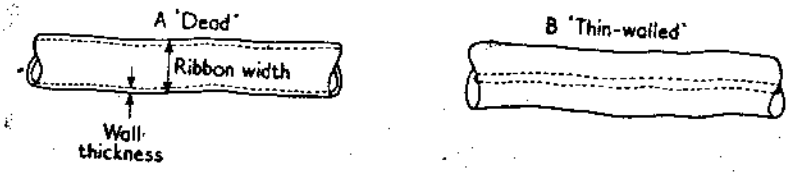


Figure 5.30. 'Dead' and 'thin-walled' cotton fibres after irrigation with 18 per cent caustic soda. Fibre A is classed as 'dead' because the wall thickness is less than one-fifth the ribbon width

The counting and classification is done in three stages:

(1) All the fibres are counted.
(2) The rod-like fibres are counted, N.
(3) The dead fibres are counted, D.

Classification and counting is carried out for each of the fibre groups, the numbers converted to percentages, and the means calculated. The result of the test is then expressed as $N - D$, e.g. 64 — 14 would mean that 64 per cent of the fibres counted were classed as normal and 14 per cent classed as dead; therefore, by subtraction, 22 per cent would be classed as thin-walled fibres.

It is desirable to express the results as a single figure which would give the actual maturity observed as a fraction of some suitably chosen standard maturity. From a sample of 100 fibres it would be *abnormal* to find that all the fibres could be classed as 'normal' fibres. A standard was chosen which was typical of fully matured cotton crops grown under the best possible conditions. The standard chosen was

$$N - D = 67 - 7 = 60$$

It is also desirable that the result should be proportional to the geometrical measure of cell wall thickening, the 'degree of thickening'.

Assuming (1) a constant specific volume, and (2) a perimeter, p, constant for a pure strain of cotton, then

$$A \propto H \text{ (hair or fibre weight per centimetre)}$$

Therefore,

$$\theta \propto H$$

The *maturity ratio* to be derived from these conclusions is the ratio which expresses the actual fibre weight per centimetre, H, in relation to a standard fibre weight per centimetre H_s. (An alternative term for standard fibre weight per centimetre is 'intrinsic fibre fineness'.) Thus,

$$\text{Maturity ratio } M = \frac{H}{H_s}$$

By definition, the standard fibre weight per centimetre, H_s, is that which the fibre would have if it were fully matured in the arbitrary sense of having an $N - D$ of 60.

The link between the immaturity count and fibre weight

Peirce and Lord found $N - D$ and H for several pure strains of cotton and within each series only the maturity varied. A linear relationship was found between H and $N - D$:

$$H = 0{\cdot}9370\,(N - D) + 135{\cdot}2$$

hence,

$$\frac{H}{H_s} = \frac{0{\cdot}9370\,(N - D) + 135{\cdot}2}{0{\cdot}9370\,(67 - 7) + 135{\cdot}2} = 0{\cdot}0049\,(N - D) + 0{\cdot}706$$

To rounded figures,

$$\text{Maturity ratio } M = \frac{N - D}{200} + 0{\cdot}7$$

The maturity ratio is therefore proportional to the degree of thickening of the cell wall. Peirce and Lord determined M and θ for the cottons and found the relationship

$$\theta = 0{\cdot}577M$$

The theoretical range for the value of M will be from 0·2, all dead, to 1·2, all mature or normal.

*Differential dyeing—the Goldthwaite test for maturity**

In a previous section it was mentioned that one of the troubles caused by immature fibres was faulty dyeing. This difference between the dyeing properties of mature and immature fibres is employed in the Goldthwaite test to give a visual indication of the maturity of a sample of cotton. Two dyes are used in the same bath, a red and a green dye. Mature fibres are stained red and immaturity fibres green, the red colour being developed in the cellulose of the secondary wall. Hence, little or no secondary wall thickening—no red.

A 3 g sample of cotton is stitched loosely into a piece of gauze to form a thin flat pad. This is thoroughly wetted out in boiling distilled water and transferred to the boiling dye bath.

The bath is prepared from 180 g of water, 1 gr of Diphenyl fast red Supra 1, and 2 gr of Chlorantine fast green BLL.

After 15 min the sample is temporarily removed to allow 1·8 gr of sodium chloride to be added to the bath. A second 15 min boiling is again followed by temporary removal to allow a further 1·8 gr of sodium chloride to be added to the dye bath. A final 15 min treatment is given to the sample before removing, draining, and washing in two changes of cold water. Next, the sample is washed in vigor-

*See also: Morton, W. E., and Hearle, J. W. S., *Physical Properties of Textile Fibres*, p. 145 (Textile Institute; Butterworths, London, 1962); Boulton, J., and Armfield, W., *Text. Res. (J.)*, **21**, 212 (1949); Boulton, J., and Armfield, W., *J. Text. Inst.* **40**, T445.

ously boiling water for 30 sec, removed, washed in cold water, and dried.

The observer assesses the incidence of immature fibre by the proportion of green present. This is, of course, a subjective test and naturally some little experience of the technique of assessment is necessary. Experiments with samples of known maturities will provide some standards against which samples may be judged.

The use of polarised light

The appearance of fibres when observed under a microscope fitted with suitable polarising equipment may be used to give a numerical estimate of fibre maturity. The test is described by Skinkle in *Textile Testing*. According to the colour, a fibre is classed as immature (two demerits), partially immature (one demerit), or mature. With a sample of fifty fibres the total number of 'demerits' gives the percentage immaturity.

An automatic device is made by Metrimpex of Budapest. A sample of fibre is prepared on a small black pad and fed into the instrument. The fibres are scanned by an optical system and the observations translated into a meter reading by an electronic circuit.

For further information, see Dischka, 'The Estimation of the Fineness and Strength of Cotton from Measurements of Maturity made by the Cotton Grader', *J. Text. Inst.* **49**, T631 (1958).*

NOTES ON FIBRE QUALITY

Cotton quality

The characteristics of cotton which are of importance in the assessment of its quality include fineness, length, maturity, uniformity, and grade. All but the latter term have been considered already but the term 'grade' requires explanation. One of the main functions of the men who handle the cotton between grower and spinner is to make available to the spinner a range of different types of cotton from which he may choose a type suitable for the purpose in view, e.g. hosiery yarn, fine yarn for shirting, etc. When the type of cotton has been decided upon, the spinner requires a certain degree of uniformity and continuity in the quality of the raw material delivered to his mill. Since cotton quality varies from year to year, field to field, and bale to bale, some system of classification or grading must be used to ensure that the spinner receives his cotton in

*See also *A.S.T.M.* D1450–57, *Maturity of Cotton Fibres (Polarised Light Method)*.

smoothly running lots, otherwise the problems of continual re-adjustment and settings of the processing machinery will become great indeed.

When grading itself is considered we again meet variation, this time in the methods used in grading and even differences in the terminology. Differences between centres separated by great distances can be understood to some extent, but we find that differences in grading cotton exist between markets relatively close together, e.g. Egypt and the Sudan. It is not intended to discuss all the grading systems but to illustrate two which employ different criteria of evaluation.

American cotton grading. The grading of American Upland cotton is based upon three main characteristics: colour, trash content or foreign matter, and preparation. It is important to note that staple length is *not* one of the three. The colour may be referred to as extra white, white, spotted, tinged, and yellow stained, in decreasing order of merit. The variety, weather, soil, picking efficiency, and so on, govern the colour.

Foreign matter or trash consists of such materials as broken leaf and pod, sand, and dirt. Some types are relatively easy to remove during processing, e.g. sand, but cut seeds with fibre still adhering to them are troublesome. Increased use of mechanical pickers leads to an increase in trash since the machine cannot exercise care or discriminate, as can a human cotton picker.

The efficiency of the ginning process is reflected in the assessment of the preparation. Poor ginning may result in damaged fibre, neps, and a stringy looking lint. Good preparation is denoted by an 'A' credit, poor preparation by a 'C', with an intermediate category 'B'.

The United States Department of Agriculture has a series of standards for cotton grade. In 1941, thirty-two grades were officially recognised but these are based on eight main grades*:

Middling fair
Strict good middling
Good middling
Middling
Strict low middling
Low middling
Strict good ordinary
Good ordinary

*But see Brown and Ware's book *Cotton* for revised 'American Upland Cotton Grade Standards'.

It is of interest to note that the grade 'Middling' is used as a basis for pricing of American cotton.

It is pointed out by Lord (*J. Text. Inst.* **47**, P184 (1956)) that, 'even when suitable type standards have been inaugurated there are still serious problems. Type standards require continual replacement if their character is likely to change over a period of time. Moreover, the interpretation of type standards in everyday practice by different people at different places also makes calls on personal skill.'

Sudan–Egyptian cotton grading. In the cotton growing region of the Gezira Plain, the cotton is graded into six full grades, 1 to 6 in descending order of quality, with half-grades denoted by 'X', a symbol for 'Extra'. The classifier includes an assessment of the staple length in his judgement of the cotton, as well as fineness, appearance, colour, and trash content. The initial grading is made on the cotton before it is ginned and may be regraded at a second examination after it has reached the shipping point of Port Sudan. The effect of the inclusion of a length assessment and the reduction of the importance of trash content as compared with American grading practice will be appreciated by a study of the graphs shown in Figures 5.31–5.33.

The reader is recommended to expand his knowledge of cottons and cotton quality by further study of the literature, in particular the papers by Lord on the production and characteristics of the world's cotton crops.

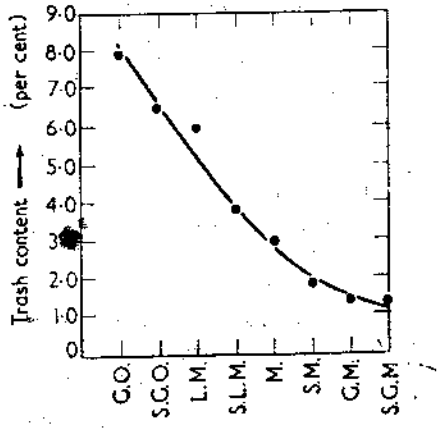


Figure 5.31. Analyser trash content and American grade

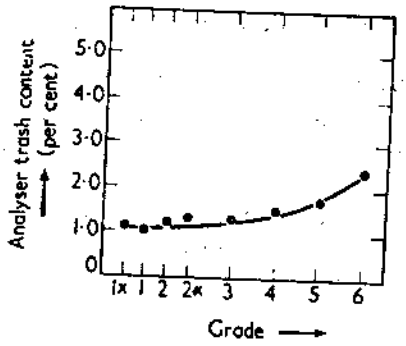


Figure 5.32. Analyser trash content and Sudan–Egyptian grading

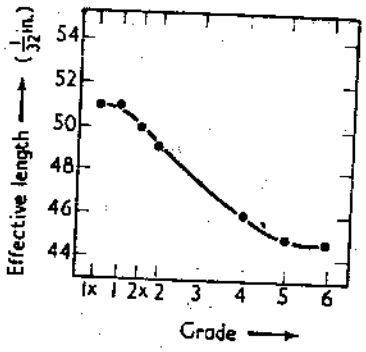


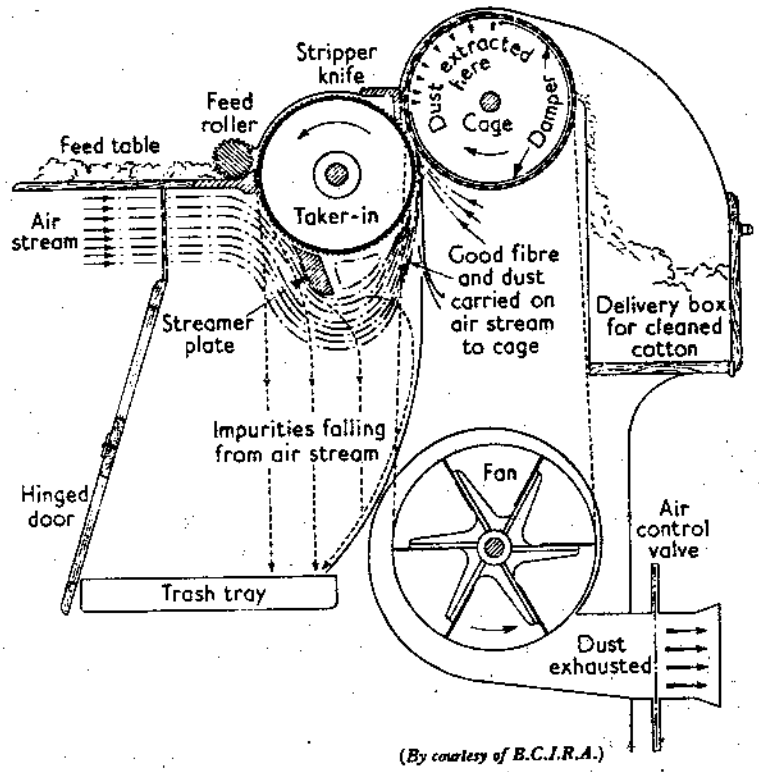
Figure 5.33. Domains Sakel grown in Gezira. Effective length and Sudan–Egyptian grading

The measurement of trash content—The Shirley Analyser

In the previous section, references to trash content have been made. The machine used for its determination is an instrument developed by the British Cotton Industry Research Association and made by Platts. The details of the analyser are given below and have been condensed from the makers' descriptive booklet.

The machine operates on the principle of 'buoyancy separation' by the use of air currents. A diagram is shown in Figure 5.34. The sample is placed on the feed table and presented to the taker-in by the feed roller. Owing to its high speed and large number of teeth, the taker-in cylinder opens up the cotton almost to the single hair state. Due to the strong centrifugal force, cotton hairs and trash particles tend to travel tangentially outwards and enter the air stream; this tendency is intensified by the action of the streamer plate which is specially shaped to permit the air currents set up by the motion of the taker-in cylinder to join the general air stream without forming eddies.

The separation of the cotton and the trash takes place as the two travel with the air stream through the settling chamber, the heavy trash particles falling almost straight down to the trash tray. On the other hand, as the single cotton hairs are entirely controlled by the air stream they are carried along with it and out of the chamber. The lighter trash particles tend to fall, but they are taken some way by the air stream. By correct adjustment of the air currents they ultimately fall into the trash tray at a point further forward than the heavier particles. The paths of the various particles are indicated by the dotted lines in Figure 5.34.



(*By courtesy of B.C.I.R.A.*)

Figure 5.34. The 'Shirley' Analyser

Cotton and light dust are carried out of the chamber and drawn on to the cage surface, the dust being sucked through the cage perforations. The cotton forms a layer on the cage and travels forward in its direction of rotation. When the foremost portions of the layer of cotton arrive over the dampered section of the cage, they are pushed forward on to the delivery plate by the cotton coming up behind, the in-draught from between the delivery plate and the cage helping to strip the layer from the cage. Ultimately, the cotton falls into the delivery box. For a complete test the time taken is only about 15 min.

The trash content is weighed and expressed as a percentage of the whole sample.

Two samples are put through the analyser and the mean is determined. Differences of less than 20 per cent of the mean are not statistically significant. For example, two cottons giving values of 1·0 and 1·2 per cent would be considered as having similar trash contents, but not if one was 1·4 and the other 1·8 per cent.

The practical uses for which the Shirley Analyser is intended are:

(1) To give the purchaser and seller of raw cotton or waste definite figures concerning the proportions of clean cotton and trash in the material.
(2) To provide the cotton spinner and the waste spinner with an accurate idea of the capabilities of his existing machinery on any particular class or mark of cotton or waste.
(3) To determine the state of cleanliness of the product at any stage up to and including carding.
(4) To ascertain the quantity of spinnable fibre in the waste from any production machine.
(5) To determine the loss of good fibre in the sequence of opening and cleaning processes.

In addition, the Shirley Analyser is useful in the preparation of cotton for Micronaire and W.I.R.A. fineness meter tests because the fibre is well opened out and free from trash.

The test for trash content is now published as a British Standard (B.S. 2889:1957).*

The Southern Regional Research Laboratory non-lint tester

The S.R.R.L. non-lint tester has been developed for the rapid and accurate determination of the non-lint or trash content of cotton.

The non-lint tester is a licker-in (taker-in) type of cleaner that efficiently and rapidly removes the foreign matter from lint cotton. It has a new type of feed system that extensively drafts the cotton, anti-turbulent grid bars that tend to prevent the ejected trash from being sucked back into the lint, a means of cleaning the cotton twice in a continuous process, and an air-doffing and air-circulating system that requires no external filter.

A 100 g sample of lint cotton is weighed, then spread out on the feed table where a pair of rollers feed it into the drafting and cleaning cylinders. The cleaned cotton is removed from a box at the delivery end of the tester and weighed. The difference between the original and final weights is the non-lint content of the sample. The cotton is processed once only and the waste is not weighed. Thus 10–20 non-lint determinations per hour can be made, depending on the method of weighing and the speed of the operator.

A comparison between the Shirley Analyser and the S.R.R.L. tester has been made. It was concluded that close agreement between the results from both machines is possible, the Shirley Analyser

*A modified version of this analyser is available for wool. The vegetable matter is separated from the wool (*Platts Bulletin*, **X**, No. 8).

giving higher values than the S.R.R.L. tester, but consistently higher, an average Shirley Analyser: S.R.R.L. ratio being 1·36:1. The main advantage of the new machine is that the test is carried out much more rapidly.

The information above has been derived from two sources to which the reader is referred; Rusca, R. A., and Latour, W. A. (*Text. Bull.* **88**, 45, No. 2 (1962), and Rusca, R. A., Latour, W. A., and Gray, W. H. (*Textile World*, **113**, 64, No. 6 (1963)).

Wool quality

When the wool sorter classifies wool he rapidly assesses such factors as fibre fineness, crimp, length, scaliness, handle, and lustre, but the most important characteristic which is judged is fineness.

Fineness. Although the mean fibre diameter is an important component quality, an indirect method of expressing the fibre fineness is used. Other things being equal, a finer fibre can be spun into a finer yarn. This being so, the original basis for assessing fineness was to estimate the finest yarn that the wool sample could produce. For example, a sample of wool could be classed as 58s, the inference being that the spinner could make a 58s worsted yarn from it. The developments in spinning techniques have enabled the spinner to produce finer counts than the quality number would suggest but, nevertheless, the original standards have been adhered to. The three main classes of wool are Merino, sometimes called Botany, with quality numbers 60s to 100s, Crossbreds, 36s to 58s, and Carpet, up to 36s.

The American standard *A.S.T.M.* D 419–61 links the measurement of wool fibre diameter by the projection microscope and the grade. Table 5.6. is taken from this standard. However, the International Wool Textile Organisation (I.W.T.O.), considers tables which imply a correspondence between wool fibre average diameter and commercial quality numbers to be misleading and very firmly suggests that their use should be prohibited (I.T.W.O. Conference, Barcelona, 1951). In a recent textbook,* *Wool*, the author discusses the components of wool quality and points out that systems of grading are still 'in a state of flux'.

The introduction of new fibre-measuring instruments will, perhaps, lead to a more rational method of expressing wool fibre quality.

Crimp. A feature of the wool fibre is its 'crimp' or waviness.

*Onions, W. J., *Wool* (Benn, London, 1961)

Table 5.6. Wool Fineness and Grade (A.S.T.M. 419–61)

Fineness range		
Average diameter μ (min.)	*Average diameter μ (max.)*	*Grade*
17·7	19·1	80s
19·2	20·5	70s
20·6	22·0	64s
22·1	23·4	62s
23·5	24·9	60s
25·0	26·4	58s
26·5	27·8	56s
27·9	29·3	54s
29·4	30·9	50s
31·0	32·6	48s
32·7	34·3	46s
34·4	36·1	44s
36·2	38·0	40s
38·1	40·2	36s

Research has shown that some form of relationship exists between the crimps per inch and the fibre fineness, the finer the fibre the greater the number of crimps per inch. The wool sorter's judgement of fineness and his subsequent estimate of the quality number is probably influenced considerably by this knowledge (see *Wool Sci. Rev.* Oct., 1953; and Lang, *J. Text. Inst.* **49**, T495 (1958)).

Length. When the length of wool fibres is considered it is found that in the main the shorter wools are fine and the longer wools coarse, a reversal of the order for cotton fibres. For worsted yarns, fibres which are long, fine, and uniform in length are desirable, and because in most cases a combing process is used in their preparation, wools suitable for worsted yarns are termed 'combing' wools. For woollen yarns where a lofty handle is wanted and where the fibres are carded, the shorter wools are chosen and referred to as 'clothing' wools.

Ellipticity. The cross-sections of wool fibres are nearly circular, but have varying degrees of ellipticity, the amount being expressed as the 'contour ratio', the ratio between the major and minor axes of the fibre contour. Some authorities are of the opinion that the nearer this ratio is to unity, i.e. the more circular the fibres, the better the wool will spin (see Barker, S. G., *Wool Quality*, H.M.S.O., 1931).

Wool quality is a big subject and these notes are, of necessity, brief. For a fuller treatment the reader is referred to the literature listed at the end of this chapter.

Flax quality

The author is indebted to the Linen Industry Research Association for the notes on the grading of flax which follow.

Flax grading. The value of a parcel of flax to the spinner depends on the quality of the yarn which may be spun and on the quantity of yarn obtained. When grading, the grader must attempt to assess the various characteristics that are related to these two factors and to integrate them into a single value or grade.

The spinning quality depends mainly on the fineness and the strength of the fibre strands and, to a lesser degree, on their length. Flax with fine strands is compact and is of better quality than flax with coarse strands and low apparent density. Colour and uniformity are also taken into account.

The quantity of yarn obtained from a lot of flax depends on the yield in hackling. Hackling yield depends on a number of factors, among which are:

(1) The handling of the flax, i.e. freedom from knots and tangles.
(2) Cleanliness, i.e. the amount of shive and dust remaining after scutching.
(3) Fibre length, especially the amount of short fibre present.
(4) Strength and fineness of the fibre strands.

The flax markets in different parts of the world each has its own systems of marking the various qualities; some of these are given in the book *The Preparation and Spinning of Flax Fibre* by S. A. G. Caldwell, pp. 17–21.

Jute

The annual production of jute is second only to cotton and the two main growing areas are Pakistan and India. A small crop is grown in Brazil but is for home consumption. Grade designations for jute are rather complicated because growers and exporters use certain systems and manufacturers use others.

The two botanical species of jute are *Corchorus capsularis* and *Corchorus olitorius*, their more common names being White Jute and Tossa Jute, respectively. Three broad classifications are used for each type: Jat, signifying the finest quality, District medium quality, and Northern, the lower quality of fibre. Within each broad class the quality may be described by the district in which the jute has been grown.

Grading is carried out in two stages, one close to its source and the second at the baling stations. The graded bales are tightly pressed, weighing 400 lb, and called 'pukka' bales. Quality is assessed by

consideration of such fibre properties as texture (firm or soft), colour, lustre, length, and cleanliness.

The pukka bales are graded to indicate their make-up:

Top. Sound fibre of good colour for the district and containing not more than 25 per cent 'cuttings' (for Tossa Jute, 15 per cent).

Middle. Sound fibre of average colour and containing not more than 25 per cent cuttings.

Bottom. Lower quality fibre but in straight condition.

Cross Bottom. Tangled fibre.

The cuttings are the ends of fibres which have been cut off to improve the uniformity of length. This operation is carried out when a rough hackling treatment is given to the fibre before baling.

A more rational system of jute grading is being considered and will, no doubt, appear in due course.

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6

YARN DIMENSIONS

THE yarn dimensions and structural details with which we will be mainly concerned in this chapter are the count and the twist. Both are of prime importance in the design of textile structures and, to a large extent, they govern the appearance and behaviour of the various types of yarns and fabrics. It must not be overlooked, however, that the chemists and other technologists in the dyeing and finishing sections of the industry can now produce a wide range of effects from the same starting material, say a plain weave cotton cloth, and this type of development is increasing in importance.

LINEAR DENSITY COUNT OR YARN NUMBER

The 'count' of a yarn is a numerical expression which defines its fineness. When an engineer requires the fineness of a wire (a wire being a reasonably close approximation to a yarn), he consults a Table of standard wire gauge values. For instance, in the Imperial Standard Wire Gauge Table we find that a wire gauge number of 10 corresponds to a diameter of 0·128 in. Alternatively, by measurement of the wire diameter by a micrometer, the corresponding gauge number can be read from the Table. Measurement of the 'diameter' of a yarn poses rather a different problem. Spun yarns are only roughly circular in cross-section and irregularity in thickness is unavoidable. Filament yarns with only a small amount of twist in them are referred to as 'flat' yarns, possibly because they flatten so easily when in contact with other more solid bodies. Since most yarns are relatively soft and compressible, the use of a micrometer for diameter measurement is ruled out. Optical methods can be used, one method being described on p. 117 of the B.S. Handbook. A magnified silhouette of the yarn is projected on to a screen which has a scale graduated in thousandths of an inch. The object of this test is not to determine the yarn count but to get an estimate of the covering power of the yarn and to obtain some indication of the yarn irregularity by the analysis of 200 such diameter readings.

One very specialised section of the textile industry, the cordage and rope-making trade, uses a counting system related to the cross-sectional area of the yarns: 'The count of the yarn is the number of

such yarns which are required to form one strand of a three-strand 3 in. circumference rope.' This is an unusual approach used for a particular job and is not met with in the normal run of things.

In Chapter 5 the problem of expressing the fineness of a fibre was discussed and the term 'linear density' was mentioned, the fibre weight per unit length. For yarns, too, this method of solving the problem is used.

A definition of yarn count is given by the Textile Institute: 'Count. A number indicating the mass per unit length or the length per unit mass of yarn. Note: various counting systems using different units of mass and length are in use, so the system used must be stated.'

Direct and indirect systems of yarn numbering

The definition above contains the phrases 'mass per unit length' and 'length per unit mass', indicating that two basic principles are employed. (For convenience we shall use 'weight' in place of 'mass' in the discussion which follows.)

Direct systems. In a direct yarn counting system the yarn number or count is the *weight of a unit length* of yarn. The units of weight and length vary from trade to trade and district to district, a state of affairs which results in a multiplicity of counting systems. This will be looked into shortly but for the moment we will consider a general formula which applies to all direct systems.

Let N = the yarn number or count,
W = the weight of the sample at the official regain in the units of the system,
L = the length of the sample, and
l = the unit of length of the system.

Then,
$$N = \frac{W \times l}{L}$$

Example. If a skein of 100 m of filament viscose yarn weighs 1·67 g, calculate its denier.

In the denier system the weight unit is the gram and the 'unit of length' is 9,000 m. The denier of a yarn is the weight in grams of 9,000 m. Thus, $W = 1{\cdot}67$ g, $L = 100$ m, and $l = 9{,}000$ m. Therefore

$$\text{Denier} = \frac{W \times l}{L} = \frac{1{\cdot}67 \times 9000}{100} = 150{\cdot}3 \text{ denier}$$

Indirect systems. In an indirect system the yarn number or count is the number of 'units of length' per 'unit of weight'. Here again there are

various units of length and weight and numerous systems. Generalising:

Let N = the yarn number or count,
W = the weight of the sample at the official regain in the units of the system.
w = the unit of weight of the system,
L = the length of the sample, and
l = the 'unit of length' of the system.

Then,

$$N = \frac{L \times w}{l \times W}$$

Example. A lea (120 yd) of cotton yarn weighs 25 gr, calculate its count in the cotton system.

In this case the 'unit of length' is the hank, 840 yd, and the 'unit of weight' is 1 lb. In 1 lb there are 7,000 gr. Hence, $L = 120$ yd, $l = 840$ yd, $W = 25/7{,}000$ lb, and $w = 1$ lb.

Therefore:

$$N = \frac{120 \times 1}{840 \times 25/7000} = \frac{120 \times 7000}{840 \times 25} = 40\text{s}$$

(The small 's' after the count number is a convention used for expressing count.)

Note. The values 7,000 and 840 appear in all such cotton yarn calculations and may therefore be reduced to a constant fraction 100/12, i.e. 7,000/840. A useful little formula is then evident:

$$\text{Cotton count} = \frac{\text{Length in yards}}{\text{Weight in grains}} \times \frac{100}{12}$$

Further, if leas are always tested, then

$$\text{Cotton count} = \frac{120 \times 100}{\text{Weight in grains} \times 12} \text{ or } \frac{1{,}000}{\text{Weight in grains}}$$

Counting systems

Table 6.1 gives the values of the units of length and weight used in some direct and indirect systems of yarn numbering—a curious Table it looks, too! The names of some will suggest to the reader that one of the reasons for this diversity is geographical. The textile industry grew up in different localities and each chose its own system to suit local conditions. Conversion from one system to another is achieved by conversion factors and constants. Where a direct to a direct system, or an indirect to an indirect system is concerned, a multiplying conversion factor is used.

Table 6.1. Units of Length and Weight in Counting Systems

Direct systems

System	*Unit of mass*	*Unit of length*
Tex	Gram	Kilometre
Denier	Gram	9,000 metres
Linen (dry-spun), hemp, jute	Pound	14,400 yards (spyndle)
Silk	Dram	1,000 yards
Woollen (Aberdeen)	Pound	14,400 yards
Woollen (American grain)	Grain	20 yards

Indirect systems

System	*Unit of length*	*Unit of mass*
Asbestos (American)	100 yards (cut)	Pound
Asbestos (British)	50 yards	Pound
Cotton bump yarn	Yard	Ounce
Cotton (British)	840 yards (hank)	Pound
Cotton (Continental)	1,000 metres	0·5 kilogram
Glass (U.S.A. and U.K.)	100 yards	Pound
Linen (wet-spun)	300 yards (lea)	Pound
Metric	Kilometre	Kilogram
Spun silk	840 yards (hank)	Pound
Woollen (Alloa)	11,520 yards (spyndle)	24 pounds
Woollen (American cut)	300 yards (cut)	Pound
Woollen (American run)	100 yards	Ounce
Woollen (Dewsbury)	Yard	Ounce
Woollen (Galashiels)	300 yards (cut)	24 ounces
Woollen (Hawick)	300 yards (cut)	26 ounces
Woollen (West of England)	320 yards (snap)	Pound
Woollen (Yorkshire)	256 yards (skein)	Pound
Woollen (Yorkshire)	Yard	Dram
Worsted	560 yards (hank)	Pound

Examples. Denier × 0·1111 = tex, direct to direct.
Cotton count × 1·5 = worsted count, indirect to indirect.

Where the conversion is from a direct to an indirect or vice versa, a constant is used into which the known count is divided to give the equivalent count in the other system.

Examples. The constant for cotton count and denier is 5315. Thus,

$$32\text{s cotton count} = \frac{5315}{32} = 166 \text{ denier}$$

and

$$100 \text{ denier} = \frac{5315}{100} = 53{\cdot}15\text{s cotton count}$$

Conversion factors and constants for a selected range of counting systems are given in Table 6.2.

Table 6.2. Conversion from One Count System to Another

Direct to Direct

Known yarn count in	*Multiplying factor to give yarn count in*		
	Tex	*Denier*	*Linen (dry-spun)*
Tex	–	9·000	0·02903
Denier	0·1111	–	0·003225
Linen (dry-spun), hemp, jute or woollen (Aberdeen)	34·45	310·0	–

Indirect to Indirect

Known yarn count in	*Multiplying factor to give yarn count in*			
	Cotton and spun silk	*Linen (wet-spun)*	*Woollen (York. skein)*	*Worsted*
Cotton and spun silk	–	2·800	3·281	1·500
Linen (wet-spun)	0·3571	–	1·172	0·5357
Woollen (York. skein)	0·3048	0·8533	–	0·4571
Worsted	0·6667	1·867	2·188	–

Direct to Indirect and Indirect to Direct

Known yarn count in	*Constant into which the known yarn count is divided in order to obtain the equivalent yarn count in the other systems*		
	Tex	*Denier*	*Linen (dry-spun), hemp, jute, and woollen (Aberdeen)*
Cotton and spun silk	590·5	5315	17·14
Linen (wet-spun)	1654	14,880	48·00
Woollen (York. skein)	1938	17,440	56·25
Worsted	885·8	7·972	25·71

*Rationalisation of yarn numbering**

Conversions of count from one system to another costs time and money and there is always the risk of a mistake. As the textile industry developed commercially and technically, it became increasingly clear that there was a need to devise a system of yarn numbering which could be used by all concerned in the production and distribution of textiles, a 'universal yarn numbering system', in fact. Recognition of this urgent need did not lead to its speedy solution. Numerous discussions and conferences have been held but it was not until comparatively recently that a firm decision was taken. In 1956 a conference of the International Organisation for Standardisation (I.S.O.) recommended the adoption of the *tex* system. (For a historical background to the recommendation the reader should consult the relevant references.)

The tex system

The yarn number or count in the tex system is the weight in grams of 1 km of yarn. This system is therefore a direct system, simply defined and simple to use. Extensions of the basic system are used in order to express the fineness of fibres and filaments on the one hand, and intermediate products and coarse yarns on the other. Hence, for fibres the fineness is expressed in 'millitex', i.e. the weight in milligrams per kilometre. For such intermediate products as slivers and coarse yarn structures like cords, the count is expressed in 'kilotex', i.e. the weight in kilograms per kilometre or, what amounts to the same thing, grams per metre.

The adoption of the tex system of yarn numbering will, of course, be a slow process and cause extra work and some headaches until everyone becomes familiar with it, but this short-term disadvantage will be more than compensated for in the future when the old systems are merely of historical interest. A number of yarn and fabric features are described numerically and in their calculation the present systems are used. For example, the twist factor for a cotton yarn indicates the degree of twist in the yarn and is related to the count and turns per inch in the following way:

$$\text{Turns per inch} = \text{twist factor} \times \sqrt{\text{count}}$$

It is immediately obvious that when the tex system is used 'turns per inch' will no longer be a suitable way of expressing twist and that a metric length unit would be appropriate, say 'turns per metre'. In addition, the value of $\sqrt{}$(tex count) will differ from $\sqrt{}$(cotton

*See also: B.S. Handbook No. 11, p. 98; *Yarn count systems and their conversions.*

count). The twist factor will therefore be different. Further, since the tex system is a direct system and the cotton system an indirect system, the form of the relationship between turns, twist factor, and count will change:

$$\text{Turns per metre} = \frac{\text{Twist factor}}{\sqrt{(\text{tex count})}}$$

Numerical examples to illustrate this point will be given when twist testing is discussed later in this chapter.

In fabric technology the openness, or, more appropriately, the closeness of a fabric, is expressed by the 'cover factor'. The 'warp cover factor' is given by:

$$K = \frac{\text{Number of warp threads per inch}}{\sqrt{(\text{cotton count})}} = \frac{n}{\sqrt{N}}$$

Again it is apparent that the inch must be replaced by a metric length unit and that $\sqrt{(\text{cotton count})}$ will be a different value to $\sqrt{(\text{tex count})}$. The cover factor could become:

$K_{\text{tex}} = \text{Number of threads per centimetre} \times \sqrt{(\text{tex count})}$

These points and other technical aspects of yarn and fabric structure will have to be gradually absorbed by textile men until they can use the new values with the facility with which they use the present ones. A report of Bayes (*J. Text. Inst.* **48**, P255 (1957)), discussing the tex system and its effects, is recommended to the reader.

Conversion of traditional counts to tex yarn number. Consider the conversion of cotton count and denier to tex:

$$(1)\ \text{Tex} = \frac{590{\cdot}5}{\text{cotton count}}$$

$$(2)\ \text{Tex} = \text{denier} \times 0{\cdot}1111$$

A few calculations will show that the equivalent tex yarn number of a 'round' traditional count is usually far from round. For example, 32s cotton count becomes 18·45 tex, and 150 denier becomes 16·67 tex. It will be appreciated that when the tex system is used commercially, inconvenient numbers such as these must be avoided. The industry will be obliged to alter its present range of yarn thicknesses slightly and spin to convenient tex yarn numbers. When the change is made the opportunity arises for the introduction of a reduced range of yarn thicknesses, an idea which has been put forward before (see Bayes, A. W. *J. Text. Inst.* **36**, P87 (1945), and *J. Text. Inst.* **38**,

Table 6.3. Standard Tex Counts and Equivalent Cotton and Worsted Counts

Tex	*Cotton*	*Worsted*
10	59·1	88·6
10·5	56·1	83·4
11	53·7	80·5
11·5	51·3	77·0
12	49·2	73·8
12·5	47·2	70·9
13	45·4	68·1
14	42·2	63·3
15	39·4	59·5
16	36·9	55·4
17	34·7	52·1
18	32·8	49·2
19	31·1	46·6
20	29·5	44·3
21	28·1	42·2
22	26·8	40·3
23	25·7	38·5
24	24·6	36·9
25	23·6	35·4
26	22·7	34·1
28	21·1	31·6
30	19·7	29·5
32	18·5	27·7
34	17·4	26·1
36	16·4	24·6
38	15·5	23·3
40	14·8	22·1
42	14·1	21·1
44	13·4	20·1
46	12·8	19·3
48	12·3	18·5
50	11·8	17·7
52	11·4	17·0
56	10·5	15·8
60	9·8	14·8
64	9·2	13·8
68	8·7	13·0
72	8·2	12·3
76	7·8	11·7
80	7·4	11·1
84	7·0	10·5
88	6·7	10·1
92	6·4	9·6
96	6·2	9·2
100	5·9	8·9

P487 (1947)). Implementation of a reduced range would simplify spinning problems and still give the textile designer scope to achieve a wide variety of textile structures.

A list of tex yarn numbers recommended at the I.S.O. Hague Conference in 1956 is given in Table 6.3 together with the equivalent traditional counts in two common systems.

During the transitional period it has been suggested that, when counts are quoted, the traditional count should be followed in brackets by the nearest tex equivalent, e.g. 12s cotton count (50 tex) and not 49·2 tex. As the new system becomes more commonly used, the yarn number should be expressed in tex with the equivalent traditional count in brackets, correct to three significant figures, e.g. 50 tex (11·8 cotton count).

In time, of course, the need for the traditional count in brackets will vanish and all yarn numbers will be expressed in tex.

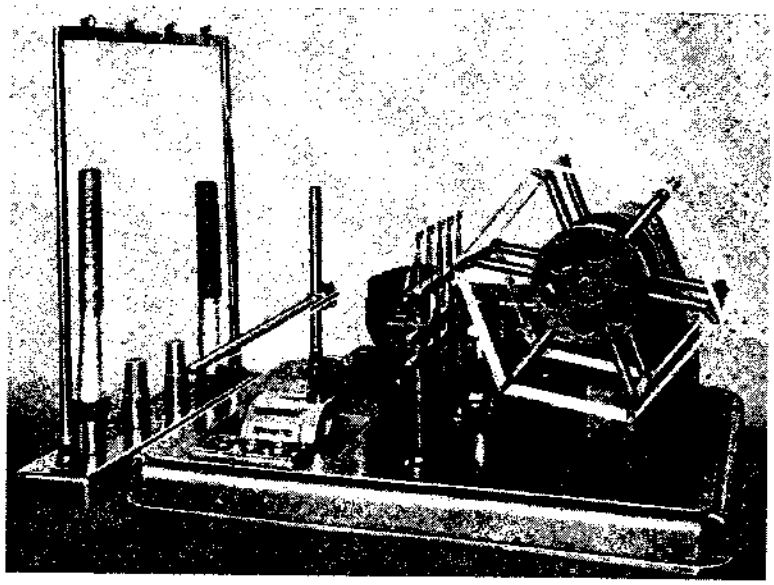
*The measurement of yarn number or count**

Irrespective of the system of yarn numbering employed, two basic requirements for the determination of the yarn number are (1) an accurate value for the sample length, and (2) an accurate value for its weight. At first glance these requirements appear simple enough, but in practice there are possible sources of error which must either be eliminated or accounted for in the calculations. The methods of determining the yarn number depend to a large extent on the form in which the yarn is available for testing. For instance, when yarn is in the form of a ring bobbin a long sample length can be taken, but if the warp and weft counts of the yarns in a 6 in. × 6 in. piece of fabric are required only a number of short lengths are available. Some of these points will now be considered.

Length measurement

Yarn in package form. Where the yarn is in package form, such as ring bobbins or cones, it is usual to wind a number of skeins by means of a wrap reel. This is a simple machine consisting of a reel, yarn package creel, a yarn guide which has a small sideways traverse to spread the loops of yarn, a length indicator, and a warning bell. The wrap reel may be hand- or motor-driven and some are fitted with yarn-tensioning devices. A typical wrap reel is shown in Figure 6.1. For cotton yarns the reel has a girth of 54 in., 1½ yd, so that eighty revolutions of the reel produces a skein of 120 yd, or a lea. The

*See also *Linear Density of Yarns*. B.S. Handbook No. 11, p. 109.



(*By courtesy of James H. Heal and Co. Ltd*)

Figure 6.1. Motorised wrap reel

reel girth and the skein length are chosen to suit the section of the trade concerned, 1 m reel girth for metric systems (and tex, of course), 36 in. for worsted, etc. A first check should be to make sure that the girth of the reel is, in fact, 54 in., 1 m, or 36 in. Inaccurate reels are not unknown and the author met one which was conical, being more than 54 in. at the back and less than 54 in. at the front.

Because yarns possess extensibility, it follows that the tension at which the skein is wrapped will affect the result—a high tension will produce a skein of '120' yd which will be too light in weight and the calculated count will be on the fine side. A skein gauge can be used to check that the reeling tension is correct. This instrument is fully described in the B.S. Handbook.* Figure 6.2(a) shows a skein of yarn on a skein gauge. The reeling tension should be such that when the skein is under a load per end equal to the weight of 440 yd of the yarn tested, the indicated skein girth should be within 0·5 per cent of the reel girth. The limits are set on the skein gauge scale with a pair of movable pointers.

When yarn is wound on to a package a certain amount of tension

*1956 Edition

is put on the yarn to eliminate weak places or give the package stability. The yarn is therefore in a state of strain and so, when the yarn is pulled freely off the package, some of this strain is recovered, i.e. the yarn relaxes and contracts. To counteract this source of error such yarns should first be wound into hank form, allowed to relax in the testing atmosphere for not less than 3 hr, and wrapped for count on the reel.

Where possible, it is always recommended that yarn should be allowed to condition in the testing atmosphere; if in hank form for at least 1 hr, and at least 3 hr for packages, after which the reeling should be carried out at the correct tension.

Yarn in short lengths. The determination of the yarn count of yarns in fabrics is usually made on a comparatively short sample length

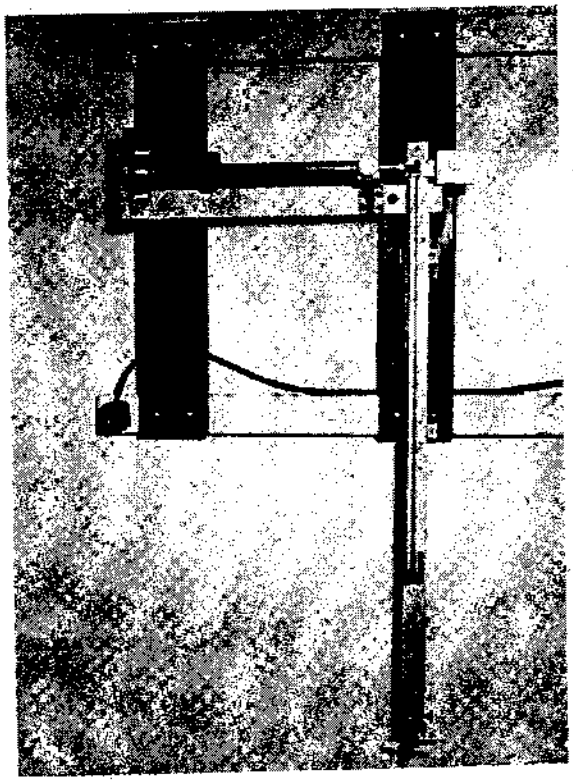


Figure 6.2(a). The skein gauge. Note the limit marks on the left-hand scale

because the piece of fabric available, even if full width, is often only a yard or so long. Sometimes only a square foot or two is available and the test method is then modified accordingly. After conditioning in the testing atmosphere (for 24 hr where possible), two rectangular warp way strips and five weft way strips are cut from the cloth. In length, the strips should be about 20 in. and wide enough to allow fifty threads to be removed from each strip. The difference between warp and weft specimens arises from the fact that 100 threads from two warp strips represent 100 warping packages and form a reasonably random sample. Threads from the weft way strips may only represent five weft packages, but even this is better than only testing the count of two weft packages.

Yarn removed from fabric is crimped due to the interlacing of the threads, and it is necessary to estimate the straightened length of the threads either by a rough crimp check, stretching the thread over a rule, or by a crimp tester. Crimp determination is discussed in Chapter 7, but we must anticipate a little and define crimp percentage.

$$\text{Crimp percentage} = \frac{\text{Straightened length} - \text{crimped length}}{\text{Crimped length}} \times 100$$

From this it will be seen that the value of the yarn length used in the final count calculation will be equal to

$$\text{Strip length} \times \text{number of threads} \times \frac{(100 + \text{crimp percentage})}{100}$$

Where very small fabric samples are offered, there are special templates for cutting the threads; these are used in conjunction with small balances designed to give a quick estimate of the count. One such balance is the Beesley balance and is described later in this chapter.

Weight measurement

Balances. The analytical balances and any other special yarn balances used in the determination of count must be accurate, and it is essential that they are well maintained and that before use they are levelled and checked. In the B.S. Handbook it is recommended that the balance and weights should be capable of giving a result to an accuracy of not less than 1 in 500.

Regain. The problem of accounting for the presence of moisture in the sample can be tackled in several ways, two of which are considered here.

(1) Determine the oven dry weight and multiply by

$$\frac{100 + \text{standard regain}}{100}$$

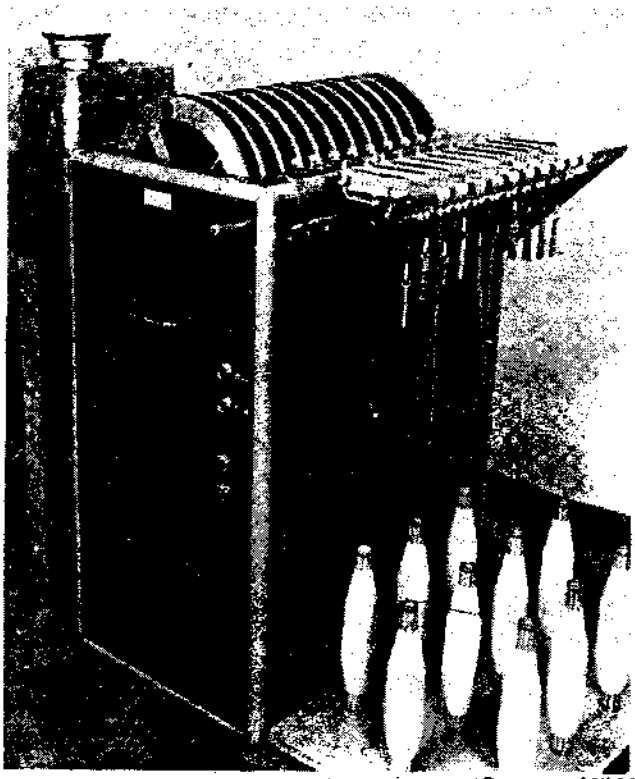
(2) Allow the sample to condition in the testing atmosphere long enough to reach equilibrium, and then weigh in the same atmosphere.

The results of the two methods will not necessarily agree since the official regain and the equilibrium regain in a standard atmosphere are not necessarily identical. Which method should be used? Method (1) should give accurate results and results which are reproducible by different laboratories, but in many instances, especially in routine control testing in mills, the second method is chosen for its simplicity and because the results are mainly for internal use.

(3) *The W.I.R.A. heated drum wrap reel*
The Wool Industries Research Association have developed a heated drum wrap reel (Figure 6.2(b)). By drying the yarn as it is measured for length the count can be obtained far more rapidly than reeling first and then drying the skeins. Under good conditions the count can be determined in about two minutes.

Added and subtracted materials. Between the spindle point and the finished fabric the yarns may undergo a number of treatments, each of which may alter their weight. Some increase the weight, e.g. sizing of warp yarns, while others reduce the weight, e.g. scouring and bleaching. The count determined from a sample may therefore require some correction if an estimate of the original spun count is wanted. Obviously, the history of the sample is a useful piece of information; without this information tests must be made to identify any added substances, such as resin, and then the relevant tests must be carried out to determine the percentage of added materials. Loss in weight cannot be determined and corrections must be made by the use of average figures based on experience.

Notes on some count testing methods (B.S. 2010:1953)
Wrap reel, skein gauge, drying oven, analytical balance. When testing spun packages, sixteen are randomly chosen and a lea from each wrapped on the reel at the correct tension (the skein gauge is used to check the reeling tension). The leas are taken to constant weight in the drying oven. The official regain is added to the oven dry weights



(*By courtesy of W.I.R.A.*)

Figure 6.2(b). The W.I.R.A. heated drum wrap reel

and the individual count results recorded. The mean count is then calculated.

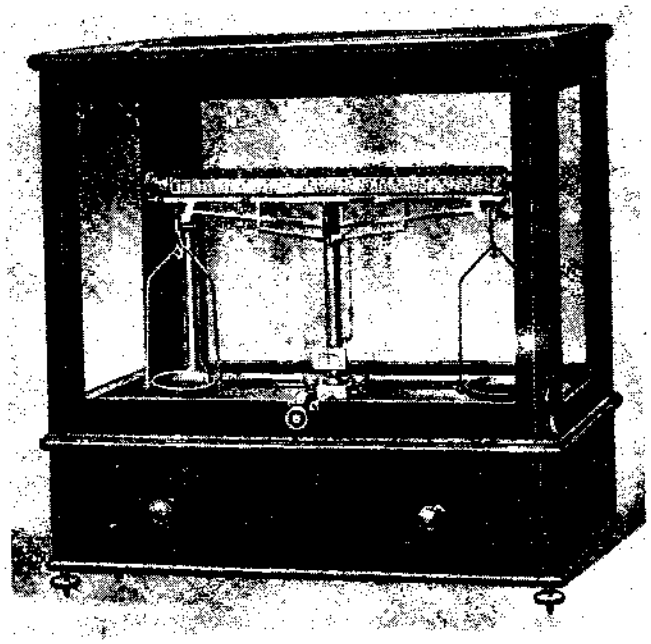
A fuller description of the procedure is given in the British Standard handbook. Modified procedures may be used for particular purposes, e.g. the reel girth may be other than 54 in. and the skein length may not be 120 yd. The use of the tex system will require a reel of 1 m and a skein length of perhaps 50 m. Twenty skeins would, in this case, be a more convenient number to test since the tex yarn number would then be given by the total corrected weight in grams of the whole sample, i.e. 1 km.

Again, the number of bobbins in the sample may be chosen to suit a particular quality control system. In some mills, e.g. worsted spinning or condenser spinning mills, only four bobbins are tested for

count from one frame, the control charts being set out on this basis. On the other hand, 'group frame control' may be operated. This means that a group of frames, nominally identical in all respects, are treated as one large spinning unit. From this unit twenty bobbins may be taken as the sample, or any other number which provides the necessary data to operate a control system to a desired degree of 'tightness'.

Another modification is the elimination of the drying of the yarn. The samples are left to condition in the testing room atmosphere and reeled and weighed in that atmosphere. The count is calculated from the weights so obtained.

Wrap reel and analytical balance. In many mills the leas of yarn are wrapped under nominally the same conditions every day, the exact reeling tension being unknown, and the leas weighed in the laboratory atmosphere. For internal routine testing purposes this method may be considered sufficiently accurate for the end in view.

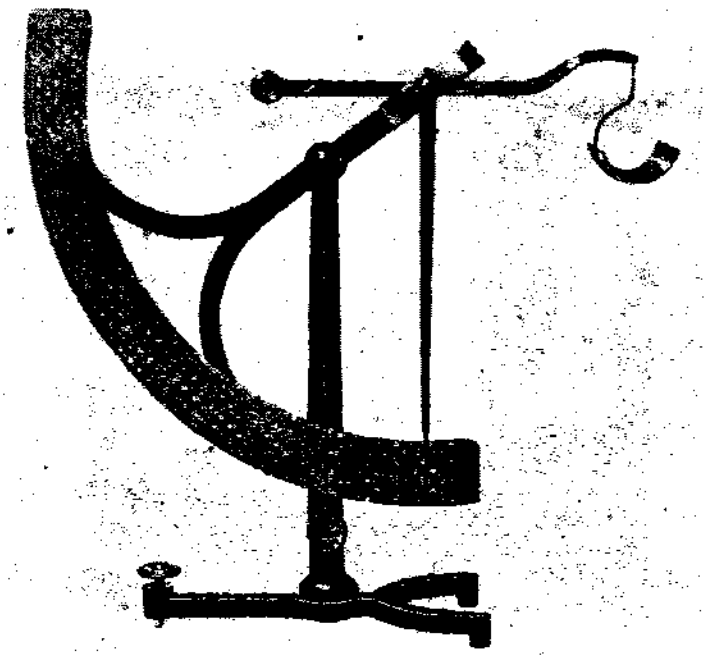


(By courtesy of Goodbrand & Co. Ltd)

Figure 6.3. The Knowles balance

Wrap reel and a Knowles balance. To cut out the arithmetic required when the weights of the skeins of yarn are obtained on an analytical balance, special direct reading balances can be used, the Knowles balance being one example (see Figure 6.3). A beam balance is used, behind which is a separate rod of hexagonal section with five of the faces lettered from A to E and engraved with a count scale to cover a certain range. In the left-hand pan a lettered weight is placed and on the beam a small lettered rider.

Suppose a cotton yarn is to be tested and is judged to be about 36s. Face B of the scale is turned to the front, weight B is placed in the left-hand pan, and rider B put on the beam. The position of the rider is then adjusted until the beam is balanced and the count read off directly from the scale, the value taken opposite a line in the middle of the rider. The Knowles balance can, of course, be designed to suit count systems other than that of cotton.



(By courtesy of Goodbrand & Co. Ltd)

Figure 6.4. Quadrant balance for indicating the counts of yarns and rovings (the radius arm is 13 in.)

Wrap reel and a quadrant balance. The quadrant balance is another type of direct reading instrument. Figure 6.4 shows a typical balance. A given length is measured out and suspended from the hook, the count is then read directly from the quadrant scale. The versatility of this type of balance is improved by engraving the scale with more than one series of values. For example, one scale may read from 0·1 to 1·0 to give the hank of a 4 yd sample of sliver or slubbing, a second scale may read from 0·1 to 6·0 for 20 yd samples of rovings, and the third scale from 4s to 80s for 840 yd samples of yarn. The scales just mentioned are in the cotton count system, but other quadrant balances are available for different ranges and different systems.

An account of the design of accurate quadrant balances, in particular balances for use in the tex system, is given in a selection of articles published in the 1954 English edition of *Rayon Review*.

Direct reading count balances. Modern laboratory balances indicate the weight by digital read-out methods. Hence, if the yarn is a skein of 100 m long its weight in grammes may be read off directly and multiplied by 10 to give the count in tex units.

Special balances. A number of special yarn balances are available which are designed to furnish a quick estimate of the count, especially when only small samples are at hand. One such balance is the Beesley balance, illustrated in Figure 6.5. This instrument consists of a simple beam with a sample hook at one end and a pointer at the other. The beam is initially levelled to bring the pointer opposite a datum line. A standard weight is hung in a notch on the beam arm on the pointer side of the pivot. A template is used to cut short lengths of yarn, the length depending upon the count system required. These short lengths are added to the hook until the pointer is opposite the datum line. The count is the *number* of the short lengths required to balance the beam.

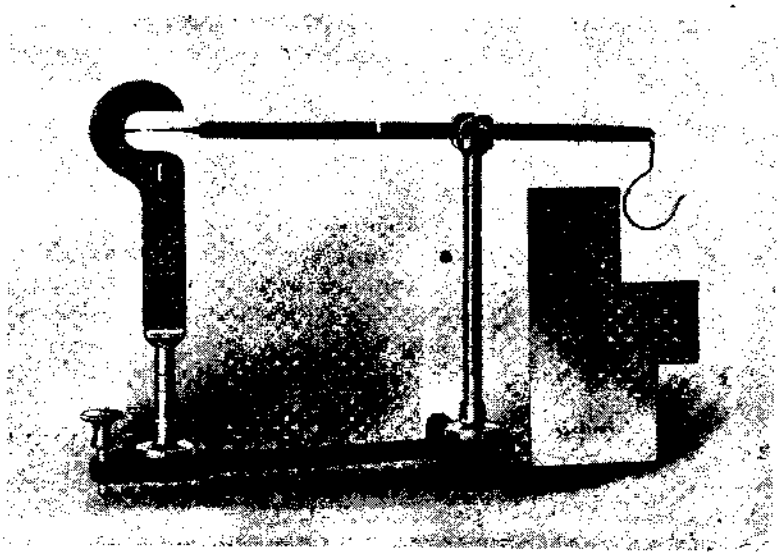
When used in the analysis of small samples of fabric, a rough estimate of the crimp should be made and the count corrected. Allowances for bleaching, resin finished, etc., are at the discretion of the operator.

Count calculations

Textbooks providing numerous examples of the arithmetic involved in yarn count calculations are available, and for practice in this branch of textile mathematics the reader is referred to them (see list of textbooks at the end of this chapter).

Doubled yarns

Yarns produced by the combination of two or more single yarns



(*By courtesy of Goodbrand & Co. Ltd*)

Figure 6.5. Beesley's yarn balance

are used in many textile structures in order to achieve effects which may not be readily obtained if single yarns were used. The resultant yarn count can be determined by methods described earlier. Where the count of the component threads must be measured it is often necessary to dissect the sample and carry out count tests on short lengths. For some of the simpler plied yarns such methods can be avoided if it is known that all the component threads are of the same count and the change in length of the threads which has taken place during the doubling process is also known.

Suppose a twofold cotton yarn, i.e. a yarn made by twisting two single yarns together, is found to have a count of 14s, and that it is known that the doubling process causes a contraction of 10 per cent in the length of the component threads. In an indirect system of yarn counting the reciprocal of the resultant count is equal to the sum of the reciprocals of the component threads (neglecting the effects of twisting on length). Thus,

$$\frac{1}{N} = \frac{1}{N_1} + \frac{1}{N_2}$$

where N = resultant count, and N_1, N_2 = component thread

counts. In our example, N_1 and N_2 are known to be the same. Hence,

$$\frac{1}{N} = \frac{1}{N_1} + \frac{1}{N_2} = \frac{2}{N_1} = \frac{1}{14}$$

Therefore, $$N_1 = 28\text{s}$$

Now, because the contraction has, in effect, caused the singles yarns to become coarser, we must correct our estimate by making it 10 per cent finer, and so the corrected estimate of the original singles count will be $28 \times 1{\cdot}1$, i.e. 30·8s. Sometimes the doubling of yarns causes the component threads to increase in length and the correction to the estimate will go the other way.

The example given is, of course, a fairly simple one; other types of plied structures are built by doubling yarns which have themselves been doubled. Nevertheless, the logical application of the principles of count testing will enable a reasonably accurate analysis of a complex yarn to be carried out. Yarn doubling and the production of fancy yarns is an interesting subject in its own right. To give only one important illustration, without the development of tyre cord technology the roads would be even more hazardous than they are today.

YARN COUNT AND YARN 'DIAMETER'

An increasingly important branch of textile technology is the geometry of fabric structure, a subject which forms a rational foundation upon which to base a scientific study of fabric construction. The appearance, handle, drape, and general behaviour of fabric are dependent upon many factors such as materials used, yarn structure, weave, and finish. Just how these factors interact is a major problem confronting the fabric engineer. One important dimension required in the study of fabric geometry is the 'diameter' of a yarn, a first assumption being that a yarn has, in fact, a circular cross-section. In practice, it is recognised that even if a yarn were circular to begin with, it would be distorted when interlaced with other threads, and later perhaps flattened during calendering. Peirce, in his paper on cloth geometry (*J. Text. Inst.* **28**, T45 (1937)) used the assumption of circularity but noted at the same time that yarns are flattened in fabric. Other cross-sectional shapes have been considered, e.g. elliptical. A recent paper by Kemp (*J. Text. Inst.* **49**, T44 (1958)) offers a new shape, the 'racetrack' section, that is, rectangular with semi-circular ends. For the moment we shall only consider the circular cross-section.

A number of simple formulae are available for the estimation of yarn diameter.

Examples. Cotton yarns:

$$\text{(1) Diameter (in inches)} = \frac{1}{\sqrt{(\text{yards per pound})} - 10 \text{ per cent}}$$

$$\text{(2) Diameter (in inches)} = \frac{1}{26{\cdot}1\sqrt{(\text{counts})}}$$

$$\text{(3) Diameter (in inches)} = \frac{1}{\sqrt{(800 \times \text{counts})}}$$

Worsted yarns:

$$\text{(1) Diameter (in inches)} = \frac{1}{\sqrt{(\text{yards per pound})} - 10 \text{ per cent}}$$

$$\text{(2) Diameter (in inches)} = \frac{1}{21{\cdot}3\sqrt{(\text{worsted counts})}}$$

$$\text{(3) Diameter (in inches)} = \frac{1}{\sqrt{(500 \times \text{worsted counts})}}$$

Peirce approached the problem from a consideration of the apparent specific volume of a yarn. By experiment, an apparent specific volume of 1·1 for cotton yarns was obtained, and from this value a formula for yarn diameter was derived:

$$\text{Diameter } d \text{ (in inches)} = \frac{1}{28\sqrt{(\text{count})}}$$

Let the yarn have a count of N tex. Assuming that the specific volume is 1·1, then 1·1 cm³ of yarn weighs 1 g. Now, 1 g of N tex yarn has a length of $1/N$ km, or $10^5/N$ cm. Hence, 1·1 cm³ of yarn has a length of $10^5/N$ cm. Since volume = cross-section × length,

$$1{\cdot}1 = \frac{\pi d^2}{4} \times \frac{10^5}{N}$$

where d is the diameter in centimetres.
Therefore,

$$d^2 = \frac{4 \times 1{\cdot}1 \times N}{\pi \times 10^5}$$

and, therefore,

$$d = \sqrt{\left(\frac{4{\cdot}4}{\pi 10^5}\right)} \times \sqrt{N} = \frac{0{\cdot}375}{100}\sqrt{N}\ (\text{cm})$$

Converting centimetres to inches, and tex to cotton counts,

$$d\ (\text{in inches}) = \frac{0{\cdot}375}{100} \propto \frac{\sqrt{(590{\cdot}5)}}{\sqrt{(\text{cotton count})}} \times \frac{1}{2{\cdot}54}$$

$$= \frac{3{\cdot}6}{100\sqrt{(\text{cotton count})}}\ (\text{in.})$$

and, to round figures,

$$d = \frac{1}{28\sqrt{(\text{cotton count})}}\ (\text{in.})$$

We could, for the sake of comparison, express this result in the form used in previous examples:

$$d = \frac{1}{\sqrt{(\text{yards per pound})} - 3{\cdot}5 \text{ per cent}}\ (\text{in.})$$

TWIST AND TWIST MEASUREMENT

In its wider connotation, the word 'spinning' embraces all the various processes which are necessary to transform fibrous raw materials into yarns. Even in the man-made continuous filament plants where extrusion processes produce the yarns, one still talks of spinning. A more particular meaning is given to the word when we consider the process in which a strand of fibres in a more or less parallel order is spun or twisted on its axis to form a yarn. The necessity for twist in yarn construction is reflected in most but not all definitions of the term 'twist':

'Twist is the measure of the spiral turns given to a yarn in order to hold the constituent fibres or threads together' (Skinkle).

'When a strand is twisted the component fibres tend to take on a spiral formation, the geometric perfection of which depends on their original formation' (Morton).

'Twist may be defined as the rotation about the yarn axis of any line drawn on the yarn which was originally, i.e. before twisting, parallel to the yarn axis' (*Wool Res.* Vol. 3).

'Twist: The spiral disposition of the components of a thread which is usually the result of relative rotation of the two ends' (*J. Text. Inst.* **38**, P626 (1947)).

Accepting the fact that twist is necessary to give a yarn coherence and strength, many questions now arise, amongst them the two important ones of 'How much twist must be inserted into a yarn?' and 'What effects have varying amounts of twist on the yarn properties?' Before dealing with such questions the methods of describing twist and expressing the amount of twist must be considered.

Twist direction (Source: B.S. 946:1952)

The direction of twist at each stage of manufacture is indicated by the use of the letters S or Z in accordance with the following convention:

A single yarn has S twist if, when it is held in the vertical position, the fibres inclined to the axis of the yarn conform in direction of slope to the central portion of the letter S. Similarly, the yarn has Z twist if the fibres inclined to the axis of the yarn conform in direction of slope to the central portion of the letter Z.

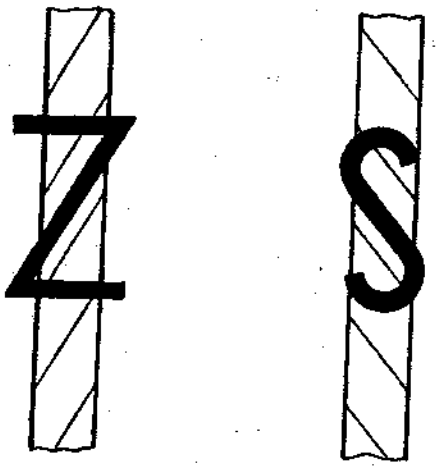


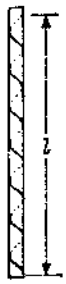
Figure 6.6. Direction of twist in yarns

Figure 6.6 illustrates these definitions. Other methods of describing the twist direction will be found in older textbooks on spinning, but since they lead to confusion it is considered wise to omit them here.

From the spinning point of view, it normally matters little which way the twist goes. However, when single yarns are plied or combined in the form of fabric, the direction of twist becomes important because it influences the character and the appearance of the finished article.

Amount of twist

In B.S. 946:1952 it is stated that 'the amount of twist in a thread at each stage of manufacture is denoted by a figure giving the number of turns of twist per unit length in the twisted condition at that stage.' Thus in Figure 6.7 we note the meaning of 20 t.p.i., twenty turns per inch.



n turns in length l
Twist amount $= n/l$
(e.g. 20 t.p.i.)

Figure 6.7. Amount of twist

For many practical purposes this method of expressing the amount of twist serves quite well, but the expression contains no reference to the count of the yarn. A coarse yarn with 20 t.p.i. has vastly different twist characteristics to a fine yarn with 20 t.p.i. By using an expression known as the 'twist factor' or 'twist multiplier' it is possible to appreciate the twist character of a yarn even without knowledge of the yarn count.

Figure 6.8 represents an idealised element of a yarn, showing one fibre on the yarn surface following a helical path and making one turn round the yarn axis. The twist angle θ is the angle between a tangent to the helix formed by the fibre and the yarn axis. By 'unrolling' the surface layer we see that the fibre becomes the hypotenuse of a right-angled triangle.

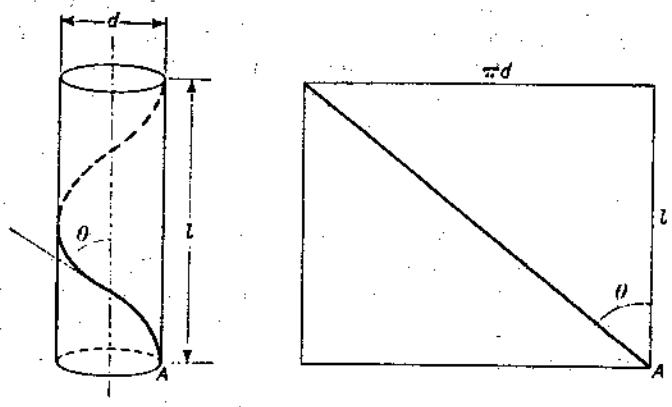


Figure 6.8. Twist angle

Let the yarn diameter be d inches and let l be the length of yarn occupied by one complete turn of twist. Then,

$$\tan\theta = \frac{\pi d}{l} \qquad \ldots (6.1)$$

and

$$\frac{1}{l} = \text{turns per inch} \qquad \ldots (6.2)$$

therefore,

$$\tan\theta \propto d \times \text{turns per inch} \qquad \ldots (6.3)$$

We noted earlier that when the count system is an indirect system, the yarn diameter is proportional to the reciprocal of the square root of the count. Thus,

$$d \propto \frac{1}{\sqrt{(\text{count})}} \qquad \ldots (6.4)$$

Using this relationship we can rewrite statement (6.3),

$$\tan\theta \propto \frac{\text{turns per inch}}{\sqrt{(\text{count})}} \qquad \ldots (6.5)$$

This is more conveniently expressed in the following form:

$$\text{Turns per inch} = K\sqrt{(\text{count})} \qquad \ldots (6.6)$$

The constant K is termed the 'twist factor' or 'twist multiplier' and is directly proportional to the tangent of the twist angle.

A range of, say, cotton yarns spun to different counts, but with the same twist factor throughout, will possess the same degree of hardness and twist character. The spinning frame overlooker can readily

calculate the t.p.i. required to spin a given count with a specified twist factor and calculate the twist wheel required from the twist constant of the frame.

In addition to describing the amount of twist in the yarn, the twist factor also describes to some extent the nature of the yarn. A cotton yarn with a twist factor of 3·0 will be soft in feel and comparatively docile, whereas a yarn possessing a twist factor of 6·0 will be hard and lively. The choice of twist factor will therefore be related to the use to which the yarn is to be put—weft, warp, knitting, etc.

When a direct system of yarn numbering is used, the form of the relationship between turns per unit length, twist factor, and count will be changed. The yarn diameter will now be directly proportional to the square root of the yarn number. Consider what happens in the tex system:

$$\text{Tex twist factor} = \text{turns per metre} \times \sqrt{(N)}$$

This results in twist factors of about 2,000 for soft twisted yarns and 10,000 for hard twisted yarns. Such values appear a little unwieldy perhaps, but if turns per centimetre were used instead of turns per metre the corresponding twist factors would be 20 and 100.

The function of twist in yarn structure

Without twist a strand of fibres has very little strength, and in the first instance a yarn must have sufficient tensile strength to withstand the stresses of preparation and fabric manufacture. It is useful to note here that twistless yarn has been employed as weft in fabrics which have shown reasonable weft way strength. This one example illustrates that the yarn properties *when in fabric form* are not necessarily those demanded by the methods used in preparation and manufacturing processes. Nevertheless, the main function of twist is to give coherence to the yarn. The theories of yarn geometry and its relation to mechanical properties are still being developed, but some general conclusions have been published and the notes which follow are condensed from Gregory's papers in *Journal of the Textile Institute*.

> 'In order to develop strength in a twisted strand of discontinuous fibres, such as a cotton yarn, and so resist breakage, the individual fibres must grip each other when the strand is stressed. This cohesion arises mainly from the twist, which presses the fibres together as the stretching force is applied and so develops friction between adjacent fibres. The pressure results from stressing the twisted strand and has its origin in the tension applied to the curved spiral lines of the individual fibres. It is important to realise that the lateral pressure has no separate existence until the twisted element is stressed.'

In his book *An Introduction to the Study of Spinning*, Morton comments on this topic:

> 'We have the somewhat paradoxical condition in which the tension which tends to pull the fibres apart induces at the same time a state of inter-fibre pressure that tends to hold them together. Which of the two tendencies gains the upper hand depends on the angle of the spiral. If the angle is small, i.e. if the twist is low, the fibres can be made to slide past one another, but if it is large they cannot and the only effect of increasing the tension is, in the end, to rupture the strand by breaking the component fibres.'

These ideas are only the beginning of a highly complex but fascinating subject, but in the present volume we can only touch upon some of the many effects of twist and fibre properties on the yarn and on the fabrics made from the yarn.

Twist and yarn strength

It has been known for many years that an increase in the amount of twist produces an increase in the yarn strength, and that this effect holds only up to a certain point beyond which further increase in twist causes the yarn to become weaker. Referring again to Gregory's paper:

> 'In order to develop the maximum strength in the twisted strand, a compromise must be reached between the increasing cohesion of the fibres as the twist is increased, and a decrease in the effective contribution to the axial loading of the strand due to the obliquity of the fibres. The familiar strength v twist curve for yarn elements can thus be divided broadly into two sections: (1) a low twist region in which the effect of cohesion outweighs that of obliquity, giving rise to an increase in strength, slow at first up to the point at which fibres may just begin to break, and increasing rapidly as more and more fibres break; (2) a high twist region in which further increase in cohesion no longer produces an increase in strength since the majority of the fibres break, whilst the increasing inclination of the fibres causes the strength to fall. The division between the two regions corresponds to the twist at which the maximum strength is realised. At this twist the greater proportion of the fibres break.'

The effect of obliquity to which Gregory refers is the result of fibres being at an angle to the yarn axis.

> 'Since the fibres are inclined to the axis of the twisted strand, only the components of the fibre stress resolved in the direction of the axis of the strand effectively balance the applied load, and the full contribution of fibre strength is not realised. This effect of obliquity is small at first, increasing more rapidly as the twist builds up.'

Not all workers in this field are prepared to discount the components of the stresses at right angles to the strand axis. Hearle (*J. Text. Inst.* **49**, T389 (1958)) has considered the influence of transverse forces in the tensile behaviour of twisted yarns and comments:

> 'The neglect of these (transverse) forces is the more extraordinary as it is well recognised that they are the only cause of resistance to breakage by slippage in staple fibre yarns.'

In the literature there are numerous examples of the strength v twist curves for many types of yarns spun from natural, man-made, and blended yarns. Examples are shown in Figure 6.9. It must not be thought, however, that yarns are always spun at twist factors to give maximum strength; the yarn properties must be controlled to suit the intended use of the yarn.

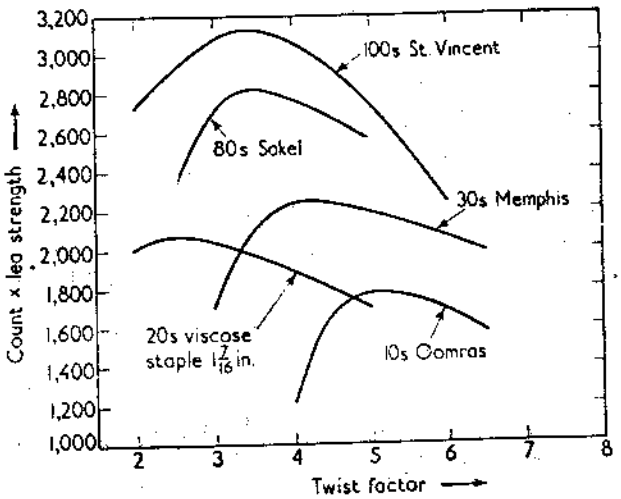


Figure 6.9. Twist factor vs strength product

Some effects of twist on fabric properties

The effects of twist on the characteristics of fabrics cannot be covered in a few paragraphs, therefore the remarks which follow serve merely as an indication of the importance of twist in the yarns from which the fabric is constructed. By varying the amount and direction of twist the fabric designer can achieve a variety of fabric effects. Some of these are visual, some are concerned with handle and drape, and some are mechanical, e.g. related to strength or resistance to abrasion.

One example of a visual effect is the 'shadow stripe'. Suppose a cloth is woven with the warp threads in alternate bands of S and Z twist. A subdued stripe effect is observed in the finished cloth due to the difference in the way the incident light is reflected from the two sets of yarns. In a way, this effect is similar to that seen when a lawn has been mowed and rolled.

The twill line in fabrics based on the twill weave can be subdued or brought into greater prominence by choice of twist direction. For example, if the warp of a twill has Z twist and the twill line runs 'down to the left', then the use of an S-way weft subdues the twill line. Conversely, the use of a Z-way weft will produce a bolder twill line.

A twisted yarn tends to untwist or assume a configuration in which a state of equilibrium is attained. Highly twisted yarn is 'lively' and tends to twist upon itself and produce 'snarls'. Fabrics made from highly twisted yarns will possess a lively handle. Crêpe yarns, for instance, have high twist factors (5·5–9·0) and are used to obtain the characteristic crêpe surface. The cloth is woven and afterwards given a wet treatment; drying is done with the cloth free from tension. These conditions allow the crêpe yarns to curl up and relax; shrinkage occurs and the well known crêpe surface is produced.

The tendency for yarns to untwist can cause the fabric to curl, especially at the corners. Curling will result if the untwisting couples of the warp and weft yarns reinforce each other instead of counteracting each other (see Figure 6.10). (See also B.S. 2888 : 1957, *Curl in Textile Fabrics*. (B.S. Handbook No. 11, p. 186.)).

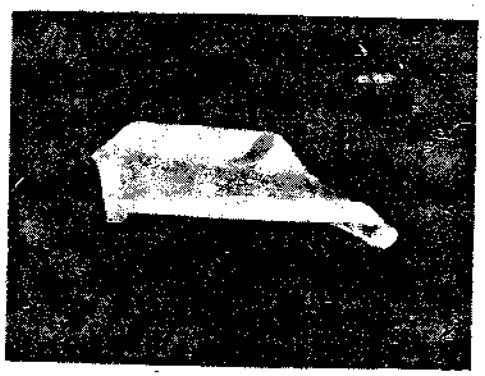


Figure 6.10. The effect of twist in yarns on fabric. Note the curling produced

The complex relationships between fibre properties, yarn properties, and fabric properties have been studied by many textile research workers, but as yet simple practical formulae are not available. It is doubtful if simple relationships will be established because of the number of variables which influence the properties of the finished fabric. Twist is but one of these variables. Nevertheless, much can be learnt from experience and experiment, and work in this field has shown that the twist factors used in the yarns influence such fabric properties as tensile strength, tearing strength, resistance to abrasion, handle, and so on. A number of references to fabric properties will be found at the end of Chapter 7 and information relating to twist effects may be obtained from them.

The measurement of twist

Several methods of twist determination are available and the choice of which to use may be governed by specification, accuracy demanded, form of the sample, and so on. The methods which are described here are, in the main, applicable to the more common types of yarn; special apparatus may be needed for twist measurement in such materials as synthetic monofilaments.

In twist testing generally, a number of points must be watched if reliable results are required.

Sampling. Twist is not usually distributed uniformly along a yarn. This characteristic of yarn structure has been investigated by a number of workers. It has been found that a relation exists between the twist and the thickness of the yarn at the point where the turns per unit length are measured, and that it is of the form 'twist × weight = constant'. This is another way of showing that the twist runs into the thin places. To avoid the introduction of bias into twist measurement, it has been recommended that the twist should be determined at fixed intervals along the yarn, 1 yd being suggested as a suitable distance. Such a practice would prevent an operator from unconsciously selecting the thicker or thinner places in the yarn, especially when the specimen length is short. The British Standard dealing with twist measurement does not stipulate such a procedure but recommends that at least 1 yd should be left between consecutive tests.

The minimum number of tests to make are given in B.S. 2085: 1954 and are reproduced in Table 6.4. Where possible, equal numbers from ten packages should be taken.

Table 6.4. The Minimum Number of Tests for Twist Determination

Type of yarn	*Minimum number of tests*	*Length of test specimen (in.)*
Plied and cabled yarns	20	10
Continuous-filament yarn (single)	20	10
Grey yarn (single) spun from long bast fibres	50	10
Spun yarn (single)	50	1

Withdrawal of yarn from the package. A nice point arises when the effect of withdrawing the yarn 'over end' from the package is considered. A simple demonstration of this effect can be made with the aid of a tape measure. Coil the tape and lay it flat on the table. Pick up the free end and raise it vertically. Twist will be developed in the tape and its direction will depend on the direction in which the tape is coiled. If, when looking from above, the tape is coiled in a clockwise direction, the tape will have a few turns of S twist, and vice versa. It is therefore necessary to decide whether to withdraw the yarn over the end of the package or from the side. The latter method will, of course, leave the twist unchanged. Guidance in this matter is given in the British Standard:

> 'In the absence of precise instructions to the contrary, agreed upon by the parties concerned, withdraw specimens for twist testing from the package in the same manner as that which would normally be used when the yarn passes to the next stage of processing or manufacture. It is essential, in all cases, that the method which has been used to obtain the specimens on which twist tests have been made should be clearly stated.'

A practical point to watch in transferring the yarn from the package to the testing device is the need for care and to avoid handling the yarn unnecessarily. By drawing the yarn between finger and thumb it is possible to disturb the distribution of the twist; the turns may be rubbed along the yarn and perhaps inadvertently removed from the test length. A similar effect is found in winding operations, especially in the case of continuous-filament yarns containing low twist. The twist disturbance occurs where the yarn passes over guide rods and through tension devices; this can lead to cloth faults.

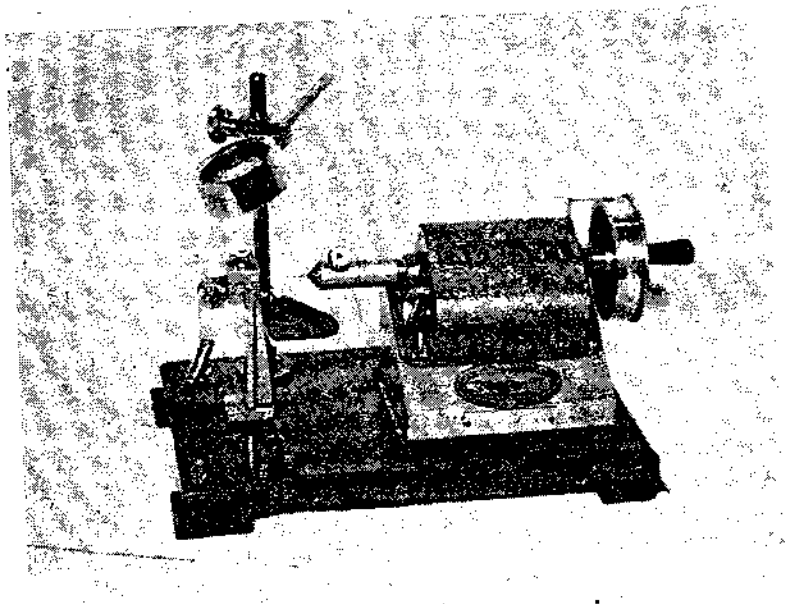
When measuring twist it is therefore recommended that where possible the yarn is handled outside the test length and that pulling the yarn between finger and thumb is to be avoided.

Tension in the specimen. In many cases the tension at which the specimen is clamped between the jaws of the twist tester is left to the discretion of the operator, but since the tension can affect the results it is preferable to use a standardised method of tensioning. The recommended amount of tension is given in B.S. 2085:1954 as tex/2 ± 10 per cent.

The straightened fibre method of twist determination

Since twist is inserted into an element of yarn by the relative rotation of its two ends, a logical method of measuring the twist is to reverse the process and count how many turns are required to untwist the fibres until they are again parallel. This direct method is outlined in B.S. 2085:1954 (B.S. Handbook, p. 114).

A typical twist tester is illustrated in Figure 6.11. This particular model has a fixed length of 1 in. between the two jaws, but other instruments are available in which the test length can be varied by sliding the non-rotating jaw along a graduated groove. To make a test the revolution counter is set to zero and the yarn clamped into



(By courtesy of James H. Heal & Co. Ltd)

Figure 6.11. A 1 in. twist tester. Note the counter which reads in both directions, fractions of turns on the handwheel, and the clip-on tension weight

the rotating jaw. (Note: the free end of yarn from a package may lose twist by untwisting itself, therefore to avoid error the first measurement must be made about 1 yd from the end.) The yarn is led through the fixed jaw, over a guide pulley, and then tensioned by clipping a small weight on to it. After closing the fixed jaw the turns are removed by rotating the handle in the appropriate direction. The end point may be judged by eye with the help of a small lens, but greater precision can be obtained by the use of a dissecting needle. When most of the twist is removed the needle is pushed through the fibres close to the fixed jaw and gently moved towards the rotating jaw. Any residual twist runs up to the latter and is removed by a final adjustment.

The number of turns removed is read from the revolution counter and recorded. From the results of fifty tests the mean and the coefficient of variation are then calculated.

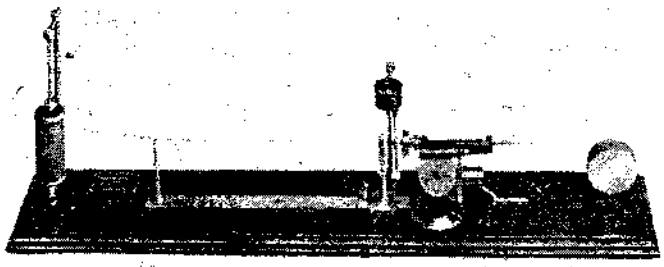
A semi-automatic twist tester based on the straightened fibre principle is the 'Rock Bank' twist tester developed by the research department of Fine Spinners Ltd. The test length is only $\frac{1}{3}$ in., but a 3:1 gear ratio between the rotating jaw and the revolution counter multiplies the actual turns removed. Features of the tester include a magnifying lens to observe the yarn and a counter system to record up to fifty tests, after which the total turns are read and the mean calculated.

The continuous twist tester

In the descriptions of the twist testers just given it will be seen that tests on consecutive lengths of yarn are not easily made because of the instrument design and the amount of yarn handling involved. For the investigation of twist variation and distribution along a continuous length of yarn, the Wool Industries Research Association have designed the Continuous Twist Tester shown in Figure 6.12. This has the extra advantage of allowing twist tests at fixed intervals without the need for excessive yarn handling which might disturb the twist.

The straightened fibre principle is still used for the actual measurement of the twist and it is the method of yarn control which is the main feature of this instrument. The yarn passes from the sample package, through a guide, through the non-rotating jaw, through the rotating jaw, and is wound on to a clockwork-driven drum. Assuming that a 1 in. length of yarn is gripped between the jaws, the twist is taken out and the number of turns noted. The handle is then turned until the counter reading is again zero, i.e. all the twist has been put

back. The spring-loaded jaws of the rotating clamp are opened and the clamp moved 1 in. forward to touch the fixed clamp. The latter is then opened and, under the tension of a light spring, the rotating clamp is pulled back to its working position and in so doing pulls a new 1 in. sample into the test zone, at the same time allowing the clockwork-driven drum to take up the slack yarn. The fixed clamp is again closed and the next test can be made.



(By courtesy of Goodbrand & Co. Ltd)

Figure 6.12. Twist tester (continuous length)

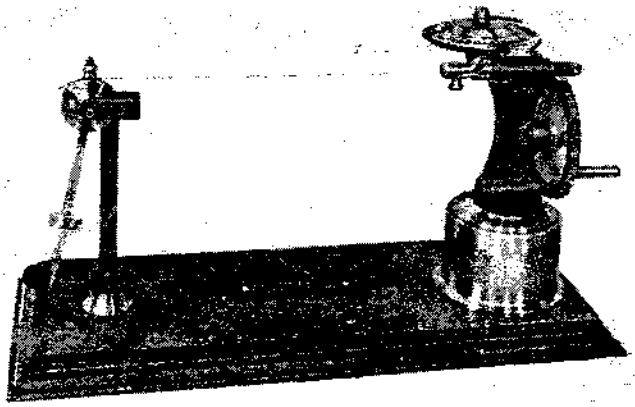
When a longer test length is required, say 5 or 10 in. for testing doubled yarns or where a fixed distance between tests is specified, the procedure is varied slightly since the rotating clamp has a limited forward movement. The sequence after a test is then: slide the fixed clamp up to the rotating clamp, open the latter and allow the drum to take up the slack yarn, close it again, slide the fixed clamp back to its original position, close it, and make the next test.

The twist contraction method

One of the effects of putting twist into a strand of fibres or filaments is to cause the strand to contract in length. Suppose a yarn is twisted Z way and has a length, h. Let the twist be completely removed to produce an untwisted strand of length $h + c$, c being the contraction due to twist. If the strand is now twisted S way with a number of turns equal to those removed, we would expect that the strand will again contract to the original length, h. Several twist testers are based upon this concept.

Figure 6.13 shows a simple instrument of this type. The yarn is first gripped in the left-hand clamp which is mounted on a pivot and carries a pointer. After being led through the rotating jaw, the yarn is pulled through until the pointer lies opposite a zero line on a

small quadrant scale; the jaw is then closed. At this stage the specimen is under a small tension and has a nominal length of 10 in. (or any other chosen test length). As the twist is removed, the yarn extends and the pointer assumes a vertical position, so removing the tension (if the tension were maintained on a strand with very little twist in it, then the fibres would probably slide apart and the test would be faulty). Eventually all the twist is taken out but the jaw is kept rotating in the same direction until sufficient twist has been inserted to bring the pointer back to the zero mark again. The total number of turns registered on the revolution counter is divided by 20, i.e. twice the number of inches in the test length. The result of this division is the turns per inch in the specimen. A moment's reflection will show that twice the number of inches is used as a divisor since only half the revolutions of the jaw actually *remove* the twist.



(By courtesy of Goodbrand & Co. Ltd)

Figure 6.13. Twist tester for single yarns

The ease of operation of this type of twist is obvious. No great operator skill is required, the end point is clear, good lighting is not essential, and a smaller number of tests than the standard method recommends may be used (about 10 tests are often regarded as enough).

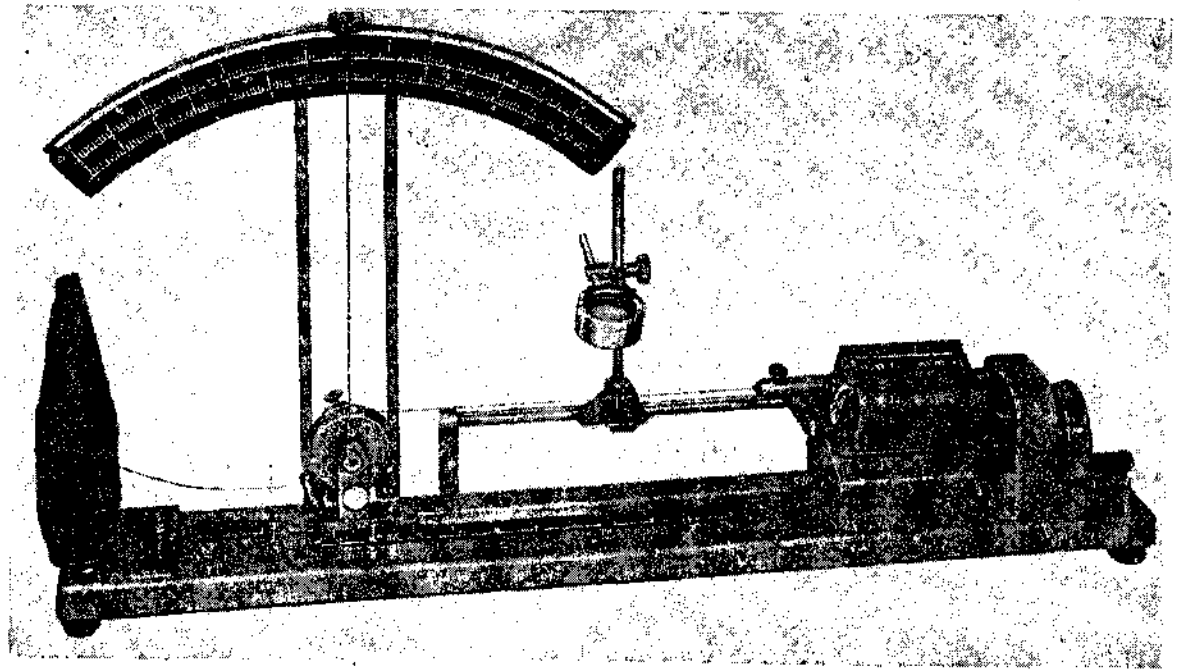
Attention must be drawn to a possible source of error when using this type of twist tester. It was mentioned earlier that one would expect that the number of turns required to cause the untwisted yarn to contract to its original length is equal to the number of turns

originally in the yarn. Unfortunately this is not always true. It has been found that for some yarns the turns per inch determined by the twist contraction method are underestimated, while for other yarns they are overestimated when the values are compared with those obtained by the standard straightened fibre method.

It is reported in the W.I.R.A. handbook *Testing and Control* that for woollen yarns the twist contraction method may give results up to 20 per cent below the straightened fibre method, whereas for worsted yarns, probably due to fibre slippage, the results in some cases may be higher by 15 per cent. An account of some experimental work on this matter is given by Worner (*Text. Res. J.* **26**, P455 (1956)). The disagreement between the results obtained by counting the turns in the yarn with the aid of a low-power microscope and the twist contraction method is noted. Carded single cotton yarns were used and Worner observes that their behaviour was similar to that of woollen yarns, i.e. the turns per inch values were underestimated by the twist contraction method. Table 6.5 gives some results obtained in the Testing Laboratory at Bolton Technical College. A mixed selection of single cotton yarns were tested and curiously enough nearly all the results by the twist contraction method were *higher*

Table 6.5. Comparison of Twist Test Results on Single Cotton Yarns using 1 in. Straightened Fibre and the 10 in. Twist Contraction Methods

Yarn count	*t.p.i. (1 in.)*	*C.V. per cent*	*t.p.i. (10 in.)*	*C.V. per cent*	*Difference per cent* $\frac{(10\text{ in.} - 1\text{ in.})}{(1\text{ in.})} \times 100$
6	8·79	17·1	9·59	5·5	9·1
6	9·3	10·1	10·25	6·0	10·2
6¾	10·9	14·7	10·50	4·6	−3·7
13	13·56	20·5	14·55	6·6	7·4
18	15·7	20·4	17·86	5·6	13·7
22	18·48	18·4	20·50	4·9	10·9
30	19·58	17·9	22·65	6·6	15·6
32	23·80	23·5	23·80	7·1	0·0
44	29·14	20·7	31·34	3·8	7·6
50	25·0	20·0	29·60	6·1	18·4
60	28·12	21·5	28·70	6·3	2·1
74	25·96	22·3	30·35	9·2	17·3
80	30·66	20·5	31·55	6·6	2·9
94	30·94	38·2	33·23	10·0	7·8
100	35·00	30·5	35·90	7·0	2·6
60	27·7	28·5	26·9	8·2	−2·9
90	39·1	26·5	34·85	9·9	−10·8



(By courtesy of James H. Heal & Co. Ltd)

Figure 6.14. Heal's quadrant twist tester No. 73

than the results given by the 1 in. straightened fibre method. More headaches!

It is quite evident that where accurate results are required the 1 in. straightened fibre method is preferable to the twist contraction test. The results from the latter method should therefore be treated with circumspection and examined in the light of experience in testing various types of yarn.

A more elaborate instrument using the twist contraction principle is shown in Figure 6.14. The pointer is long and moves over a large quadrant scale. One end of the yarn is clamped in the rotating jaw and the other led through a clamp on a small drum on the pointer axle. The required tension is applied by clipping a weight to the end of the yarn and then clamping the yarn to the drum. To prevent the yarn from being stretched when the twist has been removed, an adjustable stop on the quadrant restricts the swing of the pointer until sufficient tension has been developed in the test length, towards the end of the test, to pull the pointer back to the zero mark on the quadrant.

The 'twist to break' test

A short length of yarn is twisted in a tester such as the one shown in Figure 6.11. Twisting is continued until the yarn breaks and the number of turns required, n_1, is noted. The test is repeated, this time twisting in the opposite direction. Let n_2 be the number of turns required to break the yarn in the second test. The twist is then given by

$$\tfrac{1}{2}(n_1 - n_2)$$

Twist measurement by microscope

A microscope having a rotating stage with its periphery graduated in degrees can be used to measure the twist angle and the yarn diameter and enable the turns per inch to be derived. A filar micrometer eyepiece is employed and it is first calibrated against a stage micrometer. With the stage set at zero degrees the yarn, mounted in a suitable holder, is brought into focus and the moving hairline of the eyepiece brought into line with the yarn axis (see Figure 6.15(a)). The stage is now rotated until the hair line is tangential to the helix formed by the twisted fibres on the yarn surface (see Figure 6.15(b)). The angle through which the stage has been rotated is then recorded. The yarn diameter is measured in terms of eyepiece divisions and then converted to thousandths of an inch (or millimetres).

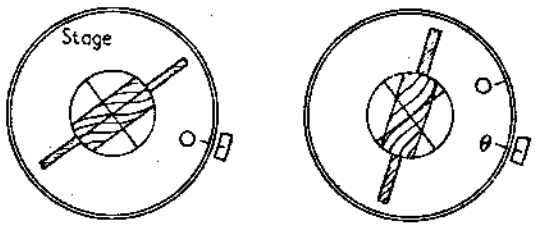


Figure 6.15. Twist measurement by microscope

At this point the yarn diameter d is known and also the twist angle θ. The length of yarn occupied by one turn of twist is therefore given by

$$h = \frac{\pi d}{\tan\theta}$$

Since turns per inch $= 1/h$,

$$\text{Turns per inch} = \frac{\tan\theta}{\pi d}$$

A number of observations will, of course, be taken since both the twist angle and the yarn diameter will vary from point to point along the yarn.

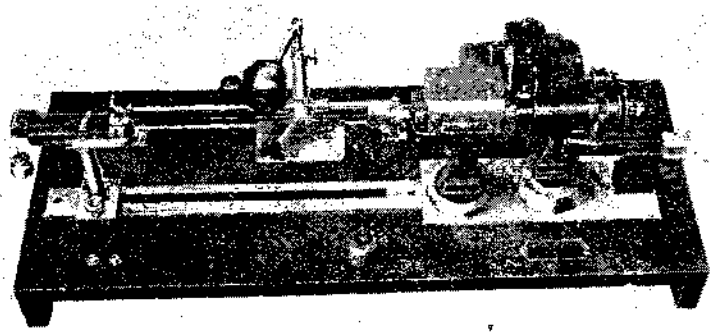
Schwartz, who describes this method in his book *Textiles and the Microscope*, comments, 'Twist determination by means of some form of twist counter is precise only for plied or cabled yarns. For single yarns an accurate determination is almost out of the question by this means. Certainly no adequate idea of twist contraction in this latter case is possible.'

Twist measurement of plied yarns

For a variety of technical reasons many textile structures are designed either completely or partly with the component yarns in doubled or cabled form. Generally speaking, the inference is that the desired properties of the structure could not be obtained, or at least to the required degree, if only single yarns were used. Lustre, regularity, strength, extensibility, elasticity, liveliness, and docility are the kind of yarn properties which may be 'built' into a plied yarn by the right selection of the single yarns and the techniques of construction. It is necessary, therefore, to be able to analyse plied yarns to determine such details as doubling twist, singles twist, take-up, resultant count, count of component yarns, and so on.

A number of papers on the properties of doubled yarns and the effects of varying structural details are to be found in the literature, two recent ones being by Coulson and Dakin (*J. Text. Inst.* **48**, T203 (1957)), and Hearle, El-Behery, and Thakur (*J. Text. Inst.* **50**, T1 (1959)). The former is concerned with cotton and staple rayon yarns, and the latter with the mechanical properties of twisted continuous-filament yarns. In the notes which follow we shall deal only with the measurement of twist and the changes in length due to twist. The simpler types of yarn will be mentioned but the basic methods can be extended to cover more complicated plied yarn structures.

'*Take-up*' *twist testers.* 'Take-up' is defined as the difference in length between the twisted and untwisted thread, expressed as a percentage of the untwisted length. It is positive or negative according to whether the doubling twist causes a contraction or extension in the folded yarns. Special twist testers are available which have devices on them to accommodate the change in the specimen length as the test proceeds, and so they are commonly known as 'take-up' testers.



(By courtesy of Goodbrand & Co. Ltd)

Figure 6.16. 'Take-up' twist tester

A commercial model of this type of instrument is shown in Figure 6.16. Basically, the tester is similar to an ordinary model so far as the twist counting and twist removal systems are concerned. The non-rotating yarn clamp is mounted on a pair of smooth rods and can slide freely along them, its movement being noted by means of a graduated scale. The complete unit of rotating jaw and revolution counter can be moved along a base scale for adjustment of specimen length. With the counter set at zero the yarn is first clamped in the

rotating jaw and then led through the sliding clamp to a spring-loaded tension grip, to which tension weights are added to give the required test tensioning conditions. If extension is expected as the twist is removed, the sliding clamp is moved up to the zero mark on the scale and then closed on the yarn. Sometimes the yarn construction may cause contraction as twist is taken out—a trial test will show whether this occurs, in which case the sliding clamp will be set in the middle of the scale. When all the doubling twist is removed the number of turns is noted and the movement of the sliding clamp recorded.

The quadrant twist tester. This instrument was previously described when the testing of single yarns was discussed. A variation in the procedure enables this type of tester to measure the doubling twist and the changes in the specimen length at the same time. When testing single yarns a stop is used to restrict the pointer movement, the pointer merely indicating the end of the test when it returns to the zero position. When testing plied yarns the pointer has freedom to move over the quadrant scale. The scale is graduated, in tenths of an inch, for example, so that the contraction or extension can be noted.

The use of ordinary twist testers. A direct count of the turns per inch in a plied yarn may, of course, be made on an ordinary 1 in. twist tester or a similar type with an adjustable test length. With plied yarns the complete removal of twist is readily judged by passing a needle between the component threads. The estimation of the change in length, however, is not so conveniently determined.

The twist in component yarns. The yarn tested may be a cabled yarn composed of yarns which have been plied and then the plied yarns twisted together; the analysis may then involve a twist test of the cabling turns, a test of the doubling turns, and finally a test of the single yarn twist. The point to bear in mind is that after the turns put in at the last process have been taken out, the component threads are then in the condition they were in before that process was started. Suppose a twofold yarn is tested; then after the doubling turns have been taken out the specimen consists of two independent single threads, each of which has the number of turns per inch it had before doubling. The twist in the single yarns may now be tested either in a 1 in. tester or the tester being used; a takeup tester is usually designed so that the sliding clamp can be locked in position and the test length reduced to 1 in. by sliding the revolving jaw along the baseboard of the tester. The quadrant tester is quickly converted for use in testing the single yarn.

When the plied yarns have been untwisted the component threads are cut out and placed on one side to await further testing. It is important that the ends are prevented from untwisting. Some operators use a blackboard of suitable width, with sticky tape along the edges to hold the thread ends.

*Designation of the structure of yarns.** The reader is referred to the Tentative Textile Standard No. 62 (*J. Text. Inst.* **51**, P87 (1960)). The Standard '. . . provides a method for specifying the structure of all yarns produced by twisting processes, in terms of linear density, number of plies (or filaments), direction and amount of twist, constituent fibres and any other features necessary for a complete description of a yarn'.

YARN HAIRINESS

One of the important differences between continuous filament yarns and yarns spun from staple fibres is that the latter are 'hairy', that is, fibre ends and loops of fibres stand out from the main body of the yarn. It is not intended to discuss this yarn property in the present volume but the interested reader may refer to a recent paper by Barella (*J. Text. Inst.* **57**, T461 (1966)), who has himself investigated the hairiness of yarns. In his conclusions Barella states that: 'The non-existence of a method sufficiently satisfactory from both a scientific and a practical point of view for the easy measurement of hairiness in routine industrial processes has been noted. The scientific methods are slow and the quicker ones are open to criticism in that they are not soundly based. It would therefore be desirable to devise a new method that is superior to the existing ones. Furthermore, according to the nature of the fabrics and the characteristics they must possess, the yarn hairiness can either be a desirable or an undesirable property, so that its measurement and control are important.' (Barella, A. 'The Hairiness of Yarns: A Review of the Literature and a Survey of the Present Position.' *J. Text. Inst.* **57**, T461 (1966).)

Textured yarns

In recent years there have been important developments in the production of special yarns based on thermoplastic continuous filament yarns. These yarns may be classified as follows:

(1) Bulk yarns. These are multifilament yarns which have been processed to produce an increased mass or bulk per unit length.

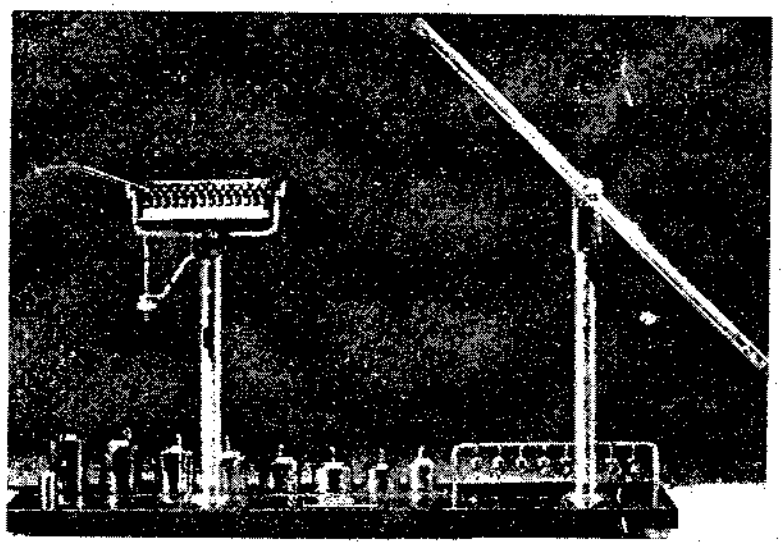
* See also B.S. Handbook No. 11, p. 103, *Designation of the Structure of Yarns.*

(2) Stretch yarns. As the term implies, these yarns have the ability to be stretched to high elongations; further, they have the power to recover rapidly from elongation, hence their use in 'stretch-to-fit' apparel.

(3) Modified stretch yarns. These are basically stretch yarns which have had their characteristics modified to suit particular end uses.

It will be appreciated that new types of yarn may require new testing techniques, for research and development of the yarns and for the routine quality control checks on the yarns supplied to the fabric producer. Several test methods have been reported but at the moment the testing situation is a little fluid. The test described below has been in use for several years but even so the method has its critics.

The H.A.T.R.A. crimp rigidity test. The ability of stretch and bulk yarns to collapse longitudinally is of importance because the degree of crimp rigidity influences the properties of the fabrics produced from these yarns. Crimp rigidity is a measure of the ability of a textured yarn to recover from stretch, and is related to the bulking potential of the yarn.



(By courtesy of Shirley Developments Ltd)

Figure 6.17. The H.A.T.R.A. crimp rigidity apparatus

In the tester developed by the Hosiery and Allied Trades Research Association, a load equivalent to 0·1 g per denier is suspended from a skein of yarn which is then immersed in water at room temperature. After 2 min its length, L, is measured. The load is then reduced to 0·002 g per denier and after a further 2 min the reduced length, L_2, is measured. The crimp rigidity is given by the formula:

$$\text{Crimp rigidity} = \frac{L_1 - L_2}{L_1} \times 100\%$$

The apparatus for the test, supplied by Shirley Developments Ltd, is shown in Figure 6.17. The gate tensioner is adjusted so that the crimp in the yarn is just removed when the skein is being wound. A range of weights is required to accommodate the various deniers encountered. Thus if the nominal denier were 20 then a skein of 50 strands would be wound and the heavy weight used would be 100 g to give the required 0·1 g per denier initial loading. The appropriate light weight would be 2 g. For a 200 denier yarn a 20-strand skein is used, the heavy weight 400 g and the light weight 8 g. A table gives the recommended skein strands and weight values.

The time taken to carry out a test is about five minutes. For firms who need to carry out large numbers of tests H.A.T.R.A. has designed a semi-automatic tester which can enable one operator to do about 60 tests per hour and with a team of three up to 180 tests per hour are possible.

It has been suggested (see Wray, *Text. Inst. Ind.*, p. 189 (July 1966)) that this crimp rigidity test does not give a satisfactory indication of the potential behaviour of the yarn when in fabric form. In mill practice, however, the test has proved valuable in reducing faults in finished fabrics by ensuring that yarns with similar crimp rigidity value are knitted together into the same fabric. Yarns from different suppliers can be matched for crimp rigidity values and used together.

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7

FABRIC DIMENSIONS AND PROPERTIES

FABRIC LENGTH

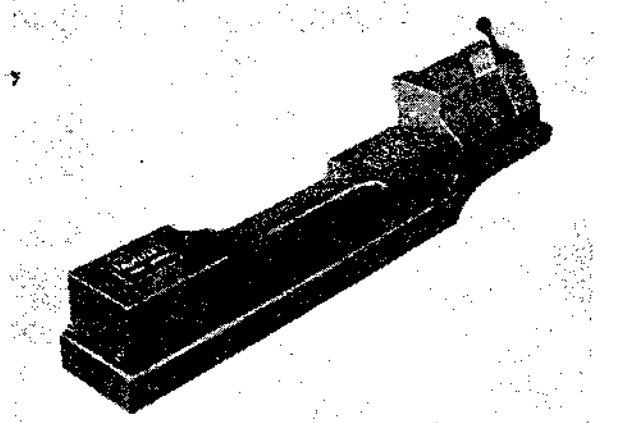
HOW long is a piece of cloth? The answer to this question is influenced by the conditions under which it is measured. During the manufacturing and finishing processes cloth is subjected to various strains. Some of these are recoverable if the fabric is allowed to relax in an open state and is free from restraint. Recovery is often greater when the fabric is immersed in water, a point which will be raised later when shrinkage is discussed.

Measurement of cloth dimensions should be made in a standard testing atmosphere whenever possible, since humidity may affect the results. A table wide enough to accommodate the open cloth width is preferred and with one edge graduated. A trial measurement is made on the cloth before it is allowed to condition. Marks are made on the selvedge at 5 yd intervals throughout the full piece; any fraction of 5 yds at the end is measured to the nearest $\frac{1}{2}$ in. After 24 hr in the testing atmosphere the cloth is measured again. If any change in length is less than 0·25 per cent of the first result, then the second measurement is taken as the correct length. Some fabrics may recover more than 0·25 per cent in the first 24 hr; if this is so, they are left for a further 24 hr and remeasured. This procedure is repeated until the change in length is less than 0·25 per cent and the final measurement taken.

It is not always possible to condition the full piece of cloth. The cloth is therefore measured without conditioning and a correction made by length measurements on a sample. With the cloth in a similar atmosphere to storage conditions, four pairs of marks across the width of the cloth are made, each pair at least 1 yd apart in the warp direction. The distance between each pair is accurately measured, the sample cut out and conditioned for at least 24 hr in a standard atmosphere, and the distances measured again. If the distance shows a change of more than 0·25 per cent, further conditioning time is allowed. The length of the bulk of the cloth is then estimated from the initial length measurement of the full piece and the average change in the distances between the four pairs of marks on the sample.

Length measurement in warehouses and inspection rooms

The checking of fabric length as the cloth moves over an inspection table, plaiting machine, or some other cloth-handling machine has been simplified by the development of accurate measuring devices which are mounted on the machine itself. One example is the 'Trumeter' illustrated in Figure 7.1. Measurement by accurate rollers is carried out, as the speed of the machine and the meter may provide the information in the form of a printed ticket in addition to indicating the length on the counter.



(*By courtesy of Trumeter Ltd*)

Figure 7.1. The 'Trumeter' cloth length measuring machine

FABRIC WIDTH

The width of the fabric, when it is removed from the loom, may not be the same when it finally reaches the customer. The loom state fabric may undergo ordeals by water, heat, pressure, tension, acids, and alkalis. Some processes cause contraction in width (wet treatments) and some may stretch the cloth (stentering). Textile materials possess powers of recovery from imposed strains and when allowed to relax free from tension, contraction may occur.

The choice of cloth width is influenced by a number of factors. Important amongst these is the end-use of the cloth. For example, handkerchief cloth may be woven so that either two gentlemen's or three ladies' handkerchiefs occupy the yarn space in the reed of the loom. Again, bedding for single beds will be woven in narrower

looms than those used for weaving for double-bed fabrics. The maker-up of fabrics buys his cloth in widths which allow him to cut out his patterns with a minimum of waste. When the cloth delivered is sub-standard in width, a maker-up may demand a discount from the weaver to off-set the potential increase in waste. It must also be remembered that a proposed change in fabric width affects not only the weaving department. Both the yarn preparation machinery and the finishing plant have to accommodate the change. Progressive manufacturing concerns make a close study of the effects of cloth width on the overall costs of manufacture (see Brunnschweiler, D. *J. Text. Inst.* **50**, P574 (1959)). The development of looms such as the Sulzer enables the manufacturer to weave several widths in one loom simultaneously, using special selvedge devices to split up the cloth into the required widths.

Measurement of fabric width

In the standard method (B.S. Handbook, p. 165) it is recommended that the fabric should be exposed to a standard atmosphere for at least 24 hr before final measurements are taken. Measurements made before and after conditioning will then show whether the change in width, if any, is within the order of accuracy required. On a piece of cloth, ten measurements should be made at points distributed at roughly equal distances throughout the full length of the piece. Where the full length is not used a sample length of not less than 1 yd should be used and its width measured at three places. The mean width and the range in width should be reported.

The accuracy of measurement is indicated in B.S. 1930:1953:

0·1 in. for fabrics 18 in. or more in width.
0·05 in. for fabrics exceeding 4 in. but less than 18 in. in width.
0·02 in. for fabrics 4 in. or less in width.

Points to watch include:

(1) The possibility of wavy selvedges due to weft tension variation or weave effects. Maximum and minimum widths should be recorded and the wavy selvedge reported.
(2) Where the width 'within lists' is required the width between the innermost selvedge threads is measured.
(3) Where only samples are measured the width of the unconditioned bulk is corrected from the measured changes in width of the samples.

Continuous measurement of width

In the methods just described only a small number of width measurements are taken. An apparatus is described by Jiewertz

(*J. Text. Inst.* **45**, T696 (1954)) which has been designed for the continuous measurement of the width of running fabrics. It is based upon a pair of photo-electric cells, one at each selvedge, which scan the edges and detect changes in width. The signals are translated into cloth width and indicated on a meter or recorded on a chart. An accuracy of ± 0·3 cm is claimed.

FABRIC THICKNESS

Engineers use calipers and screw micrometers to measure the thickness of machine parts but the textile technologist handles material which is readily compressed, therefore the instruments he uses differ from those of the engineer. The principle of the measurement of fabric thickness is expressed neatly in B.S. 2544:1954:

> 'Essentially, the determination of the thickness of a compressible material such as a textile fabric consists of the precise measurement of the distance between two plane parallel plates when they are separated by the cloth, a known arbitrary pressure between the plates being applied and maintained. It is convenient to regard one of the plates as the presser foot and the other as the anvil.'

Several points require consideration in the practical application of this principle:

Shape and size of the presser foot. A circular foot is usually used, a common diameter being $\frac{3}{8}$ in., but this may differ if desired. The ratio of the foot diameter to the cloth thickness should be not less than 5:1.

Shape and size of the anvil. When a circular anvil is used it should be at least 2 in. greater in diameter than the presser foot. In addition, where the sample is larger than the anvil, it is convenient to surround the anvil with a suitable support, e.g. a smooth plane board.

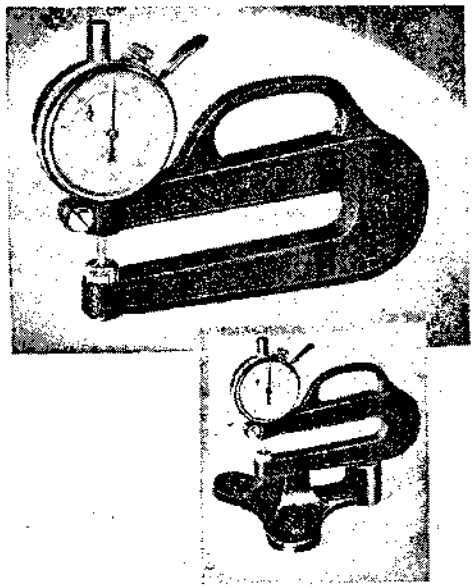
Applied pressure. Preferred pressures are recommended and may be specified, e.g. 0·1 lb/in², or 10·0 lb/in². Suitable weights may be added to the presser foot to obtain these pressures. In Chapter 10 of the W.I.R.A. handbook *Testing and Control*, two special instruments are described, one for measuring cloth thickness with very small pressures as low as 5 mg/cm², and a second which may produce pressures up to 50 lb/in².

Velocity of presser foot. The presser foot should be lowered on to the sample slowly at about 2/1,000 in/sec. Precision here is difficult, of course, but common sense will suggest a slow and careful movement.

Time. The thickness is read from the dial of the instrument when the easily visible movement of the pointer has stopped.

Indication of thickness. A clock-type dial gauge is usually built into a thickness tester. It should be rigidly mounted in a suitable frame and, after setting to zero, be capable of measuring to an accuracy of 1 per cent for cloths of 5/1,000 in. or more, and to 0·00005 in. for thinner fabrics.

A thickness tester is illustrated in Figure 7.2.



(*By courtesy of James H. Heal & Co. Ltd*)

Figure 7.2. Heal's thickness gauge

Test method

The presser foot and anvil should be cleaned by drawing some clean paper between them. After cleaning, the gauge is set to zero and any required weights added to the presser foot column. No special specimen preparation is required except that selvedges and creased areas should be avoided. Where possible, the material is tested in a standard atmosphere after conditioning for 24 hr. At least 10 determinations should be made, either at different places in the piece or on different samples. The mean value is obtained and reported to the nearest 1/10,000 in. or to 1 per cent, whichever is the greater. In the test report, details of the pressure, size of presser foot, and the time should be given.

The Reynolds and Branson thickness tester

The thickness of fabric samples can be measured by this type of instrument under pressures from 5 g/cm² upwards. Figure 7.3(a) shows that the fabric is tested in a vertical plane. The sample is pressed between two circular anvils each having a surface area of 1 cm²; one of them is fitted to a lever mounted on a flat spring which acts as a frictionless bearing. The lever has a recess in which the 5 g pan is suspended. Thus, a pressure of 5 g/cm² is obtained. Other pressures can be readily obtained by adding weights to the pan.

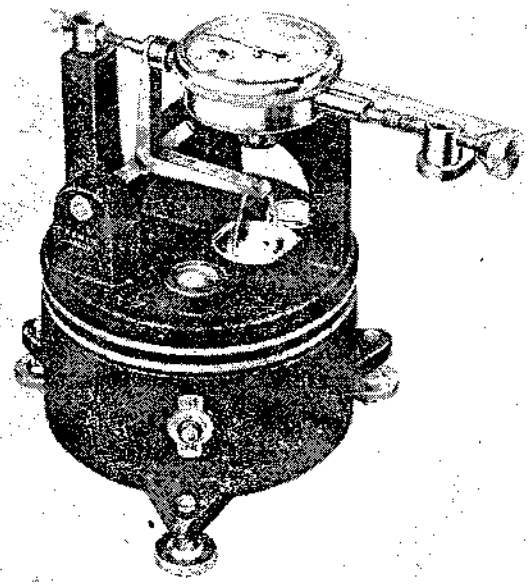


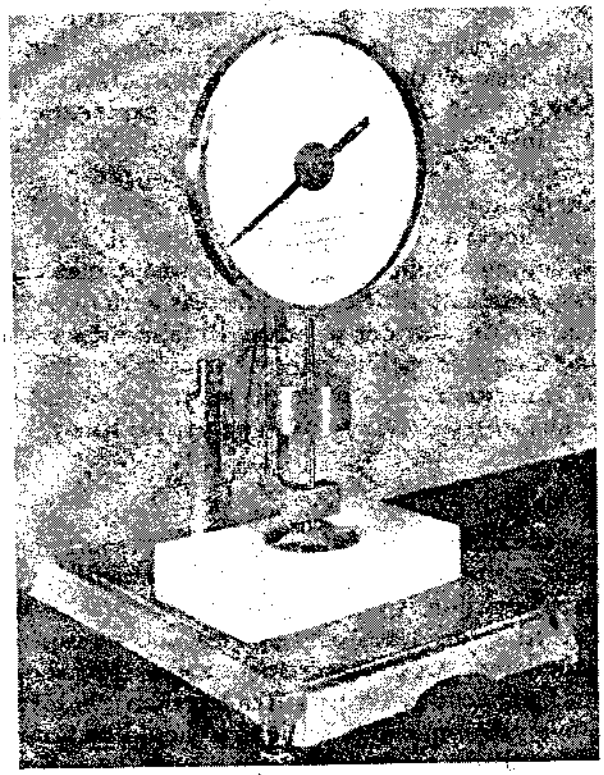
Figure 7.3(a). The Reynolds and Branson cloth thickness tester

The instrument is set level and switched on. At this point an indicator lamp glows dimly. Without the 5 g balance pan on the lever, the contact behind the lever anvil should only just touch the knurled adjusting screw. The pan is replaced and the gauge spindle advanced by means of the large knurled screw until the indicator lamp glows brightly. The pointer is now set to zero by turning the milled dial ring. With a sample of fabric between the anvils the gauge will indicate the thickness at 5 g/cm² pressure, the readings of the gauge being either to 0·001 in. or 0·01 mm.

Testing the thickness of compressible materials

A special instrument for measuring the thickness of felts and other thick materials is described in the B.S. Handbook, p. 177.

Many sheet materials are compressible, for example, carpets, sponge rubber, polyurethane foam and felts. The 'Shirley' thickness gauge, Figure 7.3(b), has been designed to measure, at known pressure, such materials. In the illustration the presser foot has an area of 10 in^2 but the foot is interchangeable with another of 1 in^2. It will be seen that on the shaft of the presser foot there are added weights. These auxiliary weights enable a range of pressures to be used. Further, by loading the presser foot in stages and then unloading it in stages the indicated thickness readings allow study of the compressibility and resilience of the material.



(By courtesy of the Cotton, Silk and Man-Made Fibres Research Association)

Figure 7.3(b). The Shirley thickness gauge

The model, with the dial graduated from 0 to 2 in., has a range o pressures from 1/1,000 to 1 lb/in² using the large presser foot, and from 1/100 to 10 lb/in² using the small foot. Each scale division is 0·005 in. and an estimate to 0·001 in. can be made. An alternative instrument is for metric measurements. In both types the maximum thickness that can be measured can be increased by half as much again, i.e. 3 in. on the inches model, by raising the measuring head.

Use of the results of thickness tests

The information obtained may be used in various ways:

(1) For checking materials against specification.
(2) In the study of other fabric properties such as thermal insulation, resilience, dimensional stability, fabric stiffness, abrasion, etc.
(3) In the study of fabric geometry.

FABRIC WEIGHT PER UNIT AREA AND PER UNIT LENGTH

The weight of a fabric can be described in two ways, either as the 'weight per unit area' or the 'weight per unit length'; the former is self-explanatory but the latter requires a little explanation because the weight of a unit length of fabric will obviously be affected by its width. To a layman, a '16 oz worsted' does not mean very much, but to a person dealing regularly with worsted cloths the description is sufficient to indicate a certain quality of material. For instance, a 20 oz worsted suiting would suggest a close weave material which would make an excellent winter suit, whereas a 16 oz worsted is a lighter material for the warmer weather. In fabric descriptions, the weight per unit length is usually referred to as the 'weight per running yard'. It is necessary, therefore, to know the agreed standard width upon which the weight per running yard is based, e.g. 56 in. for worsted.

Weight per unit area

The method of obtaining this value is implicit in the title; one has merely to weigh a known area and divide the weight by the area. The actual determination is not so straightforward since sampling, marking out, cutting, accuracy of weighing, and moisture content must all be considered. Area measurement and cutting should be to an accuracy of 1 per cent and for an area less than 100 in² a cutting die or template is recommended. Weighing should be accurate to 1 part in 500. The effects of moisture content can be accounted for either by conditioning the specimen in the standard atmosphere or by taking the specimen to oven dry weight and adding the official regain.

Some quadrant balances have one scale graduated in ounces per square yard. A template is used to cut the sample and the square of fabric suspended on the hook of the balance. For quick checks this method is useful and for particular purposes may be considered sufficiently accurate.

Weight per unit length

In general, the points to watch are similar to those mentioned above. The minimum length measured should be 18 in.

The B.S. 2471:1954 covers in detail the various procedures for the determination of both fabric weight per unit area and unit length (see B.S. Handbook, p. 167).

Conversion of values

Provided that it is assumed that the effect of selvedge construction is negligible, weight per unit area can be readily converted to weight per unit length, and vice versa.

Let W = weight per square yard,
R = weight per running yard, and
w = fabric width in inches.

then, $W = \frac{36R}{w}$ and $R = \frac{Ww}{36}$

THREADS PER INCH IN WOVEN FABRIC

In woven fabric the warp yarns are commonly referred to as 'ends' and the number of warp threads per inch width of cloth stated as so many 'ends per inch'. The threads of weft are called 'picks'. A fabric may therefore be described in terms of 'ends and picks'. For example, a cotton poplin may be woven with 144 ends per inch and 76 picks per inch. The warp yarn could be a doubled yarn, say 2/100s, and perhaps the weft, too, may be 2/100s. A short description of this poplin would be 144 × 76, 2/100 × 2/100, and to a person conversant with poplins a good quality would be indicated. The determination of the number of threads per inch may be made in several ways, five of which are given in the Textile Institute Tentative Specification No. 28, 1955. These methods will be found in the B.S. Handbook,* to which the reader should refer for details of procedure. The five methods are listed here and they are followed by a few remarks on points which are sometimes overlooked.

(1) One-inch counting glass—a simple microscope.

*B.S. 2862:1957, *Threads per Inch in Woven Fabric*. B.S. Handbook No. 11, p. 222.

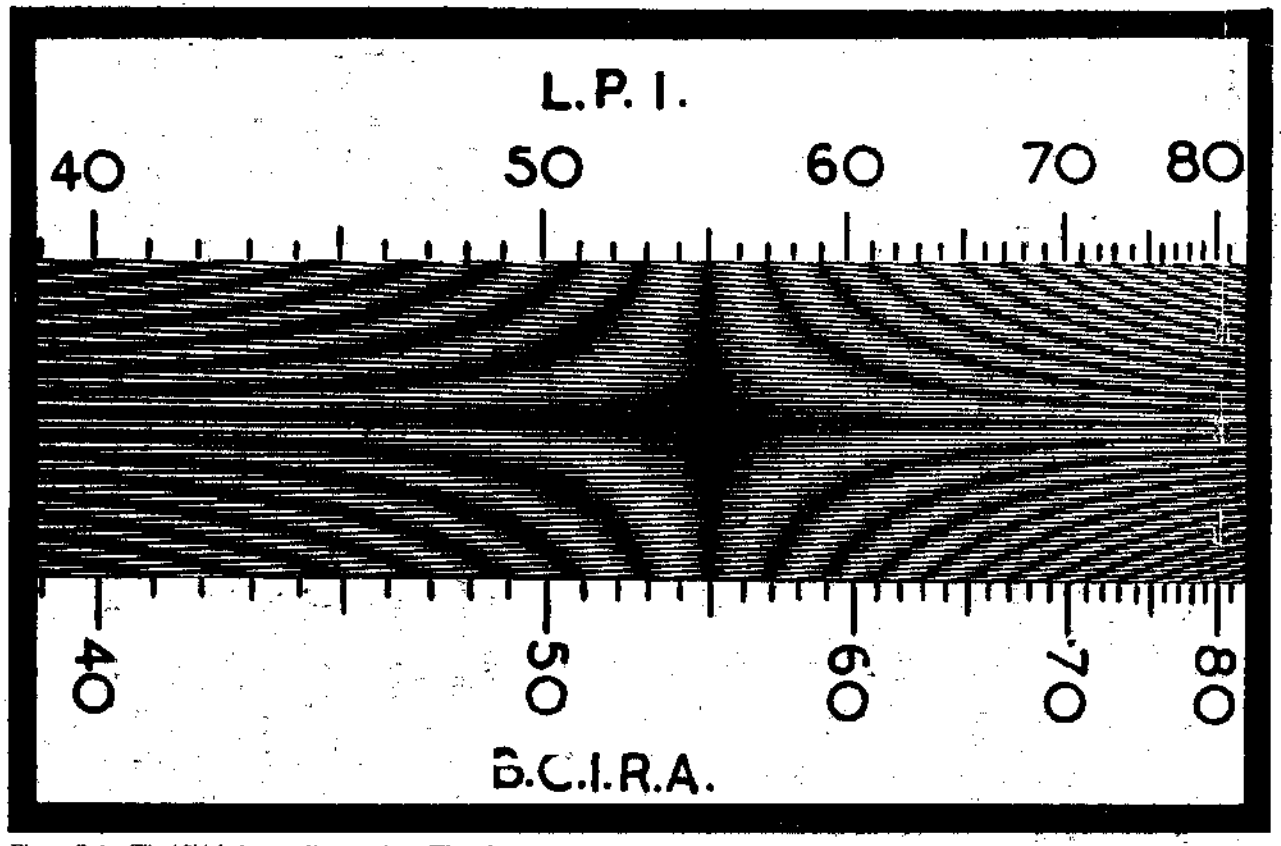


Figure 7.4. The 'Shirley' taper line grating. Threads per inch = 55, indicated by shadow cross. Long side of grating is laid parallel to threads being counted

(2) Traversing thread counter—a travelling microscope fitted with a pointer to aid counting.
(3) Fabric dissection—a known width is unravelled and the threads counted, a useful method where the threads are difficult to distinguish, as in felted threads, or where the structure is complex, e.g. plied fabrics.
(4) Parallel line gratings—a rapid optical method.
(5) Taper line gratings—a development of No. 4 (see Figure 7.4).

The 1 in. counting glass is not recommended when the number of threads per inch is less than 25. In such cases, a 3 in. sample could be unravelled and the threads counted.

A ground glass plate illuminated from below forms a useful surface on which the cloth can be laid when counting threads with a counting glass.

It is sometimes convenient to count the number of repeats of the pattern instead of the individual threads. The threads per inch are then obtained by multiplying the number of threads per repeat by the number of repeats, adding on any fraction of a repeat by counting the remaining threads individually. This method is useful when the number of threads per inch is high.

The regions near the selvedges should be avoided because the spacing of the threads is often a little different than in the body of the cloth.

In the specification it will be noted that specimens should be conditioned for at least 24 hr before testing. This must, of course, be stated in a standard, but in practice the information is often wanted quickly and this refinement is dispensed with.

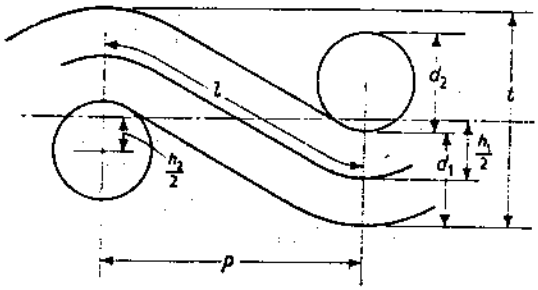
CRIMP OF YARN IN FABRIC

In *The Little Oxford English Dictionary* the first definition of crimp is: noun, 'agent who entraps men for seamen or soldiers'. A second definition is perhaps closer to its textile meaning: verb, 'to press into small folds, corrugate'.

When warp and weft yarns interlace in fabric they follow a wavy or corrugated path. Crimp percentage is a measure of this waviness in yarns. In his paper on cloth geometry, Peirce (*J. Text. Inst.* **28**, T45 (1937)) states that 'crimp, geometrically considered, is the percentage excess of length of the yarn axis over the cloth length'. It is impracticable to measure the length of the yarn axis as it lies in the cloth, therefore a definition is used which bears a close relationship to the methods used in crimp determination.

Crimp (B.S. Handbook, p. 230). 'Percentage crimp is defined as the mean difference between the straightened thread length and the distance between the ends of the thread while in the cloth, expressed as a percentage.'

A term used in the literature of cloth geometry is 'crimp amplitude' and this refers to the extent to which threads are deflected from the central plane of the cloth (see Pollitt, *J. J. Text. Inst.* **40**, P11 (1949)). Figure 7.5 illustrates the geometrical interpretation of crimp and crimp amplitude, using the assumption that the yarns are circular in cross-section and remain so when in the cloth.



$$\text{Crimp percentage} = \frac{l - p}{p} \times 100$$

Warp crimp amplitude $= h_1$
Weft crimp amplitude $= h_2$

Warp crimp amplitude is the extent to which threads are deflected from the central plane of the cloth

Figure 7.5. Crimp geometry

Crimp and fabric properties

Warp and weft crimp percentages are two of the eleven structural elements in fabric construction discussed by Peirce. The relationships between the geometry of a cloth structure and its physical behaviour in use are complex and although much pioneer work has been done there are many unresolved problems still to be investigated. The notes which follow are included to give the reader a few examples of the importance of crimp.

Resistance to abrasion. In a paper by Backer and Tanenhaus (*Text. Res. J.* **21**, p. 635 (1951)) it is pointed out that the yarns with high crimp take the brunt of abrasive action. This is because crowns formed as the yarn bends round a transverse thread will protrude from the fabric surface and meet the destructive abrasive agent first. The other set of yarns lying in the centre of the fabric will only play their part in resisting abrasion when the highly crimped threads are nearly worn through.

Shrinkage. The mechanism of the shrinkage of cotton fabrics when washed is explained by Collins (*J. Text. Inst.* **30**, P46 (1939)). When the yarns are wet they swell, and consequently a thread, say a warp thread, has a longer bending path to take round a swollen weft thread. The warp thread must either increase in length or, alternatively, the weft threads must move closer together. An increase in warp length requires the application of tension and therefore when when tension is absent as, for example, when the fabric is in a washing machine, equilibrium conditions will be attained by the weft threads moving closer together. Collins states that 'the largest amount of shrinkage is that represented by increase of crimp; yarn shrinkage takes a second place, being generally much less than increase in crimp, while fibre shrinkage is almost negligible'. (See Figure 7.41.)

Since shrinkage is mainly due to yarn swelling and the resulting crimp increase, mechanical means of controlled pre-shrinking have been developed, e.g. the Sanforizing and Rigmel processes (see Marsh, J. T. *Introduction to Textile Finishing*, Chapter 9).

Fabric behaviour during tensile testing. When a test strip of fabric is extended in one direction crimp is removed and the threads straighten out. This causes the threads at right angles to the loading direction to be crimped further. 'Crimp interchange' is said to take place. The specimen loses its original rectangular shape and 'waisting' occurs, i.e. the middle region of the strip contracts. If the testing machine is autographic the load–extension curve will show relatively high extension per unit increase in load in the early stages of the test, most of which will be due to the removal of crimp. Figure 8.48 illustrates this point.

Faults in fabric. Variation in crimp can give rise to faults in fabrics, e.g. reduction in strength, 'bright' picks and diamond barring in rayons, stripes in yarn dyed cloths, and so on. The cause of crimp variation is often loss of control over the tensions employed during yarn preparation and weaving.

Fabric design. Control of crimp percentage is necessary when a fabric is designed to give a desired degree of extensibility. Again, some fabrics require control of crimp in the finishing processes to give the correct crimp balance between warp and weft so that the finished appearance is satisfactory. The tensions applied must therefore be carefully controlled.

Fabric costing. Since crimp is related to length it follows that the amount of yarn required to produce a given length of cloth is affected by the crimp percentages of warp and weft. Knowledge of

values is useful in calculating the cost and the yarn requirements.

From the notes above it will be appreciated that the measurement of crimp can be of service in fabric analysis, fabric research and design, process control, and in the economics of fabric production.

The measurement of crimp percentage

From the definition of crimp two values must be known, the cloth length from which the yarn is removed and the straightened length of the thread. In order to straighten the thread, tension must be applied, just sufficient to remove all the kinks without stretching the yarn. In practice, it is seldom possible to remove all the crimp before the yarn itself begins to stretch. The standardised tensions recommended in the B.S. Handbook p. 234, are given in Table 7.1.

One quick non-standard check on crimp can be made when the only instruments to hand are a pair of scissors and a rule. Two cuts are made in the cloth sample and the distance between them noted. Threads are removed and placed over the rule, one end held by a forefinger and the thread smoothed along with the other forefinger, and the straightened length observed. The thread length will be only a few inches and the accuracy of the method is not great.

Table 7.1

Yarn	*Count*	*Tension (g)*
Cotton	Finer than 7 tex	0·75 tex
	Coarser than 7 tex	0·20 tex + 4
Woollen and Worsted	15 to 60 tex	0·20 tex + 4
	60 to 300 tex	0·07 tex + 12
All man-made continuous-filament yarns	All counts	Tex/2

Where a higher degree of accuracy is necessary special crimp testers are used. Five groups of threads are selected for test, two warp way and three weft way groups. The mean crimp percentage is calculated warp way and weft way. Rectangular strips are carefully marked on the cloth and each strip cut into the form of a flap as in Figure 7.6. From each strip ten threads will be removed. Removal of threads is as follows: the central part of the first thread is separated from the flap fringe by means of a dissecting needle, but the two extreme ends are left secured. One end is then removed and placed in the grip of the tester, and the other end is removed and placed in

the second grip. In this way the thread is transferred from the cloth to the crimp tester without loss of twist and with a minimum of handling.

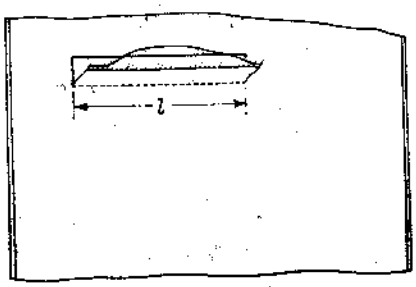


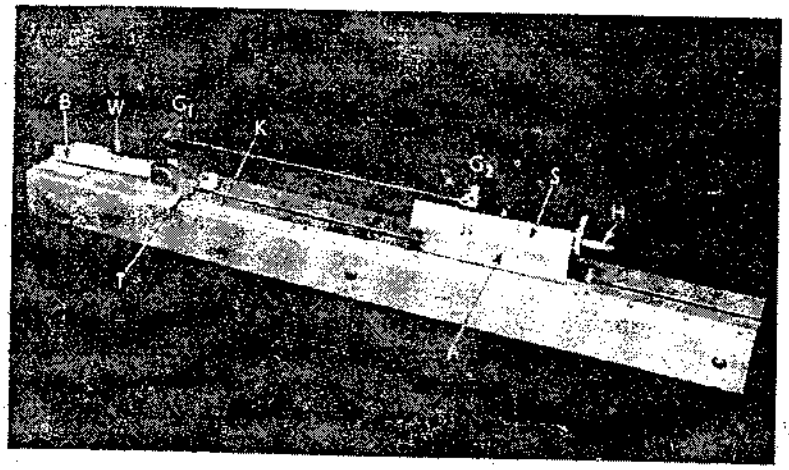
Figure 7.6. Preparation of specimens for crimp testing

Several crimp testers are available, three of which were designed and developed by British research associations, B.C.I.R.A., W.I.R.A., and B.R.R.A. The Shirley and W.I.R.A. models are primarily for spun yarns, whereas the B.R.R.A. model has been designed to meet the demand for greater accuracy when very small differences in crimp in continuous-filament fabrics must be measured, differences which in spun yarns would make negligible difference to the cloth appearance, but with rayons may be the cause of a fabric defect such as warp stripiness.

The W.I.R.A. crimp meter. Test lengths up to 16 in. can be handled in this instrument. In Figure 7.7, G_1 is a grip on the vertical arm of the pivoted beam B. When the beam is horizontal it just touches a contact and the torch bulb T lights up. On the long arm of the beam a sliding weight W can be set by means of a scale marked on the beam to the recommended tension in grams. The other grip G_2 is carried on a plate which is in turn mounted on a screwed rod in the assembly A. When G_2 is at its extreme position to the left a pointer is at 'zero' on the scale S. By turning the handwheel H, G_2 has a maximum movement to the right of 5 in.

To make a test the assembly A is set to a scale K on the base of the tester to a length equal to the strip length, the pointer of grip G_2 being at zero. The weight W is set to the required tension. One end of the thread is then clamped in grip G_1 with its extreme tip in line with a datum line marked in the transparent upper face of the grip. The other end is then clamped in grip G_2 in a similar manner. At this

stage the thread will usually sag and the beam will be tilted. The handwheel H is turned, grip G_2 moves to the right, the thread straightens up, and eventually the beam touches the contact. As soon as the bulb lights, the movement of G_2 is noted. This value is the increase in length due to the crimp removal. The results from the twenty warp way threads and the thirty weft way threads are recorded and the mean warp and weft crimp percentages calculated.



(By courtesy of W.I.R.A.)

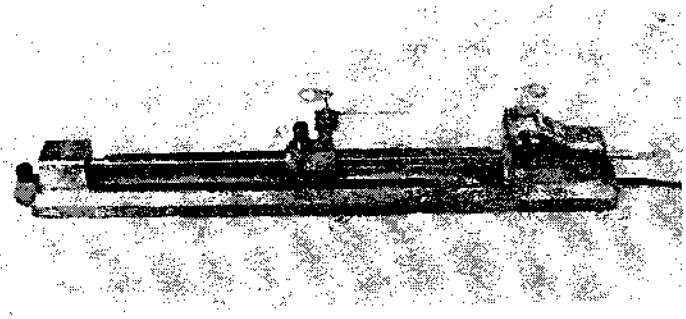
Figure 7.7. The W.I.R.A. crimp tester

The Manra crimp tester. This description of the crimp tester designed by B.R.R.A. is based on the maker's leaflet (Louis Newmark Ltd).

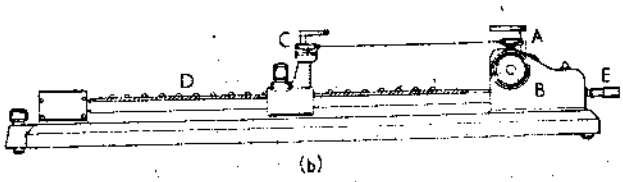
The Manra crimp tester was specially designed to facilitate the measurement of very small differences in the crimp of yarns taken from continuous-filament fabrics. By means of this instrument, determination of crimp can be made within an accuracy of less than 0·1 per cent. The instrument is mounted on a rigid casting and is precision-built to eliminate errors due to vibration, backlash, etc. A pivoted grip A, Figure 7.8, is tensioned by a spiral spring, the tension indicates the tension necessary to bring the arm to its zero position. The grip C is mounted on a carriage carried by rail D in such a way that it can be set at any one of a number of fixed distances from grip A. The upper face of each grip is of transparent plastic on which is engraved a fine line so that the ends of the length of yarn under test can be accurately located in the grips. The

rail D carrying the grip C can be moved horizontally through a distance of 25 mm by means of the micrometer E which is graduated 0·01 mm.

The micrometer is set to zero and the grip C is set at a convenient position on rail D. Knob B is set to give the approriate tension for the yarn to be tested. A thread is removed from a strip of fabric whose length is the same as the selected distance between the grips, care being taken to avoid loss of twist. The thread is inserted into the the grips so that its ends coincide with the datum lines. The distance between the grips is increased by turning the micrometer until the grip A reaches its zero position, indicated by the extinction of an indicator light. The increase in the length of the thread due to the removal of crimp is indicated directly on the micrometer scale.



(a) (*By courtesy of Newmark Ltd*)



(b)

Figure 7.8. The Manra crimp tester

Other methods. The reader is referred to Garner, *Textile Laboratory Manual*, p. 177, and to Skinkle, *Textile Testing*, p. 80, for descriptions of the determination of crimp by other methods, especially from examination of the load–extension curve of the crimped thread.

TEXTILE STRUCTURE

In the earlier sections of this chapter fabric dimensions have been discussed individually, more or less in isolation. However, a few moments' reflection will reveal that a fabric is a structure characterised by the interdependence of most of its dimensional values. In any discussion on fabric structure and fabric geometry, Peirce's classical paper, 'The Geometry of Cloth Structure' in *J. Text. Inst.* March 1937, will be referred to. His paper has formed a basis upon which a number of other workers have developed the subject. An excellent summary and comment on cloth geometry is given by Pollitt (*J. Text. Inst.* **40**, P11 (1949)). The notes which follow are largely derived from Peirce and Pollitt's work. It is not intended to deal with cloth structure as a subject in itself but to illustrate how the fabric dimensions are inter-related, more particularly in plain weave cloth.

*Yarn count, diameter, and cloth cover**

The yarn diameter of a cotton yarn count N has been shown to be

$$d = \frac{1}{28\sqrt{N}}$$

where d is the diameter in inches.

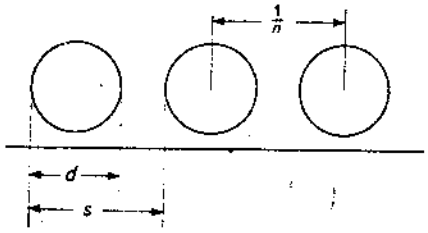


Figure 7.9. Cover factor

Figure 7.9 represents the cross-sections of threads in a fabric. If the number of threads per inch is n, then the distance, s, from one thread to the next will be $1/n$ in. The ratio d/s will therefore represent the fraction of the spacing, s, covered by the projection from a thread. This fraction may be expressed in terms of yarn count and ends per inch.

* See also
Morton, T. H. 'A Direct Reading Cover Photometer.' *J. Text. Inst.* **53**, T22 (1962).

Thus,

$$\frac{d}{s} = \frac{1}{28\sqrt{N}} \times \frac{n}{1} = \frac{n}{28\sqrt{N}}$$

For convenience, this last formula is multiplied by 28 to give a value known as the *cover factor*. Hence,

$$\text{Cover factor } K = \frac{\text{Threads per inch}}{\sqrt{(\text{Counts})}} = \frac{n}{\sqrt{N}}$$

If all the threads just touched, the cover factor would be 28. However, since space between the threads must be left to allow the transverse threads to interlace, a cover factor of 28 is theoretically impossible. This theory assumes, however, that the threads remain circular in cross-section, but as threads can, in practice, be compressed and distorted, cover factors even in excess of 28 can be achieved. Figure 7.10 shows a square plain weave structure, i.e. a structure with warp and weft counts equal and ends and picks per inch equal. In this simple case the fraction d/s is $1/\sqrt{3}$, giving a maximum cover factor of 16·2 for both warp and weft.

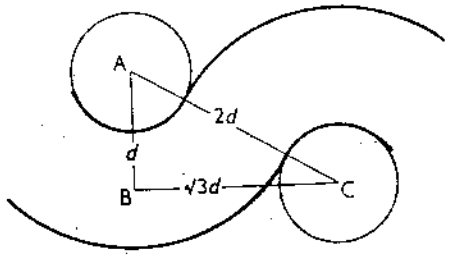


Figure 7.10. Square plain cloth structure

Cover factors are calculated for warp and weft, therefore pairs of values can be quoted in descriptions of fabric in much the same way as pairs of counts or pairs of threads per inch. The chief value of cover factors comes from their continued use to establish familiarity with different values and pairs of values as represented by different types of cloth. Thus, for open muslin 5·4 × 5·4 might be quoted, 8 × 8 for voile, 16 × 16 for canvas, 22 × 10 for a poplin, and so on. For an opaque, soft, and inexpensive cloth 11 × 10 could be chosen, and for a well covered domestic cloth 13 × 12. At higher values the fabric becomes stiffer and drapes less easily.

Cover factors do not necessarily indicate textile merit because differences in count, twist factor, fibre, etc., all play their part.

The fraction of the area covered by both sets of threads is given by

$$\frac{K_1 + K_2}{28} - \frac{K_1 K_2}{(28)^2}$$

where K_1 = warp cover factor, and
K_2 = weft cover factor.

Again, multiplying by 28 for convenience, we obtain the cloth cover K_c.

Hence, $$\text{Cloth cover } K_c = K_1 + K_2 - \frac{K_1 K_2}{28}$$

Although this last value is logically desirable, pairs of values seem to be more useful in practice. It is worth noting, too, that the actual 'cover' of a cloth is usually better than the calculated value would indicate. This is because threads flatten and spread, an effect accentuated by calendering. A paper by Kemp (*J. Text. Inst.* **49**, T44 (1958)) extends the principles of cloth geometry to non-circular threads and suggests a 'race track' cross-section (see Figure 7.11).

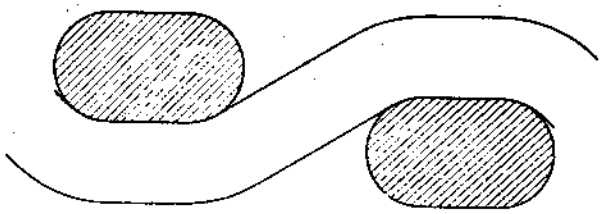


Figure 7.11. The 'race track' cross-section

Cover factors and cloth weight per unit area

An approximate relationship between the sum of the warp and weft cover factors and the cloth weight per unit area is

$$K_1 + K_2 = 1\tfrac{1}{6}\sqrt{[W(n_1 + n_2)]}$$

where W = cloth weight per square yard in ounces,
n_1 = number of warp ends per inch, and
n_2 = number of picks per inch.

An estimate of the closeness of the weave can be made when only the cloth setting and the weight per unit area are known.

Crimp, count, and cloth setting

The above fabric dimensions are related by the following formula:

$$\frac{\sqrt{c_1\%}}{n_2} + \frac{\sqrt{c_2\%}}{n_1} = 0{\cdot}28e\left(\frac{1}{\sqrt{N_1}} + \frac{1}{\sqrt{N_2}}\right)$$

where $c_1\%$ = warp crimp percentage
$c_2\%$ = weft crimp percentage
n_1 = warp setting
n_2 = weft setting
N_1 = warp count (cotton counts)
N_2 = weft count (cotton counts)
e = factor to accommodate yarn flattening

The formula is not absolutely true but the loss in accuracy is not great and is compensated by the relative simplicity of the equation.

Crimp, crimp amplitude, cloth setting, and cloth thickness

Crimp amplitude has been defined earlier as the extent to which threads are deflected from the central plane of the fabric. This is shown diagrammatically in Figure 7.5 where h_1 and h_2 are the warp and weft crimp amplitudes. The values, in thousandths of an inch, are given by

$$h_1 = \frac{136\sqrt{c_1\%}}{n_2} \qquad \text{and } h_2 = \frac{136\sqrt{c_2\%}}{n_1}$$

Since yarn diameter as a fraction of an inch is equal to $1/(28\sqrt{N})$, the diameter in thousandths of an inch will be $1000/(28\sqrt{N})$ or $36/\sqrt{N}$. Taking the flattening into account, the yarn thickness now becomes $36e/\sqrt{N}$.

Cloth thickness, t, will thus be the higher of the two values which follow:

$$t = h_1 + \frac{36e}{\sqrt{N_1}} \quad \text{or} \quad h_2 + \frac{36e}{\sqrt{N_2}}$$

Concluding note on fabric dimensions and cloth geometry

The examples given above serve merely as an introduction to a complex subject. Furthermore, only a simple plain weave has been considered. Clearly, weaves other than plain must be studied and also other types of structures found in warp and weft knitted fabrics. The reader is referred to such papers as those by Doyle, Grosberg,

Munden, Hamilton and others (see Further Reading). As Pollitt points out, the value of the study of cloth geometry 'will only be appreciated by those who make use of it to rationalise their experience, and at first the going may seem heavy and the return small'.

AIR PERMEABILITY

Due to the manner in which yarns and fabrics are constructed, a large proportion of the total volume occupied by a fabric is, in fact, airspace. The distribution of this airspace influences a number of important fabric properties such as warmth and protection against wind and rain in clothing, and efficiency of filtration in industrial cloths. A common example of the latter is found when the domestic vacuum cleaner bag is considered; the fabric must allow air to pass through but at the same time prevent the passage of dust and dirt. The theory of air flow through different assemblies of materials lies outside the scope of this volume and will not be discussed.

Before describing an instrument used in the measurement of the air flow through fabrics it is necessary to define the terms used.

Air permeability. The air permeability of a fabric is the volume of air measured in cubic centimetres passed per second through 1 cm^2 of the fabric at a pressure of 1 cm of water.

Air resistance. The air resistance of a fabric is the time in seconds for 1 cm^3 of air to pass through 1 cm^2 of the fabric under a pressure head of 1 cm of water.

Air porosity. (1) This term is used in some papers on fabric properties and has the same meaning as air permeability. (2) An alternative definition of porosity is given by Skinkle in *Textile Testing*. The porosity of a fabric is the ratio of airspace to the total volume of the fabric expressed as a percentage. This is a calculated value based on an estimation of the volume of the component fibres and the estimation of the volume of the fabric from measurement of length, width, and thickness.

From the definitions above it will be realised that air resistance is the reciprocal of air permeability. The advantage in using air resistance values in preference to air permeability values lies in the fact that when a number of fabrics are superimposed to form a multi-layer assembly, the total air resistance is merely the sum of the individual values. Porosity as defined by Skinkle is, of course, a static property, i.e. air flow is not directly involved and although there will be some relationship between porosity and air flow it will not necessarily be simple. Skinkle points out that the

type of finish given to a fabric can have a considerable effect on the permeability even though the porosity may remain the same.

Measurement of air permeability

A number of instruments* have been designed to measure the air permeability of fabrics and the reader will find references to them at the end of this chapter. The 'Shirley' Air Permeability Apparatus has been selected for description here.

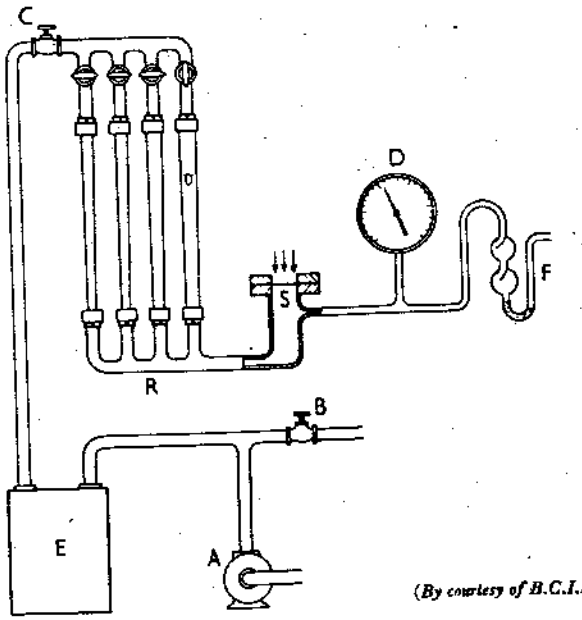


Figure 7.12. The 'Shirley' air permeability apparatus

The apparatus is illustrated in Figure 7.12. Air at 20 ± 2° C and 65 ± 2 per cent r.h. is drawn from the laboratory through the test specimen S by means of a suction pump A, the rate of flow being controlled by means of the by-pass valve B and the series valve C. The rate of flow is adjusted until the required pressure drop across the fabric is indicated on a draught gauge D, graduated from 0 to 25 mm head of water. For fabrics of high resistance, the rate of flow of air through the specimen is inadequate for proper operation of the suction pump; this is overcome by opening the by-pass valve B

* See B.S. Handbook No. 11, p. 308 *W.I.R.A. Air Permeameter.*
B.S. Handbook No. 11, p. 313, B.S. 3321:1960 *Equivalent Pore Size of Fabrics.*

which supplies air to the pump directly. For fabrics of low resistance, when high rates of flow are attained, valve B is closed or permitted to supply only a small volume of air; fine control is obtained by adjusting valve C. E is a reservoir which smooths out any disturbance due to the varying velocities of the streams of air drawn through the various paths by the pump.

When the required pressure drop, which is normally 1 cm of water, is attained and the indicator of the draught gauge is steady, the rate of flow of air is read off one of the four Rotameters R, selected according to the permeability of the test specimen. The Rotameters are calibrated, at 20° C and 760 mm of mercury, to indicate air flow in cubic centimetres per second and they cover the following ranges: R1 0·05–0·5, R2 0·5–3·5, R3 3–35, and R4 30–350. It is easy to select the most suitable Rotameter for any fabric. The test is commenced with R4 open and the other Rotameters closed. If the flow is less than 30 cm^3/sec, R3 is opened and R4 closed. This procedure is repeated until the most suitable range for the fabric under test has been selected. To prevent damage to the draught gauge, should the pressure drop across the fabric inadvertently be allowed to exceed the range of the gauge, a safety valve F is provided.

The test area is 5·07 cm^2, since a 1 in. diameter circle is exposed when the specimen is clamped in the holder. From the readings on the Rotameter either the air permeability or the resistance can be computed. The average rate of flow from five specimens is calculated and by dividing by 5·07 we obtain the air permeability of the fabric in cubic centimetres per second at 1 cm head of water. Alternatively, 5·07 may be divided by the mean flow; this gives the air resistance of the fabric in seconds per cubic centimetre per square centimetre under a pressure of 1 cm of water.

Air permeability and fabric properties

A concise summary of the results of experimental work carried out by a number of research workers is given by Kaswell in his book *Textile Fibres, Yarns, and Fabrics*, to which the reader is referred. However, it is useful to look at just one aspect of the relationships which exist between air permeability and other fabric properties.

Permeability and cloth cover. One would expect that there should be some relation between the openness of the weave and the rate at which air flows through it, the more open the structure the greater the air permeability. This is borne out in practice but the relationship is not always a simple one. For example, using given yarns the

ends and picks per inch may be varied and the air permeability found to follow the variation in cloth cover more or less as expected. However, it is possible to arrange a series of fabrics built from yarns of different counts with the yarn spacings adjusted to give each fabric the same cover and to find large differences in their air permeabilites.

Table 7.2. The Effect of Cloth Cover on Air Permeability

Warp count: 44s. Ends per inch: 143. Warp cover factor: 21·6.
Weft count: 50s. Picks per inch: varied. Weft cover factor: varied.

Cloth	*Warp cover factor* K	*Picks per inch*	*Weft cover factor* K	*Cloth cover* K	*Permeability* P
A	21·6	36·1	5·1	22·8	8,290
B	21·6	46·3	6·5	23·1	5,570
C	21·6	56·2	7·9	23·4	2,880
D	21·6	66·3	9·4	23·8	1,070
E	21·6	77·1	10·9	24·1	562
F	21·6	87·5	12·4	24·5	248
G	21·6	98·1	13·8	24·8	128
H	21·6	106·1	15·0	25·0	90
I	21·6	108·4	15·3	25·1	86

Table 7.3. The Effect of Weft Twist Factor on Air Permeability

Warp count: 43s. Ends per inch: 143.
Weft count: 50s. Picks per inch: 75.

Cloth	*Weft twist factor*	*Permeability*
A	2·6	507
B	3·1	702
C	3·6	671
D	4·0	755
E	4·7	869
F	5·1	920

Some results of tests on experimental fabrics were published by Clayton in a paper, 'The Measurement of the Air Permeabilities of Fabrics' (*J. Text. Inst.* **26**, T171 (1935)). These are tabulated in a modified form in Tables 7.2 and 7.3. The warp count is 44s and the ends per inch 143, giving a cover factor of 21·6 for the series of fabrics. By varying the picks per inch the weft cover factor is varied from 5·1

to 15·3. From each pair of cover factors the cloth cover has been calculated by using the following formula:

$$K_c = K_1 + K_2 - \frac{K_1 K_2}{28}$$

where K_c = cloth cover,
K_1 = warp cover factor, and
K_2 = weft cover factor.

Clayton used a permeability value P, calculated as follows:

$$P = \frac{100V}{Ap}$$

where V = volume of air in cubic centimetres per second flowing through the specimen
A = area of the test piece in square centimetres, and
p = pressure head in 1 cm water.

Thus, P is 100 times the air permeability as defined earlier. The values of P are plotted against cloth cover K_c in Figure 7.13 and a curve is produced. In Figure 7.14 log P is plotted against K_c and an almost linear relation is noted (see also Pollitt's pape: on Cloth Geometry, *J. Text. Inst.* **40**, P11 (1949)).

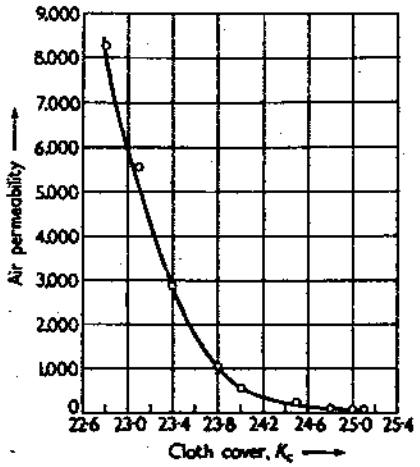


Figure 7.13. Air permeability vs cloth cover

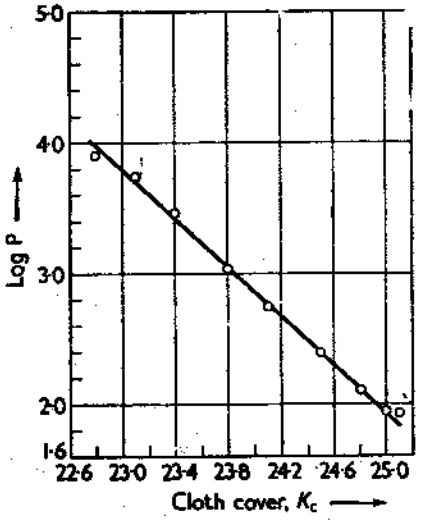


Figure 7.14. Cover factor vs log P

Clayton's work also showed that the twist factor in the yarns has a great influence on air permeability. In an experiment the warp and weft cover factors were kept constant but the twist factor of the weft varied between 2·6 and 5·1. Figure 7.15 shows how the air permeability increases linearly with increase in twist factor. As the yarn becomes more highly twisted and therefore more compact, the airspace in the yarn is reduced. The fabric moves towards a structure similar to a wire mesh and the permeability increases. Kaswell quotes Robertson (*Text. Res. J.* **20**, p. 838 (1950)), 'For a given fabric no other constructional variable was found to have nearly as great an effect (as twist) on porosity'.

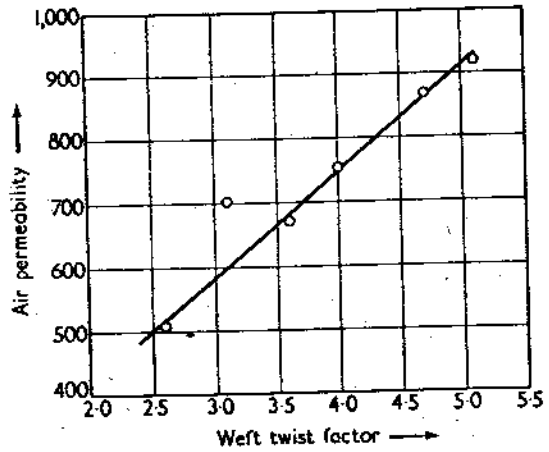


Figure 7.15. Air permeability vs twist factor

THERMAL PROPERTIES OF FABRICS

Measurement of the 'warmth' of fabrics is perhaps more likely to be made in research laboratories than in the testing laboratory of the mill. Rather than omit reference to this subject altogether, the following notes are included in order to direct the reader's attention to some authoritative sources of information.

Perhaps the most important point to note is that the warmth of a fabric is largely a function of the airspace and its distribution in the structure and not, as one might at first suppose, related to the thermal conductivity of the fibres used. Marsh tested many types of fabric and plotted their 'Thermal Insulation Values' (T.I.V.) against their thickness and obtained a fairly linear relationship, thus showing that the air in the fabrics plays the most important part. Cassie observes that the air is not 'entrapped', as many people

tend to think, but clings to the fibre surface, a fact that probably explains the excellent properties of wool fabrics as wool yarns are open yarns and expose maximum fibre surface.

Various test methods are described in the literature* and several units have been put forward which may express the thermal properties of a fabric numerically. Some of these values are determined in nominally still air, whereas in practice the warmth value of a fabric is appreciated most in windy conditions.

The T.I.V. mentioned above is the percentage saving in heat loss from a surface due to covering it with the fabric:

$$\text{T.I.V.} = \frac{100(H_o - H_c)}{H_o}$$

where H_o = the heat lost per second from the uncovered surface, and

H_c = the heat lost per second from the covered surface.

FABRIC STIFFNESS, HANDLE, AND DRAPE

A person selecting a fabric for a given purpose usually knows what characteristics of the material are required for optimum performance in use. Where mechanical or industrial fabrics are concerned, detailed information on strength, extensibility, resistance to chemical attack, and so on is required and in many cases suitable tests are available which furnish this information in numerical form. When a fabric is chosen for, say, dress material, its technical merit is almost taken for granted and other fabric properties are examined, many of which are difficult to describe by numerical values. Such properties include appearance, lustre, smoothness or roughness, stiffness or limpness, and good or poor draping qualities. With a range of materials to choose from, the person making the selection must handle and examine all the fabrics and decide which one is the most suitable for the purpose in view; he must therefore assess many properties simultaneously and subjectively and rank the fabrics in order of preference.

Fabric handle, as its name implies, is concerned with the feel of the material and so depends on the sense of touch. It will be appreciated that a term such as 'smooth' may have several connotations. For example, the smoothness of a high quality worsted suiting is a differ-

*See also

A.S.T.M. D1518–57T, *Thermal Transmittance of Textile Fabric and Batting Between Guarded Hot Plate and Cool Atmosphere.*

ent type of smoothness to that of a cotton sateen. Peirce, in his paper *The Handle of Cloth as a Measurable Quantity*, observes that when the handle of a fabric is judged the sensations of stiffness or limpness, hardness or softness, and roughness or smoothness, are all made use of.

Drape has a rather different meaning and very broadly is the ability of a fabric to assume a graceful appearance in use. Not all fabrics, of course, are expected to drape gracefully and indeed would be considered unsuitable if they did. One thinks of ballet skirts and stiff petticoats.

Over the past thirty years or so investigations have been made into possible methods of overcoming the difficulties associated with subjective assessment of handle and drape. Two main lines of attack on the problem have been followed. First, the isolation of the various ingredients which make up handle and drape, and the design of suitable instruments with which to measure the individual fabric properties. Second, the application of statistical techniques to discover how closely the conclusions reached from examination of test results agree with the judgement of individuals or groups of judges. A number of papers on these topics are given in the references.

Experience has shown that Peirce's conclusions were well 'on target' in that fabric stiffness is a key factor in the study of handle and drape. Peirce describes the 'Flexometer', an instrument designed to measure stiffness. Since the paper was published (1930), new versions of this instrument have been produced by the British Cotton Industry Research Association. One is the 'Shirley' Combined Stiffness and Creasing Tester; a more recent version is the 'Shirley' Stiffness Tester. While the use of the two instruments may differ slightly, they are both based on the same principle.

The 'Shirley' Stiffness Tester

A rectangular strip of fabric; 6 in. × 1 in., is mounted on a horizontal platform in such a way that it overhangs, like a cantilever, and bends downwards, see Figure 7.16. From the length l and the angle θ a number of values are determined.

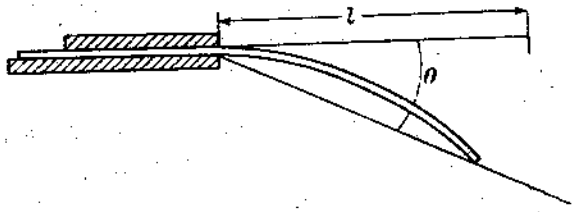


Figure 7.16. Fabric stiffness, cantilever principle

Bending length, c. This is the length of fabric that will bend under its own weight to a definite extent. It is a measure of the stiffness that determines draping quality. The calculation is as follows:

$$c = lf_1(\theta)$$

where $$f_1(\theta) = \left(\frac{\cos \frac{1}{2}\theta}{8 \tan \theta}\right)^{\frac{1}{3}}$$

The labour of calculating the function of θ is avoided by consulting a prepared Table.

Flexural rigidity, G. This is a measure of stiffness associated with handle. A recent paper by Abbott (*Text. Res. J.* **21**, p. 435 (1951)) suggests that the flexural rigidity as determined by this test shows a close relationship between this value and the personal judgement of stiffness. The calculation is as follows:

$$G = 3{\cdot}39 w_1 c^3 \text{ mg/cm} \quad \text{or} \quad w_2 c^3 \times 10^3 \text{ mg/cm}$$

where w_1 = cloth weight in ounces per square yard, and
w_2 = cloth weight in gram per square centimetre.

Bending modulus, q. This value is independent of the dimensions of the strip tested and may be regarded as the 'intrinsic stiffness'. Peirce points out that this value may be used to compare the stiffness of the material in fabrics of different thicknesses. For its calculation the thickness of the fabric must be measured at a pressure of 1 lb/in^2. The bending modulus is then given by:

$$q = \frac{732G}{g_1^3} \text{ kg/cm}^2 \text{ or } \frac{12G \times 10^{-6}}{g_2^3} \text{ kg/cm}^2$$

where g_1 = cloth thickness in thousandths of an inch, and
g_2 = cloth thickness in centimetres.

The Shirley Stiffness Tester is described in the B.S. Handbook p. 194 and the tests are now B.S. 3356:1961 *Determination of Stiffness of Cloth.* Three specimens warp way and three weft are usually tested and since the relative humidity can affect the results the test should be made in a standard testing atmosphere.

The horizontal platform of the instrument is supported by two side pieces made of plastic. These side pieces have engraved on them index lines at the standard angle of deflection of 41½°, at which angle $f(41\frac{1}{2}°) = 0{\cdot}5$. Attached to the instrument is a mirror which enables the operator to view both index lines from a convenient position. The scale of the instrument is graduated in centimetres of bending length and it also serves as the template for cutting the specimens to size.

To carry out a test the specimen is cut to size with the aid of the template and then both template and specimen are transferred to the platform with the fabric underneath. Both are slowly pushed forward. The strip of fabric will commence to droop over the edge of the platform and the movement of the template (i.e. the scale) and the fabric is continued until the tip of the specimen viewed in the mirror cuts both index lines. The bending length can immediately be read off from the scale mark opposite a zero line engraved on the side of the platform.

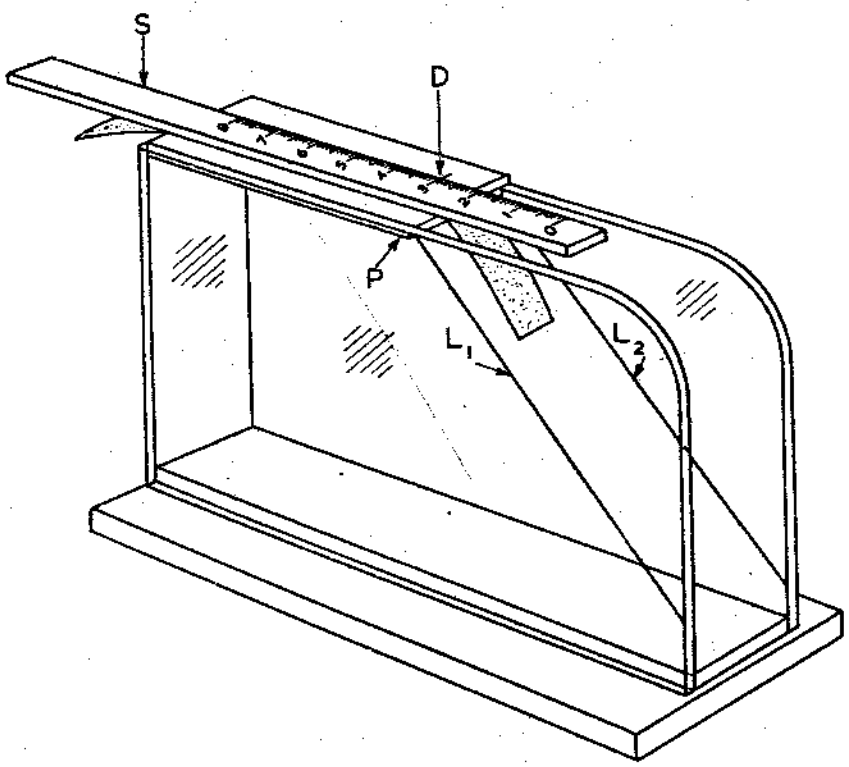


Figure 7.17. Fabric stiffness tester (From B.S. Handbook No. 11, *Methods of Test for Textiles* reproduced by permission of the British Standards Institution, 2 Park Street, London W.1)

Each specimen is tested four times, at each end and again with the strip turned over. Mean values for the bending length in warp and weft directions can then be calculated and, if required, values for flexural rigidity and bending modulus.

The use of an instrument such as this is recommended in finishing departments where the control of the process is aided and the effects of varying the process noted.

The heart-loop test

Some fabrics are too flexible or limp to be tested by using the cantilever principle, and for such materials Peirce put forward the heart-loop test. Figure 7.18 shows a loop of fabric formed by clamping the free ends as indicated. A stiff fabric will hang as in Figure 7.18, whereas a very limp fabric will hang vertically as in Figure 7.19. Stiffness in this test is therefore inversely related to the length, l, measured from the top edges of the clamps to the base of the loop.

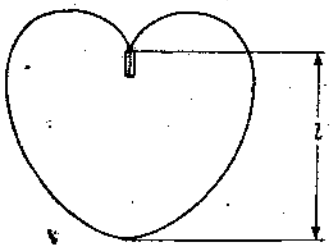


Figure 7.18. The heart-loop test (stiff fabric)

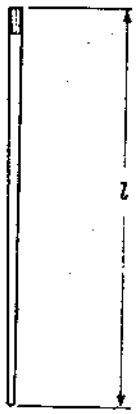


Figure 7.19. The heart-loop test (limp fabric)

The bending length is calculated from the formula

$$c = l_0 f_2(\theta)$$

where $\theta = 32{\cdot}85^\circ \times d/l_0$,
$d = l - l_0$,
l = actual length of the loop,
$l_0 = 0{\cdot}1337\ L$,
L = specimen length, and
$f_2(\theta) = (\cos\theta/\tan\theta)^{\frac{1}{2}}$.

Here again, a Table is prepared for the function $f_2(\theta)$.

In both the cantilever and the heart-loop tests the stiffness values are measured only in one direction at a time. Criticism has been made on the grounds that in practice fabrics drape in all directions. Peirce did in fact consider this point, and he measured stiffness at

angles to the warp and weft directions. He found that the value in any selected direction could be calculated from the known warp and weft way values, therefore no great purpose would be served by actual measurement on specimens cut obliquely.*

The Drapemeter

The Fabric Research Laboratories of U.S.A. have developed a method of measuring drape in which the warp and weft way characteristics interact and produce the type of graceful folding seen in tailors' shop windows when suiting is draped over circular supports. The development of this instrument is given in a paper by Chu, Cummings, and Teixeira (*Text. Res. J.* **20**, 539 (1950)) and the method is also described by Kaswell.

A circular specimen about 10 in. diameter is supported on a circular disk about 5 in. diameter and the unsupported area drapes over the edge (see Figure 7.20). If the specimen were, say, a 10 in. gramophone record, no draping would occur and the area of projection from the periphery would equal the area of the record. With fabrics the material will assume some folded configuration and the shape of the projected area will not be circular but something like the shape shown in Figure 7.21.

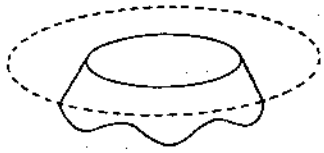


Figure 7.20. The Drapemeter. The circular specimen is 'draped' over the circular support

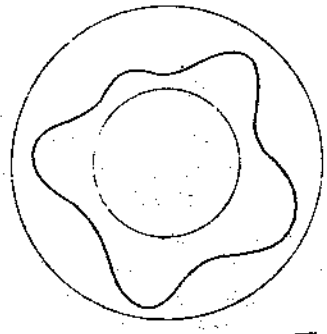


Figure 7.21. The Drapemeter. The projected outline of the 'draped' specimen

A value known as the drape coefficient, F, is determined by considering areas.

Let A_D = the area of the specimen,
A_d = the area of the supporting disk, and
A_s = the actual projected area of the specimen.

* See also
Cooper, D. N. E. 'The Stiffness of Woven Fabrics.' *J. Text. Inst.* **51**, T317 (1960).

The drape coefficient, F, is the ratio of the projected area of the draped specimen to its undraped area, after deduction of the area of the supporting disk. Thus,

$$F = \frac{A_s - A_d}{A_D - A_d}$$

Other values are obtained by further analysis of the shape of the projected outline. (See Kaswell.)*

Several other special instruments for the measurement of drape and related fabric properties are described in the literature given in the references.

CREASE RESISTANCE AND CREASE RECOVERY

A useful review of the literature on creasing and related fabric properties is given by Kaswell. The crease-resisting process, however, was invented by Foulds, Marsh, and Wood, of Tootal Broadhurst Lee Co. Ltd, and for a background to the whole subject we are well served by Marsh in his book *An Introduction to Textile Finishing*. A few extracts are given here.

Resistance to creasing

'Cellulosic materials are notoriously susceptible to creasing and the removal of this defect may perhaps be regarded as one of the greatest achievements in the history of textile finishing.'

'. . . many materials resist creasing, which means they resist deformation and are therefore rigid, but what is required is a product which can be deformed but rapidly recovers from deformation—there must be a resilience which includes some resistance to creasing, but also a powerful and rapid recovery therefrom.'

'Wool, of course, is famous for its elastic recovery, and is greatly prized for its powers of resistance to and recovery from creasing; these properties, however, are affected to a large extent by the type of woven structure in which the wool is employed—where the fibres are parallel and highly twisted, the elastic recovery or crease resistance is much less rapid and powerful than in the typical woollen construction with its random arrangement of the fibres and the open construction of the fabric.'

'The crushing or creasing of textile material is a complex effect involving tensile, flexing, compressive, and torsional stresses. The tensile

* The use of the Drapemeter for investigating the properties of non-woven fabrics is described by Cusick et al. 'Physical Properties of Some Commercial Non-Woven Fabrics.' *J. Text. Inst.* 54, 52 (1963). (The Rotrakote–Cusick Drape Tester is now available from Rotrakote Ltd., Moss Industrial Estate, Leigh, Lancs.)

extension plays a relatively small part in elastic recovery, and measurements of the modulus of elasticity are little guide to the creasability of the various fibres, for the most "elastic" materials in the engineering sense are apt to crease most readily.'

'The bending elasticity seems to be of the greatest importance in the phenomenon of creasing; creases appear when the material is distorted in such a manner that part of it is stretched beyond its small power of elastic recovery. The bending of the fibres or filaments which takes place during creasing leads to an extension of the cellulose on the upper surface, and a compression on the under surface.'

'Amongst the common textile materials the order of diminishing crease resistance is wool, silk, acetate rayon, viscose rayon, cuprammonium rayon, cotton, flax.'

'Fabrics of linen are notoriously bad in respect of creasing, possibly on account of the high degree of the orientation of the cellulose in this fibre.'

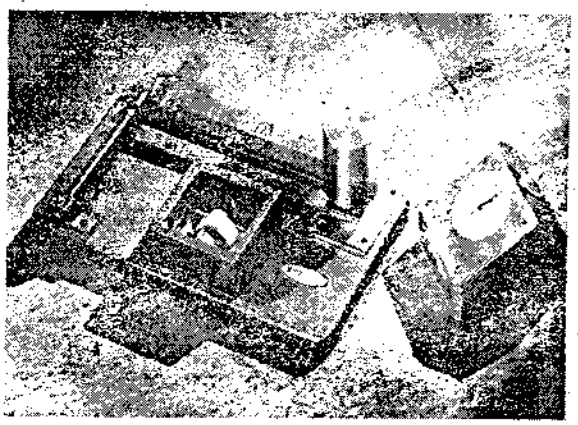
Advantages of resin treatments

Improved resistance to and recovery from creasing.
Smooth-drying properties after laundering.
Durable effects may be imparted by intermediate mechanical treatment.
Reduced laundry shrinkage.
Increased dry tensile strength and greatly increased wet tensile strength of rayon.
Improved fastness to washing and rubbing of most dyes.
Decreased water-imbibition and more rapid drying.
Improved handle and drape of fabrics.
Increased weight.
Increased resistance to distortion of fabrics with improved retention of garment shape and freshness.
Improved resistance to slippage and fraying.
Vehicle for modern flame-proofing.
Increased resistance to photo-degradation and weathering.
Increased resistance to rotting.

It should be noted that the many real advantages of a correctly applied crease-resist may be accompanied by a few disadvantages, especially if the finish is misapplied. Lower abrasion resistance and tearing strength have been reported and even unpleasant odours under certain conditions. Such shortcomings are, no doubt, being thoroughly investigated by the textile chemists and will, in time, be either eliminated completely or reduced.

Measurement of crease recovery

The Tootal test. This test method is a good example with which to demonstrate simplicity combined with effectiveness in practical application. Test specimens are cut from the fabric in both warp and weft directions, 4 cm long by 1 cm wide. The specimen is folded over and creased by placing it under a strip of spring steel with a 500 g weight to supply the pressure for creasing. After 5 min the specimen is removed and suspended over a wire. Altogether 3 min are allowed for recovery, after which the distance between the ends of the inverted 'V' is measured. To avoid touching the specimen, this distance may be read from a scale engraved on a mirror below the wire. Figures 7.22 and 7.23 show a neat testing rig designed and used by Tootal Ltd.

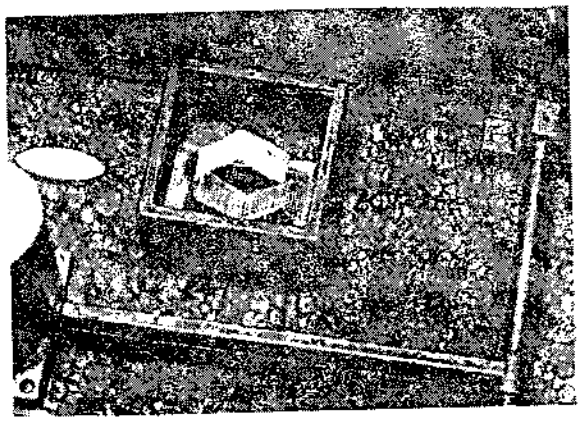


(By courtesy of Tootal Ltd)

Figure 7.22. The Tootal crease recovery tester. Note the weight, timing clock, and graduated mirror

If the fabric exhibited perfect recovery the distance between the ends would be 40 mm but, as Marsh points out, such a fabric would possess no draping qualities. Experience has shown that in order to retain good draping qualities while still having good crease recovery, the crease recovery of good-quality wool or worsted, about 33 to 35 mm, should not be exceeded.

The test must, of course, be on conditioned fabric and be made in a standard testing atmosphere.



(*By courtesy of Tootal Ltd*)

Figure 7.23. Close-up of the suspension wire and graduated mirror

The 'Shirley' crease recovery test. The use of the combined stiffness and creasing tester is described in the B.S. Handbook. A more recent model is now available which tests crease recovery only and is described here.

The instrument consists of a circular dial which carries the clamp for holding the specimen (see Figure 7.24). Directly under the centre of the dial is a knife edge and an index line for measuring the recovery angle. (Note here that the angle is measured, not a distance as in the Tootal test. Some authorities hold the view that errors due to gravity are present in the Tootal test. However, such errors do not appear to have prevented the successful development of the 'Tebilised' process.) The scale of the instrument is engraved on the dial.

A specimen is cut from the fabric with a template, 2 in. long by 1 in. wide. It is carefully creased by folding in half, placing it between two glass plates, and adding a 2 kg weight. After 1 min the weight is removed and the specimen transferred to the fabric clamp on the instrument and allowed to recover from the crease. As it recovers, the dial of the instrument is rotated to keep the free edge of the specimen in line with the knife edge. At the end of the time period allowed for recovery, usually 1 min, the recovery angle in degrees is read on the engraved scale.

Warp and weft way recovery are reported separately to the nearest degree from the mean values of ten tests in each direction. The load,

time of creasing, and recovery time may be altered to suit particular cases.

As for most fabric tests, the specimens should be conditioned and tested in a standard testing atmosphere. A random sample should be taken but the selvedges, piece ends, and creased or folded regions should be avoided.

Figure 7.24. The 'Shirley' crease recovery tester

Continental method. At a conference at Göteborg, in October 1956, it was stated that the most certain test method for evaluating crease resistance was measurement of crease recovery angle and that a German test was considered the most sensitive. Briefly, a strip of fabric is folded over at one end, loaded by 1 kg [illegible] 1 hr and allowed to recover. The specimen lies in a horizontal position and the folded piece recovers in an upward direction. The angle of recovery is then

measured after 5 min and again after 1 hr. A time schedule for measurement of ten warp way and ten weft way specimens is set out so that testing proceeds smoothly without undue delays.*

The L.I.N.R.A. sunray crease evaluator

A quick test of crease recovery is the 'clenched fist' test in which the fabric is crushed in the hand and then allowed to recover. A visual appraisal of the recovery property is made. (Try comparing the behaviour of a silk handkerchief with a cotton or a linen handkerchief.) The Linen Industry Research Association has developed a test which is somewhat based on the clenched fist principle.

A circle of fabric, 4 in. in diameter, is cut along one radius, folded fanwise and inserted in a specially designed loading device. The folded specimen is loaded with a 10 lb weight for 3 min, at the end of which time it is removed and placed in a polished glass Petri dish. A standardised method of shaking the specimen is used to assist recovery. The sample is then scanned whilst rotating on a turntable by a beam of light at right-angles to the radial creases and at an angle of 20° to the horizontal.

The varying amount of light reflected vertically upwards is picked up by a photocell and the fluctuations in the voltage output are fed into a circuit which enables the degree of crease recovery to be derived. A correction is made to the value obtained, since even a flat fabric would reflect some light vertically. This instrument is described in detail by Archibald et al. (*J. Text. Inst.* **55**, T477 (1964)). An earlier version is described by Archibald and Ewing (*J. Text. Inst.* **53**, P135 (1962)).

Visual comparison against standards

Another approach to the problem of assessing crease recovery is to crease a fabric in some random manner and then to assess it against either photographic standards or against three-dimensional replicas of creased fabrics. The former method is described by Lako and Veer (*J. Text. Inst.* **53**, P99 (1962)), and the latter method by Sudnik (*J. Text. Inst.* **53**, T196 (1962)). Sudnik's paper describes the technique for preparing the replicas for use with the Celanese Wrinkle tester. This tester causes creasing by suspending the fabric specimens in a rubber tube and then partially exhausting the air, causing the tube to collapse and thus crease the fabric.

*See also

Conference Report 'Crease Resistance and Crease Recovery.' *J. Text. Inst.* **53**, 5 (1962). Anderson, S. L., and Sattle, S. E. 'A Crease Recovery Test for Fabrics.' *J. Text. Inst.* **52**, T298 (1961).

SERVICEABILITY, WEAR, AND ABRASION RESISTANCE

The prediction of the performance of a fabric in actual use from the results of tests on laboratory instruments has up to the present eluded the textile technologist. It is not for want of trying, since upwards of sixty types of abrasion and 'wear' testers have been invented, each achieving varying degrees of success and acceptance. Evidently, wear testing is a vexed subject. Rather than attempt to discuss the whole problem it is proposed to define some of the terms employed, to outline the principles of abrasion testing, to describe one or two abrasion testers and, perhaps most important of all, to direct the reader to sources of detailed information.

Serviceability. An article which is serviceable is capable of performing useful service; its serviceability ceases when it can no longer do so. To a lady of fashion, her last season's outfit is unserviceable as far as being 'in the fashion' is concerned even though the clothes may still be in as-new condition. Of course, serviceability is a relative term. A musician friend of the author has a shooting jacket; as he needlessly points out, it is shooting out at the elbows, but even so it renders useful service to its owner when worn in his studio. The end-point of usefulness is governed by the use to which the article is put and the standards demanded or set by the user. A new lease of serviceability may be given to an article by putting it to some new use; most textiles at some stage become useful cleaning rags.

A time element is included in serviceability. Starting with two apparently similar articles from different sources, the one which outlasted the other would be considered the more serviceable. Further, the end-point is not necessarily determined by the degree of 'wear' which has taken place; a dress which may be unworn but whose colour has faded may be classed as unserviceable.

Serviceability trials are undertaken by various organisations, Tattersfield and Thomas summarising the purpose of such trials in an interesting paper 'Serviceability Testing as a Means of Assessing Suitability for Purpose' (*J. Text. Inst.* **44**, P541 (1953)):

> *Purpose of serviceability testing*
>
> In a use-development organisation, such as that in which the authors serve (Courtaulds Ltd), the main purposes of trials by users are:
>
> (1) To determine as objectively and precisely as possible whether the application under investigation is a valid and suitable use for the fibre, yarn, or fabric, and consequently will have reasonable prospects of commercial success as a long term proposition. It will be appreciated that this statement applies particularly to the launching of a new fibre, yarn, or fabric, which can bring credit or discredit to the company.

(2) To compare a number of different fibres, yarns, or fabrics, as part of market research.
(3) To determine the influence of cloth structure and finishing on performance.
(4) To assess suitability for purpose in instances where the fabric or article is considered 'borderline' by laboratory testing against a performance specification.
(5) To determine suitability for making up, e.g. seaming properties, pleating and creasing properties, and other tailoring requirements.
(6) To assist in establishing criteria for laboratory testing and standards of performance.

Wear. Broadly speaking, 'wear' is the net result of a number of agencies which reduce the serviceability of an article. Some of the more important of these are bending and stretching, tearing, abrasion, laundering and cleaning. The nature of these wearing agents is so varied in type and severity that it is virtually impossible to design a wear tester which will reproduce their effects simultaneously. The laboratory approach, therefore, is to design instruments which may test fabric reactions to individual wearing agents, although even this approach is bedevilled by uncertainty. The task of the textile technologist is to study all the test results and search for the relationships between laboratory tests and fabric performance in actual service.

Abrasion. Abrasion is just one aspect of wear and is the rubbing away of the component fibres and yarns of the fabric. Abrasion may be classified as follows:

Plane or flat abrasion – A flat area of material is abraded.
Edge abrasion – For example, the kind of abrasion which occurs at collars and folds.
Flex abrasion – In this case rubbing is accompanied by flexing and bending.

The three types of abrasion given above are broad divisions only, since in actual service a complex mixture of some or all types is found; the objects covered by fabrics are of all shapes and sizes, are of varying degrees of hardness or softness, and come into contact with a wide variety of other surfaces.

An excellent account of the wear that occurs in service is given by Clegg (*J. Text. Inst.* **40**, T449 (1949)) who reports on the critical examination of worn textile articles. Some particularly fine drawings and photographs of the effects of wear on the fibres are included. The conclusions reached by Clegg are given in this extract:

> The investigation has shown that although textiles in service undergo a varying amount of chemical deterioration through laundering, exposure

to light, and atmospheric conditions, failure is mainly due to a weakening of the structure caused by mechanical breakdown of the individual fibres and the mechanism of breakdown is substantially the same for all fibres, cotton, wool, linen, silk, and rayon. Only those fibres held firmly by tension, pressure, or filling suffer intense abrasive action. The breakdown of a large proportion of the fibres is caused by transverse cracking which, judging by the location of the position of maximum weakness in the textiles examined, is the direct result of flexing and bending stresses suffered during wear. Fibres on the surface which are only lightly held suffer gentle abrasion.

The general weakening of the fabric structure and the majority of the tears and splits which occur in many worn garments are a direct consequence of this fibre breakdown.

Papers by Backer and Tanenhaus (see the references at the end of this chapter) go into the theoretical and practical mechanics of abrasion and the effects of fabric geometry on abrasion resistance. Authorities on the subject recognise abrasion as a series of repeated applications of stress, therefore a capacity to absorb punishment is required of the fibres. Inherent fibre properties, for example work of rupture, must be exploited to the best advantage by the choice of suitable yarn and fabric construction so that the finished product possesses a high resistance to abrasion while at the same time retaining other desirable fabric characteristics. At all times, of course, the end-use of the fabric must be kept in view.

The testing of abrasion resistance

A number of important points require consideration before abrasion resistance tests are carried out. The choice of method may be governed by the type of apparatus available, the precision demanded, and so forth. Some of the more important points are outlined below.

Condition of specimen. Unless directed otherwise, the fabric will be conditioned and tested in a standard testing atmosphere.

Choice of testing instrument. The multiplicity of types has been mentioned earlier and the instrument chosen may depend upon the character of the testing desired, e.g. flat abrasion, flexing abrasion, etc.

Choice of abrasive motion. The rubbing movement may be reciprocating, rotary, or multi-directional. On some instruments the movement can be varied.

Direction of abrasion. When the abrasive motion is unidirectional the abrasion resistance in specific directions can be measured. In many cases differences will be observed between warp way and weft

way abrasion resistance. If desired, the direction of abrasion can be at angles to the warp and weft directions (see Figure 7.25).

Choice of abradant. The severity of the abrasion will vary with the nature of the abradant. Where possible the abrasive qualities of the material used should remain constant during the test and be capable of being reproduced for successive tests. Steel and silicon carbide, for example, will give reasonably constant abrasive qualities. In other instances the abradant may be a second piece of the tested fabric, a standard worsted or canvas fabric, emery cloth of various grades. With such materials, however, there is the risk of their abrasive properties changing during a test and a tendency for bits of abraded fibre to clog the surface. Some instruments have special methods of removing the lint from the abradant.

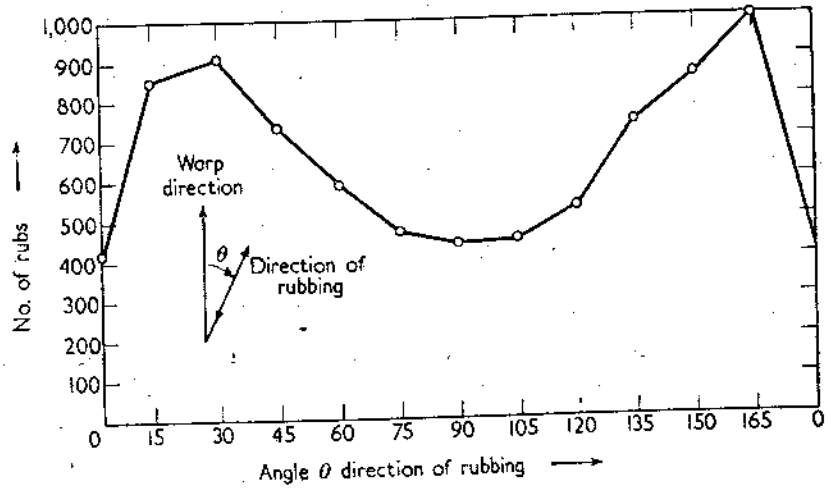


Figure 7.25. Effect of direction on rubbing on ball toughness test results for a viscose filament rayon satin fabric

Backing the specimen. The hardness of the backing of the specimen may affect the results. In some tests a hard backing is used, in others a felt or foam rubber. In one instrument the sample is mounted over an inflated rubber diaphragm.

Cleanliness of the specimen and instrument. The region to be abraded should be handled as little as possible and be free from foreign matter such as the wax from crayons or the graphite from pencils. These substances tend to act as lubricants. For the same reason the accessories of the instrument which may rub the fabric, e.g. the blade of a flex abrasion tester, must be spotlessly clean and free from grease.

Tension on the specimen. Standardised methods of mounting the specimen should be used to avoid errors due to variation in the tension used.

The pressure between abradant and specimen. The severity of the abrasion will obviously be affected by the pressure applied. Here again suitable standards must be set up. High pressures will reduce the time taken to reach the end-point of a test but the acceleration of the destruction of the fabric may lead to false conclusions.

The end-point of the test. The end-point may be the completion of a given number of abrasion cycles, the appearance of a hole or broken threads, the rupture of the specimen. Automatic stop motions are often built into the tester so that the motor is switched off as soon as a hole appears or the specimen breaks.

Assessment of abrasion damage. Several methods of judging the amount of damage are used:

(1) Appearance against an unabraded specimen.
(2) The number of cycles required to produce a hole, broken threads, or broken strip.
(3) Loss in weight, often plotted against the number of cycles.
(4) Change in thickness, e.g. loss of pile height. In some cases the napping or raising effect of abrasion may cause an increase in thickness particularly in the early stages of a test.
(5) Loss in strength, e.g. tensile, bursting, or tearing strength. The loss may be expressed in percentage of unabraded strength. Some laboratories may determine residual strength after a given number of cycles.
(6) Change in other properties, e.g. air permeability, lustre.
(7) Microscopic examination of damage to yarns and fibres.

*The interpretation of the results.** No general rules can be given on the interpretation of the results from abrasion tests. So much depends upon the object of such tests. The operator may wish to rank a series of submitted samples in order of probable serviceability. Because different instruments may rank them in different orders, a certain amount of risk is involved. The effects of special finishing treatments may be assessed by 'before and after' tests and the test results used mainly as a guide to further development.

Preliminary 'sorting' tests may be carried out on a series of fabrics in order to separate the obviously unsuitable types from the possibly suitable types. For such a purpose a relatively simple tester may be used, and for more precise comparisons of the 'possibles' a second tester may be brought into use.

*See B.S. Handbook No. 11, p. 555, *Notes on Abrasion Testing.*

For quality control purposes certain levels of performance may be set up in the light of experience.

Critical examination of fabrics by carrying out a series of different tests can lead to the 'merit rating' of materials, abrasion resistance tests being just one of the series (see Stoll, R. G. *Text. Res. J.* **19**, p. 394 (1949)).

Even when the result of the test may be a numerical expression, e.g. 1,000 cycles to produce a hole, it must not be assumed that a sample which took 2,000 cycles would necessarily last twice as long in service.

Perusal of some of the references given will illustrate the many ways in which the results of abrasion tests may be interpreted.

Inter-laboratory abrasion tests

An investigation has been made to determine the extent of the agreement between several different wear test methods, including the agreement between the results of tests on similar instruments in different laboratories. The conclusions reached were as follows:

'There are important differences between the various types of abrasions test in comparisons between the cloths that have been examined. These differences appear to be associated with the operating conditions of the machine, and particularly with the pressure between the abrasive and the sample. The differences are such that it cannot be assumed, without independent evidence, that the results obtained from a particular abrasion test are necessarily a reliable guide to the behaviour in a particular practical situation. Agreement between laboratories using the same abrasion test under nominally the same conditions is likely to be very poor' (Final Report on Inter-Laboratory Abrasion Tests, *J. Text. Inst.* **55**, P1 (1964)).

*Abrasion testing instruments**

Limitation of space precludes the description of a range of abrasion testing instruments. A short list of machines is given here with a brief note on each and a reference which will provide fuller descriptions. The British B.F.T. tester will be described in greater detail.

*Notes on several types of abrasion testers are given in *Friction in Textiles* (Howell, Mieszkis, and Tabor) Chapter 12 (Textile Institute; Butterworths, London, 1959).

The Wool Industries Research Association abrasion tester. Circular specimens are mounted in holders and rubbed over pads of abradant. A standard worsted fabric may be used as the abradant. Multi-directional or uni-directional rubbing is possible. Assessment is by appearance, loss in weight, thickness. This tester may also be used for dye fastness to rubbing tests or pilling tests (*W.I.R.A. handbook; Wool Research*, Vol. 3, *Testing and Control*, p. 158).

The Linen Industries Research Association abrasion tester. Two-inch wide strips of fabric, under tension, are rubbed by a carborundum abrader which has a reciprocating motion. The number of rubs to break are noted, or change in strength after a given number of rubs (B.S. Handbook, 1949 edn, p. 170, or Lomax, p. 86).

The Taber abraser (*American*). A flat circular specimen is rubbed by two abrasive wheels mounted so that multi-directional abrasion is achieved. An annular area of abraded material is produced and visually examined (*A.S.T.M. Handbook, A.S.T.M.* D1175–61T, or Skinkle, p. 142).

The Shiefer machine (*American*).* A flat circular specimen and a flat circular abrasive surface are used. Both rotate in the same direction but their axes are slightly out of line in order to produce multi-directional abrasion. A thickness gauge is built into the tester. Visual examination or fabric properties measured (*A.S.T.M. Handbook, A.S.T.M.* D1175–61T).

The Wyzenbeek abrasion tester (*American*). A strip of fabric rests on a cylindrical abrasive surface which is given an oscillatory angular movement. Emery paper is used as abradant. Percent loss in strength or residual strength noted after 250 cycles (*A.S.T.M. Handbook, A.S.T.M.* D1175–61T).

The Stoll universal wear tester (*American*). The Stoll is a multi-purpose instrument which can test fabrics under various conditions – flat, flex, edge, etc. The sample may be tested wet or dry. In one test condition the sample is mounted over an inflated pad, presenting a resilient curved surface to a flat abradant (Stoll, R. G. *Text. Res. J.* **19**, p. 394 (1949)). Some flex test results from the Stoll are quoted in an article on fibre blends by Dennison and Leach (*J. Text. Inst.* **43**, P473 (1952)).

The L.I.N.R.A. wear tester. On the L.I.N.R.A. wear tester two small samples of the material to be tested are mounted over rubber diaphragms inflated to a hemispherical shape. These samples are

*See also

Anderson, S. L., and Clegg, D. G. 'Abrasion Tests on Carpets Using Different Abradants.' *J. Text. Inst.* **51**, T385 (1960).

then carried in weighted heads so that they rest on a steel turntable covered with an abradant base cloth. Small steel balls are embedded in the turntable under the base cloth so that, as the turntable revolves under the samples, the latter are lifted and flexed. They are also given a slight rotation every revolution of the turntable to ensure that the samples are given equal wear in all directions. The resulting wear is a combination of abrasion and flexing, and the end-point is determined by inspection. Results are expressed as the number of turntable revolutions required to reach the end-point.

The Accelerotor. This is an American instrument which uses the 'impeller tumble' method to abrade the specimen. The impeller is a two-bladed unit of an elongated S shape, $4\frac{1}{2}$ in. long and mounted on a central shaft inside a cylindrical chamber. This chamber is about $5\frac{1}{2}$ in. in diameter and $2\frac{3}{4}$ in. deep, its inside surface being lined with the selected abrasive backed by foam rubber. The 3 g fabric specimen is whisked and tumbled about inside the chamber and hence suffers abrasion damage. (See Elder and Mehta, *J. Text. Inst.* **57**, T574 (1966).)

The B.F.T. abrasion testing machine

This machine was designed in the laboratories of Courtaulds Ltd. The aim of the designers was to produce an abrasion testing instrument incorporating a series of mechanisms to abrade textile materials which would provide numerical results which could be correlated with serviceability. Examination of many rayon staple garments which had been treated with resin finishes showed that *erosive* wear at cuffs, collars, raised seams, etc., was, in the main, the type of damage which caused the garment to be classed as unserviceable or poor wearing: flat abrasion resistance and loss of tensile strength did not appear to be major factors.

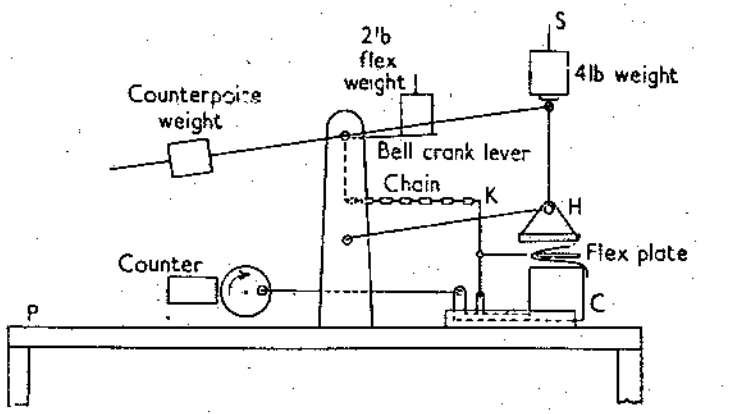
In the B.F.T. machine the designers have eliminated many of the variables normally associated with abrasion testing, variables which tend to fog the issue. Special attention has been paid to the following points:

(1) The end-point of the test is determined by the machine—it stops automatically when the end-point is reached.

(2) The abradant used in the various accessories is made of special steel whose abrasive characteristics remain constant and are capable of being reproduced to an engineering specification.

(3) The machine is sturdily built and capable of being run smoothly at high speeds for a long time.

(4) The results of tests on the machine have been examined against a large volume of data on the serviceability of fabrics in field trials and customer complaints. These results can be analysed and expressed numerically and fabrics may be ranked in order of merit.



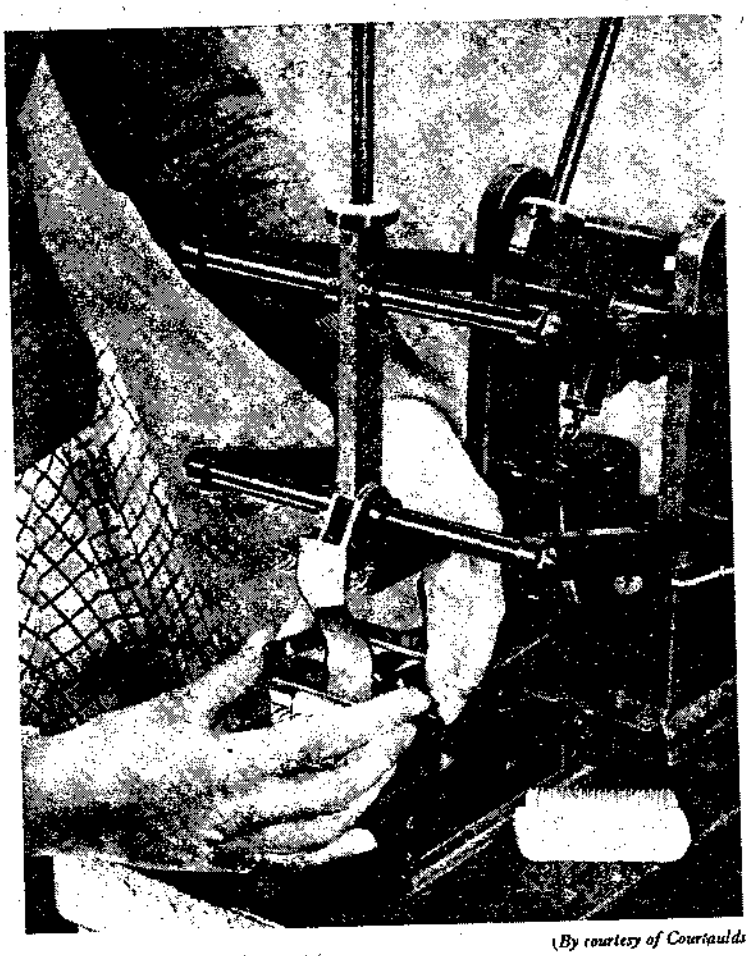
(*By courtesy of Courtaulds Ltd*)

Figure 7.26. The B.F.T. abrasion testing machine set up for flex abrasion testing

Features of the B.F.T. machine. The mechanical parts (see Figures 7.26 and 7.27) are mounted on a rigid platform P. A solid aluminium carriage C is reciprocated with a 1½ in. stroke at 700 rev/min by a crank and connecting rod; a six-digit counter records the number of cycles. The head H is mounted over the top of the reciprocating carriage and moves vertically due to the parallel link motion. Counterpoise weights are employed, so that with no weights on the spigot S the movement is just in balance; hence known vertical loadings can be obtained by adding the required weights to the spigot. The control unit and the electric motor are mounted below the platform.

Three types of test are made and three sets of interchangeable accessories are provided (see Figures 7.28, 7.29, and 7.30).

Flex abrasion. The flex plate is a stainless steel plate about 0·037 in. thick with one edge tapered off and rounded to 0·017 in. diameter. This plate is carried in a stirrup and given a reciprocating motion. Tension is applied to the test strip by the weight on a bell crank lever acting through a chain link to the stirrup. In Figure 7.26, point K is a dead point in the system and hence the machine can run at high speeds with the flex tension weight almost stationary, thus avoiding inertia effects.

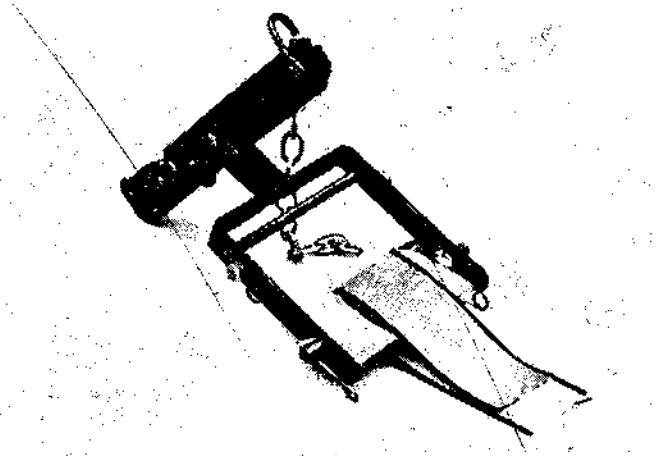


(*By courtesy of Courtaulds Ltd*)

Figure 7.27. Setting up for the flex test on the B.F.T. machine

The test strip is 5 in. long by 1 in. wide. It is secured at one end over a row of stenter pins on the carriage C and led round the radiused edge of the flex plate; the free end is then secured over stenter pins on the head H. A load of 4 lb is added to the spigot S and a 2 lb weight to the bell crank lever, a 2:1 velocity ratio causes the tension in the specimen to be 4 lb. The head H is shown lifted in Figure 7.26 for the sake of clarity, but during the test it rests on top of the test specimen and flex plate. When the machine is switched on

the reciprocation of the carriage causes the fabric to be repeatedly pulled back and forth round the edge of the flex plate and continuous flexing is achieved. Eventually the fabric breaks and a switch is operated, automatically stopping the machine. The number of cycles is read from the counter and recorded. The mean of five tests is taken—warp way, weft way, or in both directions if necessary.



(*By courtesy of Courtaulds Ltd*)

Figure 7.28. Flex apparatus

Since quite high numbers of cycles are obtained the mean values are reduced to more manageable proportions by using a 'normalising factor' of 10^{-3}, i.e. dividing the mean value by 1,000. Hence,

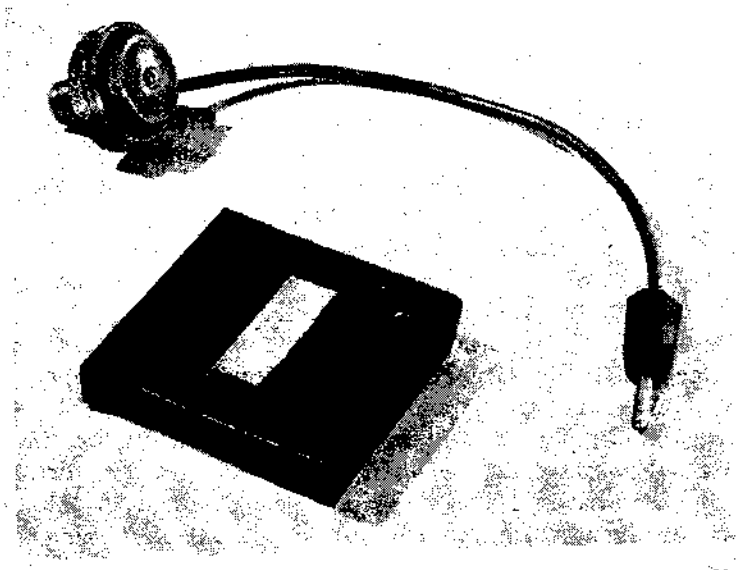
$$\text{Flex result, } P, = \frac{\text{Mean value of five tests}}{1000}$$

Breens and Morton (*J. Soc. Dy. Col.* **71**, 513 (1955)) state that the flex test value, P, '. . . is related to the behaviour of the fabric in internal motion. It is related certainly to the coherence of the fabric structure and also, in general, to its ruggedness, which is presumably a function of the ruggedness of the individual fibres. Microscopic examination of a fabric slowly flexed round a plate shows that the structure is in considerable internal motion; that, not only do the yarns bend as they go round the flex edge, but also they twist and untwist in quite remarkable fashion. The debris from the flex test

suggests that the fibres fail by tensile breaks; the internal motion of the structure tends to set up local stresses which may be occasionally so high that an individual fibre or filament is broken.

The addition of fibre lubricant increases *P* and the anti-lubricating effect of a finish which binds fibres or filaments together tends to diminish *P*.

On the whole, the effects of flexing may be described as the application of short range elastic strains to the interior of the fabric; these are of an oscillatory nature, so that they tend to break down coherence, and this breakdown is accelerated by lack of lubrication.



(By courtesy of Courtaulds Ltd)

Figure 7.29. Ball toughness apparatus

Ball toughness. In this test a cover plate with a hardened tool-steel strip is clipped on to the top of the carriage C. The test strip is mounted over this steel plate and secured by stenter pins on either side of the carriage. The abradant is a $\frac{1}{16}$ in. ball bearing in a special holder which is pushed home into the upper head H. A load of $1\frac{1}{2}$ lb is added to the spigot.

Note here that if the *warp* ball toughness is to be tested, the long side of the 6 in. × 1 in. specimen is parallel to the *weft*, so that the ball rubs *across* the warp threads.

With the motor running, the carriage reciprocates beneath the ball and in time the ball penetrates the fabric and then contacts the hardened strip. When this happens a very small current flows, small enough to avoid any chance of sparking and so roughening the ball surface; this tiny current triggers off a special circuit which in turn switches the machine off.

The number of cycles is 'normalised' by a factor 10^{-2}. Thus,

$$\text{Ball toughness, } B, = \frac{\text{Mean value of five tests}}{100}$$

Here again, both warp and weft values of B may be determined if required.

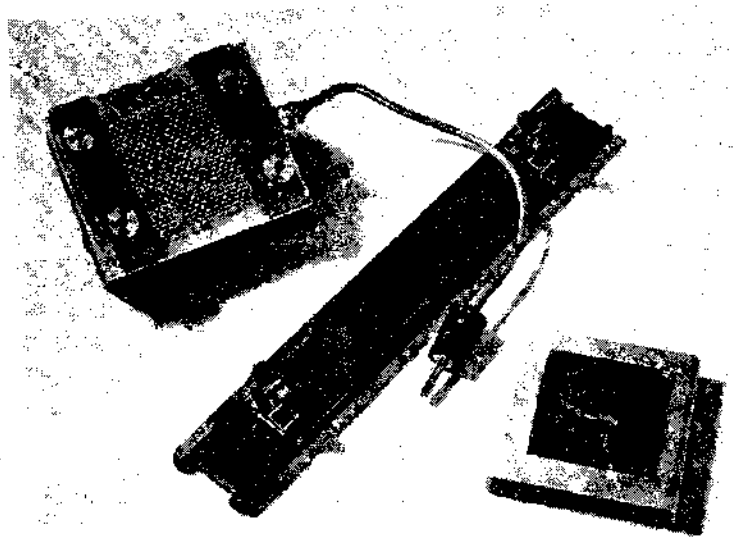
On the ball toughness test, Breens and Morton comment, 'The ball penetration test value B depends to some extent on fabric structure factors, but it is most nearly related to the toughness or lack of brittleness of the individual fibres: a treatment which increases fibre brittleness reduces the B value considerably. Lubrication has a comparatively small effect on B, increase of lubrication tending to decrease the B value a little'.

From these remarks we can appreciate that crease resist embrittlement and constructional or chemical fabric degradation are emphasised by the ball penetration test.

Flat abrasion. The abradant used in the flat abrasion test is a stainless steel gauze in a special holder which is fixed to the upper head by springs. An extra counterpoise weight is clipped to the rear end of the upper link of the parallel motion in order to balance the mass of the gauze holder. The test specimen is stretched over a resilient pad of conducting material and clipped to the carriage. A 2 lb load is added to the spigot S. After a certain amount of rubbing the steel gauze contacts the pad, a current flows, and the machine is switched off automatically. The normalising factor for the flat abrasion test is 10^{-3}, and so the flat resistance, F, is given by

$$F = \frac{\text{Mean of five values}}{1000}$$

Special control fabric with tested calibration levels is available so that all the test values, P, B, and F can be checked and the reliability of the instrument confirmed.



(*By courtesy of Courtaulds Ltd*)

Figure 7.30. Flat abrasion apparatus

Interpretation of results

For routine interpretation of results in terms of correlating machine levels to consumer wearability, two methods of wear assessment have been developed which give valid predictions of commercial behaviour.

Method 1 – The 'duty factor', D. The ball and flex results are presented as a harmonic mean and this mean is termed the 'duty factor'. Thus,

$$\text{Duty factor, } D, = \frac{2}{(1/B) + (1/P)}$$

In the development of this machine the duty factors of many materials were determined. The samples included fabrics of known good and bad performance and it was found that poor fabrics had low duty factors and good fabrics higher duty factors. For example, a poor overall had values of $B = 2{\cdot}6$ and $P = 3{\cdot}5$. The duty factor was, therefore,

$$D = \frac{2}{(1/2{\cdot}6) + (1/3{\cdot}5)} = 3{\cdot}0$$

A good overall had values of $B = 24{\cdot}7$ and $P = 46{\cdot}4$, giving a duty factor of $D = 32$.

Breens and Morton report that by exhaustive testing and trials it has been possible to suggest duty factor levels for rayon staple fabrics finished with a crease-resistant finish (see Table 7.4).

Table 7.4. Levels of Practical Duty Factor on Rayon Staple Fabrics with a Crease-resistant Finish

Fabric type	*Satisfactory wear*	*Outstanding wear*	*Wear properties greater than practical requirements*
Light-duty group: Dress fabrics	1 – 4	4 – 7	7+
Heavy-duty group: Gym slips, slacks, and men's suitings	6 – 10	10 – 20	20+
Shirtings	5 – 8	8 – 15	15+
Overalls	7 – 12	12 – 25	25+

Method 2 – The 'Figure of Merit', M. The 'Figure of Merit' is the harmonic mean of the ball, flex, and flat test values.

$$M = \frac{3}{(1/B) + (1/P) + (1/F)}$$

Low values of any of the three results will reduce the figure of merit; thus, if a fabric has a 'weak link', M will be reduced. For example, if $B = 100$, $P = 100$, and $F = 100$, M would also equal 100; but if, say, $F = 2$, then M would drop to 5·7. The fabric designer would then need to find out the reason for the material's low flat abrasion value.

The harmonic mean has the advantage of weighting a merit figure towards the weakest link in the chain. In many commercial end-uses no weak links are permissible, e.g. in shirtings, trouserings, and suitings generally, heavy work cloths require higher standards than cloths for leisure wear, but the principle is the same—adequate durability depends upon adequate levels for each machine test. These levels become a matter of marketing policy by manufacturers of textiles intended for specific end uses; a policy which is related to complaint level and cost. The extensive trials mentioned

earlier have enabled many levels to be established for ensuring satisfactory commercial behaviour.

The reader is referred to the work of Breens and Morton for a more detailed discussion of the B.F.T. abrasion machine and the concepts of duty factor and figure of merit (see also Elder and Mehta, *J. Text. Inst.* **57**, T574 (1966)).

THE 'PILLING' OF FABRICS

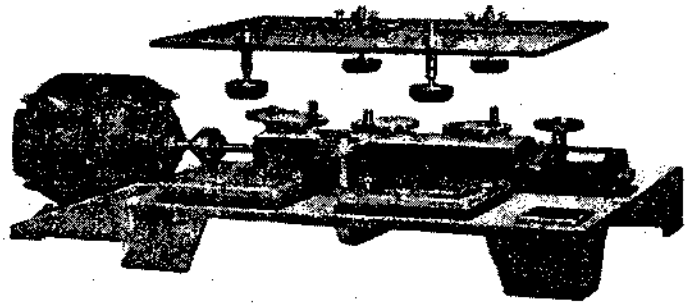
Pilling is a fabric-surface fault characterised by little 'pills' of entangled fibre clinging to the cloth surface and giving the garment an unsightly appearance. The pills are formed during wear and washing by the entanglement of loose fibres which protrude from the fabric surface. Under the influence of the rubbing action these loose fibres develop into small spherical bundles anchored to the fabric by a few unbroken fibres. Should stray foreign fibres become part of the pills, then the colour of the pills may differ from the body of the garment and the fault is emphasised. Pilling has long been recognised as a fault, especially in fabrics such as woollen knitted goods made from soft twisted yarns, but the introduction of the newer man-made fibres appears to have aggravated its seriousness. An explanation is that with wool the fibres which anchor the pills to the fabric are relatively weak and the pills break away fairly easily, whereas fibres like Terylene, Orlon, nylon, etc., are strong and the pills remain keyed to the garment, accumulate, and become more and more unsightly.

As pills form due to the migration of fibres from the constituent yarns in the fabric, it follows that the reduction or prevention of pilling may be effected by reducing this migratory tendency. The The methods used include the use of higher twist factors for the yarns, the brushing and cropping of the fabric surface, and special chemical treatments. The pilling of fabrics is discussed by Baird, Hatfield, and Morris (*J. Text. Inst.* **47**, T181 (1956)) in a paper which deals mainly with fabrics made from nylon and nylon blends. One conclusion reached was that pilling is reduced by increasing the nylon filament denier. The authors point out that 'this is accounted for by an increase in the stiffness of the nylon fibres, making it more difficult for them to bend round each other and form pills, and also by a considerable reduction in the number of nylon fibres protruding from the fabrics'. Of course, it must be remembered that whatever anti-pilling technique is used, the fabric must not lose its desirable handle or other qualities.

*Pilling tests**

At the time of writing a standard pilling test has not been published, but a number of test methods and instruments have been developed in various laboratories. After rubbing under controlled conditions the pilling of the sample may be assessed *numerically* by counting the number of pills formed; alternatively, the *appearance* of the test specimen may be compared with standard samples and given some form of rating.

Numerical assessment of pilling. The Martindale Abrasion Tester, Figure 7.31, can be used. The normal sample holders are replaced with lightweight square holders which are keyed so that they may have vertical movement but cannot turn on their axes. The samples are given a multi-directional movement and are rubbed against a standard fabric. After a certain number of rubs the samples are examined and the number of pills counted. This may be repeated, say, in stages of 500 cycles up to 3,000 or 5,000, and the rate of development of pills noted.



(By courtesy of Goodbrand & Co. Ltd)

Figure 7.31. The 'Martindale' abrasion tester which may be used in pilling tests

Baird, Hatfield, and Morris describe an instrument substantially similar in principle to the above. For an abradant material they use a 15 oz cotton canvas or the test material itself. The test specimens are mounted on rectangular blocks, $1\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in., and after a given number of rubs the number of pills are counted and recorded, e.g.

*See also

Richards, N. 'The Pilling of Plain and Rib-knit Wool Fabric.' *J. Text. Inst.* **53**, T357 (1962). Hargreaves, M. A., and Brooke, B. I. 'Properties and Performance of Terylene Polyester Staple Fibres,' *J. Text. Inst.* **54**, 112 (1963).
A.S.T.M. D1375–59T.

after 100, 300, 500, 1,000, 1,500, and 3,000 rubs. In their paper the authors discuss the effects on pilling of such factors as protruding fibres, cropping, chemical treatments, nylon content of the blend, filament denier, twist, staple length, doubling, weave, and other fabric properties and treatments.

A different approach to a numerical assessment of pilling is used by the Hosiery and Allied Trades Research Association. The following description of the H.A.T.R.A. method is taken from an article published in the *Hosiery Trade Journal* (January, 1957, p. 70), 'Pilling in Knitted Fabrics':

> As is well appreciated by outerwear manufacturers, the pilling of fabrics in wear is considerably affected by conditions of wear. Whilst any results on pilling must always in the end be interpreted in terms of wear conditions, it is obviously advantageous for experimental purposes to establish a routine test method. This should simulate wearing conditions as closely as possible, allowing the pills to be produced under carefully controlled experimental conditions by a conveniently quick test. It is also of advantage if the resultant pilling can be assessed numerically, so as to give a measurable indication of differences between fabrics. To fulfil these requirements an apparatus has been designed in the H.A.T.R.A. laboratories for the comparison of the pilling properties of knitted fabrics. The instrument consists essentially of two circular plates to which the knitted fabric under test is attached. By mechanical movements the two disks are rotated in an oscillatory manner in opposite directions. During each complete backward and forward movement the plates are separated by means of an eccentric cam to allow temporary disengagement of the surfaces. By this means a clean single pill is obtained at the centre of the rubbed fabric which can easily be removed from the fabric by tweezers and weighed on a torsion balance. The pill weight after a given number of rubs may be taken as a measure of the pilling properties of the fabric; the higher the pill weight the greater the tendency of the fabric to pill. The pressure between the plates can be adjusted to any desired value. To produce pills most closely resembling those produced in wear, conditions of low pressure are required.
>
> The advantage offered by this method compared with other standard pilling methods are: (1) The rubbing action more closely simulates the light rubbing action to which knitted outerwear fabrics are subjected in wear; (2) The method of attachment of fabrics, and the rubbing cycle, are quick and allow a rapid assessment of results (normally about 300 rubs are given to each fabric); (3) The results are highly reproducible. A small number of rubbing tests are usually sufficient to obtain a satisfactory numerical average of the pill weight; (4) Accurate numerical assessment is possible by the measurement of pill weight; (5) The pills produced are similar to those obtained in wear. This is confirmed by a comparison of

the histograms of fibre lengths taken from pills produced on a given garment during wear and when pilled by means of the instrument. [*Author's note:* The histograms referred to are frequency distributions of fibre lengths, and the two distributions are very much alike.]

It is pointed out by H.A.T.R.A. that the method of a standard number of rubs and assessing on pill weight can only be carried out under the following conditions:

(1) The fabrics have the same fibre content, i.e. all wool or all nylon, etc.

(2) It is known from wearing trials what a given pill weight from fabrics of different fibres means in terms of pill formation.

The I.C.I. pilling box test

The notes which follow are taken from an I.C.I. publication, *Pilling – Methods of Test and Interpretation of Results.*

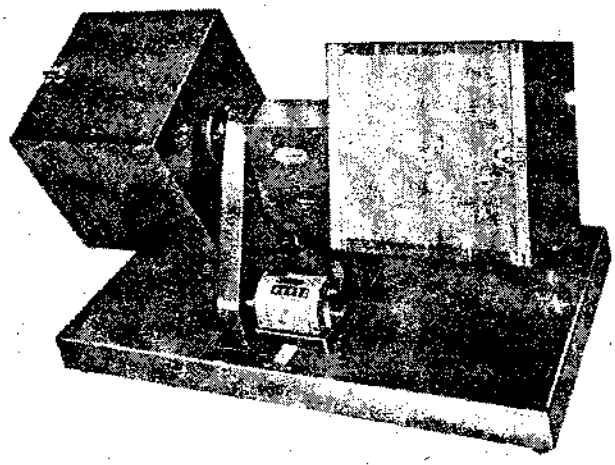
It is considered that any fabric which pills under the conditions of test is not completely satisfactory, but interpretation of the results should be governed by the following principles:

(1) The extent of pilling, exemplified by the appropriate standard, will not be produced by every person but only by those who are particularly hard on their clothes.

(2) Experience has shown that when pilling does occur is it usually limited to the most susceptible parts of a garment, e.g. collars, cuffs, pocket edges, front skirt panels. When, however, pilling is severe under the conditions of test, it is probable that the body of the garment will become an affected area, and that the number of persons who will produce the effects is also likely to increase.

(3) From a pilling point of view, shirts, blouses, lingerie, and dresses are considered to be critical end-uses. These garments will be frequently laundered between wearing, while medium and heavy weight garments will not normally be washed or cleaned with similar frequency. In this latter group, trousers and suits are considered to be more critical than skirts, costumes, and rainwear.

The method of test adopted is as follows: a piece of fabric measuring 5 in. × 5 in. is sewn so as to be a firm fit when placed round a rubber tube 6 in. long, $1\frac{1}{4}$ in. outside diameter, and $\frac{1}{8}$ in. thick. The cut ends of the fabric are covered by cellophane tape and four tubes are placed in a box (9 in. × 9 in. × 9 in.) lined with cork $\frac{1}{8}$ in. thick, which is then rotated at 60 rev/min for 5 hr (see Figure 7.32).



(*By courtesy of James H. Heal & Co. Ltd*)

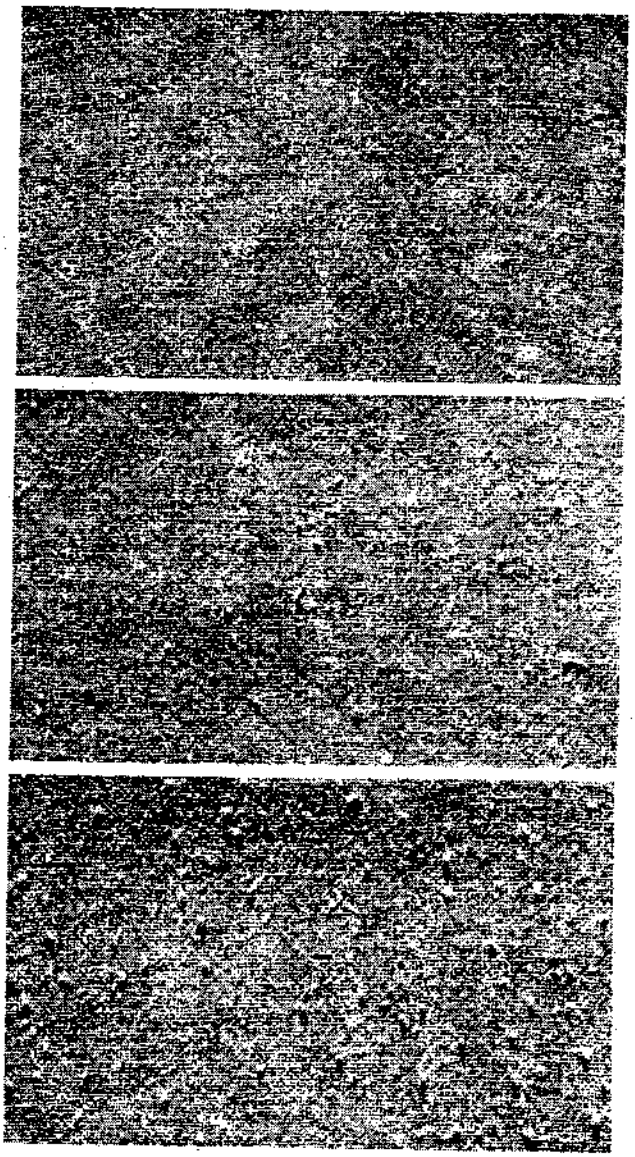
Figure 7.32. Heal's pilling boxes

For garments normally subjected to repeated washing as well as to wear, washing may be desirable prior to preparing the tubes of fabric. Hence, it is the practice to apply a standard hand wash in $\frac{1}{2}$ per cent soap at 45° C for 15 min to Terylene/cotton and Terylene/viscose shirt and dress fabrics, etc.

After tumbling, the extent of pilling is assessed visually by comparison with the arbitrary standards 1, 2, and 3 (see Figure 7.33). Under test conditions fabrics of Standard 1 become hairy but do not pill, fabrics of Standard 2 become hairy and pill slightly, while fabrics of Standard 3 become hairy and pill more severely.

The du Pont random pilling tester

This tester was developed in the laboratories of du Pont de Nemours and Co. of America and has been described by Baird, Legere, and Stanley (*Text. Res. J.* **26**, p. 731 (1956)). A six-unit tester is used, each unit consisting of a cylindrical chamber 6 in. long by $5\frac{3}{4}$ in. inside diameter, horizontally mounted, containing a two-bladed impeller which rotates at 1,200 rev/min. The inside of the chamber is lined with neoprene, about $\frac{1}{8}$ in. thick, which can be changed when necessary. Into each unit three 5 in. × 5 in. fabric samples are loaded together with a small amount of cotton lint, the latter being used because the pills which are formed bear a closer



(a)

(b)

(c)

(By courtesy of I.C.I. Ltd)

Figure 7.33. Pilling standards: (a) Standard 1; (b) Standard 2; (c) Standard 3 ($\frac{3}{5}$ original size)

resemblance to pills formed during wear than those formed when the lint is absent.

After 1 hr whisking and tumbling the test fabrics are examined visually and compared with standard samples. Five ratings are used:

(1) No pilling.
(2) Slight but tolerable pilling.
(3) Moderate pilling of borderline acceptability.
(4) Unacceptable pilling.
(5) Extremely high pilling.

Intermediate ratings are possible. The average rating of at least three specimens, preferably six or nine, is determined by two assessors and used as a figure from which the fabric's performance in actual use may be predicted. Laboratory tests and field trials have shown that such prediction is reasonably sound.

FLAMMABILITY

Flameproof fabrics are absolutely necessary for protective clothing in many industrial processes where the chances of inflammable fabrics being ignited are high. In the domestic sphere many serious and tragic accidents are the results of clothing catching fire, e.g. a dress is ignited when a young lady is powdering her face and using a mirror placed over the mantelpiece. The notes which follow are intended to serve as a guide to further reading and most of the information has been gathered from the publications of the British Standards Institution and papers on flammability in the *Journal of the Textile Institute.*

Some definitions and terms used relating to flammability

Flammable. A flammable fabric is one which propagates flame, i.e. it continues to burn after the igniting flame has been removed.

Flame-resistance rating, M. A figure derived from the flammability testing of fabrics and is of the same order as the time in seconds necessary for the propagation of flame 100 in. in a vertical strip.

Flame-proof. A flame-proof fabric is one which does not propagate flame, i.e. any flame goes out quickly when the igniting flame is withdrawn, the material complying with the requirements of Clauses 3 and 4 of B.S. 3120.

Flame-resistant. A flame-resistant fabric is one whose flame-resistance rating is high, i.e. above 150.

Inherently flame-proof material. Material which, although not submitted to a flame-proofing process, is flame-proof.

Durably flame-proof material. Flame-proofed material which, after being submitted to a washing treatment, remains flame-proof.

Temporarily flame-proof material. Material which complies with the requirements of Clause 3 of B.S. 3120, before, but not after, the prescribed washing treatment.

Factors affecting flame-resistance

Some general conclusions on the factors which affect the flame-resistance of fabrics are included in a report published by the British Standards Institution, *The Flammability of Apparel Fabrics in Relation to Domestic Burning Accidents*, P.D. 2777:1957.

Fibre content. The flame-resistance of a fabric is partly dependent on the fibre from which it is made. Cellulosic fibres such as cotton, flax, and viscose rayon give fabrics of low flame-resistance; wool fabrics are usually difficult to ignite; nylons and Terylene, both thermoplastic fibres, shrink from the flame and tend not to ignite, although special stiffening treatments and certain dyes may result in the flammability of nylons and Terylene.

Type of yarn. It has been found that for all practical purposes yarn structure in itself does not affect the flame-resistance of a fabric.

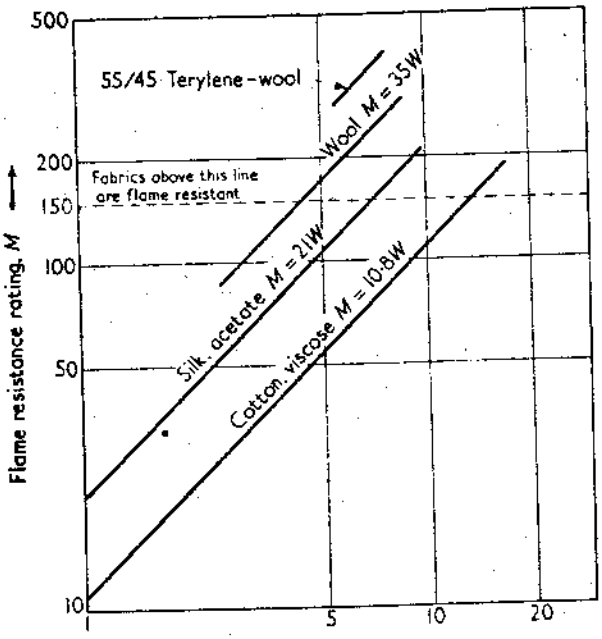
Fabric structure. The flame-resistance of a fabric appears to be largely independent of the manufacturing process by which it has been made, e.g. weaving, knitting, twisting, lace making, fibre bonding, felting.

Fabric weight. (1) For fabrics which propagate flame it has been found that flame-resistance is related to their weight as well as to their fibre content; for any given fibre, the heavier the fabric the higher will be its flame resistance; (2) For a given fibre the flame-resistance rating of a fabric has been found to be directly proportional to its weight in ounces per square yard; a 6 oz cotton fabric, for instance, will have twice the flame-resistance of a similar cotton fabric weighing 3 oz. The graphs in Figure 7.34 illustrate this relationship.

Review of available methods of test (From P.D. 2777:1957)*

It is not easy to measure directly the vertical flame speed over rapidly burning fabrics as the flame front is not well defined. It is, however, possible to measure the vertical flame speed indirectly by weighing the fabric continuously on a torsion balance while it is burning (see Lawson, D. I., Webster, C. T., and Gregsten, M. J. J.

*American methods are given in the *A.S.T.M. Handbook.*
A.S.T.M. D626–55T, *Fire Retardant Properties of Treated Textile Fabrics.*
A.S.T.M. D1230–61T, *Flammability of Clothing Textiles.*



(*Derived from B.S. Publication P.D. 2777:1957*)

(1) Nylon and Terylene fabrics do not spread flame

(2) Wool fabrics 8·1 oz/yd² and above did not propagate flame

Figure 7.34. Flame-resistant rating in terms of fabric weight

Text. Inst. **46**, T453 (1955)). The vertical flame speed is then readily calculated from the rate of loss of weight, the initial weight of the fabric, and the weight of the residue.

Although the torsion balance procedure is considered valid for all types of fabric, it is unsuitable for practical purposes in industrial conditions. This fact has led to the development of alternative procedures which are specified in detail in various British Standards. Among these alternatives are:

(1) The visual timing test—in which the rate of flame spread is determined over fabric suspended vertically (see B.S. 2963:1958, *Tests for the Flammability of Fabrics*).

(2) The 45° test—in which the time, t, for the flame to travel 5 in. over fabric sloping at an angle of 45° is measured in seconds. The flame resistance rating, M, is then given by $2{\cdot}5 \times t$ (see B.S. 2963:1958).*

*See also
Wraight, H. G., and Thomas, P. H. 'Comparison between Two Methods of Measuring the Flammability of Fabrics.' *J. Text. Inst.* **51**, T203 (1960).

(3) The hoop test—in which the rate of flame spread is determined over the fabric mounted on a semicircular frame (see B.S. 476:1955, Part 2; this is to be found in the B.S. Handbook, p. 224 (1956); also read Lawson, Webster, and Gregsten, given above).

All of these have their merits for special purposes, but research has demonstrated that none of them is valid for all types of fabric. Method (1), for instance, is impracticable for those which are highly flammable and burn very quickly, but it is very good for slow burning ones; the results yielded by Method (2) do not show good statistical correlation with those of the torsion balance method throughout the whole range of fabrics. Methods (2) and (3) are not suitable for fabrics which 'drip' while burning. The results of tests using the torsion balance procedure have accordingly been preferred as the basis of consideration by the B.S.I. Committee, and the flame-resistance ratings recorded in Figure 7.34 and Tables 7.5 and 7.6 were calculated from such tests.

Table 7.5. Data for Mixture Fabrics

Description	*Weight per unit area* (oz/yd^2)	*Rating*
20% wool, 80% cotton	3·7	56
20% wool, 80% cotton	4·0	48
40% wool, 60% cotton	3·5	45
40% wool, 60% cotton	4·4	50
50% wool, 50% viscose	7·7	149
55% wool, 45% cotton	3·9	50
60% wool, 40% cotton	3·7	44
60% wool, 40% cotton	4·1	59
50% wool, 50% nylon	8·5	∞
50% wool, 33% viscose, 17% nylon	7·7	213
50% wool, 33% nylon, 17% viscose	8·6	∞
67% viscose, 33% Fibrolane	5·4	56
67% viscose, 33% Fibrolane	5·6	63
67% viscose, 33% Fibrolane	7·4	77
67% viscose, 33% Fibrolane	9·1	71
Viscose–Orlon	8·7	56
Viscose–Terylene	9·0	100
Winceyette:		
50% Fibroceta, 33% Fibrolane, 17% nylon	3·9	91
Wool–Orlon	6·4	91
Wool–polyacrylonitrile	8·7	125

Table 7.6. Data for Fabrics Treated with Flame-resistant Processes

Description	*Weight per unit area* (oz/yd^2)	*Rating*
Cotton, Erifon (Lifeguard) treated	5·9	∞
Cotton, Erifon (Lifeguard) treated	6·3	∞
Cotton, Erifon (Lifeguard) treated	8·5	∞
Canvas, Erifon (Lifeguard) treated	15·3	∞
Cotton, Proban treated	5·1	∞
Viscose, Proban treated	8·5	∞
Canvas, Proban treated	9·9	∞
Cotton twill, Proban treated	12·2	∞
Cotton, Antiflamm treated	5·5	∞
Cotton, Antiflamm treated	5·7	∞

Recent progress in flammability testing

An interim report on flammability testing was published in 1965 (*J. Text. Inst.* **55**, P39 (1965)). Both the vertical strip test and the 45° test were examined critically and several recommendations on further work to be done were made. In February, 1967 the Flammability Working Party was established and in January, 1968 a revised Draft British Standard for the testing of the flammability of fabrics was published (*J. Text. Inst.* **59**, 46, No. 1 (1968)). Three test methods are given:

Method A. Basically, this method is the vertical strip test in which the rate of propagation of the flame is measured in terms of the distance in millimetres per minute that the base of flame travels up a strip 900 mm long and 75 mm wide. The time to travel between two markers 500 mm apart is observed. The rate of propagation is then given as $(500/t) \times 60$ mm/minute, where t is in seconds.

Other information derived and reported includes the duration of 'after-flame', i.e. the time in seconds that elapses between the removal of the standard gas lighting flame and the flame extinction. 'After-glow' is also noted—the time in seconds between flame extinction and the end of any glowing. The extent of charring is given by 'char length'. This is the difference in millimetres between the original specimen length and the undamaged length of the specimen.

Method B. Some fabrics, particularly those made from thermoplastic materials, do not burn in a convenient manner for a satisfactory strip test to be made; they melt, shrink or curl away from the

flame. In *Method B* the test specimen is hung in sheet form and the igniting flame applied at right-angles to the sheet and near to the bottom edge. The amount of damage and time taken is observed and reported.

Method C. This test is concerned with the transmission of flame across pile fabrics.

Where required these flammability tests may be repeated after washing and dry cleaning, or leaching, in order to determine the durability of any flame-resistant treatments.

Conclusions from available data

All cellulosic materials, wood, paper, and textiles, propagate flame at a rate which is inversely proportional to their weight per unit area. In fact, a useful formula to have in mind for cotton and viscose rayon fabrics is

$$WV = 9{\cdot}3$$

where W is the weight in ounces per square yard, and
V is the vertical flame speed in inches per second.

Since the flame resistance index M is the time taken for flame to be propagated vertically 100 in., the above result may be written

$$M = 10{\cdot}8W$$

The corresponding expressions for other fibres have been determined with less precision because up to the present it has not been possible to test such a wide range of materials as for cellulosic fabrics, and because of the variations in the results for various thermoplastic fibres. The following relations are put forward tentatively:

$WV = 8$ or $M = 12{\cdot}5W$	(wool and cotton mixtures containing up to 60 per cent wool)
$WV = 5$ or $M = 21W$	(silk and acetate)
$WV = 2{\cdot}9$ or $M = 35W$	(wool)

These figures would indicate that for fabrics of comparable weights, wool–cotton mixtures are about as flammable as cotton and viscose. The lower speed of propagation of flame over acetate, silk, and wool fabrics is due to the fact that they melt and drip during burning, and as each burning drip falls the flame front is momentarily checked, some of the heat from combustion having been removed.

Fabrics comprising mixtures of fibres have a flammability intermediate between that of the two fibres, and very often characteristic of the more flammable constituents. Pure nylon and Terylene do

not propagate flame continuously in a vertical direction, but some nets made from these fibres which have been stiffened with melamine resins do propagate flame.

Flame-proofing and flame-resistant finishes

Special chemical finishing processes have been developed which reduce the flammability of the treated fabrics. Marsh discusses some of these processes in *An Introduction to Textile Finishing*. Some recent developments have led to the introduction of such finishes as 'Proban', 'Antiflamm', and 'Lifeguard' and are mentioned in the B.S.I. publication P.D. 2777:1957. Generally speaking, in addition to reducing the flammability of the fabric, such finishes should

(1) Be permanent and not disappear at the first laundering or cleaning.
(2) Be non-toxic.
(3) Be non-irritant to the skin.
(4) Leave the handle and other desirable fabric properties unaffected.

WATER AND FABRIC RELATIONSHIPS

The merit of a fabric intended for rainwear, waggon covers, or tents is judged, amongst other properties, by its ability to keep water out; conversely, when intended for hose pipes or canvas buckets, to keep water in. In another direction, some fabrics must exhibit the ability to absorb water rapidly, towelling being an obvious example. Literature on the subject of water–fabric relations tends to be a little confusing because of the terminology employed, e.g. labels on raincoats may say 'Stormproof' or 'Showerproof'. Before discussing the methods of testing such properties it would be useful to look at a few definitions given in *Terms and Definitions*, 3rd Edn, 1957, published by the Textile Institute.

Proof (*water*) (verb). To treat textile materials, e.g. with fats, waxes, or rubber, to prevent the absorption of water. The additions may be physical films or coatings or may be physically combined. The feature of a waterproof (fabric) is the low degree of permeability to air.

Proof (*shower*) (verb). To treat textile materials in a manner to delay the absorption and penetration of water. The fabrics retain a degree of permeability to air. Note: By proper choice of fibre and of yarn and fabric constructions, cloths can be made which of themselves are showerproof.

Water-repellent (adjective). A state characterised by the non-spreading of a globule of water on a textile material.

These definitions show the trend to restrict the use of the term 'waterproof' to fabrics in which the spaces between the fibres and threads have been filled with the rubber or other proofing material. Since the fabrics are almost impervious to air, such materials would be uncomfortable to wear; in practice, where these materials are used for outer wear, it is usual to punch ventilation holes in the garment, e.g. under the sleeves.

The term 'wettability' is not defined but in general one could say that the time factor is involved, i.e. the rate of wetting is the property being considered. Different test methods may time different phenomena and 'wettability' may be given different meanings. This point will be clearer when the relevant test methods are described.

The problem of why textile materials get wet is a complex version of the general problem of how liquids wet solids. In standard physics textbooks such as C. J. Smith's *Intermediate Physics*, a classical approach is made and the solid surface considered is assumed to be smooth. More advanced papers discuss the wetting of rough surfaces and when textile materials are studied there is, in addition to a rough surface, a porous surface to complicate matters. Textile technologists must therefore apply the fundamental principles to solve practical problems. An excellent account of work done on these lines is given by Baxter and Cassie (*J. Text. Inst.* **36**, T67 (1945)) whose work is also described in Volumes 2 and 3 of *Wool Research* (W.I.R.A. publications). The work and conclusions of a number of research workers is considered by Kaswell in his book, *Textile Fibres, Yarns, and Fabrics.*

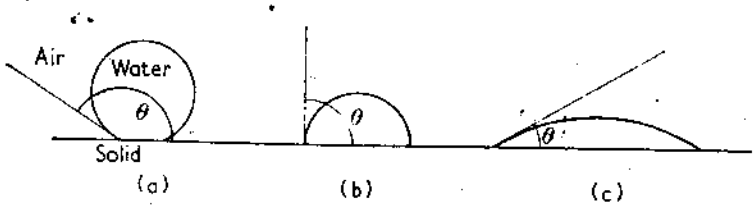


Figure 7.35. Contact angles

Before the various testing methods are described a look at some of the basic concepts of wetting and water repellency is suggested. Suppose a drop of water is put on each of three smooth solid surfaces and in each case its behaviour observed. It may assume an almost spherical shape, Figure 7.35(a), it may become nearly flat, Figure 7.35(c), or it may assume some intermediate form between these

two extremes, Figure 7.35(b). The angle θ is known as the 'contact angle' and may be defined as the angle between the solid surface and the tangent to the water surface as it approaches the solid, the angle being measured in the water. As the water properties are the same, the differences in the behaviour of the drops of water on the three surfaces must be due to differences in the properties of the water/surface combinations. A solid surface on which a drop of water forms a sphere, i.e. shows a high contact angle, will tend to shed the water, the drop will 'pearl' and roll off leaving the surface dry. Where a low contact angle occurs the drop spreads over the surface and 'wets' it.

As an illustration of these effects, two microscope slides should be prepared. One is thoroughly cleaned and the other given a thin coating of paraffin wax. A small globule of water is placed on each. On the waxed surface the water will become nearly spherical and when the slide is tilted the water will roll away and leave the wax surface dry. The drop on the clean slide will spread out and wet the slide.

It is natural to ask why different surfaces should produce these varied effects on water. The answer revolves around the mechanics of surface energies and surface tensions at interfaces, an interface being the surface between two media, e.g. solid–liquid, liquid–air, solid–air, etc. The mechanics of these interfacial tensions and energies are discussed in detail by Baxter and Cassie who extend the theories to the problem of wetting rough and porous textile surfaces. In their experiments it was observed that with a water repellent material a high receding contact angle is exhibited. Contact angles may be 'advancing' or 'receding'. The advancing contact angle is that shown when the liquid advances on to a dry surface; the receding contact angle is the angle when the liquid recedes from a wet surface. Baxter and Cassie give as an example of a high advancing contact angle coupled with a low receding contact angle, the angles shown by a drop of rain rolling down a dirty window pane.

Wetting of Fabrics in Rain (From Baxter and Cassie's paper)

'No wetting of a porous surface takes place until pearling ceases as during pearling all the water falling on to the surface rolls off and no water films are formed between fibres. A drop of water falling on to a fabric will penetrate most deeply into the pores between the yarns. The ability of the water to withdraw from the pore depends on the yarn–water receding contact angle being high. With a reasonably proofed fabric the initial yarn receding contact angle will be high

and this ensures that the water will contract out of the pore into the drop and pearl off. As successive drops fall into the same pore, water films are formed between some fibres, the yarn–water receding contact angle decreases and the water will not be withdrawn completely from the pore. Succeeding drops falling in the pore will then force the water further into it and the water will withdraw to a less extent because the yarn–water receding contact angle has decreased. This process of penetration of the fabric by rain will continue until the kinetic energy of the falling drops is not sufficient to force the water column deeper into the pore. When this condition is attained the absorption of the fabric will have reached a limiting value and further exposure to rain will result in no further absorption. If the thickness of the fabric is greater than the maximum depth of penetration of the drops, no water will pass through, but if the thickness is less, penetration of the water through the fabric will take place. Thus the maximum absorption of a fabric and the penetration are determined by the fibre-water advancing contact angle and the physical construction of the fabric, while the rate of pick-up of water depends on the effective receding contact angle θ and its decay with time. It is necessary to conclude that a practical test for water repellency should be influenced both by the effective advancing and receding contact angles as both are equally important in the wetting of a fabric in rain.'

*Methods of testing**

The wetting time test. This test was developed by Baxter and Cassie following their research work on water repellency. The apparatus used throws an enlarged image of a strip of fabric, end-on, as it is slowly withdrawn from the surface of water in a small tank. Distilled water at 20° C is used and the speed of withdrawal is 8 mm/min. At the start of the test a large receding contact angle is seen but after a time, noted by a stop watch, the angle decreases to 90 degrees (see Figure 7.36). The time taken to drop to 90 degrees is called the 'wetting time'. In a series of comparative tests it was found that this method was the most sensitive to assessment of proofing efficiency on heavy wool cloths, whereas on cotton fabrics all three methods used, wetting time, hydrostatic head, and the Bundesmann, ranked the fabrics in roughly the same order.

*American methods are described in *A.S.T.M. Handbook.*
A.S.T.M. D583–58, *Water Resistance of Textile Fabrics.*
See also
B.S. 3449:1961 *The Resistance of Fabrics to Water Absorption (Static Immersion Test).*
B.S. Handbook No. 11, p. 327.

A detailed description of the apparatus is given in Baxter and Cassie's paper and also in Volumes 2 and 3 of the W.I.R.A. handbook, *Wool Research*. The wetting time test is given on p. 337 of the British Standard handbook.

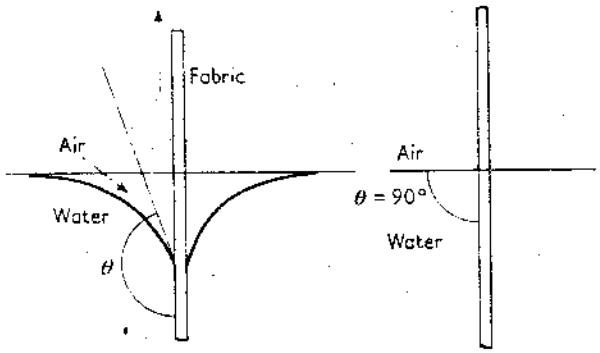


Figure 7.36. The 'wetting time' test

Wettability of Cotton fabrics. The contact angle is again considered in this test developed by the British Cotton Industry Research Association. A drop of water (or sugar solution) is placed on to the specimen fabric which is mounted horizontally. The time taken for the contact angle to drop to 45 degrees is noted. The reciprocal of the time taken is called the 'wetting velocity' or simply 'wettability'.

*The spray test.** In this test a small-scale mock rain shower is produced by pouring water through a spray nozzle. The water falls on to the specimen which is mounted over a 6 in. diameter embroidery hoop and fixed at an angle of 45 degrees (see Figure 7.37).

To carry out the test, 250 cm^3 of water at 70° F are poured steadily into the funnel. After spraying has finished the sample holder is removed and the surplus water removed by tapping the frame six times against a solid object, with the face of the sample facing the solid object. The tapping is in two stages, three taps at one point on the frame and then three times at a point diametrically opposite. The assessment of the fabric's water repellency is given by the 'spray rating'. After the removal of the surplus water is accomplished the fabric surface is examined visually. The American Association of Textile Chemists and Colorists recommend the use of a chart of

*See B.S. Handbook No. 11, p. 330.

photographs against which the actual fabric appearance is compared.* The ratings are as follows:

100 No sticking or wetting of the upper surface.
90 Slight random sticking or wetting of the upper surface.
80 Wetting of upper surface at spray points.
70 Partial wetting of whole of upper surface.
50 Complete wetting of whole of upper surface.
0 Complete wetting of whole of upper and lower surfaces.

Five tests should be made and the nearest rating assigned to each, since no interpolation is allowed, i.e. a rating for a specimen cannot be 75. The mean of the five ratings is reported.

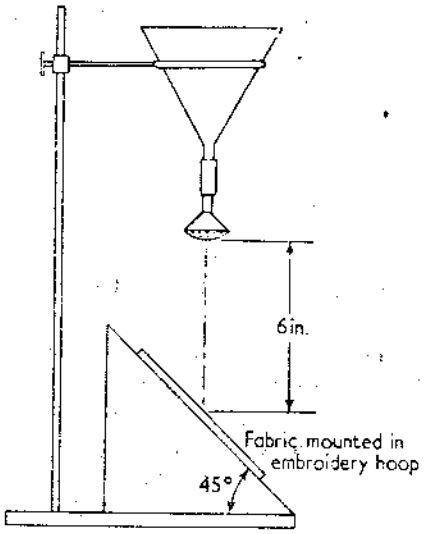


Figure 7.37. The spray test

The drop test or drop penetration test. It was noted earlier that in the initial stages of wetting the drops of water pearl off the fabric, but in time pearling ceases and the fabric becomes wet. The drop test is a count of the number of drops required to penetrate through to the underside of the fabric when all the drops fall on to the same spot.

*British Spray Rating:
1. Complete wetting of the whole of the sprayed surface.
2. Wetting of more than half of the sprayed surface.
3. Wetting of the sprayed surface only at small discrete areas.
4. No wetting, but adherence of small drops to the sprayed surface.
5. No wetting and no adherence of small drops to the sprayed surface.

The apparatus used may be quite simple, but a number of refinements have been developed by various laboratories (see *A.S.T.M. Handbook*, p. 222 (1954)).

The basic apparatus is shown in Figure 7.38. The fabric specimen is clipped on to a glass plate with a piece of filter paper sandwiched between the fabric and the glass. A frame holds the assembly at an angle of 45 degrees directly under the drop-forming device. The latter is prepared from a fine-bore glass tube to produce a certain number of drops of a given size in a minute, with a constant head of water. To ensure that the drops fall on to the same spot, a draught shield of large diameter is used.

With the specimen in position the water supply is started and the drops begin to fall on the fabric. The end-point is reached when the filter paper shows signs of water, a mirror underneath the specimen assembly facilitates observation. Various methods have been tried to determine the end-point with greater precision. One method is to use filter paper impregnated with a chemical which changes colour when wet, e.g. cobalt chloride turns blue. Alternatively, the water could be tinted. Another method is to use a pair of electrical contact strips under the filter paper which has been impregnated with a

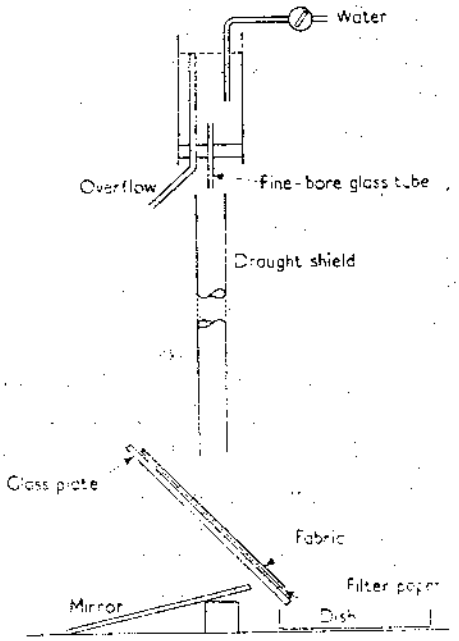


Figure 7.38. The drop penetration test

solution of sodium chloride and dried. When the water penetrates the fabric the wet filter paper becomes a conductor and a lamp in the circuit lights.

Details of the drop size, rate of dropping, height of drop, and other dimensions are not given here since different laboratories may use their own. In many control schemes the determinations are not intended to provide absolute values but to give comparative values on specimens tested under nominally identical conditions.

A more elaborate apparatus, using drop-forming tubes and a different method of measuring water penetration is described in *A.S.T.M. Handbook*, p. 222 (1954). The water which penetrates the specimen is collected and the time taken to collect 10 cm^3 under specified conditions is observed to the nearest second.

*The Bundesmann test.** Both the spray and the drop penetration tests simulate the action of rain drops falling on to a fabric. This approach to testing for water repellency is carried a stage further in the Bundesmann test introduced by Dr. Bundesmann (*Melliand Textilber.* **16**, p. 128 (1935)). Briefly, fabric specimens are mounted over special cups or bezels and subjected to a shower of water from a multi-nozzle drop producer. Water which penetrates the fabric is collected in the bezels and measured; so also is the water which is retained by the fabric specimen. The general arrangement of the tester is seen in Figure 7.39. The shower producer is mounted 150 cm above the four bezels which are mounted on an assembly rotating slowly at 5 rev/min. As the fabrics circulate in the shower of water, special wipers inside the bezels rub the undersides of the specimens in order to reproduce mechanically the rubbing action which occurs in practice when a raincoat is worn. This rubbing action will help the water to penetrate the fabric.

After a 10 min shower of controlled severity the fabric specimens are removed and two values determined:

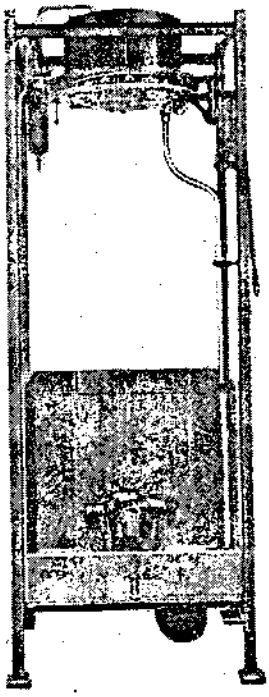
(1) Penetration. The water collected in each of the bezels is measured and the mean volume calculated to the nearest millilitre.

(2) Absorption. From the weight of each specimen before and after the test the percentage of water retained by each specimen is calculated,

$$\frac{100 \times \text{weight of water absorbed}}{\text{Original weight of test specimen}}$$

The mean of the four results is calculated and reported to the nearest 1 per cent.

*B.S. Handbook No. 11, p. 317.



(By courtesy of Goodbrand & Co. Ltd)

Figure 7.39. The 'Bundesmann' water-repellency testing machine

From the above description this test would seem straightforward enough, but in common with other 'realistic' tests a certain amount of caution must be exercised in the interpretation of the results. A special technical committee of the Textile Institute organised inter-laboratory trials on this test (see *J. Text. Inst.* **44**, S50 (1953)). Differences in the results obtained were investigated and in turn this led to the formulation of a recommended test procedure which should reduce the variation. The test procedure is fully presented in the B.S. Handbook and the reader should consult this for details, but to illustrate some of the points which require careful consideration a few of the recommendations are quoted here.

Temperature of the water, 18–20° C.

pH of the water, 6–8.

Rate of flow, 62–68 ml/min per bezel.

Drops to be uniformly spaced and to be of average weight 0·075 ± 0·005 g.
Fabrics to be conditioned for at least 24 hr in a standard atmosphere.
Specimens to be weighed in airtight containers.
Surplus water to be removed by six sharp shakes with arm outstretched in a horizontal position.

Such attention to detail, plus accuracy in the dimensions of mechanical parts and control of speeds, etc., clearly demonstrates the need for caution when interpreting the results of an apparently simple imitative test. Baxter and Cassie point out that the kinetic energy of the 'Bundesmann' drops is about 5·8 times the value for a cloudburst, 91 times the value for heavy rain, 480 times the value for moderate rain, and 21,000 times the value for light rain. Like other forms of imitative tests, the intensity of the action is exaggerated in order to reduce the time taken for a test.

The penetration of fabrics by water under pressure

The pressure required to force water through a fabric may be determined, and the information used is the assessment of the fabric's ability to do a particular job. From experimental work, Baxter and Cassie concluded that such a measurement is insensitive to differences in the proofing of some fabrics since the results are influenced to a large degree by the size of the pores between the component yarns. Nevertheless, the resistance to the passage of water of air-permeable fabrics is useful information to the fabric technologist. In B.S. 2823:1957, *Resistance of Fabrics to Penetration by Water* (*Hydrostatic Head Test*), B.S. Handbook No. 11, p. 324, a description is given of the test method. Shirley Developments Ltd now manufacture a suitable apparatus which complies with the requirements of this Standard. The following description is taken from a publication by Shirley Developments Ltd.

The main features of the instrument are shown in Figure 7.40. The specimen holder consists essentially of a double-chambered cell; the internal diameter of the inner chamber A is 5 cm. Circular specimens are clamped between rubber gaskets over the orifice. Compressed air enters the outer chamber C through a tube B and displaces the distilled water contained in C through communicating passages into the inner chamber A, thereby forcing water up against the specimen. The clamp is provided with a skirt E which prevents air from leaking continuously across the test specimen from C to A or to the atmosphere. Tube B is also connected to a U-tube manometer D and the pressure of water against the fabric is, for all prac-

tical purposes, the pressure shown on the adjustable scale mounted on one arm of the manometer tube. The air supply for the test is drawn from a reservoir of about 3 l. capacity which is itself fed through a flow control device F from a source which may vary between 4 and 20 lb/in². The flow control device is so designed that once it has been set to give the required rate of increase of pressure of 10 cm of water per minute, the rate of loading will be within the specified limits of 10 ± 0·5 cm/min up to the limit of the instrument. The maximum head attainable is 150 cm of water.

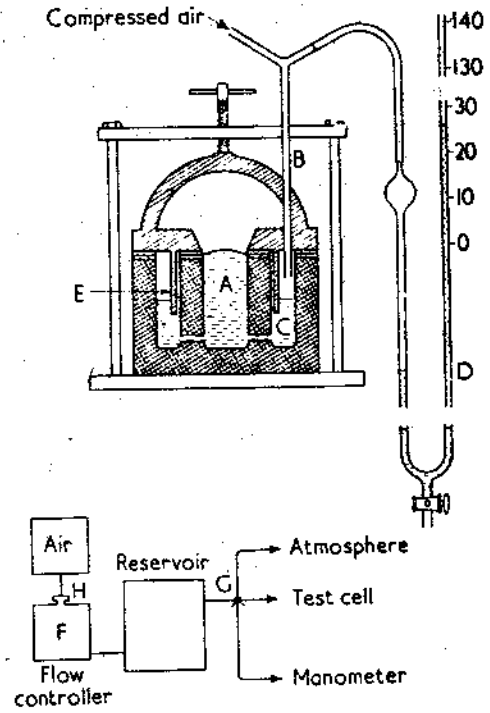


Figure 7.40. The 'Shirley' hydrostatic head test

Test procedure. Circular specimens 6 cm in diameter are cut from the fabric to be tested in such a way as to represent the material available as fully as possible. They may be marked with a template and cut with scissors with as little handling of the material as possible, or they may be cut directly with a circular knife. The test cell is rinsed thoroughly with distilled water and filled to approximately 0·3 cm of the top. The inner rubber gasket is thoroughly dried by wiping with a clean absorbent cloth and a test specimen is

laid over the orifice. The clamp, which is similarly dried, is placed in position and screwed down. A control tap (not shown in Figure 7.40) is turned to position No. 1; this means that the air supply, manometer, and test cell communicate. The pressure on the under surface of the specimen is allowed to increase at the specified rate of loading until water appears at a third place in the specimen. The control tap is then immediately turned to position No. 2. This allows the air supply and the test cell to discharge to atmosphere while the manometer remains at the pressure at which breakdown of the test specimen occurred; this value can thus be noted at leisure. The manometer scale is designed so that the hydrostatic head may be from one arm of the U-tube manometer to the accuracy required by B.S. 2823:1957, i.e. to the nearest 0·5 cm of water. The control tap is next turned to position No. 3 which allows the manometer to discharge to atmosphere. The test specimen is removed, the used water thrown away, fresh distilled water is poured into the test cell, and the cycle is recommenced. A satisfactory mean may generally be obtained from tests on eight specimens.

The water percolation test

After being tested in the hydrostatic head apparatus, the samples may be immersed in water for 24 hr and then subjected to a head of 100 cm of water. The amount of water which percolates through the fabric in the first 500 sec is collected and measured. The percolation may be expressed thus:

$$\text{Percolation} = \frac{w}{3{\cdot}92} \text{ ml/1,000 sec at 1 m water head}$$

where w is the weight of water in grams collected from four specimens in 500 sec.

This type of test is suitable for measuring the performance of fabrics intended for use as tent cloth, water buckets, etc. Details of the test will be found on p. 200 of the B.S. Handbook (1956 Edn.)

Sinking test

A simple test of wettability of fabric is to cut small square specimens, e.g. 1 in. × 1 in., and to drop them on to the surface of a beaker of water. The time taken for the specimens to sink below the surface is observed, the shorter the time the greater the wettability.

Wetting by wicking

The ability of a fabric to absorb water, especially by a 'wicking' or capillary action, may be observed by timing the rate at which water climbs up a narrow strip of fabric suspended vertically with its lower end dipping into the water (see Garner, W. *Text. Lab. Man.*, p. 185). In the reference just given a simple absorption test is described. A square of fabric, 2 in. × 2 in., is fully immersed in water at 20° C for 20 sec, removed, and weighed. From its known dry weight the percentage water absorbed is calculated. Garner states that good towelling should absorb 100 per cent of its own weight.

Shrinkage tests

A fabric would have great technical merit if its dimensions remained constant throughout its useful life. Suits would retain their shape and shirts would retain their size if fabrics could be produced which maintained their original finished settings. One very important dimensional change is that which occurs when a fabric is washed (see Figure 7.41). It is common practice to buy shirts and similar clothes a little on the large size in the hope that after a few washings they will have shrunk to the desired fit. It is not proposed to go into the theories of shrinking or the technology of its prevention, but it is necessary to define the different types of shrinkage.

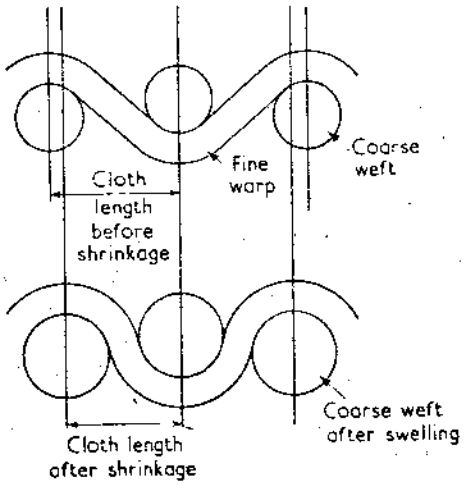


Figure 7.41. The shrinkage theory. Note the increase in warp crimp percentage

Relaxation. During manufacture, fabrics and their component yarns are subjected to applied tension under varying conditions of temperature and moisture content. In the finished state the fabric may be temporarily 'set' in a stretched condition. When crimp was discussed earlier it was noted that such stretching upsets the balance of warp and weft way crimp percentages. The hot and wet conditions of washing allow the strains to relax and therefore the material shrinks. (Shrinkage due to yarn swelling is discussed in the section dealing with crimp.)

Felting. Wool fibres possess the ability to mat together or felt, an effect closely related with their scaly surface features and one which is accentuated in aqueous solutions. This ability to felt is exploited in the production of non-woven felts and special effects on worsted and woollen fabrics. Unfortunately, since felting is accompanied by shrinkage it is a disadvantage where the finished fabrics are made up into goods which require periodical washing, e.g. underwear and socks.

Testing for shrinkage

It is logical to assume that the shrinkage test on a particular type of material should put the fabric through a washing procedure similar to that which it would go through in practice. The wide variety of fabrics on the market today encourages the manufacturers of soaps and detergents to issue washing instructions for the different types of material. In the B.S. Handbook the test procedures include detailed instructions on the preparation of washing solutions for cotton and linen, rayon and synthetic fibres, and wool. (One test on wool fabrics requires the use of a small milling machine in order to simulate the type of treatment meted out to socks during wear.)

The principles of shrinkage tests are simple but it is necessary to follow the standard procedures in order to obtain comparative results. Essentially, the tests are carried out in the following stages:

Preparation of specimens. The fabric should be conditioned in a standard testing atmosphere before marking out. Usually three pairs of datum lines are marked out in each direction. The marking out may be done with indelible ink or with fast-dyed sewing thread.

Washing. The sample is washed in the relevant washing solution in a washing machine conforming to certain specifications. After the specified time has elapsed the sample is rinsed.

Drying. After rinsing, the surplus water is removed by centrifuge (preferably) or by hand squeezing, rubber-covered roller wringer, or rolling in towelling. Drying is completed by means of a flat-headed press or a heated flat iron.

Conditioning and remeasuring. After drying, the specimen is conditioned in a standard testing atmosphere and the distances between the datum lines remeasured. (Variations in the methods are required for certain materials and samples, e.g. wool and small complete articles.)

Percentage shrinkage

This is calculated from the mean changes in the distance between the datum lines.

$$\text{Percentage shrinkage} = S = \frac{100(L_0 - L_1)}{L_0}$$

where L_0 is the distance between the datum lines before washing and
L_1 is the distance between the datum lines after washing.

CARPET TESTING

The rising standard of living in many parts of the world appears to have led to an increasing demand for carpets. In addition to the more traditional woven carpet structures, such as Wilton and Axminster, there has been a sharp increase in the production of tufted carpets. This expansion in carpet production and sales has been reflected in the development of instruments specifically designed to evaluate carpet quality. Carpet details, such as yarn count, fibres used, blend composition, and so on, can be found by standard techniques but some other carpet characteristics may not be so simple. This leads us to ask the questions: 'which carpet properties are of major importance and are they measurable?'

In an article on carpet grading (Angus, *Text. Inst. Ind.*, p. 235 (Oct. 1964)) it was suggested that the major properties are: (1) durability; (2) retention of appearance, and (3) pile height and density. To take the last property first, the density of the pile may be derived from a knowledge of the pile height and the carpet construction. For example, a good Axminster may have 8 rows per inch, with 7 tufts per inch width, i.e. 56 tufts/in^2. If the pile height is determined (difference between total thickness and backing thickness) and found to be 0·5 in. then the length of pile per square yard would be given by

$$\frac{56 \times 0{\cdot}5 \text{ in.} \times 36 \times 36}{36} \text{ yd} = 1{,}008 \text{ yd}$$

With a carpet yarn of 55 yd/oz the pile weight per square yard would be 18·2 oz. A lower quality Axminster with 36 tufts/in², a $\frac{1}{4}$ in. pile and a 50 yd/oz yarn would only have a pile weight per square yard of about $6\frac{1}{2}$ oz.

This approach to an expression of pile density, although apparently logical, is not really explicit enough. Two carpets could have similar weights of pile per square yard, one with long, loosely packed tufts and the other with short, densely packed tufts, but the characters of the two carpets would be different.

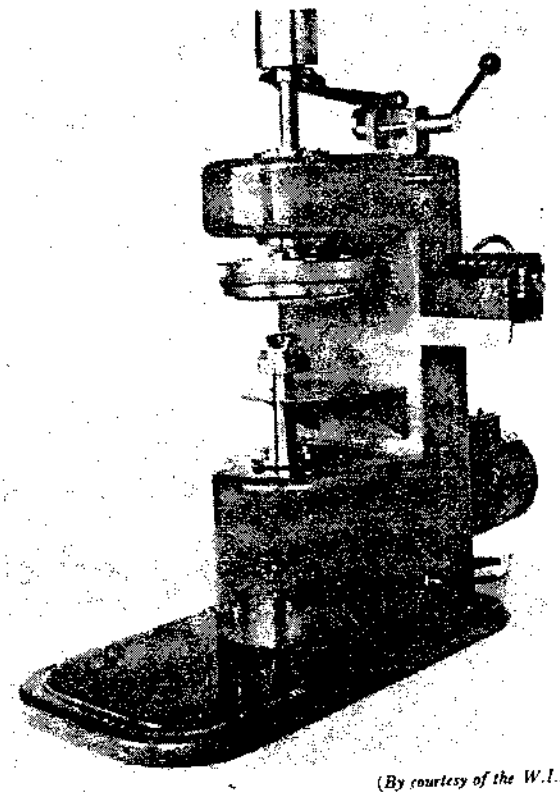
Durability of carpets

A cheap carpet in the spare bedroom could last for tens of years, a high-quality carpet in a busy corridor of a hotel may only last a few years. How long a carpet will last (how durable?) is clearly a very difficult question to answer. As with apparel and other fabrics the prediction of the performance from laboratory tests is virtually impossible. Nevertheless, carpet testing instruments have been designed and used both for comparative evaluation of carpets by laboratory tests and for the comparison of laboratory results with carpet performance in field trials. In order to obtain useful results reasonably quickly field trials are usually located in an area where the walking traffic is high, e.g. in the foyer of a hotel, in a busy corridor of an office block. The actual laying and disposition of carpet specimens in such trials must be carefully considered. It is essential that all types of carpet in a multi-type trial should receive a similar amount of traffic.

Some of the abrasion testing instruments described or mentioned elsewhere in this chapter can be adapted to carry out abrasion tests on carpets, e.g. the Martindale and the Shiefer. The instrument described below is one developed by the Wool Industries Research Association. The descriptive notes are from W.I.R.A. literature.

The W.I.R.A. carpet abrasion machine

Although only one specimen is tested at a time, this machine, like the W.I.R.A. abrasion machine, is designed for comparative testing for wear. It is not intended to give an estimate of the useful life of a carpet. Figure 7.42 shows the general arrangement of the tester. Two vertical shafts rotate in the same direction at approximately the same speed, but their centres are offset. The specimen of carpet, a circle of $1\frac{1}{2}$ in. in diameter, is clamped at the top of the lower shaft; it is rubbed against a larger circle of standard worsted cross-bred fabric clamped at the bottom of the top shaft.



(By courtesy of the W.I.R.A.)

Figure 7.42. The W.I.R.A. carpet abrasion machine

The arrangement and rotation of the shafts is based on the motion described by Shiefer, which gives a constant relative velocity between specimen and abradant at all parts of the specimen. The specimen is abraded at a constant pressure of either 6 or 8 lb/in², and the machine can be set to stop after a predetermined number of revolutions.

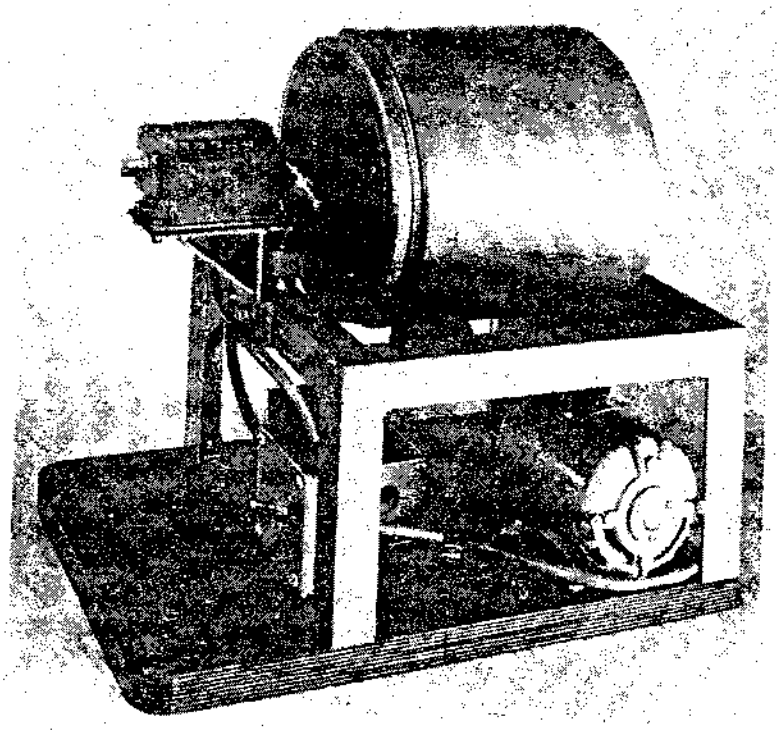
The amount of wear can be estimated either visually or by weighing the specimen after a given number of rubs. Carpet specimens can be rubbed through to the backing in times ranging from 30 to 60 min. Comparison tests with a series of wool carpets have shown that there is a good correlation between the results of testing with the W.I.R.A. carpet abrasion machine and the results of actual wear tests with the same carpet.

The method of test based on the use of this machine has been approved by the Technical Committee of the Federation of British Carpet Manufacturers, and has been included in B.S. Handbook No. 11.

The Tetrapod Walker Carpet Tester

This instrument, Figure 7.43(a), is a comprehensive carpet testing machine which can be used to test carpet samples for durability, appearance retention in both dry and damp conditions, and soil resistance. Courtaulds Engineering Ltd., who supply the machine, describe it as follows:

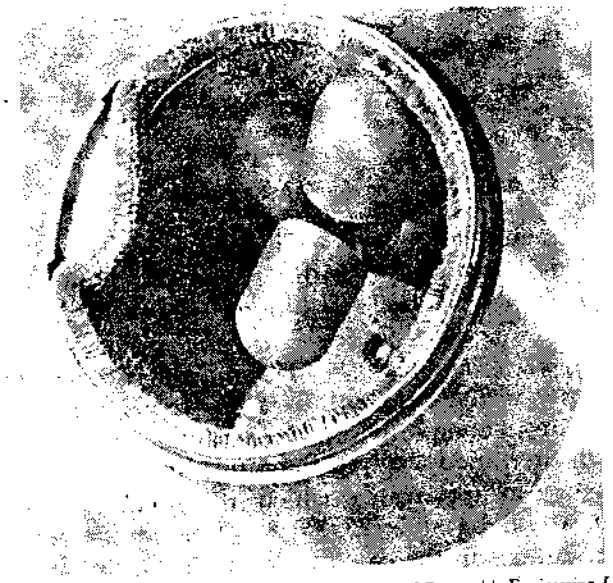
The machine comprises a drum which is driven at a speed of 50 r.p.m. by a 12 W electric motor via P.V.C. rollers. Carpet samples



(By courtesy of Courtaulds Engineering Ltd)

Figure 7.43(a). The tetrapod walker carpet tester

are placed inside the drum with the pile facing inwards. The tetrapod itself is made in cast iron with four legs, heavily coated in P.V.C., of constant hardness. The tetrapod is placed inside the drum with the carpet – Figure 7.43(b). When the drum is rotated the tetrapod falls on each of its legs in turn, and effectively 'walks' over the carpet sample with a heavy beating and rubbing action which simulates the actual action of walking. A counter is fitted to the machine to register the number of revolutions completed by the drum. The counter can also be set to switch off the motor after a required number of revolutions. This allows the machine to be run 24 hours a day until the test is completed without the need for constant supervision.

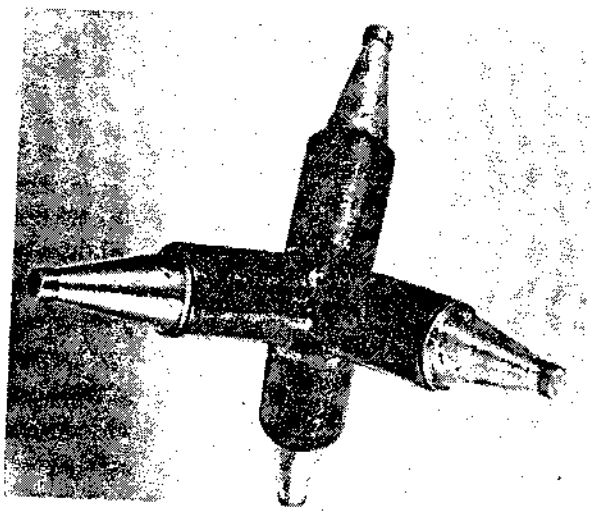


(By courtesy of Courtaulds Engineering Ltd)

Figure 7.43(b). Inside view of the tetrapod walker showing step

Figure 7.43(c) shows the stiletto-pointed tetrapod testing unit which has been developed by Courtaulds especially for evaluating their super-wearing Hartuft carpeting. The treatment inflicted by this unit is very much more intensive than that of a conventional tetrapod.

Durability test. The durability test investigates the length of life of the carpet before backing becomes visible due to fibre or tuft loss. A step can be fitted between the back of the carpet and the inside face



(*By courtesy of Courtaulds Engineering Ltd*)

Figure 7.43(c). The stiletto-pointed tetrapod testing unit

of the drum to accelerate wear—Figure 7.43(b). Light to medium carpets would be expected to withstand at least 175,000 revolutions and heavier carpets 500,000 revolutions before the backing became visible.

Appearance and texture retention. These properties are tested in a similar manner to the durability but the step is removed from the drum. The carpet sample is subjected to the beating and rubbing action of the tetrapod for sufficient time to bring about a substantial change in appearance which in the case of a low density pile carpet would be after 25,000 revolutions, whereas it can be 200,000 revolutions in the case of a high density pile.

A similar test is the appearance retention in damp conditions. This test is carried out in exactly the same way as the dry appearance retention test except that a ball of damp cotton wool is placed in the drum with the tetrapod. The drum is rotated for 10,000 or 20,000 revs according to quality.

Soiling test. In order to test the carpet sample for soil resistance, a measured amount of artificial soil is placed in the drum with the tetrapod and the drum is rotated for 10,000 revolutions. The carpet is then removed and examined for the degree of soiling. All tests are evaluated visually and in most cases the sample should be compared with a sample of high quality such as an AO Axminster or a plain,

top-quality Wilton. Because such tests as appearance and texture retention do not wear the carpet to the point of destruction, the effects of subsequent treatment, such as shampooing, can be evaluated and if necessary the carpet sample can be retested to investigate appearance retention after shampooing.

Resilience. A desirable property of a carpet is the ability to recover from the compression of walking traffic, furniture feet, etc. One approach to an assessment of the resilience of a carpet is by studying dimensional changes. A carpet could be measured for thickness before and after tetrapod action, using conventional thickness gauges. In this way objective measurement of resilience retention could be made in relation to pile fatigue.

In addition to testing samples of carpets, the tetrapod walker machine can be used for testing other types of fabrics such as those used for upholstery.

Papers by Ainsworth and Cusick give further information on the tetrapod walker (see Further Reading).

Carpet thickness

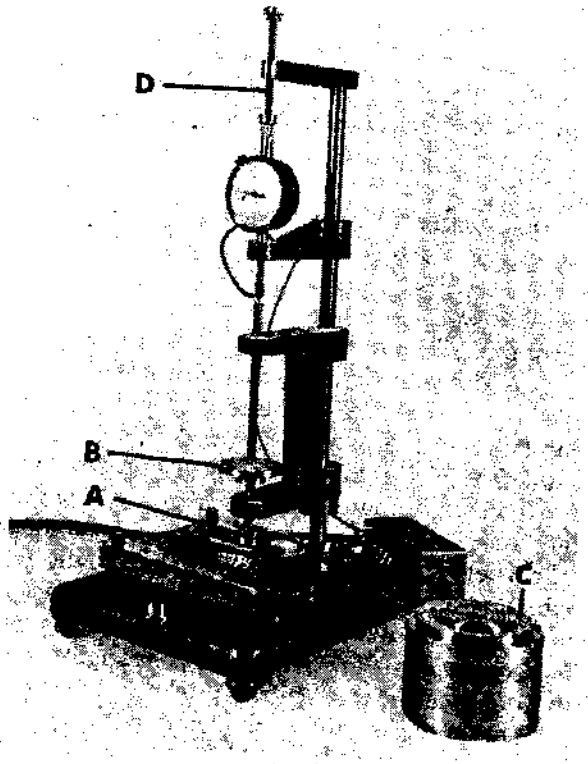
A carpet is compressible and therefore it is necessary to specify at what pressure its thickness is to be measured. Anderson and Clegg (*Text. Inst. Ind.*, p. 6 (Feb. 1963)) state: 'Thickness as estimated by eye is similar to that measured by an instrument at low pressure, and by measuring thickness at increasing and decreasing pressures in the range exerted by a human foot, pressures of the order of 0–12 lb/in² normally being encountered, we can obtain a measure of the behaviour of carpets to imposed loads. Thickness falls and then rises to a value which is somewhat short of the original thickness. Thickness under a pressure of 0·25 lb/in² will be similar to that appreciated by eye, as at this pressure there is negligible compression.'

Apart from the measurement of the thickness of a new carpet it is clearly useful to measure loss of thickness during use or during carpet trials. Descriptions of carpet thickness testers will be found in the papers of Cusick and Dawber (*J. Text. Inst.* **55**, T531 (1964)), and Dilworth (*J. Text. Inst.* **48**, T377 (1957)). The instrument described below has been introduced by the Wool Industries Research Association, from whose literature the notes have been taken.

The W.I.R.A. Carpet Thickness Gauge

This instrument, Figure 7.44, is designed to measure carpet thickness at pressures from 0·25 to 12 lb/in². The compression and

recovery from compression can be measured during a complete loading and unloading cycle. The lowest pressure of 0·25 lb/in² is such that, although protruding fibres are bent down, there is little average compression of a carpet. The highest pressure of 12 lb/in² is intended to represent an average maximum pressure exerted during normal walking.



(*By courtesy of the W.I.R.A.*)

Figure 7.44. The W.I.R.A. carpet thickness gauge

The presser foot A at the bottom of the loading shaft presses on the carpet during measurement. The collar B serves as a support for the additional weights C, which produce pressures of 0·75, 3, 6, 9 and 12 lb/in². The dial gauge is graduated in thousanths of an inch. The moving stem of the gauge has, at its lower end, a contact which is connected to a 4·5 V bulb, the return lead being through the frame.

The spring mechanism of the dial gauge is arranged to keep the top of the gauge stem pressed against the screw D. Rotation of this screw moves the stem of the dial gauge downwards until the contact touches the loading shaft and lights the bulb.

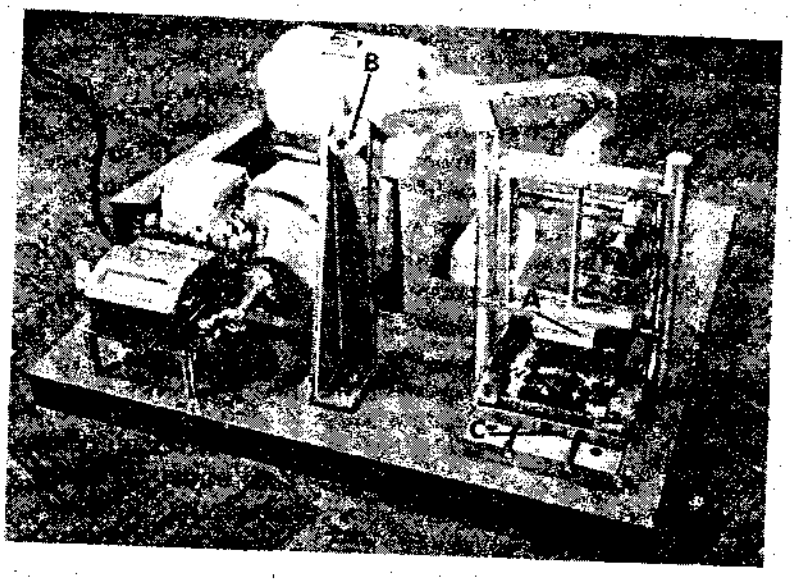
With no carpet specimen in position, the screw D is turned until the bulb lights; a zero reading on the dial is then taken. The presser foot is then raised, and a carpet specimen at least 3 in. sq. is inserted. Readings are taken of the thickness of the specimen, first with no additional weights, and then with the weights added in successive stages. Finally, readings are taken during the unloading cycle.

Alternatively, by a simple modification of the base plate, tests can be made in the centre of a larger area of carpet.

Carpet compression

When a householder has a new carpet fitted the supplier usually tells him (or, more commonly, her) not to use a vacuum cleaner on it until the carpet has 'bedded down'. The initial luxurious, thick feeling under one's (clean) shoes does not last; the carpet loses some of its thickness fairly quickly during the bedding down process and thereafter at a much slower rate. The greater part of the carpet's practical life is thus spent in a compressed state. To provide information on this bedding down process the Wool Industries Research Association have designed an instrument specially for the job. The Association describe the instrument below.

The W.I.R.A. dynamic loading machine. The machine simulates two of the main actions of walking – compression, and the shearing effect at the edge of the shoe. Figure 7.45 shows the machine. The weight A has two rectangular steel feet, 2 in. by $\frac{1}{4}$ in. and $\frac{3}{8}$ in. deep, attached to its underside $1\frac{1}{2}$ in. apart. By means of an arm pivoted at B, a cam raises the weight and then allows it to fall freely from a controlled height on to the carpet specimen about every five seconds. The steel plate C, to which the specimen is clamped, is slowly and continuously traversed in such a way that there is a $\frac{1}{8}$ in. movement between each drop of the weight; there is thus a half-overlap by the steel feet at each impact. A complete traverse, forwards and backwards, is made for 25 impacts, which produces a uniformly compressed area 2 in. wide by $3\frac{1}{2}$ in. long. Normally, the carpet specimens are measured for thickness (using a W.I.R.A. carpet thickness gauge) immediately after 50, 100, 200, 500 and 1,000 impacts (see also Anderson and Clegg, *Text. Inst. Ind.*, p. 4 (Jan. 1963) and *J. Text. Inst.* **53**, T347 (1962)).



(*By courtesy of the W.I.R.A.*)

Figure 7.45. The W.I.R.A. dynamic loading machine

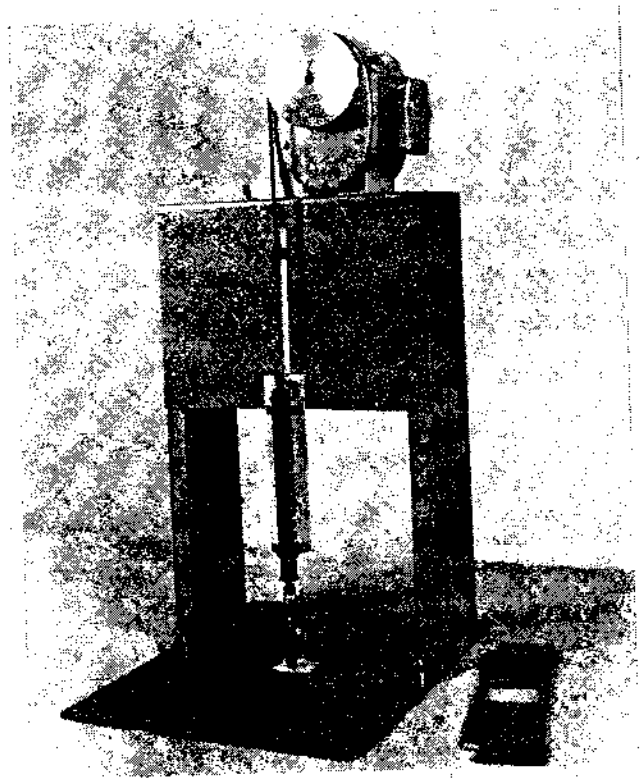
Tuft bind in carpets

The tuft bind of a carpet may be regarded as the force required to extract a tuft from the carpet. Snowden and van Issum have described the use of an Instron strength tester to measure this force (*J. Text. Inst.* **54**, T269 (1963)). The Wool Industries Research Association studied the problem of measuring tuft bind and designed a special instrument for the purpose.

The instrument shown in Figure 7.46 is called the W.I.R.A. tuft withdrawal tensometer and it provides a simple method for measuring the force required to withdraw a single tuft of pile from a carpet, i.e. the binding force between carpet pile and backing. It can be used on small samples of a few square inches of carpet or at a selected position in a large area. Small samples are put on the base plate and held down by a rectangular steel plate with a $1\frac{1}{2}$ in. $\times$ $1\frac{1}{2}$ in. hole at its centre. When a test is to be made in a large area the rectangular plate is removed and the instrument is placed in the required position. There is a hole in the base plate corresponding to that in the detachable plate.

A spring balance, reading from 0 to 1,000 g, has a sliding pointer

which indicates the maximum force exerted. The balance is supported by a light chain which passes round a pulley driven by a small motor, and is thus moved upwards and downwards by the motor, which can be reversed by a switch. A pair of jaws for gripping the single pile tuft is linked to the balance hook and is easily detachable.



(By courtesy of the W.I.R.A.)

Figure 7.46. The W.I.R.A. tuft withdrawal tensometer

To make a test, the jaws are detached and a single pile tuft in the centre of the square hole is gripped. The jaws are then hooked on to the chain at the lower end of the spring balance, and the motor is switched on. The force required to withdraw the tuft is then read from the sliding pointer.

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8

THE TENSILE TESTING OF TEXTILES

WHEN students are asked 'Why do we test textiles?' the usual answer is 'To find out how strong they are'. This indicates that the strength of fibres and fibre structures is commonly regarded as the criterion of quality. That strength is of great importance goes without saying, but it must be remembered always that properties such as flexibility, resilience, moisture absorption, dye affinity, etc., should be included in the assessment of the 'goodness' or quality of a textile material. The relative importance of one particular property will depend in many cases on the end-use; e.g. the resistance to acid attack of synthetic fibres such as Terylene has led to their use in chemical filter cloths. Nevertheless, the measurement of the tensile properties of textiles is an important branch of textile testing, but before considering the methods and principles used it is essential that the units and terminology employed are clearly defined and understood.

TERMINOLOGY AND DEFINITIONS

Load

The application of a load to a specimen in its axial direction causes a tension to be developed in the specimen. The 'load' is usually expressed in grams weight or pounds weight like gravitational units of force. Where great precision is demanded (e.g. for comparative tests in different parts of the world) the loads measured must be corrected by multiplying by the local value of g, the acceleration due to gravity, and dividing by 981 cm/sec^2 or 32·2 ft/sec^2, the standard value.

It is common practice to leave out the word 'weight' and quote loads in grams or pounds.

Breaking load

This is the load at which the specimen breaks, usually expressed in grams weight or pounds weight.

Stress

Where the merits of fine and coarse structures have to be compared, suitable units must be chosen. In engineering the term 'stress'

is used. This is the ratio between the force applied and the cross-section of the specimen:

$$\text{Stress} = \frac{\text{Force applied}}{\text{Cross-sectional area}}$$

The force is accurately expressed in dynes or poundals. Hence, the stress on a fibre may be given in terms of dynes per square centimetre (dyn/cm²).

Mass stress

The cross-sections of many fibres and fibre structures are irregular in shape and difficult to measure. To simplify matters a dimension related to cross-section is used, the 'linear density' of the specimen. The linear density may be expressed in denier or tex count and the 'mass stress' then becomes the ratio of the force applied to the linear density (mass per unit length):

$$\text{Mass stress} = \frac{\text{Force applied}}{\text{Linear density}}$$

The units of the mass stress therefore become grams weight per denier or grams weight per tex. Here again, abbreviations are used; 'mass stress' is usually shortened to 'stress' and quoted in grams per denier or grams per tex.

Tenacity or specific strength

The 'tenacity' of a material is the mass stress at break, the units being, of course, grams per denier per tex. An alternative term for tenacity is 'specific strength'.

The value used for the denier of a specimen is usually the nominal denier before testing, no account being taken of the decrease in denier as the specimen is stretched and becomes finer. For some purposes this change is noted and suitable correction made.

It is useful to note that by expressing the breaking strengths of different materials in terms of tenacity, comparisons can be made directly between specimens of varying fineness.

Breaking length

The 'breaking length' is the length of the specimen which will just break under its own weight when hung vertically. Naturally we do not build tall towers in order to measure this breaking length but calculate it from the results of tests on short lengths. The expression

of strength in terms of breaking length is useful for comparing the strength of different fibre structures, e.g. for comparing single fibre strength with the yarn strength. An interesting study which uses this type of comparison is found in Gregory's papers on the structure of cotton yarns (*J. Text. Inst.* **44**, T499 and T515 (1953)). The unit for breaking length is the kilometre.

If, for example, a 100 denier viscose rayon yarn broke at a load of 185 g, the breaking length would be:

$$\frac{185 \times 9000}{100 \times 1000} = 16{\cdot}65 \text{ km}$$

Strain

When a load is applied to a specimen a certain amount of stretching takes place. The amount will vary with the initial length of the specimen. The 'strain' is the term used to relate the stretch or elongation with the initial length:

$$\text{Strain} = \frac{\text{Elongation}}{\text{Initial length}}$$

Extension

By expressing the strain as a percentage we obtain the 'extension':

$$\text{Extension} = \frac{\text{Elongation}}{\text{Initial length}} \times 100 \text{ per cent}$$

The extension is sometimes referred to as the 'strain percent'.

Breaking extension

The 'breaking extension' is the extension of the specimen at the breaking point.

The load–elongation curve

An extremely important curve is produced when the load on a specimen is plotted against the elongation. This curve describes the behaviour of the specimen from zero load and elongation up to the breaking point. (Loading up to the breaking point is not always required and the test method is varied to suit the object in view.)

From a close study of this curve much important information can be gained, initial Young's modulus, work of rupture, yield point, etc. These characteristics will be defined shortly.

The stress–strain curve

For some purposes it is more convenient to convert the load–elongation curve to a stress–strain curve, thereby enabling more direct comparisons to be made between different types of materials and structures.

Figure 8.1 shows the load–elongation curves of a 250 denier viscose rayon yarn and a 30 denier nylon yarn. The test length in each case was 20 in. and the yarns were tested on a Scott Serigraph which operates on the inclined-plane principle to give a constant rate of loading. To convert the curves to stress–strain curves we must draw up a Table of values of stress and strain derived from measurements on the load–elongation curves. Stress values are obtained by dividing load values by the denier; strain values are calculated by dividing the actual elongation by 20 in., the test length. For instance, at 1 in. elongation the load on the viscose was 272 g. The stress at this point was therefore 272/250, 1·08 g/denier. The corresponding strain was 1/20 or 0·05.

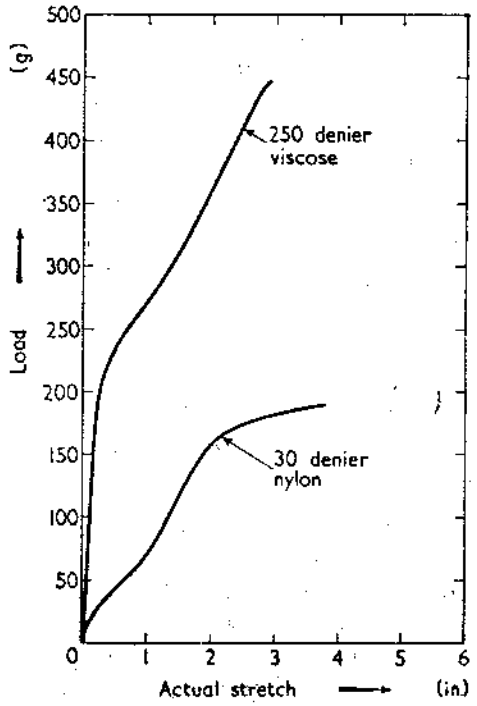


Figure 8.1. Load–extension curves of nylon and viscose obtained on the Scott Serigraph. A C.R.L. testing machine using the inclined-plane principle

Figure 8·2 shows the stress–strain curves derived from the load–elongation curves. The general shape of the curves remains the same but their relative positions have changed. The superior strength of the nylon is more clearly seen and the comparison between the two types of fibre made easier. Meredith's paper on the tensile behaviour of fibres includes numerous stress–strain curves of a range of materials (*J. Text. Inst.* **36,** T107 (1945)).

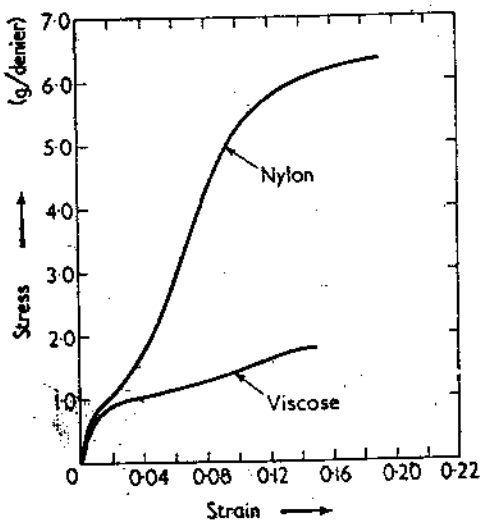


Figure 8.2. The stress–strain curves derived from the load–extension curves for nylon and viscose (Figure 8.1)

The reader may ask 'Why is a stress–strain curve the shape it is and why do different materials have different types of curves?' The stress–strain curves of fibre structures such as fabrics and yarns will reflect the characteristics of the fibre or fibres from which they have been built, modified according to methods used in their construction, e.g. twist, weave, physical and chemical finish, etc. A study of the properties of the fibres is therefore of paramount importance. The shape of the stress–strain curve of a fibre is governed mainly by its molecular structure; for a full discussion of this branch of technology the reader is referred to the standard literature (see the Further Reading list at end of this chapter). A general and simplified note is offered here in order to focus attention on the problem. (See Figure 8.3.)

When an external force is applied to a material it is balanced by internal forces developed in the molecular structure of the material.

From his knowledge of fibre structure the reader will be aware of the three-dimensional pattern of long-chain molecules; some are arranged in an orderly manner, known as the crystalline regions, and some are in a more haphazard manner, known as amorphous regions. In the early stages of stretching the material, the elongation is mainly concerned with the deformation of the amorphous regions in which primary and secondary bonds are stretched and sheared. If the stress were removed at this stage most of the extension would be recovered and the material would exhibit elastic properties.

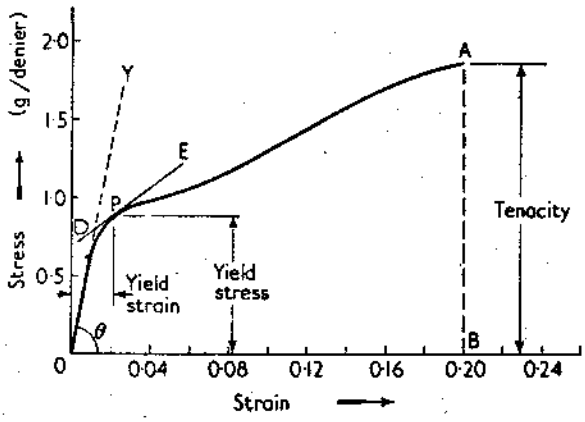


Figure 8.3. Stress–strain curve of viscose derived from a load–extension curve of a 300 denier yarn in approximate standard atmosphere

(1) DE || OA, P is the yield point.
Therefore, Yield stress = 0·88 g/denier
Yield strain = 0·02

(2) Initial Young's modulus = $\tan\theta = \frac{1{\cdot}66}{0{\cdot}02} = 83$ g/denier

(3) Tenacity at break = 1·85 g/denier

(4) Extension at break = 0·20 × 100 = 20 per cent

By increasing the stress further, the stress–strain curve bends sharply and large strains or extensions are produced by small increases in stress. A sort of plastic 'flow' of the material occurs. The long-chain molecules rearrange themselves with further breaking of secondary bonds.

This rearrangement of the molecules puts the material in a better position to withstand further stresses and the rate of extension decreases. The stress–strain curve begins to bend towards the stress axis until finally the breaking point is reached.

Since different materials have different molecular structures it follows that their stress–strain curves will be different. Figure 8.4

shows a number of stress–strain curves for the more commonly used fibres. Since physical and chemical treatments affect the stress–strain properties of textiles, a testing instrument which produces an accurate autographic record of a tensile test is a valuable aid to the textile technologist.

Hamburger's papers on the engineering approach to textile structure emphasise the importance of the stress–strain properties of textile materials (*J. Text. Inst.* **40**, P700 (1949)), and *Marburg Lecture, 1955* (A.S.T.M.).

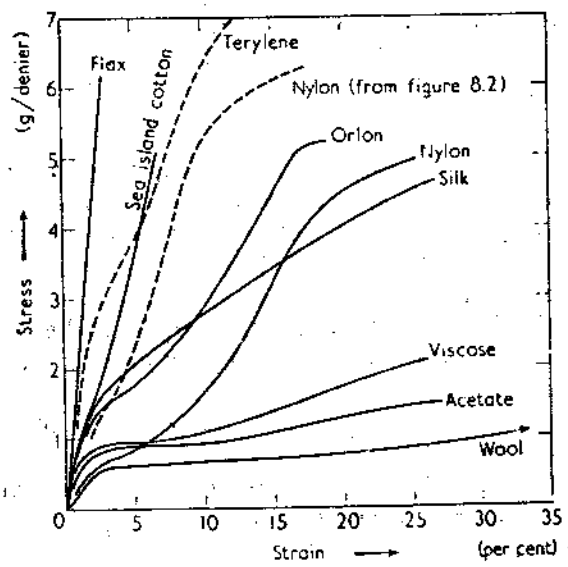


Figure 8.4. Stress–strain curves for various materials. Note: These curves are intended for general comparisons only. The properties of man-made materials can be varied by special processing techniques and their corresponding stress–strain curves are changed. For more precise information consult the references

The initial Young's modulus

A particularly important part of the stress–strain curve is the initial portion starting at zero stress and strain. In Figure 8.3 it will be seen that the first portion of the curve is fairly straight, indicating a linear relationship between the stress and the strain. In other words, the material behaves like a spring and obeys Hooke's Law. In fact, this part of the curve is sometimes referred to as the 'Hookean Region'. The significance of this is that when the load is removed the material recovers its original length or very nearly so.

The tangent of the angle between the initial part of the curve and the horizontal axis is the ratio stress:strain. In engineering science this ratio is termed *Young's modulus*. It gives a measure of the force required to produce a small extension. A high modulus indicates inextensibility and a low modulus great extensibility. In textiles we use the term *initial Young's modulus* and it describes the initial resistance to extension of a textile material.

If the stress is in units of grams per denier, then the initial Young's modulus will also be in grams per denier because the strain is a fraction and has no units.

Another way of expressing the initial Young's modulus is in kilometres weight of the material considered. (Meredith, R. *J. Text. Inst.* **37**, P469 (1946)).

Yield point

The straight part of the curve gives way to a bend and beyond this point, or rather region, the material no longer behaves like a spring or elastic. Large extensions are produced by relatively small increases in the stress and most of the stretch is irrecoverable. This bending or yielding region is located by the *yield point*, which is determined geometrically. The point at which the tangent to the curve is parallel to the line joining the origin and the breaking point is taken as the yield point.

Hence, the yield point may be defined in terms of the yield stress and the yield strain.

Alternative terms for the yield point are 'limit of proportionality', i.e. where the extension ceases to be proportional to the stress, and 'elastic limit'.

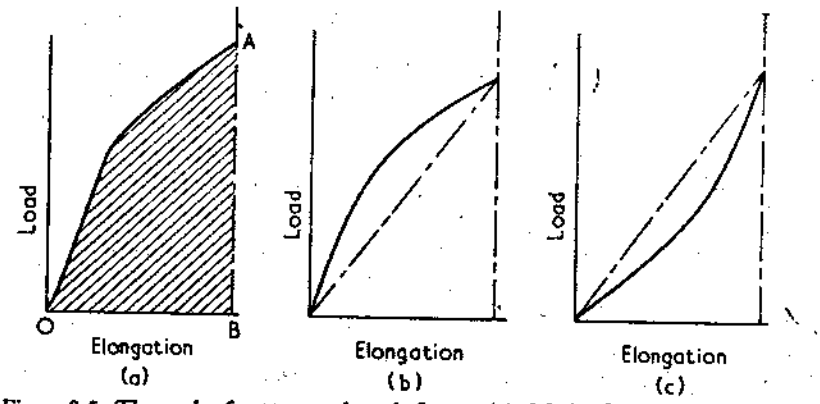


Figure 8.5. The work of rupture and work factor: (a) Work of rupture = area OAB; (b) Work factor > ½; (c) Work factor < ½

The 'work of rupture'

This is a measure of the 'toughness' of the material (see Figure 8.5). It is the energy or work required to break the specimen. The *area* under the load–elongation curve represents the work done in stretching the specimen to breaking point and therefore the units of the work of rupture will be in units of work, e.g. gram-centimetres.

The work of rupture will be proportional to the cross-section of the specimen and to its length. Therefore, in order to enable comparisons to be made the work of rupture may be expressed in gram-centimetres per denier per centimetre length:

$$\frac{\text{Gram.centimetres}}{\text{Denier per centimetre}}$$

i.e.

$$\frac{\text{g.cm}}{\text{den.cm}}$$

This may now be shortened to read as grams per denier. A work of rupture value will indicate the resistance of the material to sudden shock. The 'Ballistic' Tester, discussed later, is used to measure the energy required to break hanks of yarn and to tear fabrics, but in this case the work of rupture is read directly in inch-pounds.

Work factor

If Hooke's Law were obeyed throughout the test, from zero load to breaking load, the stress–strain curve would be a straight line. The ratio

$$\frac{\text{Area under the curve}}{\text{Breaking stress} \times \text{breaking strain}}$$

would therefore be equal to one-half.

For a particular curve this ratio is known as the *work factor*. Thus, for a curve which is concave towards the strain axis (horizontal), the work factor is greater than one-half and, conversely, if the curve is concave towards the stress axis, the work factor is less than one-half (see Figure 8.5).

Elastic recovery

Elasticity may be defined as that property of a body by which it tends to recover its original size and shape after deformation. In an earlier section it was stated that specimens stressed to values within the elastic limit recovered their original size after the stress had been

removed. The power of recovery from a given extension may be expressed by the *elastic recovery* value:

$$\frac{\text{Elastic extension}}{\text{Total extension}}$$

For example (see Figure 8.6), if the original specimen length was AB and it was stretched to a length AD, the total extension would be BD. After removal of the load the length may become AC. The length CD is thus the 'elastic extension'. Therefore,

$$\text{Elastic recovery} = \frac{CD}{BD}$$

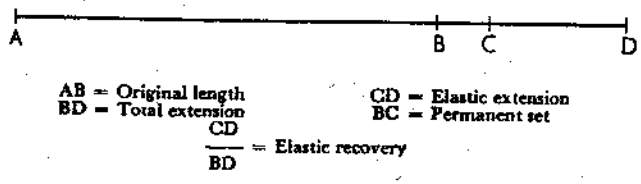


Figure 8.6. Elastic recovery

Perfectly elastic materials will have an elastic recovery of 1·0, while materials without any power of recovery will have a recovery of zero. Elastic recovery may be expressed as a percentage.

Elastic recovery values are affected by several factors, including the time allowed for recovery, the moisture in the specimen, and the total extension used in the test. Therefore, in order to make comparisons between different materials, it is necessary to specify the conditions under which the elastic recovery is determined. It is perhaps useful at this point to have a brief look at the effect of time and extension on elastic recovery values.

Instantaneous and time dependent effects

The study of the behaviour of a specimen can be split into the 'instantaneous effects' and the 'time dependent effects'. Consider the graphs shown in Figure 8.7. A constant load is applied to a specimen for a period of time, OT. Initially the specimen extends rapidly, the instantaneous effect, and then less rapidly, the time dependent effect. The total extension is thus composed of two elements, the 'instantaneous extension and the 'time dependent' extension which we term 'creep'. On the removal of the load the specimen recovers rapidly at

first and then more slowly with perhaps a small amount of residual extension which we call 'permanent set'.

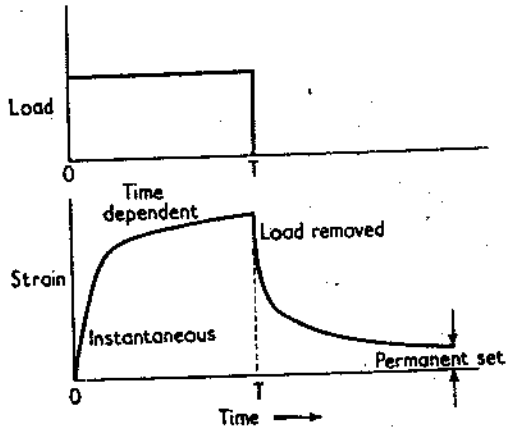


Figure 8.7. Instantaneous and time dependent effects

The instantaneous extension is composed of two quantities, the 'elastic extension' which is recoverable, and the 'plastic' or 'permanent extension' which is not recoverable. Similarly, the time dependent 'creep' may be considered in two parts, 'primary creep' which is recoverable and 'secondary creep' which is not.

Loading the specimen beyond the yield point

Figure 8.8 shows the behaviour of a 300 denier viscose yarn when tested on a Scott Serigraph. The yarn was first loaded to 200 g and then unloaded to zero again. At point X the stress was 0·67 g/denier, below the yield stress of approx. 0·85 g/denier. Because of this most of the total extension OA is recovered at zero load and the elastic recovery is very nearly 1·0. The yarn was then loaded up to about 360 g, the corresponding stress being 1·2 g/denier. It will be noted that point Y is well past the yield point P. The total extension this time was OD. As the load was removed the yarn recovered some of the extension until at zero load the extension was OC. Thus, in this second case the elastic recovery was equal to CD/OD, about 0·25, a very different value to the first one.

In the processing of filament rayons this effect must be fully appreciated and running tensions adjusted to values which are well below the yield point. Over-stretched yarn becomes more lustrous and a fault known as 'shiners' is produced in the fabric.

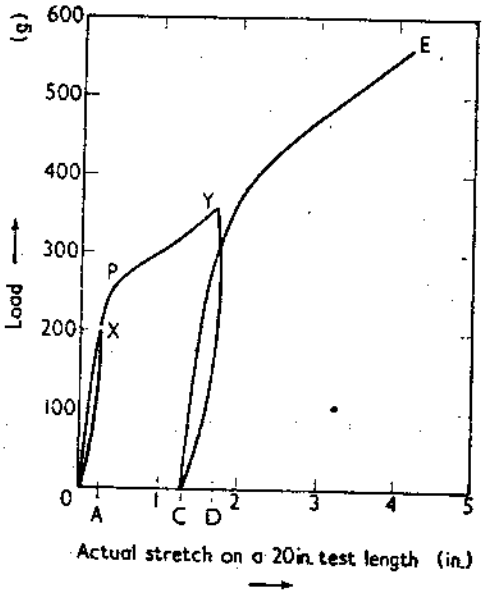


Figure 8.8. Load–extension curve for 300 denier filament viscose yarn showing the effect on elastic recovery when the specimen is loaded beyond the yield point

The yarn in the test was then taken to its breaking point. The final stress–strain curve, CE, is a different shape to OY. This illustrates the point that the previous history of a specimen can alter its tensile behaviour. In this case the 'history' was mechanical conditioning by stretching.

Elastic recovery and dimensional stability

One aspect of dimensional stability, especially in clothing, is the ability of a garment to keep its shape. A suit made from a material with poor elastic recovery properties would very soon exhibit baggy knees in the trousers and baggy elbows in the jacket.

SOME FACTORS AFFECTING THE TENSILE PROPERTIES OF TEXTILES AND THE RESULTS OBTAINED FROM TESTING INSTRUMENTS

Test specimen length

Consider the graph in Figure 8.9(a), which shows the strength or 'breaking load' of the specimen at infinitely small increments of length along the complete length AB. If we tested the specimen at a gauge length AB the strength recorded would be that of the weakest

point and the value would be S_1. If we had tested the specimen in two halves we would have obtained two breaking loads, S_1 and S_2, the mean of which would be *higher* than S_1. Hence, by testing the yarn at a shorter gauge length the apparent yarn strength has increased. This effect is known as the 'weak link' effect and is discussed in Peirce's paper on testing (*J. Text. Inst.* **17**, T355 (1926)).

The more irregular the material is, the greater will be this effect. Suppose an irregular yarn A, Figure 8.9(b), and a regular yarn B were being compared with respect to their single thread strength properties. If the test length chosen were long, then the regular yarn B would produce the higher strength, but with shorter test lengths the mean strength of yarn A would approach the value S_a, a higher value than S_b. Hence, by adjusting the test lengths it would be possible to reverse the ranking of the two yarns.

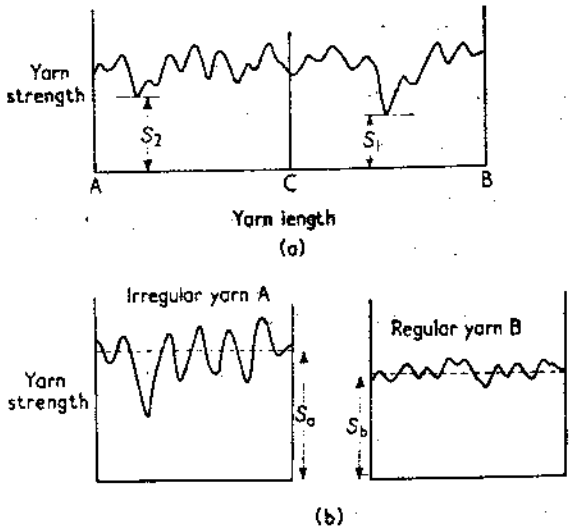


Figure 8.9. The 'weak link' effect: (a) The strength or 'breaking load'; (b) Yarn A would give a higher mean strength, S_a, *than yarn B,* S_b, *if tested over short lengths, but would give a higher end-breakage rate in processing due to incidence of very weak places*

From a processing point of view a yarn with a slightly lower mean strength but of greater uniformity is preferable to a yarn of higher mean strength but irregular. It is the incidence of weak places which is one cause of excessive end-breakages in winding and weaving, etc.

A relationship between the strength, test length, and irregularity has been established (see Peirce's paper above).

Table 8.1. Some Test Lengths Used in Tensile Tests

Test length	*Type of test*
Zero	Pressley fibre bundle test
0·125 in.	Stelometer, Clemson fibre bundle test
1·0 cm	Single fibre tests (Meredith, R. *J. Text. Inst.* **36**, T107 (1945))
7 in.	Yarn from cloth samples (B.S. Handbook, p. 139 (1963))
8 in.	Fabric, B.S. 2576:1959 (B.S. Handbook, p. 249 (1963))
20 cm	Fabric, B.S. 2576:1959 (B.S. Handbook, p. 249 (1963))
20 in.	Yarn from packages, B.S. 1932:1953 (B.S. Handbook, p. 135)
50 cm	Yarn from packages, B.S. 1932:1953 (B.S. Handbook, p. 135)
1·25 in., 2 in., 4 in., and 7 in. diameter	Specimen dimensions for bursting test (B.S. Handbook, p. 260 (1963))
10mm and 50mm	Fibre and Filament Tests (*J. Text. Inst.* **50**, P776 (1959))

Let S_l = the mean strength of the specimen at test length l
S_{rl} = the mean strength of the specimen at test length rl, and
σ_l = the standard deviation of the measured strength at length l.

Then,

$$S_l - S_{rl} = 4{\cdot}2(1 - r^{-\frac{1}{2}})\sigma_l \qquad \ldots (8.1)$$

It is more convenient to use the coefficient of variation than the standard deviation. Therefore,

$$\text{Let the coefficient of variation, } V, = \frac{\sigma_l}{S_l} \times 100$$

Dividing equation (8.1) throughout by S_l, we get

$$1 - \frac{S_{rl}}{S_l} = 4{\cdot}2(1 - r^{-\frac{1}{2}})\frac{V}{100} \qquad \ldots (8.2)$$

From equation (8.2) we obtain the ratio

$$\frac{\text{Strength at test length } rl}{\text{Strength at test length } l}$$

$$\frac{S_{rl}}{S_l} = 1 - \left[\frac{4{\cdot}2(1 - r^{-\frac{1}{2}})\ V}{100}\right]$$

(Note: The irregularity considered is that for strength results, *not* irregularity of cross-section or linear density.)

The rate of loading and the time to break the specimen

A rapid test produces a higher breaking load than a slow test. An

empirical relationship has been established between the strength values obtained and the time taken to break the specimen (Midgley, E., and Peirce, F. T. *J. Text. Inst.* **17**, T330 (1926)).* Since this relationship appears to apply to yarns and fabrics as well as to fibres, it is evidence to show how yarn and fabric properties depend mainly on fibre properties.

Let F_T = the breaking load for a time to break of T sec, and
F_{10} = the breaking load for a time to break of 10 sec.

Then,

$$F_T = F_{10}(1{\cdot}09 - 0{\cdot}09 \log T)$$

By rounding off the figures we obtain

$$F_T = F_{10}(1{\cdot}1 - 0{\cdot}1 \log T)$$

Therefore, $\dfrac{F_T}{F_{10}} = 1{\cdot}1 - 0{\cdot}1 \log T$

$$\frac{F_T}{F_{10}} - 1 = 0{\cdot}1 - 0{\cdot}1 \log T = 0{\cdot}1(1 - \log T)$$

$$= 0{\cdot}1 \ (\log 10 - \log T)$$

Therefore,

$$\frac{F_T - F_{10}}{F_{10}} = 0{\cdot}1 \log \left(\frac{10}{T}\right)$$

Example. A yarn gave a strength of 200 g when the time taken to break was 10 sec. Estimate the breaking load if the rate of loading was increased to cause the yarn to break in 1 sec.

$$F_1 = F_{10}\ (1{\cdot}1 - 0{\cdot}1 \log 1{\cdot}0)$$
$$= 200(1{\cdot}1 - 0{\cdot}1 \times 0{\cdot}0)$$
$$= 200 \times 1{\cdot}1 = 220 \text{ g}$$

The percentage increase $= \dfrac{F_1 - F_{10}}{F_{10}} \times 100$

$$= \frac{220 - 200}{200} \times 100$$
$$= 10 \text{ per cent}$$

If some other standard time than 10 sec is chosen, S sec, then

$$\frac{F_T - F_S}{F_S} = 0{\cdot}1 \log \left(\frac{S}{T}\right)$$

*See also Morton, W. E., and Hearle, J. W. S. *Physical Properties of Textile Fibres*, p. 353 (Textile Institute; Butterworths, London, 1962).

Figure 8.10 shows the load–extension curves produced when testing a sample of 60 denier nylon at different rates. (The curves are the results of only one test at each speed.)

In the B.S. Handbook, No. 11, p. 135 (1963), the time to break recommended for single thread testing is 20 ± 3 sec, but it should be noted that this standard is applied to constant rate of loading testers only. For constant rate of traverse machines no time is specified.

On the 'Uster' single thread tester there is a speed control which allows the rate of loading to be adjusted so that the specimen breaks in approximately 20 sec.

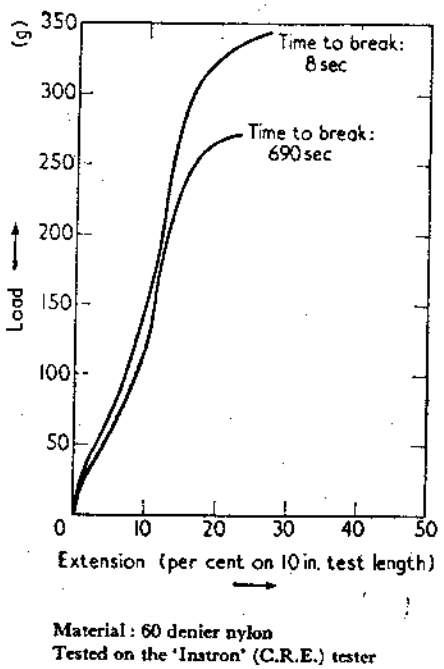


Figure 8.10. Load–extension curves obtained at two rates of extension

The capacity of the machine

If a weak specimen is tested on a high-capacity machine the time to break it will be short, and therefore an optimistic strength result will be produced. The capacity of the machine should be chosen so that the time required to break the specimen is close to the recommended time.

The effects of humidity and temperature

The mechanical behaviour of textile fibres and fibre structures is influenced by the amount of moisture in the specimen. The moisture relationships of the various fibre types differ and naturally the degree to which the fibre properties are modified will vary. The stress–strain curve for a hydrophobic material such as Terylene when tested in the dry state will be similar to the curve obtained from a wet test. On the other hand, the curves obtained when testing say acetate rayon dry and wet will exhibit significant differences (see Figure 8.11).

For routine testing it is essential that a standard testing atmosphere is maintained in the laboratory. The standard atmosphere is defined in B.S. 1051 : 1953 as 'an atmosphere at the prevailing barometric pressure with a relative humidity of 65 per cent and a temperature of 20° C'. A tolerance of ± 2 per cent r.h. and a tolerance of ± 2° C are allowed for a testing room atmosphere.

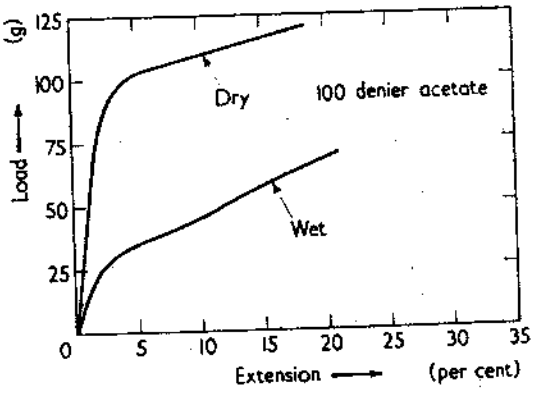


Figure 8.11. The effect of moisture on load–extension characteristics

Even though a testing laboratory may have a controlled atmosphere, it is not good practice to take in samples and immediately start to test them. Sufficient time should be allowed for the samples to reach equilibrium conditions before the tests are made. The time required will vary and depend mainly on the form in which the material is available. Some examples which follow are taken from B.S. Handbook No. 11 (1963).

Fibres (tested for linear density): 15 min in a standard atmosphere.
Sample skeins of yarn (count test): Not less than 4 hr in 10 per cent r.h. and then allowed to reach equilibrium.

Yarn reeled into hank form for single thread strength testing: Precondition at a r.h. not exceeding 10 per cent at a temperature of 50° C for 4 hr. Condition in a standard atmosphere for 24 hr.
Fabrics (breaking strength): Similar procedure to that for single thread test.

For special testing in research and in the critical evaluation of materials destined for use under extreme conditions of moisture and temperature, the testing conditions will obviously be varied over a wide range, e.g. tyre cords in tropical and Arctic conditions. For further details the reader is recommended to study the literature, in particular Meredith's *Mechanical Properties of Textile Fibres*, Kaswell's *Textile Fibres, Yarns, and Fabrics*, Morton, W. E., and Hearle, J. W. S. *Physical Properties of Textile Fibres*, and Hearle and Peters *Moisture in Textiles*. In all these books numerous examples and references are given.

The previous history of the specimen

We have seen already that the behaviour of a specimen after it has been strained beyond its yield point differs from its behaviour in an unstrained condition. Chemical treatment, too, may also affect the tensile properties of the specimen. Damage to the fibre by chemical attack can cause serious tendering of the fibre. It is therefore desirable to know the previous history of the specimen if erroneous conclusions are to be avoided.

The form of the test specimen

In many tests the specimen is a composite structure built up from individual fibres or filaments. The complexity of the structure may range from a relatively simple flat bundle, as for the Pressley strength test, through the more complicated structure of single and plied yarns to woven and knitted fabrics and other forms of manufactures. The fundamental fibre properties, while still being the foundation on which the structure is built, may be modified by the interaction of structural details. A very simple example is well known to spinners of staple fibres. Changes in the twist factors used cause changes in the yarn strength, elasticity, liveliness, lustre, and other yarn characteristics. The fabric designer comes up against problems involving the effect on warp way properties of changes in weft way construction details such as picks per inch, count, and crimp.

The man who carries out the testing of the specimens must be aware of these interrelated factors, noting any curious behaviour or unexpected results and asking himself 'why?'

THE MECHANICS OF TENSILE TESTING MACHINES

The range of tensile testing machines is quite wide since the specimen may be anything from a single fibre to a conveyor belt. No matter which instrument is used it is only a means to an end. The important part of the test is the result, its interpretation and the action taken when a decision is made, based on the result.

Testing instruments of near perfect accuracy are few in number and require the attention of experts. When tests are carried out in the mill, the requirements of the instruments used, with regard to extreme accuracy, are not high. The testing conditions are kept more or less the same and nominally the same material is being tested from day to day. Similarly, the techniques used need not be of research standards. In research and in accurate mill experiments the requirements are much more exact; differences in behaviour which may be overlooked in everyday routines may now assume greater importance. Moreover, tests in research involve comparison between different materials; hence, special demands are made on the instruments used and a greater range of information is frequently required.

The merits of a testing instrument are great if it can be used for both mill testing and experimental work.

THE APPLICATION OF LOAD AND ELONGATION TO TEXTILE SPECIMENS

Basically, two methods are used to observe the effect of tensile forces on textile specimens, 'constant rate of loading' (C.R.L.) and 'constant rate of extension' (C.R.E.).

Consider two identical specimens A and B in Figure 8.12. Specimen A is gripped in a fixed-top jaw J_1 and in a bottom jaw J_2 which

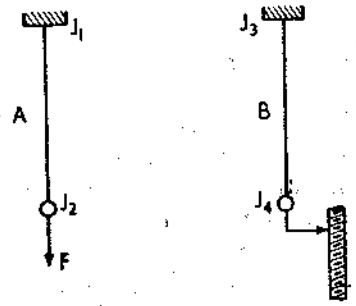


Figure 8.12. C.R.L. and C.R.E. principles

is movable. A force F, initially zero but increasing at a constant rate, is applied to the specimen in a direction shown. The effect of applying this force is to extend the specimen until it eventually breaks. The loading has thus caused the elongation. Here we have C.R.L. conditions.

Specimen B is gripped in the fixed-top jaw J_3 and in the bottom jaw J_4 which can be moved downwards at a constant velocity by means of a screw mechanism. Initially, the tension in B is zero but when the bottom jaw J_4 moves downward the specimen is extended and an increasing tension is developed until the specimen finally breaks. In this case the cause and effect are the other way round, extension causes loading. Here we have C.R.E. conditions.

Let OA in Figure 8.13 be the load–elongation curve of a specimen, and suppose that it is obtained when tested under both C.R.L. and C.R.E. conditions. Further, let us assume that the time to break the specimen was 10 sec in both cases. It will be noted that when tested under C.R.E. conditions the tension developed in the specimen is quite high after only 3 sec and that the specimen spends most of the duration of the test at the higher loads. In practice, the stress–strain curves obtained by testing under both may not in fact be identical.

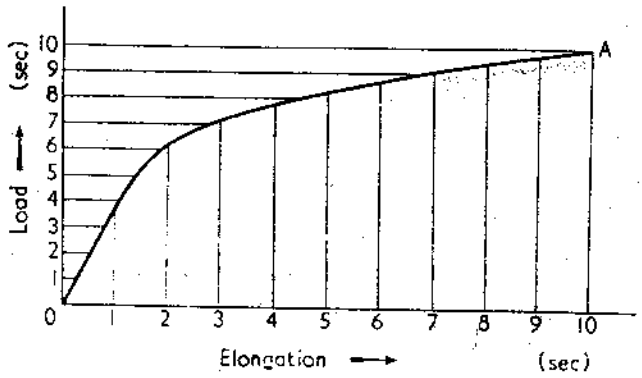


Figure 8.13. Testing under C.R.E. and C.R.L. conditions

In some testing instruments based on the C.R.E. principle the top jaw is not fixed but needs a certain amount of movement in order to operate the load-indicating mechanism. This movement relative to the bottom jaw prevents the extension of the specimen at an absolutely constant rate. Nevertheless, the bottom jaw *traverses* downwards at a constant rate and therefore the machines are referred to as *constant rate of traverse* testers, or C.R.T. machines.

At first glance it might appear that it is immaterial which method is used, but a closer study will reveal some important differences.

The effect of the specimen length

Under C.R.L. conditions the rate of loading both short and long specimens is the same. On the other hand, if the specimen length in a C.R.E. machine is *increased*, the rate of loading will be *decreased*.

Figure 8.14 shows load–elongation curves obtained on the Scott Serigraph, a C.R.L. instrument, and on the Instron, a C.R.E. machine.

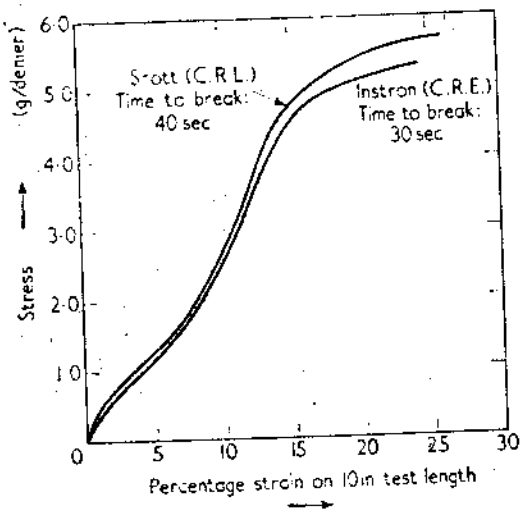


Figure 8.14. Stress–strain curves for 60 denier nylon yarn tested on C.R.L. and C.R.E. testing machines

Constant rate of stress

A third method of loading the specimen is to increase the stress at a constant rate. Since stress is the force per unit area it follows that any change in the cross-sectional area of the specimen during the test will affect the value of the stress. Thus, even if the load is increased at a constant rate a reduction in the cross-sectional area will cause the rate of increase in stress to increase. Some research instruments are designed or used in special ways to achieve a constant rate of increase in stress.

Table 8.2. Some Types of Tensile Strength Testing Instruments

Principle	*Application*	*Type*
Pendulum lever	Single fibre	Balls Magazine Hair Tester (Matthews. *Textile Fibres* (6th Edn), p. 1228); Baer (*Baer Catalogue*)
	Fibre bundle	Stelometer; Clemson
	Single thread	Goodbrand; Baer; Scott; Moscrop Automatic (Lomax. *Textile Testing* (2nd Edn), p. 80)
	Lea or skein	Goodbrand; Baer; Scott; Heal
	Fabric (vertical and horizontal)	Goodbrand; Baer; Scott; Heal; Avery Type 7105 CCG Multi-purpose (yarns, cloth)
Balance	Single fibre	Barratt, loading by solenoid (*J. Text. Inst.* **13**, T17 (1922)); De Meulemeester and Nicoloff, chainomatic (*J. Text. Inst.* **26**, T147 (1935)); Krais-Keyl, water loading (Matthews. *Textile Fibres* (6th Edn), p. 1227)
	Fibre bundle	Pressley
	Fabric	Denison Model T42F Multi-purpose (single threads, cords, skeins, fabrics); Goodbrand, lead shot loading (Garner, *Textile Laboratory Manual* (2nd Edn), p. 141))
Spring	Single fibre	Cambridge Extensometer (fibres and fine yarns); Cliff (fibres and yarns, coil spring in torsion) (*J. Text. Inst.* **24**, T351 (1933))
	Single yarns	Shorter Hall, flat spring (*J. Text. Inst.* **14**, T493 (1923))
	Fabric	Harrison, torsion bar (*J. Text. Inst.* **46**, T226 (1955))
Inclined plane	Single yarn	Uster Automatic; Scott I.P.2
	Fabric	Scott I.P.4 (heavy yarn, cords, fabric); Brown (*J. Text. Inst.* **43**, T119 (1952))
Ballistic or impact	Fibre bundle	Lang (*J. Text. Inst.* **42**, T314 (1951))
	Yarns and fabric	Goodbrand

Principle	*Application*	*Type*
Strain gauge or transducer	Yarn	Strainometer, British Rayon Research Association (Technological Reprint No. 16); Enka and Breda AKU Electronic Dynamometer (*Ray. Rev.* **9**, Nos. 4 and 5); Enka and Breda Continuous E Modulus Meter (*Ray. Rev.* **11**, No. 5)
Strain gauge or transducer	Multi-purpose	Instron (fibres, yarns, fabrics); Scott Accr-o-meter (fibres, yarns, fabrics (*Scott Catalogue*))
Constant-tension winding test	Running yarn	B.C.I.R.A. (B.S. Handbook No. 11, p. 102 (1956)); Cook (Cook's publication *The Principle of Continuous Testing*, by A. H. Milnes); Goshawk (*J. Text. Inst.* **42**, P1 (1951))
Dynamic testers	Special research instruments for measuring the modulus of dynamic elasticity and stress–strain properties at high speed	(Ballou and Siverman. (*Text. Res. J.* **14**, p. 282 (1944)); (de Vries. *Ray. Rev.* **10**, No. 2 (April, 1956)); (Cross and Garrett. (*J. Text. Inst.* **47**, T222 (1956))
Hydraulic testers	Bursting testers for fabrics	Goodbrand Catalogue

THE PENDULUM LEVER PRINCIPLE WITH CONSTANT RATE OF TRAVERSE

In Figure 8.15 consider a specimen clamped in the upper jaw J_1 and the lower jaw J_2. J_1 is attached to a steel tape which runs over a small pulley of radius r. J_2 is given a constant rate of traverse in a downward direction, perhaps by a screw mechanism. The small pulley is pulled round and in doing so swings the pendulum P from the vertical. Let the mass of the pendulum be M and its centre of gravity at a distance R from the pivot of the small pulley.

Assuming the specimen to be inextensible and an absence of any dynamic effects, let us consider the conditions obtaining at any chosen instant when the angle through which the pendulum has moved is θ radians. Taking moments about the pivot of the small pulley:

$$F_T = Mgx = MgR\sin\theta$$

The values of MgR and r are constant,

Therefore, $$F \propto \sin \theta$$

Since F is the force acting in the tape, it is also equal to the tension in the specimen. Thus, the tension in the specimen is proportional to the sine of the angle through which the pendulum has been swung.

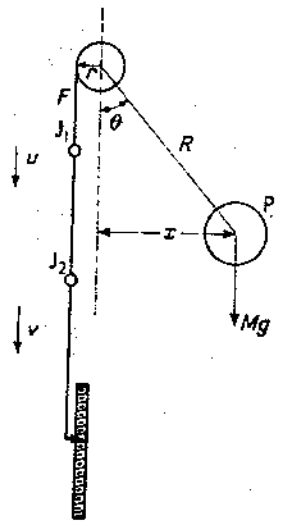


Figure 8.15. The pendulum lever principle

The 'machine rate of load' (μ)

This is the increase in the load per unit increase in the displacement of the upper jaw.

At the instant chosen, let θ increase by a small amount $d\theta$, giving rise to an increase in load dF. Then,

$$\frac{dF}{d\theta} = \frac{MgR}{r} \cos \theta$$

The corresponding movement of J_1 is $r d\theta$. Hence, μ, the machine rate of load, becomes

$$\frac{dF}{r d\theta} = \frac{MgR \cos \theta}{r^2}$$

The 'time rate of loading' (L)

This is the rate at which the load on the specimen increases with respect to time. Let v be the velocity of the lower jaw J_2. Then,

$$v\mathrm{d}t = r\mathrm{d}\theta$$

(velocity × time = distance, and also radius × angle θ = distance).

Therefore,
$$\frac{\mathrm{d}\theta}{\mathrm{d}t} = \frac{v}{r}$$

Then,
$$L = \frac{\mathrm{d}F}{\mathrm{d}t} = \frac{\mathrm{d}F}{\mathrm{d}\theta} \times \frac{\mathrm{d}\theta}{\mathrm{d}t} = \frac{MgR\cos\theta}{r} \times \frac{v}{r}$$

$$= \frac{MgRv\cos\theta}{r^2}$$

$$= \mu v$$

Because
$$\mu = \frac{MgR\cos\theta}{r^2}$$

Hence, L is proportional to $\cos\theta$.

Thus, the time rate of loading varies throughout the test. It is a maximum at the start when θ is 0 and $\cos\theta$ is 1, and minimum when the pendulum has swung through 90 degrees, i.e. $\pi/2$ radians and $\cos\pi/2$ equals 0.

The 'standard machine rate of load' (μ_o)

The quantity MgR/r^2 is a constant for any particular machine and is referred to as the 'standard machine rate of loading', μ_o. In practice, θ must be restricted to 45 degrees. In this case, for any given rate of traverse (still assuming an inextensible specimen) the maximum change in the rate of loading is in the ratio cos 45 : cos 0, i.e. 0·707. Thus, the rate of loading is approximately 30 per cent less at the 45 degree limit than at the start.

In order to give comparable conditions of test between machines in different laboratories, both v and μ_o must be standardised. Many commercial machines are standardised at μ_o = 1,100 lb/in. The traverse speed of the bottom jaw is often specified as 12 in./min for single yarns and yarns in lea form, and 4½ in./min for fabric testing.

It is undesirable to use any instrument, especially the pendulum type of machine, at breaking loads less than 10 per cent of the capacity of the machine. Thus, a restricted range is offered on a

particular machine. Where a wide range of materials is to be tested a range of machines is required. In theory, it should be possible to have machines all having the same standard machine rate of load; in practice, this cannot be done for small capacity machines and so many small capacity testers use 240 lb/in.

The effect of specimen extension

The discussion above has assumed that the specimen tested was inextensible, giving the upper jaw the same velocity as the bottom jaw. The rate of loading and the time to break are influenced by the extension of the specimen. The velocity of the upper jaw is less than that of the lower jaw by an amount depending upon the extensible properties of the material.

Let P_{max} = the breaking load in pounds,

m = inches per pound (the reciprocal of μ_o in pounds per inch), and

e = the elongation of the specimen.

Assuming a linear load–extension curve and neglecting the effect of changes in θ, the movement of the upper jaw at the breaking load is mP_{max} inches. The movement of the bottom jaw is $mP_{max} + e$ (inches).

The time, T, to break the specimen is given by

$$T = \frac{mP_{max} + e}{v} \text{ (seconds)}$$

i.e. the distance moved by the bottom jaw divided by its velocity.

Example. Let extension at break be 7 per cent,
specimen length be 8 in.,
breaking load be 220 lb (P_{max}),
standard machine rate of loading, μ_o, be 1,100 lb/in.,
and rate of traverse be v.

Extension, e, $= 8 \times 0{\cdot}07 = 0{\cdot}56$ in.

$$m = \frac{1}{1100} \text{ in./lb}$$

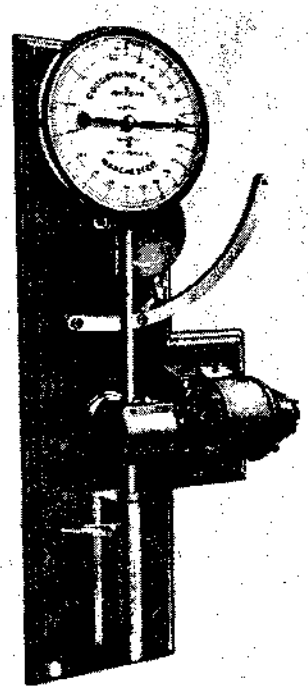
$$\text{Time to break, } T, = \frac{(220/1100) + 0{\cdot}56}{v}$$

$$= \frac{0{\cdot}2 + 0{\cdot}56}{v}$$

This last equation shows that the extension of the specimen plays a greater part in determining the time to break than the standard machine rate of loading.

The effects of inertia

Overthrow. When the specimen breaks the pendulum will have an angular velocity depending upon the rate of traverse of the bottom jaw and on the extension of the specimen. The pendulum possesses kinetic energy and will continue to move until the energy has been dissipated. The recorded load will therefore be excessive by an amount depending upon the angular velocity of the pendulum at the moment of break. This 'overthrow' error is greatest for small loads but may be reduced by having a lower rate of traverse. Materials whose breaking load is less than 10 per cent of the machine capacity should be tested on a lower capacity machine.



(By courtesy of Goodbrand & Co. Ltd)

Figure 8.16. Pendulum lever machine. The lea tester

Further, inextensible materials will give higher overthrow errors because the velocity of the upper jaw will be near to the velocity of the bottom jaw, giving the pendulum a higher angular velocity.

Acceleration error. At the start of a test the specimen will stretch before a load is recorded. During this initial period tension is being developed in the specimen until it is sufficient to overcome the inertia of the pendulum. Eventually the force is high enough and the pendulum begins to move. The force is then greater than the force required to keep the pendulum moving at its required angular velocity. Overshooting occurs and the specimen *slackens* when, in fact, an *increase* in load is being *recorded.*

On an autographic machine the load–elongation curve will be initially flat (extension without apparent load), and the curve will be rather wavy in the earlier stages. The error is again higher for high rates of traverse and for inextensible materials.

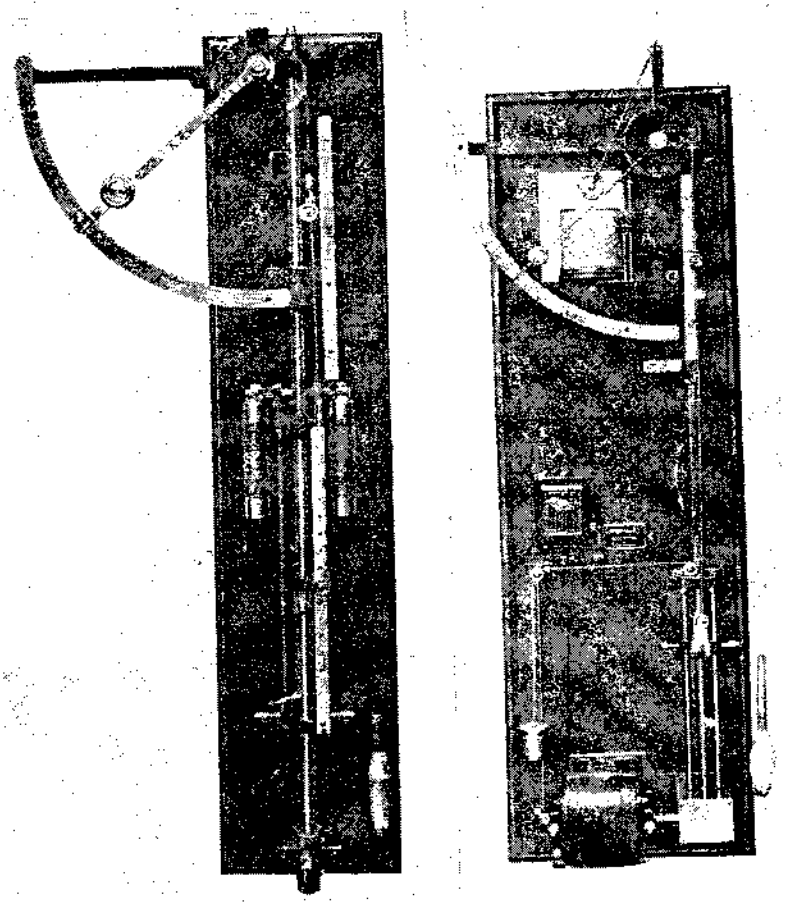
Note: This treatment of the mechanics of the pendulum lever principle is based on the work of Peirce (*J. Text. Inst.* **17**, T342 (1926)) and Martindale and Woods (*J. Text. Inst.* **33**, S24 (1942)). For a fuller discussion the reader is referred to these papers.

*The scales of pendulum lever testing machines**

We have seen that the load on the specimen is proportional to the sine of the angle through which the pendulum has moved. This relationship causes the scale spacing of the recording or indicating device to be uneven. The calibration marks are close at the start of the scale, gradually becoming more widely spaced. In lea testers this uneven calibration is accepted, but on some single-thread testers special arrangements are made to obtain an evenly calibrated scale. One method is to use an eccentric top pulley over which the steel tape runs. The tape acts on a maximum radius at the start of the test and the radius decreases as the pendulum swings further out. A second method is to use an auxiliary pendulum acting in conjunction with the main pendulum. Figure 8.17 illustrates these two methods.

It must be appreciated that an even scale does not mean that the tester therefore becomes a constant rate of loading machine.

*See also Bakker, E., and Burton, R. H. 'Device for Checking the Calibration of Pendulum-type Tensile Testers under Dynamic Conditions.' *J. Text. Inst.* **54**, T267 (1963).



(a) (b)

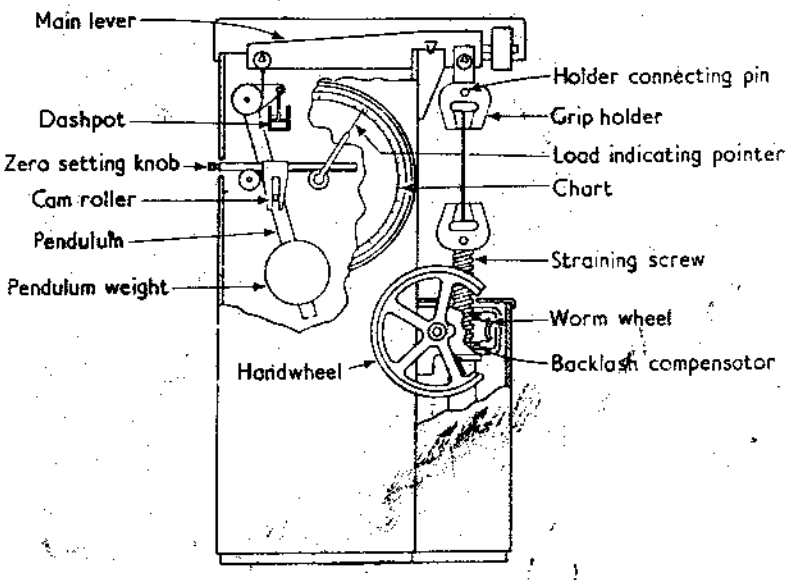
(By courtesy of Goodbrand & Co. Ltd)

Figure 8.17. Pendulum lever machines. Single-thread strength testers: (a) An eccentric top pulley to obtain an even scale; (b) An auxiliary pendulum to obtain an even scale. Note the autographic recording device

Constant rate of loading with a pendulum lever machine

One of the disadvantages of the pendulum lever machine is that the rate of loading varies throughout the test, the reasons for this having already been discussed. Machines are available, however, which although using the pendulum lever principle incorporate a special load pacing device which enables C.R.L. tests to be made.

Figure 8.18 shows the general mechanism of an Avery machine. To obtain C.R.L. conditions a disk concentric with the dial scale is rotated by a motor-driven variable-speed gearing (Figure 8.19). This disk has a series of spots near its edge. When a test is made the rate of loading is selected and the speed of the disk adjusted. The pointer which indicates the load is then kept in step with the disk by means of a handwheel control, the spots on the disk helping the operator to keep the pointer in step. In effect, the operator accounts for the extension of the specimen and at the same time maintains a constant rate of loading, or very nearly so.



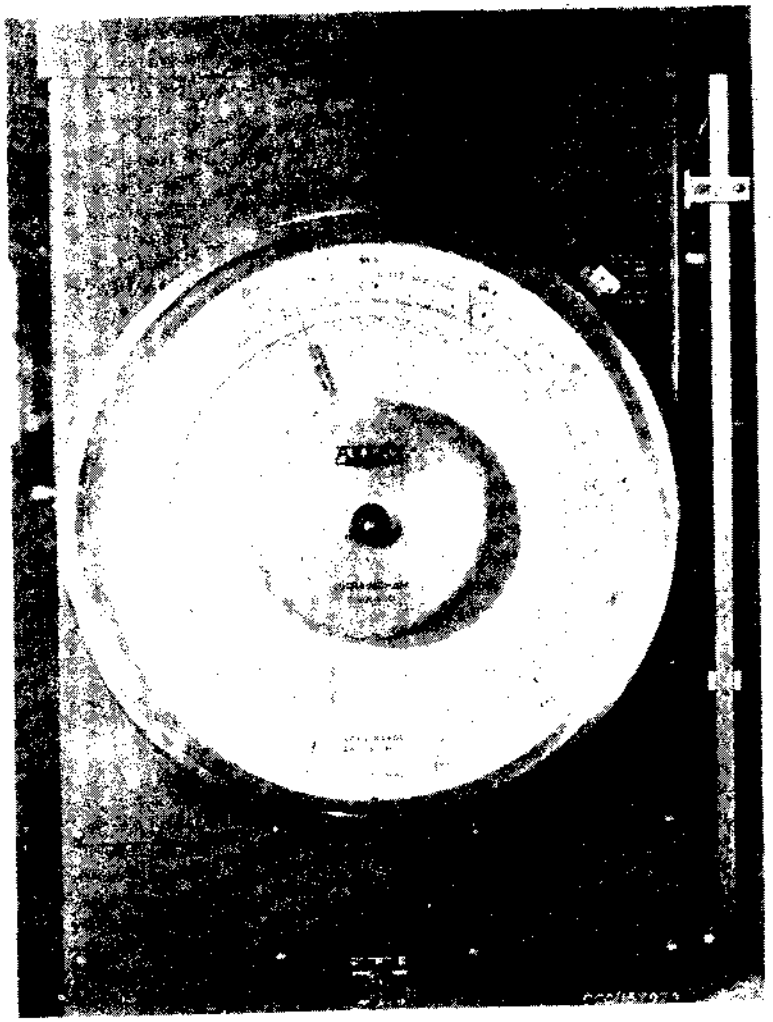
(By courtesy of Avery Ltd)

Figure 8.18. The Avery tester

The Stelometer

The pendulum lever principle of loading is used in this cotton fibre bundle strength testing instrument designed by Hertel and made by Special Instruments Laboratory Inc. of U.S.A. Its name is coined from ST-rength and EL-ongation, the two fibre properties measured. Measurement of elongation is possible since the sample may be tested with the Pressley jaws separated by $\frac{1}{8}$ in., as opposed to the more usual zero gauge length used in flat bundle testing. An

important feature of the instrument is the ingenious method by which its designer has eliminated the inertia errors normally associated with pendulum lever instruments.



(*By courtesy of Avery Ltd*)

Figure 8.19. The load indicator and load pacing disk of the Avery tester

A random sample of cotton fibres is prepared, short fibres being removed by combing so that all the fibres in the test specimen extend all the way through the jaws. Figure 8.20 shows the main components of the Stelometer. One of the Pressley jaws, J_1, is mounted in the adjustable jaw holder carried by the beam. The other jaw, J_2, is mounted at the top end of the pendulum. The beam carries the pendulum which is pivoted at O. The centre of gravity of the beam is to the right of its axis of rotation, A, and therefore when a retaining catch is taken off, the beam rotates in a clockwise direction. The centre of gravity of the pendulum coincides with the axis of rotation, A; thus, the heavy mass of the pendulum bob has minimum movement and inertia effects are largely eliminated. Consider the conditions obtaining when the beam is inclined at an angle θ to the vertical. Assuming for the moment that the specimen has not stretched, the pendulum will also be inclined at an angle θ to the vertical. In Figure 8.21 let GOQ represent the pendulum and let F be the force in the fibre bundle. The design of the instrument

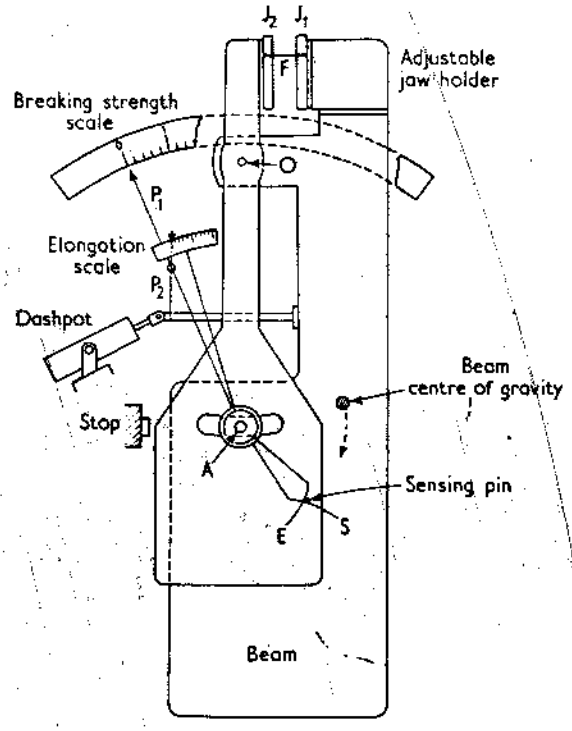


Figure 8.20. The Stelometer

ensures that the force F will nominally act at right angles to GOQ. The clockwise moment of F about the pendulum pivot O will be

$$F \times OQ$$

This moment is balanced by the anticlockwise moment of W, the weight of the pendulum, about O,

$$W \times OG \sin \theta$$

Hence, $$F \times OQ = W \times OG \sin \theta$$

Therefore, $$F = W \times \frac{OG}{OQ} \sin \theta$$

and $$F = k \sin \theta$$

(since W, OG, and OQ are constant)

Hence $$F \propto \sin \theta$$

Thus, the load on the fibre bundle is directly proportional to the sine of the angle through which the pendulum has moved. Therefore, if the rotation of the beam can be so controlled that sin θ varies at a constant rate, then the rate of loading will be constant.

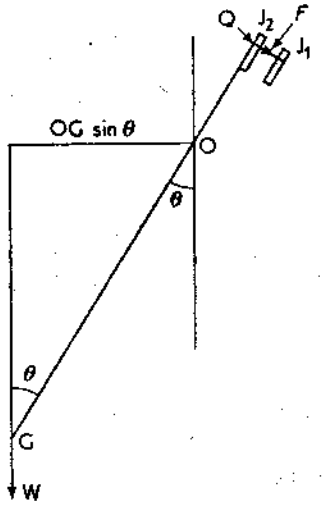


Figure 8.21. The principle of the Stelometer

Beam rotation is controlled by a special dashpot device. A rod secured to the beam is connected to the piston rod of the dashpot, thereby applying a restraining force to the beam as it swings round the axis A (Figure 8.20). The geometry of the system is so designed that the angular velocity of the beam is such that sin θ varies at an

approximately constant rate and therefore the rate of loading is approximately constant. Dashpot adjustment is made so that the rate of loading normally used is 1 kg/sec.

The breaking load is indicated by the pointer P_1 which moves over the large scale graduated from 2 to 7 kg. This pointer, P_1, is freely mounted on the axis A and is driven by the sensing pin fixed in the pendulum, the pin pushing the cam S. As soon as the test fibre bundle breaks, the sensing pin falls away from the cam S and the pointer P_1 stops immediately; the breaking load can then be read directly from the scale.

The percentage of elongation is indicated on a small scale by the pointer P_2 which is suspended from the arm of pointer P_1. The scale itself is driven by the sensing pin pushing along cam E; in this way the scale is given a clockwise movement. Now, if no elongation at all took place then both the pointer P_1 and the elongation scale would move together and the pointer P_2 would remain opposite the zero mark on the scale. Elongation of the fibre bundle causes the sensing pin to change its position along cam E and the scale lags behind the movement of P_1. Thus, the movement of the elongation pointer P_2 relative to the scale is to the right and hence P_2 indicates the percentage elongation. When the sample breaks, the sensing pin moves away from both cams S and E and both pointer P_1 and the elongation scale stop. The breaking load and the elongation are then noted directly.

Even with a sample tested at zero gauge length on the Stelometer some elongation will be indicated due to the fibre slippage between the faces of the jaws, and it follows that part of the elongation indicated at a $\frac{1}{8}$ in. test length will be this unavoidable error. To get the true elongation two tests should be made. If E is the true elongation, E_0 the elongation at zero, and E_1 the elongation at $\frac{1}{8}$ in., then

$$E = E_1 - E_0$$

After the bundle has been broken, the fibres are collected and weighed. From the indicated breaking load at $\frac{1}{8}$ in. and the fibre weight in milligrams the tensile strength of the material is calculated.

$$\text{Tenacity in grams per tex} = \frac{\text{Breaking load in kilograms} \times 1{\cdot}5 \times 10}{\text{Sample weight in milligrams}}$$

The sample length is 1·5 cm when the $\frac{1}{8}$ in. gauge length is used, hence the 1·5 in the formula; the tenacity calculation at zero gauge length will use 1·18, i.e. the sample length is then 1·18 cm.

From our earlier discussion on the effect of sample length on the strength of textile samples it is not surprising to learn that the tenacity obtained at $\frac{1}{8}$ in. test length is less than the tenacity at zero gauge length. It is possible to test two cottons and find that although their tenacities are similar at zero gauge length, a difference of up to 20 per cent may be found when tested at $\frac{1}{8}$ in. The ratio between the tenacity at $\frac{1}{8}$ in. and at zero is approximately 0·5 but will vary, of course, with the nature of the cottons tested; for long staple uniform cottons the ratio will be higher than for short less-uniform cottons. About sixteen specimens should be tested in order to obtain average values with confidence limits of about ± 1·5 per cent. Further discussion on the use of the results will be found later in this chapter when fibre testing is considered generally.

For those readers with a working knowledge of technical French, a more detailed account of the kinematics of the Stelometer is given by de Meulemeester, Raes, Fransen, and de Backer in *Annales Scientifiques Textiles Belges*, p. 49 (Sept., 1956).

THE BALANCE PRINCIPLE

The balance type of tester is based upon the 'principle of moments'. In Figure 8.22 let AB be a beam having a fulcrum at point K. A force F is applied at a distance d_1 from K and the beam is kept in equilibrium or balance by the tension P developed in the specimen. P acts at a distance d_2 from K.

Since the sum of the clockwise moments is equal to the sum of the anti-clockwise moments,

$$P \times d_2 = F \times d_1$$

The load on the specimen may be varied by changing the value of the force F or by changing the distance from the fulcrum at which a constant force F acts.

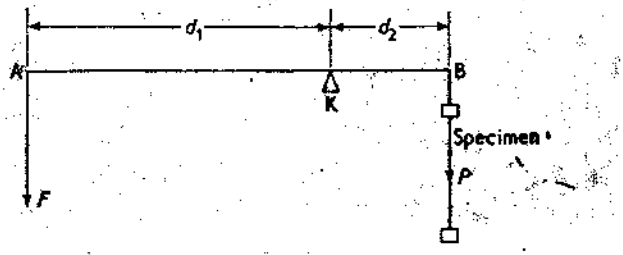


Figure 8.22. The balance principle

Several single-fibre testing instruments have been designed round a balance, e.g. the Barratt and the Krais-Keyl. Such instruments are generally intended for use in research laboratories. Descriptions of them will be found in a paper by Osumi and Kato (*J. Text. Inst.* **28**, T129 (1937)) and in Chapter 22 of Matthews' *Textile Fibres* (6th Edn). The testing instruments described here are modern machines which are commercially available.

The Pressley fibre strength tester

The Pressley instrument tests a small flat bundle of parallel fibres gripped between special clamps. From the bulk of the cotton several small tufts of fibre are selected at random and manipulated into a parallel ribbon about $\frac{1}{4}$ in. wide. A coarse hand comb is used initially, and for the final combing a small comb mounted on a vice is used. The ribbon is placed across the two black clamps which are held in the vice (Figure 8.23). The top jaws of the clamps are then snapped over the ribbon and tightened to a predetermined limit. When the clamps are removed from the vice a fringe of fibres will protrude from each side. These are trimmed-off flush with the faces of the clamps.

At this stage we have a small ribbon of parallel fibres of known

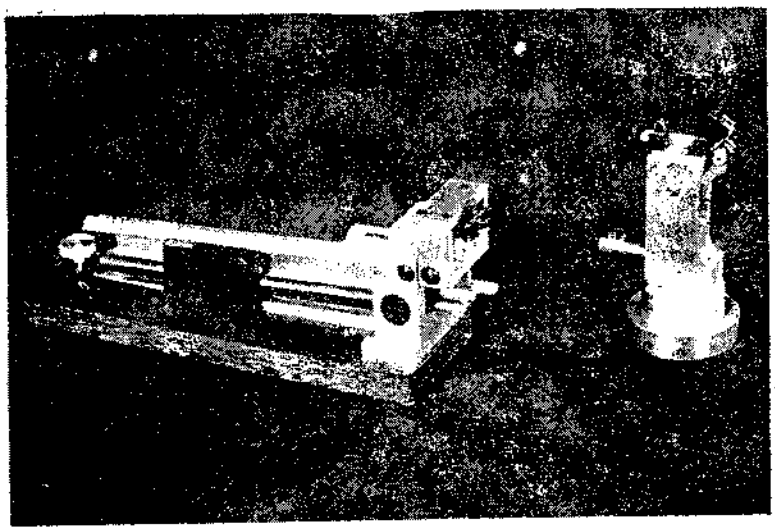


Figure 8.23. The Pressley fibre strength tester

length, 0·464 in., but of unknown weight, gripped at zero specimen length between the leather-lined jaws of the clamps.

The loading device or Pressley tester proper is basically a beam balance. A photograph of the instrument is shown in Figure 8.23 and a line diagram to illustrate its principle of operation is given in Figure 8.24. AB is a beam pivoted at O. When the end B rises, the upper clamp C_1 moves upwards and away from the fixed lower clamp C_2. To carry out the test the clamps are inserted into the end of the tester, as shown in Figure 8.23, and the instrument levelled with the aid of a spirit level built into the beam. When the main body of the tester is level the beam has a slight inclination of a few degrees to the horizontal. The heavy rolling weight W is initially held in position by a catch, but as soon as this is lifted the weight is released and rolls down the beam. As W moves away from the beam pivot the leverage of the arm AO increases until the force exerted on the ribbon of fibres is sufficient to break it. As soon as the break occurs the arm AO drops and a braking device causes W to be stopped instantly.

The distance travelled by the rolling weight is a measure of the load required to break the specimen. A scale calibrated in pounds is engraved on the beam and an auxiliary scale on the weight enables an accurate reading to be made.

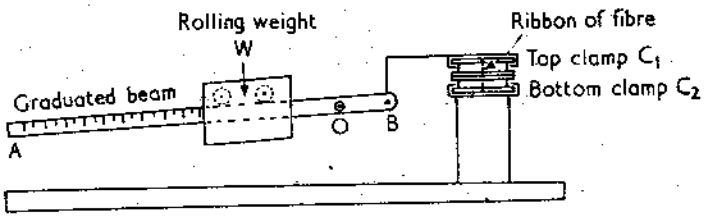


Figure 8.24. Schematic diagram of the Pressley fibre strength tester

The clamps are removed from the tester, the two halves of the broken specimen are collected, and then accurately weighed on a suitable torsion balance. At this point the information available is the breaking load in pounds and the weight in milligrams. These two quantities are used to calculate several measures of the fibre strength.

(1) The Pressley index (P.I.)

$$= \frac{\text{Breaking load in pounds}}{\text{Bundle weight in milligrams}}$$

(2) Tensile strength in pounds per square inch*
$= [(10{\cdot}8116 \times \text{P.I.}) - 0{\cdot}12] \ (\times 10^3)$

(3) Tensile strength in grams per tex
$= 5{\cdot}36 \times \text{P.I.}$

(4) Breaking length in kilometres
$= 5{\cdot}36 \times \text{P.I.}$

It is recommended that at least six breaks should be made on a sample of cotton and that the difference between each break should not be greater than 0·8 in the Pressley index. Lord and Underwood (*Emp. Cott. Gr. Rev.* **35**, No. 1 (1958)) point out that the level of test results depends to some extent on the preparation of specimens by the operator and on the degree of wear in the leather of the faces of the clamps. By testing a series of standard samples at the same time as the test samples, corrections may be applied to overcome the errors due to operator differences and wear in the clamps. Lord and Underwood further point out that at least sixteen bundles per sample must be tested to obtain average values with confidence limits of about ± 2 per cent.

The normal specimen length for the Pressley is zero, but recent developments in fibre testing indicate that a test length of $\frac{1}{8}$ in. is more useful. It is possible to modify the Pressley tester in order to use a specimen of this length. Due to the 'weak link effect' discussed elsewhere in this chapter, the strength obtained at $\frac{1}{8}$ in. will be less than that obtained at zero gauge length. The ratio between the two results is about 0·5 and will vary with the degree of uniformity of the cottons tested. Long fine cottons give higher ratios than short coarse cottons.

Rate of loading. Since the load on the specimen is proportional to the distance between the beam pivot and the centre of gravity of the rolling weight, the rate of loading is governed by the speed at which the weight rolls down the beam. In the normal test the weight is released at zero velocity and it gradually increases in velocity as it rolls. Hence, the rate of loading increases throughout the test. For research purposes it is possible for the laboratory concerned to control the velocity of the weight by a specially made device and achieve C.R.L. test conditions.

The Denison T42F

Cords, ropes, and heavy industrial fabrics require high capacity testing machines. The Denison T42F series offers a maximum of 15,000 lb. Naturally the machines are of robust design. Although

*See also Lord, E. *The Characteristics of Raw Cotton*, p. 217 (Textile Institute, 1961).

C.R.L. conditions are of primary importance these machines can be operated to give C.R.T. testing, but in the description which follows C.R.L. is discussed. A schematic diagram of the machine is shown in Figure 8.25.

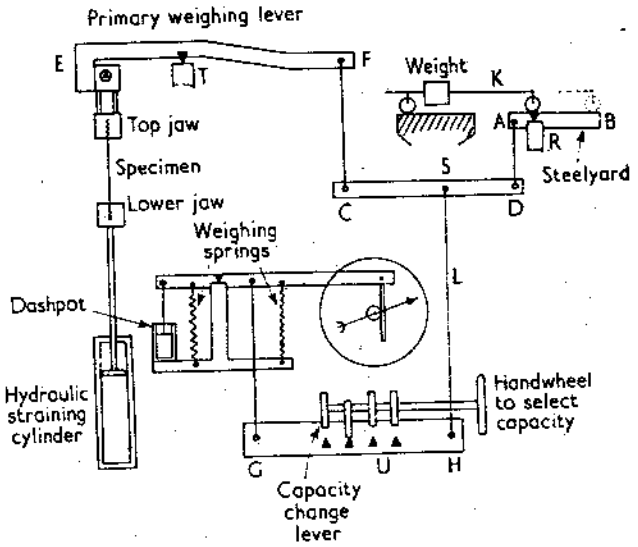


Figure 8.25. Schematic diagram of the Denison T42F tensile testing machine

The C.R.L. mechanism consists of a steelyard AB having a fulcrum at R, and a primary weighing lever EF having a fulcrum at T, with the two levers coupled through the parallel lever CD. The steelyard is traversed by the front axle of a carriage K, the rear wheels running upon non-weighing rails.

Initially the front axle of the carriage is directly above the fulcrum of the steelyard and thus no moment is present. The distribution of the carriage weight between the front and rear axles can be adjusted by altering the position of a weight on the carriage. In this way the rate of loading is adjusted, the reason being understood when the operation of the machine is grasped. The carriage is traversed at a constant rate by a screw and therefore the rate of increase of moment about R is constant.

The load on the specimen is applied through the linkages and levers shown; as long as the steelyard 'floats' or is in equilibrium, the load increases at a constant rate. In order to maintain equilibrium the extension of the specimen is taken up by the downward movement of the lower specimen grip. An oil control valve is operated by

the movement of the steelyard. The effect is to control the downward movement of the piston in the hydraulic straining cylinder. Thus, the stretch of the specimen is accommodated and equilibrium conditions are maintained automatically.

The magnitude of the load on the specimen is measured and indicated by a special device. The effect of the tension in the specimen is to produce a force in an upward direction in the link FC. An upward force in the link AD is produced by the moment of the front axle load on the steelyard. These two parallel forces in an upward direction are balanced by a downward force in the link L, pivoted at S on the parallel lever and at H on the capacity change lever GH. This force is measured by a lever and spring system, translated into the actual load on the specimen, and indicated by a pointer on a calibrated dial, the maximum load reached being indicated by an auxiliary pointer.

An important part of the measuring system is the capacity changing device. The change lever GH to which the link L is connected may have a fulcrum at any one of several points U, the selection being made by a hand-operated cam. By shifting the fulcrum position the mechanical advantage of the lever is altered. Thus, is the fulcrum nearest end H is selected the capacity of the machine is at its highest range.

Since many types of specimen are tested on a machine such as this, it is necessary to have a suitable range of specimen jaws or grips. A further refinement is an autographic device to record the load–elongation behaviour of the specimen.

LOADING BY SPRINGS

A useful property of a spring is the linear relationship which exists between the amount by which its initial state has been changed and the force required to produce that change. The use of a helical spring in tension is found in the Cambridge Extensometer.

The helical spring S in Figure 8.26 has a linear strain curve and therefore the tension developed in it is proportional to the extension. Thus, by extending the spring at a constant rate a load may be applied at a constant rate. The specimen is mounted between the grips G_1 and G_2. As this instrument is designed to test single fibres and fine yarns, special methods are used for mounting the specimens.

The upper grip G_1 is connected to a leaf spring which has a restricted movement between the electrical contacts C_1 and C_2. This

leaf spring is also connected to the helical spring whose upper end is clamped into a holder H_1 which has a vertical movement controlled by the motor M_1 driving a screwed rod R. The vertical movement of the lower grip G_2 is controlled by the motor M_2.

To test with C.R.L. conditions the motor M_1 runs continuously, the rate of loading being controlled by the speed of rotation of the screwed rod (variable by gear changes), and the stiffness of the spring (interchangeable).

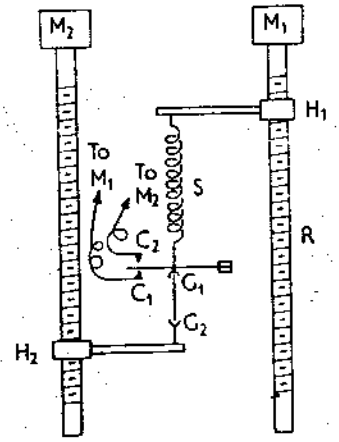


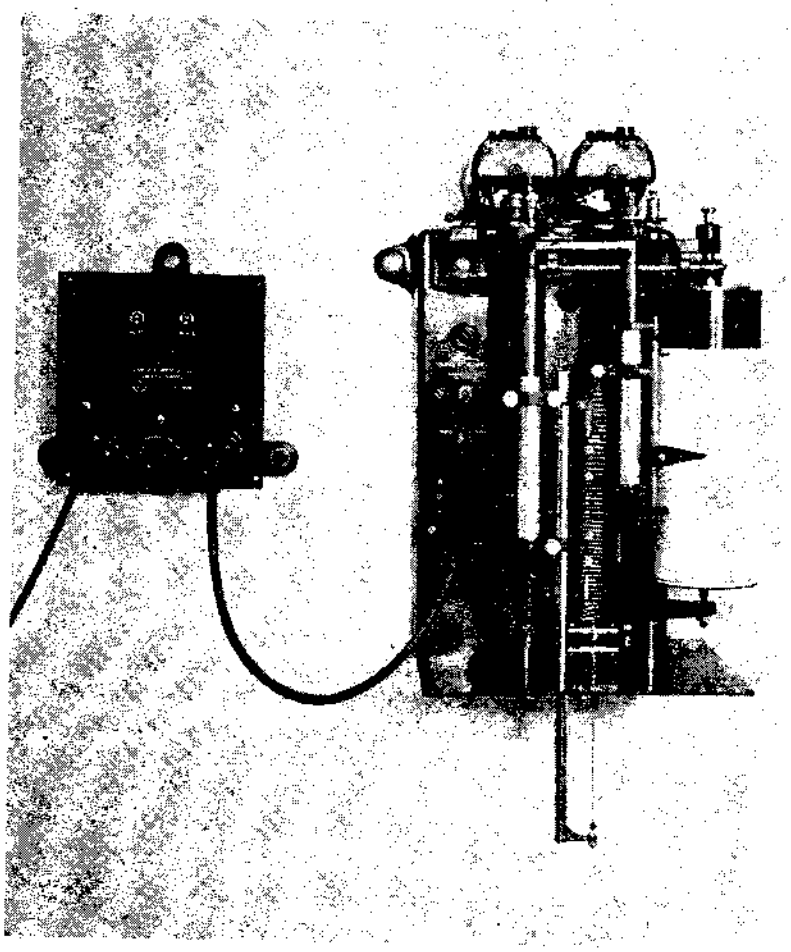
Figure 8.26. Schematic diagram of the Cambridge Extensometer

At the start of a test, with zero load on the specimen, the leaf spring will be floating between the contacts. Motor M_1 is switched on and the holder H_1 moves upwards at a constant speed. The spring extends and a load is applied to the specimen at a constant rate. The extension of the specimen causes the leaf spring to be deflected upwards and touch the upper contact C_2. This switches on motor M_2, causing the lower grip to move downwards for a short period and so take up the extension. In doing so, the leaf spring is pulled off the upper contact and motor M_2 is switched off. This cycle of events continues until the specimen breaks.

To record the behaviour of the specimen a chart is mounted on a vertical cylinder (see Figure 8.27). The movement of the holder H_1 is a measure of the load; therefore a pen which has an identical vertical movement to H_1 records the load. The motor M_2, which runs only when the specimen extension is being taken up, also rotates the chart cylinder, angular movement of the latter being

proportional to specimen extension. Hence, a load–elongation curve is produced with the load on the vertical axis and the elongation on the horizontal axis, i.e. a curve with rectangular co-ordinates.

Due to the intermittent movement of motor M_2 the curve will be slightly stepped, but by suitable selection of gear ratios this effect will be kept to a minimum.



(By courtesy of the Cambridge Instrument Co.)

Figure 8.27. The Cambridge Extensometer

Constant rate of extension tests on the Cambridge Extensometer

To test with C.R.E. conditions the motor M_2 runs continuously, extending the specimen at a constant rate. The leaf spring is deflected downwards as the tension is developed in the specimen. When contact is made with C_1 the motor M_1 is switched on, extending the spring until the tension in it balances the tension in the specimen. The leaf spring is eventually pulled away from C_1 and motor M_1 stops. Again the cycle of events continues until the end of the test.

Test methods. The specimen need not be taken to the breaking point. Loading up to a given value, followed by unloading, may be carried out through one cycle or perhaps through a number of cycles. Special limit switches are incorporated in the instrument for this purpose. Similarly, extensions to given percentages may be used. In addition to accommodating various fibre lengths by adjusting the position of the grips, it is possible to add extension rods to enable the specimen to be tested when immersed in liquid. The reader is referred to Farrow's paper on the stress–strain properties of a number of fibres (*J. Text. Inst.* **47**, T58 (1956)). The Cambridge Extensometer was used in the experimental work.

Another useful article concerning the Cambridge instrument is by Miss S. Fletcher (*Hexag. Dig.* No. 26, p. 26 (March, 1958)).

THE INCLINED PLANE PRINCIPLE

Constant rate of loading test conditions are obtained by using the Inclined Plane type of machine. Figure 8.28 shows the essential parts of an I.P. tester.

The plane DB is a rail, pivoted at K, along which a heavy carriage C can roll. The specimen is clamped in a fixed jaw J_1 and also in the

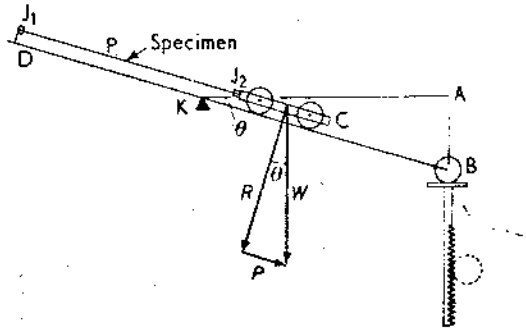


Figure 8.28. The Inclined Plane principle

jaw J_2 on the carriage. The plane is tilted by dropping the end B. Let the plane be inclined to the horizontal by an angle θ. If the weight of the carriage is taken as W, then the force applied to the specimen can be calculated by resolving the vertical force W in two directions—parallel to the plane and at right angles to the plane.

Let P be the force parallel to the plane, i.e. the force applied to the specimen.

Then $P = W \sin \theta$

Therefore, $P \propto \sin \theta$

Hence, the load on the specimen is directly proportional to the sine of the angle of inclination.

In the triangle KAB, $\sin \theta = AB/KB$. Since for a particular machine KB is constant, $\sin \theta \propto AB$. If we can increase the value of $\sin \theta$ at a constant rate, the load on the specimen is increased at a constant rate. All we have to do, therefore, is to increase AB at a constant rate. This is achieved by lowering the end of the plane, B, at a constant speed. On the Scott Serigraph the end B takes the form of a wheel which sits on a small platform. The latter is lowered and raised by a gear mechanism.

It will be noticed that the extension of the specimen will not affect the rate of loading, the carriage merely rolling further down the plane.

An instrument of this type is not entirely free from errors of inertia. Some inclination must be given to the plane before the carriage begins to roll. On an autographic tester such as the Scott, the inclination of the plane causes the pen to record a load on the chart; therefore, at the start of the test a load is recorded without any apparent extension. The inertia effects produce a slightly wavy load–elongation curve (see Figure 8.29).

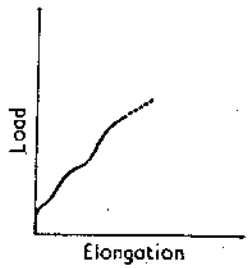


Figure 8.29. A wavy load–extension curve caused by inertia effects in the Inclined Plane tester. Apparent loading of specimen without elongation at start of test

Other potential sources of error include friction in the wheel bearings, dirt on the wheel rims and the rail, pen friction, deviations

from the horizontal when the plane is in the neutral position, misalignment of the chart in its holder, etc. In an efficient testing laboratory all these points will be attended to, regular cleaning and checking being an essential part of the running of test equipment.

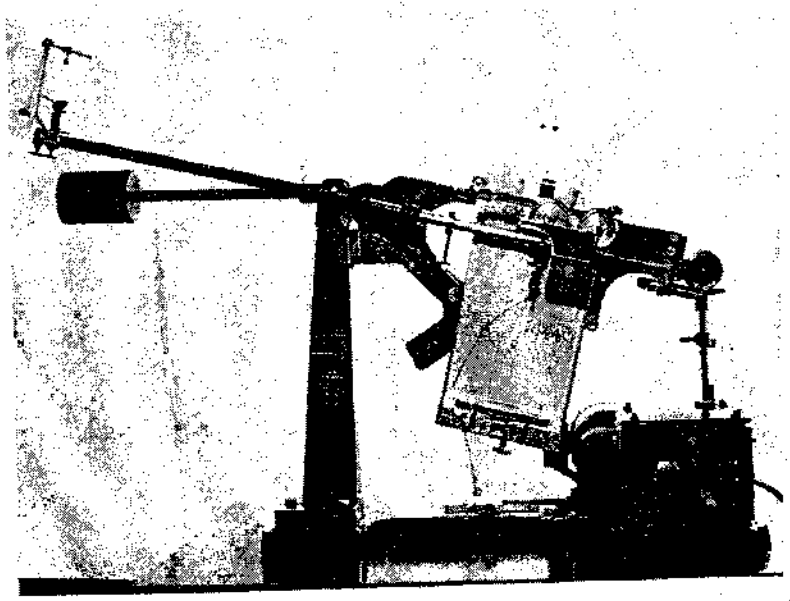


Figure 8.30. The Scott Inclined Plane tester. Note the rolling carriage, the autographic device, and the wheel at the end of the rail resting on the platform

The Scott Serigraph

The Scott I.P.2 is an excellent example of the application of the inclined plane principle. The main features of the instrument can be seen in Figure 8.30:

(1) A smooth rail along which the two-wheeled carriage rolls.
(2) Additional weights which are added to the carriage to increase the capacity to 1,000 g.
(3) An antifriction wheel on the right-hand end of the carriage rail. This wheel sits on a small platform fixed to a vertical rod which is driven upwards and downwards to incline the carriage rail.
(4) Gearbox and controls which enable load cycling tests to be carried out. Hysteresis and elastic recovery properties can be studied conveniently.

(5) Specimen clamps which can be set to any test length between zero and 20 in. This is a useful feature which enables short lengths to be tested, e.g. threads from small samples of fabric.
(6) A chart holder, holding a chart ruled with rectilinear ordinates.

A development in the Scott range of inclined plane testers is an automatic version of the I.P.4 model used for testing tyre cords and similar yarns. The test material is fed to the machine which then carries out a preset number of tests, the results being printed out on a paper tape. Test values are recorded in groups of 10, and as each group is completed the totals for the stress and strain columns are printed out, allowing an easy mental calculation of the averages.

The 'Uster' yarn strength tester

This Swiss instrument is an automatic single-thread tester. The heart of the 'Uster' is seen in Figure 8.31, which shows the inclined plane, the screwed rod which inclines the plane, and the rolling carriage. Two carriages are available, each with additional weights, and so the capacity can be changed in steps between 0–200 and 0–2,000 g. Once the yarn has been threaded, the instrument carries out the functions of testing, recording, removing the broken yarn, and threading up the next test length; after this the cycle is repeated until the required number of tests have been made. Figure 8.31 shows a general picture of the tester and some of the following important features of the 'Uster' can be seen:

(1) The jaws, set to give a test length of 50 cm.
(2) A magnetic tension disk adjustable to give the desired pre-test tension.
(3) The control panel containing the start–stop button, a switch to set the required number of tests from 20 to 200, and counters to indicate the number of tests made, the total breaking load, and the total elongation.
(4) A chart which records the individual breaking loads and extensions.
(5) The lower panel is a novel feature. This is a grid on which the frequency distribution of the breaking loads is displayed by columns of steel balls. The heights of the columns represent frequency, i.e. one ball per test, and the horizontal base line is graduated from 0 to 10. Thus, a ball dropping three-quarters of the way along the horizontal, with the capacity of the tester set to 600 g, represents a breaking load of 450 g. If a permanent record of the distribution is required, an impression can be transferred on to a special chart. By a geometrical construction

on the chart an estimate of the standard deviation can be made relatively quickly.

A feature not seen in the photograph is a variable-speed control which enables the rate of loading to be adjusted to give a time to

Figure 8.31. The 'Uster' single-thread tester. Note the rolling carriage on the inclined plane

break the specimen of 20 sec, the time recommended in the B.S. Handbook.

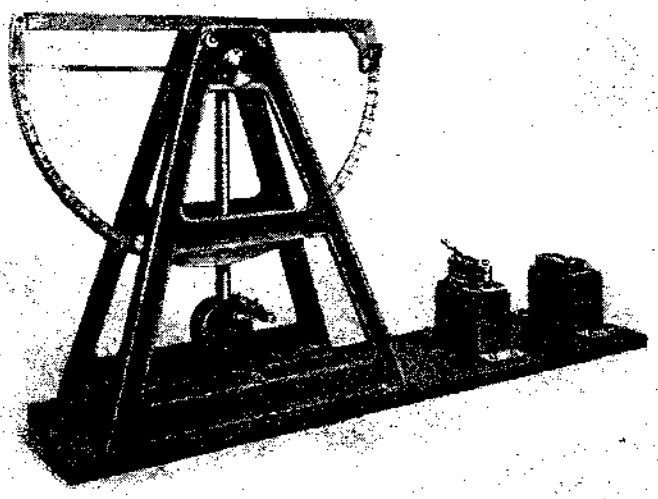
When the set number of tests have been carried out, a buzzer draws the attention of the laboratory assistant to the tester. The buzzer also sounds when something amiss occurs during the test, e.g. the yarn tangles when being drawn off the package.

An accessory to the 'Uster' is a device which enables ten packages to be creeled behind the tester and a chosen number of tests made from each package automatically.

With the development of such automatic single-thread testers as the 'Uster', one of the major disadvantages of the single-thread test as a routine control technique is eliminated. The operator's time taken per test is extremely short and as the tests are being made he or she can be otherwise occupied. Further, since the threading is mechanical, the difference between operators is no longer present.

THE BALLISTIC OR IMPACT TESTER

The results from testing on an impact or ballistic tester (see Figure 8.32) are given in units of work or energy, e.g. inch-pounds. This means that we measure the 'work of rupture' of the specimen



(By courtesy of Gondbrand & Co. Ltd)

Figure 8.32. The ballistic testing machine

instead of the maximum load that it will stand before breaking. The values obtained on the ballistic tester and the usual type of tensile tester are not, therefore, directly comparable.

Figure 8.33 shows a heavy pendulum pivoted at A. The specimen is anchored at a fixed point J_1 and also connected to a grip J_2 on the bob of the pendulum. Let G be the centre of gravity of the pendulum and let W lb be its weight. Initially, the pendulum is in position 1, with the centre of gravity at a height h_1 above its lowest point. The potential energy of the pendulum in this position is therefore $W \times h_1$ in. lb.

When the pendulum is released it swings downwards and when nearly vertical begins to pull on the specimen. Continuing its swing, the pendulum stretches the specimen, breaks it, rises to position 3, finally coming to rest in position 2.

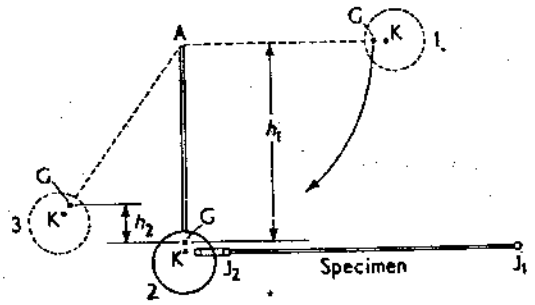


Figure 8.33. Schematic diagram of the ballistic testing machine

The work required to break the specimen can be calculated by considering the height to which the centre of gravity rises after the break. Let h_2 be the height of G above its lowest point. The potential energy in this position is $W \times h_2$ in. lb. Thus, the difference in the potential energies in positions 1 and 3 is the energy or work required to break the specimen. Therefore,

$$\text{Work of rupture} = W(h_1 - h_2) \text{ in. lb.}$$

The specimen is anchored to the pendulum in line with a point K and not the centre of gravity G. This point K is known as the 'centre of percussion of the pendulum'. Technically speaking, the centre of percussion is a point on the axis of the pendulum where a force may be applied without causing a reaction about the fulcrum. Less technically, an analogy with a cricket bat and ball may be drawn. If the ball is hit by the bottom of the bat or the splice, with any power, a shock or jar is experienced in the hands. If, however, the ball is hit off the 'meat' of the bat, no shock is felt and the ball travels fast and far (we hope!).

In the case of the ballistic tester, a reaction at the pivot would mean that part of the energy of the pendulum would be dissipated in the pivot instead of being used to break the specimen. The results would be too high, i.e. indicated strength would be actual specimen strength plus wasted energy.

The Goodbrand tester is a commercially available example of a ballistic tester. The illustration is almost self-explanatory. An auxiliary pointer remains at the height to which the pendulum rises and the work is indicated directly in inch-pounds on the calibrated scale. The capacity of the machine can be altered quite simply by releasing the pendulum from different heights.

The specimens tested may be in the form of hanks of yarn, cords, and fabrics; on the latter it is possible to carry out tearing tests in addition to straightforward strip tensile strength tests. Discussion of these tests will be found later in this chapter.

THE STRAIN GAUGE, TRANSDUCER, OR ELECTRONIC DYNAMOMETER

This type of tester is in effect a modified form of spring-loading. machine. The Shorter Hall tester (*J. Text. Inst.* **17**, T316 (1926)) uses a long flat spring and the deflections of the free end are large enough to be measured and recorded directly. In the electronic dynamometer a stiff flat spring or beam is mounted as a cantilever, see Figure 8.34. The upper jaw J_1 is attached to the free end of the beam and the lower jaw J_2 has a controlled vertical movement through a screw mechanism. By moving J_2 downwards a tensile force is developed in the specimen which causes the free end of the beam to be deflected. The effects of the deflection are used to measure the magnitude of the load on the specimen.

When the beam bends the length of the upper face AB increases and the length of the lower face CD decreases, these changes in length being proportional to the applied load. Between the two outer faces there is a neutral plane NL whose length remains unchanged.

When a piece of resistance wire is stretched its electrical resistance increases; conversely, if it contracts its resistance decreases. Further, the change in the resistance value is proportional to the change in length.

Consider a resistance wire R firmly bonded by cement to the face AB of the beam so that elongation of AB will produce an elongation of R. Thus, a load applied the end BC causes a change in the length of the resistance wire, and the change in the value of the resistance is

proportional to the magnitude of the load. It is now necessary to convert this change in resistance into a visual recording of the load. This conversion is usually achieved by means of a Wheatstone bridge.

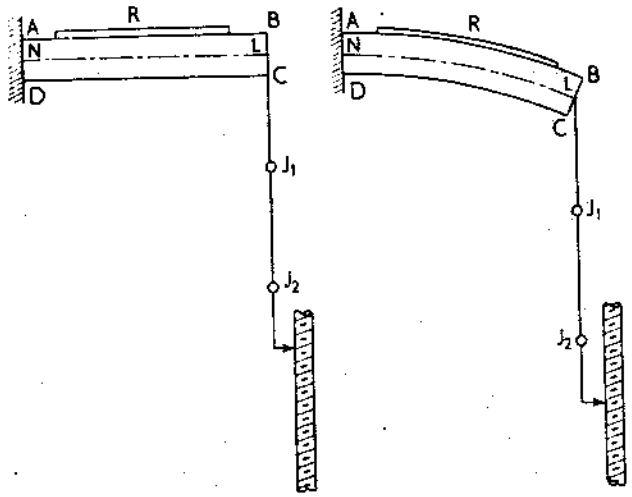


Figure 8.34. The strain gauge principle

If four resistances are employed in the loading system, two on the upper and two on the lower surface, they are connected in the form of a Wheatstone bridge as in Figure 8.35. With the beam undeflected, no voltage will be developed across CD when a voltage is applied across AB. The bridge is said to be 'balanced'. When a load is applied to the beam the deflection causes changes in the values of the

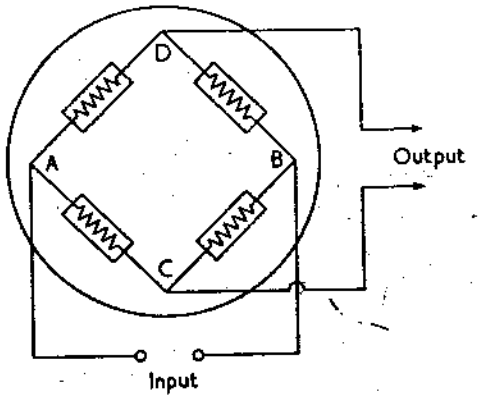


Figure 8.35. Four resistances in the load cell connected in the form of a Wheatstone bridge

resistances and a voltage is produced across CD, its value being proportional to the load. This voltage output is fed to suitable electronic circuits which finally drive a pen recording instrument.

Some advantages of a strain gauge instrument

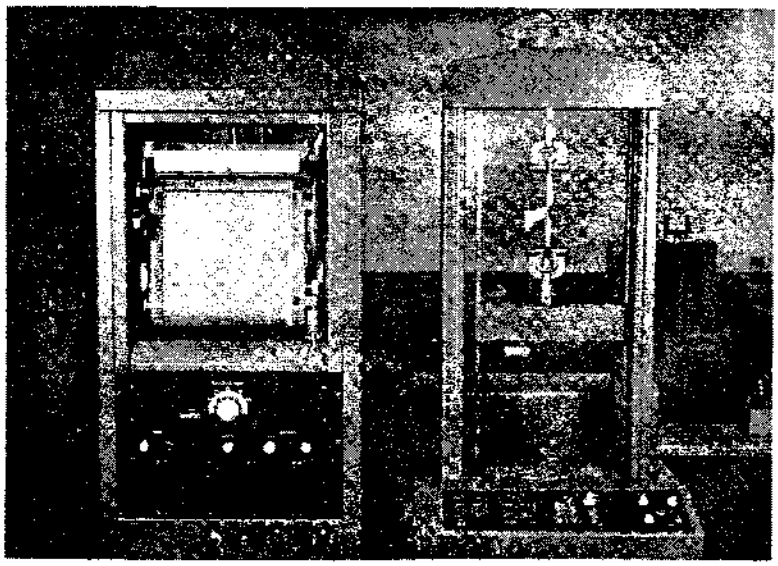
(1) Free from inertia errors and friction.
(2) The deflection of the end of the beam is very small, therefore the tester virtually tests under 'constant rate of extension' conditions.
(3) Versatility in the types of testing possible.

Some disadvantages

(1) The services of expert technicians required for maintenance and repair.
(2) Constant checks required to counter 'drift' in electronic circuits.
(3) High initial cost.

The Instron tensile testing instrument

The Instron is an American tester which uses the bonded-wire type of strain gauge. A general view of the table model is seen in Figure 8.36. In order to accommodate a wide variety of specimens,



(By courtesy of Instron Engineering Corp. (U.S.A.))

Figure 8.36. The Instron table model

several interchangeable load cells containing the strain gauges are used. In this way a range from 2 to 100,000 g is possible. The load cell is located centrally in the fixed crosshead. The upper jaw is suspended from the cell through a universal coupling The lower jaw is mounted on the traversing crosshead which is driven upwards and downwards by screwed rods on each side. A range of gear changes enables the speed of the crosshead, i.e. the rate of extension of the specimen, to be varied in steps from 0·02 to 50 in./min. On the bottom panel of the crosshead assembly the controls which govern the movement of the crosshead can be seen.

The load cell output is fed by cable to the control cabinet which houses the various electronic circuits and the pen recording equipment. The main controls for load range selection, calibration, etc., are mounted on the front panel below the recording chart.

The load weighing system. The load cell contains a metal beam in the form of a cantilever. Strain gauges, consisting of a grid of very fine wire, are bonded to the surface of the beam. Four strain gauges are used and are connected in the form of a Wheatstone bridge each gauge having a nominal resistance of 120 Ω. The block circuit diagram, Figure 8.37(a), shows a simplified picture of the method of converting the unbalancing of the bridge into a record of the behaviour of the specimen under load.

The Wheatstone bridge network of strain gauges in the load cell is excited from an oscillator at a frequency of 375 c/s. The amplitude of this oscillator is stabilised at a constant value by a separate circuit. An applied load on the cell changes the resistance balance of the bridge and the resulting signal is amplified by a circuit which also includes means for initially balancing the bridge.

The gain of the amplifier can be varied in steps by a *load selector* switch, and a *calibration* control can also vary the sensitivity continuously between any of these steps. A *zero* button shorts out the input to the following amplifier so that the zero position of the recorder may be adjusted without the presence of any load cell signals.

The signal is further amplified and then rectified by a circuit which includes the *zero* adjustment for the recorder.

From this last circuit the output is a d.c. signal which is fed to the potentiometer type of recorder, where it is compared electrically with the voltage across a balancing slidewire. Any unbalance between the two voltages is converted by a vibrator into a 60 c/s a.c. signal and amplified to operate the pen drive motor, which simultaneously moves the pen and also the slidewire shaft until the recorder is again in balance.

Hence, the effect of extending the specimen is to cause the pen to move across the chart a distance proportional to the tensile force in the specimen. If the chart were stationary a straight line whose length represented the size of the load would be drawn, but by moving the chart simultaneously a load–elongation curve is traced by the pen.

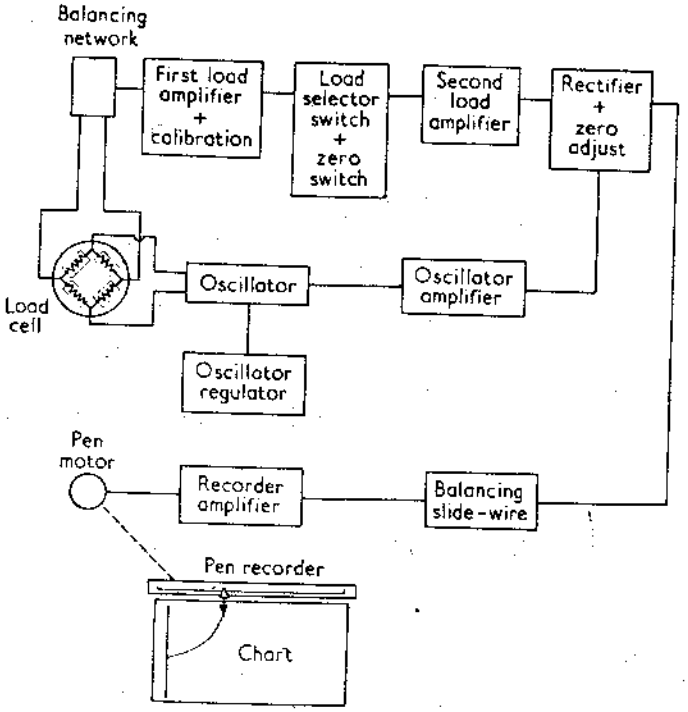


Figure 8.37(a). Block circuit diagram of the Instron tester

Types of test

The Instron is a versatile instrument which even in standard form can be used for many types of test. Various accessories are available which extend the scope of the tester. A selection of the types of test possible are outlined briefly:

(1) Load–elongation from zero load to breaking point.
(2) Elastic recovery from various loads and percentage elongations above and below the yield point.
(3) Performance of different types of knots in filament yarns.
(4) Load cycling, i.e. repeated loading and unloading between chosen limits.

(5) Extension cycling.
(6) Maintenance of a constant load, the creep being taken up automatically.
(7) Relaxation, measurement of the decay in tension when the specimen is maintained at a constant extension.
(8) Tearing tests on fabrics.
(9) Adhesion tests, the measurement of the force required to separate surfaces glued together.
(10) Compression tests.

The Instron instrument and others of a similar type, such as the Scott C.R.E. Tester, the new Denison machines, and the continental Drage and Zwick testers from Switzerland and West Germany, respectively, offer the textile technologist a useful tool for investigation work.

The W.I.R.A. single fibre strength meter

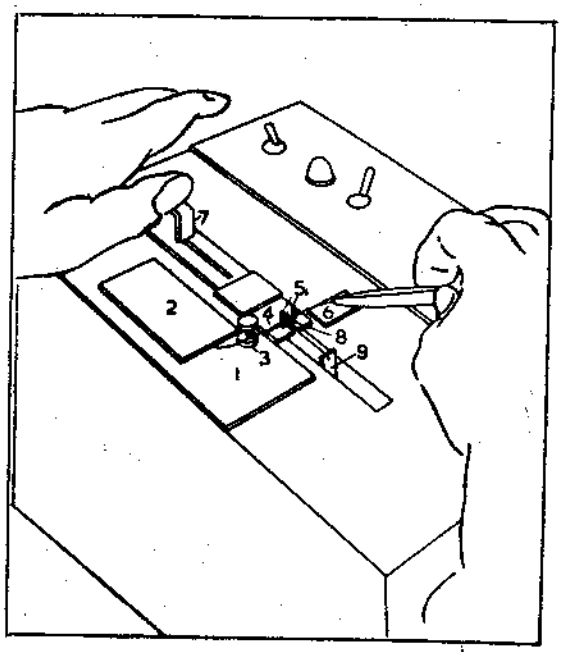
Another example of an instrument employing a strain gauge is the single fibre tester developed by the Wool Industries Research Association from whose literature the following description has been taken.

Measurements of the stress/strain relationship and the breaking strength of natural fibres are complicated by the inherent variability of the material. It is therefore usually necessary to make a large number of tests, possibly two to three hundred, for the results to be statistically significant.

Single fibres are difficult to handle, so the work can be very tedious and time consuming. The chief advantage of this new instrument is that fibre handling is kept to a minimum, enabling a comparatively unskilled person to obtain useful results within an hour or so. A simple electromagnetic clamp is used in place of the conventional screw type and the meter automatically clamps the correct length of fibre during its withdrawal from the sample bundle that is being examined.

Figure 8.37(b) shows the layout of the meter. The sample is prepared on the velvet pad (1) and covered with the pressure plate (2) so that the free ends adjacent to guide (3) protrude slightly. A single fibre is selected with tweezers and drawn round the guide (3) and between the fixed anvil (4) and the two loose clamps (5), so that it passes between the clamps (5) and the hook (8). It is finally held, still in the tweezers, on the rubber pad (6) under a light tension due to friction of withdrawal from the velvet pad. The operating

lever (7) is now moved steadily with the thumb. The first part of the motion moves the hook (8) forward until the required test length of fibre has been withdrawn in a U form between the clamps (5). The hook then moves backwards very slightly to release the initial loading tension. Further motion of the lever causes a solenoid to be energised with a predetermined current. This magnetises the anvil so that it attracts the loose clamps, holding both ends of the fibre with a suitable force. Finally, the hook moves forwards at a constant rate, stretching the fibre to breaking point.



(*By courtesy of the W.I.R.A.*)

Figure 8.37(b). The W.I.R.A. single fibre strength meter

The tension in the fibre during this time is measured by single crystal silicon strain gauges on the cantilever (9) to which the hook is attached, and for each fibre a complete load/extension curve is drawn on a chart paper which moves at a constant speed corresponding to the constant rate of extension of the fibre. Up to 500 wool fibres per hour may be tested.

For industrial use, where a manufacturer may be looking for possible degradation of fibres due to chemical processing, the mean

breaking load is often the most relevant information. In this case the chart speed is reduced, compressing the load/extension curves to a set of lines whose heights represent the individual breaking loads of the fibres.

The Courtronic Type 5 filament tensile tester

The introduction of this single fibre or filament tester illustrates admirably the reduction of both error and tedium in single fibre testing by the use of electronic equipment and mechanised fibre handling. The system offers semi-automatic specimen mounting and loading and automatic result analysis and print-out and in this way a single operator can produce the required information. Four items of equipment form the system: a filament mounting device, a filament loading device, the tensile testing unit and the statistical analyser. The filament mounting device is mentioned later in this chapter under the section describing jaws and clamps for tensile testing. All the items are mounted on a special desk-like bench, with space for a seated operator.

Constant rate of extension testing conditions are achieved by an electronic servo-system and the rate of extension is variable from 0 to 300 per cent per min. Two extension ranges are available: 0–30 per cent and 0–120 per cent. The load ranges are from 0–5 g to 15–150 g in seven overlapping stages. The test specimen length is variable from 1·5 cm to 4 cm, where manual loading is used, but is fixed at 2 cm where magazine loading is used. A useful addition is the possibility of both dry and wet testing conditions. Under the latter system the immersion time can be varied in 5-second steps from 5 to 60 sec.

The instrument tests filaments mounted 'slack', and automatically relaxes each filament prior to the start of each extension cycle. At a preset load level, pre-tension point is automatically registered, the true gauge length at this point being used as the reference for correct extension velocity and extension percentage result. The gauge length is registered on a meter. The breaking load and extension percentage results are displayed on direct-reading rotating scales, with selective illumination. The high sensitivity (0–30 per cent extension) is provided for low extensibility samples, knot and loop tests. In addition to displayed information the use of the statistical analyser enables the results to be processed and provides means, standard deviations and coefficients of variations of the breaking extensions and breaking loads. The print-out gives both an original and a carbon copy of the results.

THE CONSTANT-TENSION WINDING TEST FOR YARN

A good yarn possesses the ability to be transferred, under tension, from one package to another and to undergo processes such as knitting and weaving with a minimum amount of breakage. High breakage rates reduce productivity and increase faults and costs. The tensions to which yarns in process and in use are normally subjected are below the 'average' strength of the yarns, i.e. the strength as determined by single thread tests on 20 in. lengths. Nevertheless, weak places will occur in the yarn which will be unable to withstand the processing tensions and will therefore break.

In many yarn preparation processes the yarn is wound at high speed from one package to another and the whole length is inspected mechanically by means of clearing devices and yarn tensioning systems. Hence, the yarn is 'tested' under a relatively low load before it is wound on to the cone, etc. From a quality control point of view, the early stages in the yarn preparation provide effective yarn 'fault filters'. End-breakage studies in the preparation department can provide very useful information about the yarn quality.

The lea strength test is relatively insensitive in the detection of weak places which may occur only at intervals of thousands of yards. It should be borne in mind, of course, that a weak place at every 2,000 yd could mean an end down every 2 min on a modern high-speed winding unit.

The single-thread test, too, has its limitations. If 100 tests are made on 20 in. test lengths the actual yardage examined is only about 55 yd, an amount which can be wound in a matter of seconds. The weak places which we are considering form the extreme 'tail' of the frequency distribution curve of the single-thread test results. Unfortunately, the frequency of these weak places is difficult to estimate from consideration of the mean and the standard deviation of this distribution because at this extreme tail the distribution is no longer normal. For cotton yarns it has been found that the normal or Gaussian distribution holds only as far as about 2·5 standard deviations below the mean (Stout, H. P., and Stern, S. *J. Text. Inst.* **47**, T621 (1956)).

The constant-tension winding test provides testing conditions somewhat similar to actual processing, since a tension is imposed on a running yarn. In order to obtain sufficient breaks in the length of yarn tested, higher tensions are used than would be used in practice but even so the test is closer to actual running conditions than the lea or the single-thread tests.

Basically, the instrument consists of two fixed centre pulleys and pulley P, Figure 8.38, which is mounted on a movable centre. During the test, the pulley P 'floats' because the load L applied to P in the direction shown is balanced by the sum of the tensions in the two halves of the loop of yarn. Under static conditions the tension throughout the loop would be uniform and be equal to $0{\cdot}5L$, but under running conditions fluctuations in the tension occur. The tension imposed on the yarn will cause it to stretch. It follows that the take-up speed V_t will be higher than the input speed V_i. If e is the extension per unit length at the tension used, then

$$V_t = V_i(1 + e) \qquad \ldots (8.3)$$

The instruments therefore incorporate the necessary means for adjusting the relative input and take-up speeds to accommodate yarns with different extension properties and also to enable the same yarn to be tested at different tension levels. Figures 8.39 and 8.40 show two types of tester.

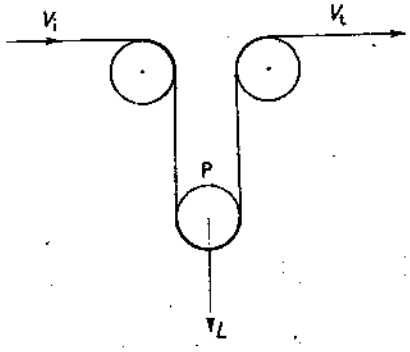


Figure 8.38. The constant-tension winding test principle

The incidence of breaks

One way of carrying out a winding test is to estimate the tension required to produce a given breakage rate, e.g. 8 breaks per 1,000 yd. Alternatively, the breakage rate at a chosen tension level may be determined. If a long length of yarn were tested in successive units of, say, 1,000 yd, the number of breaks in each unit would not necessarily be equal. When the frequency distribution of the number of breaks per unit length is plotted, the curve produced takes the form known as a 'Poisson' distribution, see Figure 8.41. This is an example of the asymmetrical or skewed distribution mentioned in Chapter 2.

Breakage rates and the applied tension

Experiments with this type of instrument have shown that there is a logarithmic relationship between the number of breaks per given length and the running tension. The graph in Figure 8.42 shows this linear relationship.

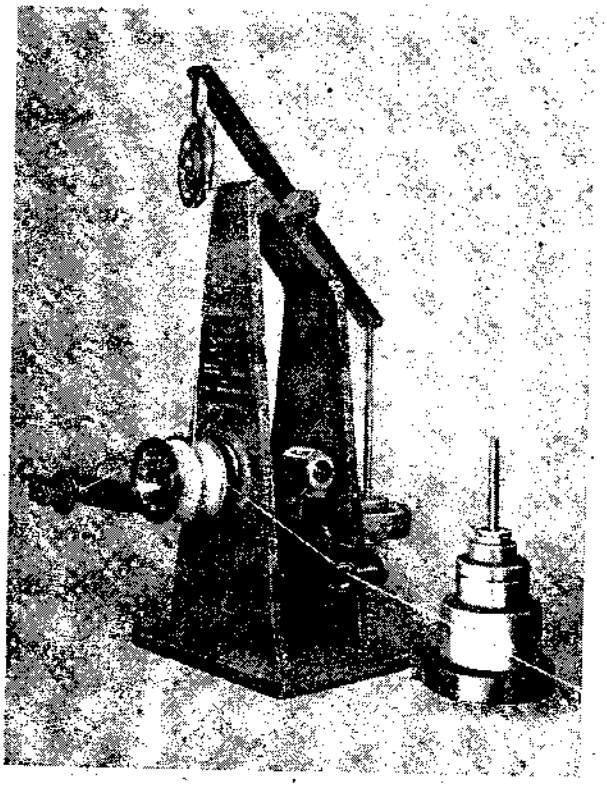


Figure 8.39. The 'Shirley' constant-tension winding tester. Note the 'floating' top beam

Let n_1 = breakage rate per 1,000 yd at tension t_1, and
n_2 = breakage rate per 1,000 yd at tension t_2.
The slope of the graph is, therefore,

$$\frac{\log n_2 - \log n_1}{t_2 - t_1} = c$$

We can now estimate the tension t which is required to produce x breaks per 1,000 yd:

$$t = t_1 + \frac{\log x - \log n_1}{c}$$

Therefore,

$$t = t_1 + (t_2 - t_1)\frac{\log x - \log n_1}{\log n_2 - \log n_1} \quad \ldots (8.4)$$

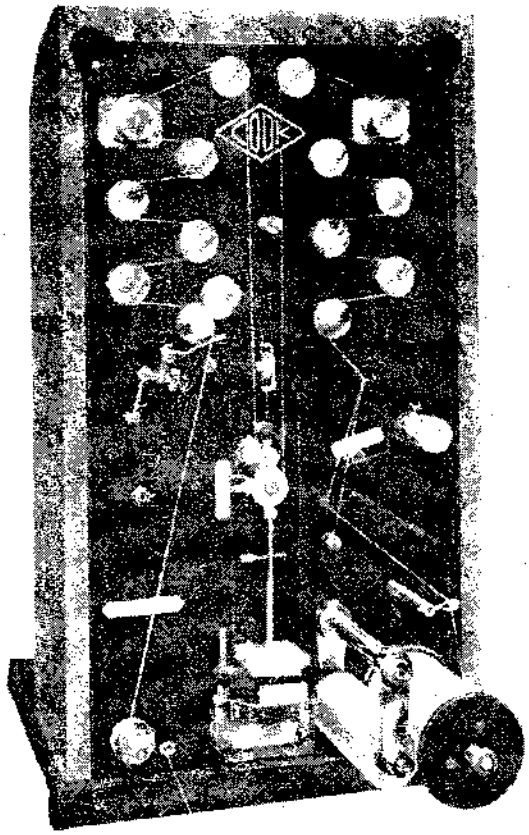


Figure 8.40. Cook's constant-tension winding tester

The breakage rate, the running tension, and the single-thread strength

Investigations have shown that a relationship can be established between the results obtained from single-thread tests and the winding tests for specific types of yarn.

Let T = tension required to produce n breaks per 1,000 yd,
$\bar{X}$ = mean single thread strength at a given test length, and
σ = standard deviation of the single-thread strength.

Then,
$$T = \bar{X} - k\sigma \qquad \ldots (8.5)$$

The factor k varies with n and will also be governed by the test length used in the single-thread test.

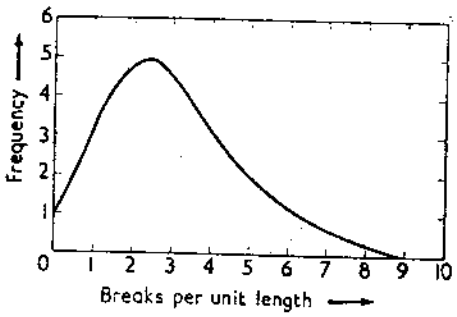


Figure 8.41. Frequency distribution of breaks per unit length

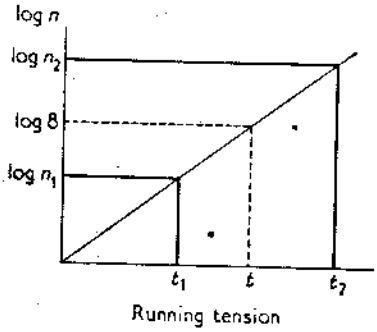


Figure 8.42. Running tension vs log breaks

In the B.S. Handbook a first estimate of the tension required to produce eight breaks per 1,000 yd is given as

$$T = \text{Average single-thread strength} \times \left(1 - \frac{\sigma}{30}\,\%\right)$$

Since
$$\sigma\% = \frac{\text{Standard deviation}}{\text{Average strength}} \times 100 \text{ per cent}$$

the formula becomes

$$T = \bar{X} \times \left(1 - \frac{\sigma}{\bar{X}} \times \frac{100}{30}\right)$$

$$= \bar{X} \times \left(1 - \frac{3{\cdot}3}{\bar{X}}\sigma\right)$$

Therefore,
$$T = \bar{X} - 3{\cdot}3\sigma \qquad \ldots (8.6)$$

Thus, for cotton yarns, with a 20 in. test length and eight breaks per 1,000 yd the factor k becomes 3·3.

Measurement of the breakage rate

Ten packages are selected at random. The aim of the standard test is to determine the tension required to produce a breakage rate of eight per 1,000 yd. A first estimate is given by the formula

$$\text{Tension} = \text{Average single-thread strength} \times \left(1 - \frac{\sigma}{30}\%\right) \text{grams}$$

Preliminary trials are made by running 200 yd from each package at this tension and noting the breakage rate. If the tension needs to be changed in order to bring the breakage rate closer to eight per 1,000 yd, the adjustment is made by assuming that a 10 per cent increase in tension will double the rate and a 10 per cent decrease will halve the rate.

When a suitable tension has been determined, five packages are taken. A yarn from each package is run through the instrument until five breaks have occurred. The yardage is noted for each break. If a break occurs in the first 5 yd when starting off after a break, it is ignored. The breakage rate at this first tension is given by the following formula:

$$\text{Breaks per 1,000 yd} = \frac{22\tfrac{1}{2} \times 1{,}000}{\text{Yardage for 25 breaks}}$$

The figure $22\frac{1}{2}$ is used because each new package begins with a forced break and on the average the length between the starting point and the first break will be half the average distance between the weak places which break. Thus, five breaks are recorded after only $4\frac{1}{2}$ intervals; therefore twenty-five breaks correspond to $22\frac{1}{2}$ intervals.

With the other five packages a second test is made at a new tension. If the breakage rate in the first test was below eight, the tension is increased by about 10 per cent; if above eight, the tension is decreased by about 10 per cent.

The information available at this point is as follows:

t_1 = tension used in the first test,
n_1 = breakage rate in the first test,
t_2 = tension used in the second test, and
n_2 = breakage rate in the second test.

We can now determine the tension t required to produce eight breaks per 1,000 yd by substituting in equation (8.3),

$$t = t_1 + (t_2 - t_1)\frac{\log 8 - \log n_1}{\log n_2 - \log n_1}$$

The application of the constant-tension winding test

The results obtained may serve as a guide to the behaviour of the yarn in subsequent processing. An extension of this guide into a forecast of the probable end-breakage rates, while highly desirable, is clearly impracticable since end-breakage rates depend on other factors as well as weak places. Other types of yarn faults, winding machine characteristics, faulty yarn guides and clearers, dirty machines, etc., all contribute to the end-breakage rate (see also Pollitt, *J. Text. Inst.* **42**, P754 (1951)).

Comparison of yarn quality

It is common practice to compare yarns on the basis of the 'count strength product' or the average single-thread strength. Only part of the answer is given by these methods and the winding test can usefully supplement the lea and the single-thread tests. Goshawk (*J. Text. Inst.* **42**, P1 (1951)) gives the following examples:

	Process 'A'	*Process 'B'*
Yarn count	110s	110s
Count strength product	2675	2530
Breaks per 1,000 yd	17·5	11·8

The yarn spun by Process 'A' had the higher breakage rate in spite of having the higher lea strength:

	Yarn A	*Yarn B*	*Yarn C*
Mean yarn count	55·8s	57·0s	56·9s
Count strength product	2255	2170	2265
Single-thread strength (g)	150·9	147·5	150·8
Breaks per 1,000 yd	6·8	18·8	23·0

Comparison of the three yarns on the basis of C.S.P. and single-thread strength reveals little apparent difference between them, but the winding test shows Yarn A to have a much lower breakage rate than the other two yarns.

Yarn strength regularity

By carrying out both a single-thread test and a winding test, an assessment of the yarn strength irregularity can be made. To get an accurate measure of the mean and standard deviation by the single-thread test a large number of tests must be made. With a non-automatic tester this would be a time-consuming job. An alternative method of estimating the standard deviation is to determine mean single-thread strength from a small number of tests and then carry out a winding test.

Let $\bar{X}$ = mean single-thread strength of 20 in. test lengths, and

T = tension required to produce eight breaks per 1,000 yd.

We can now use equation (8.6) to calculate the standard deviation:

$$T = \bar{X} - 3{\cdot}3\sigma$$

Therefore,

$$\sigma = \frac{\bar{X} - T}{3{\cdot}3}$$

Another index of irregularity is given by dividing the mean single-thread strength by the tension required to produce eight breaks per 1,000 yd. The more regular in strength the yarn is, the lower this value will be.

Control testing

In addition to the tests for comparison and irregularity, the winding test may be used for control purposes. From past experience, standard test tensions are determined for the various types of yarn spun. Samples are tested as a routine and if the breakage rate exceeds the set limit, steps are taken to find the cause and put it right. It has been found that the winding test results are often related to the end-breakage rate of the ring frame. In fact, the spinning process itself may be thought of as a low-tension winding test.

It is essential that adequate surveys are made before the control standards are set up, otherwise unrealistic standards of performance may be expected or perhaps the limits will be too wide to be of real use.

THE CONTINUOUS MEASUREMENT OF THE ELASTIC PROPERTIES OF CONTINUOUS-FILAMENT YARN

The autographic tensile testers described earlier in this chapter record the behaviour of one test length of material at a time. For some purposes it is desirable to note the elastic behaviour of a yarn at successive intervals along the yarn. This requirement has led to

the design of instruments which allow the continuous measurement of the stress–strain properties of a running thread. One such instrument has been developed by the laboratories of Dutch Enka and is described in *Rayon Review* **9**, No. 5 (Nov., 1957). The British Rayon Research Association has designed the 'Strainometer'. The description of this instrument is taken from the leaflet of Louis Newmark Ltd, who are the makers.

It is known that overstraining of continuous filament yarn caused by excessive winding tensions, tension relaxation of yarn held on packages, and other factors such as rate of drying, results in changes in its physical properties. The physical properties affected include the lustre, the elastic modulus, the dye-uptake, and the orientation and thickness of the filament skin. These properties are to some extent interrelated. Changes in lustre and dye-uptake are readily seen when the yarn is used as weft in cloth. These changes are usually periodic (i.e. caused, for example, by regular tension peaks occurring every chase in package winding), and they build up to form objectionable patterning in the cloth, such as the well-known weft bars and diamond patterning.

In the estimation of damage to yarn caused by overstrain, etc., it is more convenient to measure changes in the value of the longitudinal elastic modulus rather than to measure such things as lustre variations or changes in dye-uptake.

The 'Strainometer'

Basically, the 'Strainometer' consists of two pairs of rollers, A and B (Figure 8.43) which impose a strain of, for example, 5 per cent on the yarn under test, and a tension measuring head, C, that measures the yarn tension caused by this strain.

The front pair of rollers, A, consists of a top precision ground roller (approximately 1 in. o.d.) and a bottom rubber covered pressure roller ($\frac{3}{4}$ in. o.d.) which is spring-loaded against the top roller. The back pair of rollers is similar, except that the top one is larger in diameter according to the required strain.

These steel rollers are geared together and are driven so that they rotate at the same speed (about 100 rev/min in most instances). The nips of the pairs of rollers are about 2 in. apart. It will be apparent that, as yarn is fed through the rollers, the 2 in. of yarn between the nips will be subjected to a constant extension of, for example, 5 per cent. Care has been taken to reduce the eccentricity of the rollers to a minimum, as any roller eccentricity would, of course, result in a periodic variation in the applied strain.

The tension measuring head, C, is mounted between the front and back rollers in such a way that the tension of the strained yarn is measured. The head is connected to a bridge and amplifier unit. This, in turn, is connected either to a recording milliammeter or to a high-speed pen recorder, depending upon the detail required in the record.

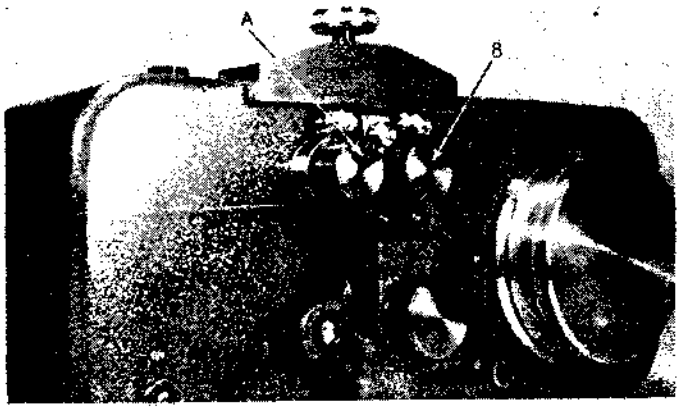


Figure 8.43. The B.R.R.A. 'Strainometer'

This type of equipment is used to determine the uniformity of filament rayon and synthetic yarns. It is also used to locate faults in yarn taken from a wide variety of packages such as cakes, pirns, bottle bobbins, cheeses, cones, etc. Typical traces are illustrated in Figure 8.44.

The Lawson dynamic stress/strain analyser

Another instrument designed for the continuous testing of yarns is the Lawson dynamic stress/strain analyser in the Scott tester range. As with the Strainometer, the test yarn is subjected to a selected strain (i.e. elongation) and the tension developed at that strain is detected and plotted on a chart, variations in tension indicating variation in the tensile behaviour of the yarn along its length. With one model of the analyser it is possible to adjust the elongation over a wide and continuous range. This is achieved by using input and output 'heads' whose circumferences can be expanded and contracted as the machine runs. On an alternative

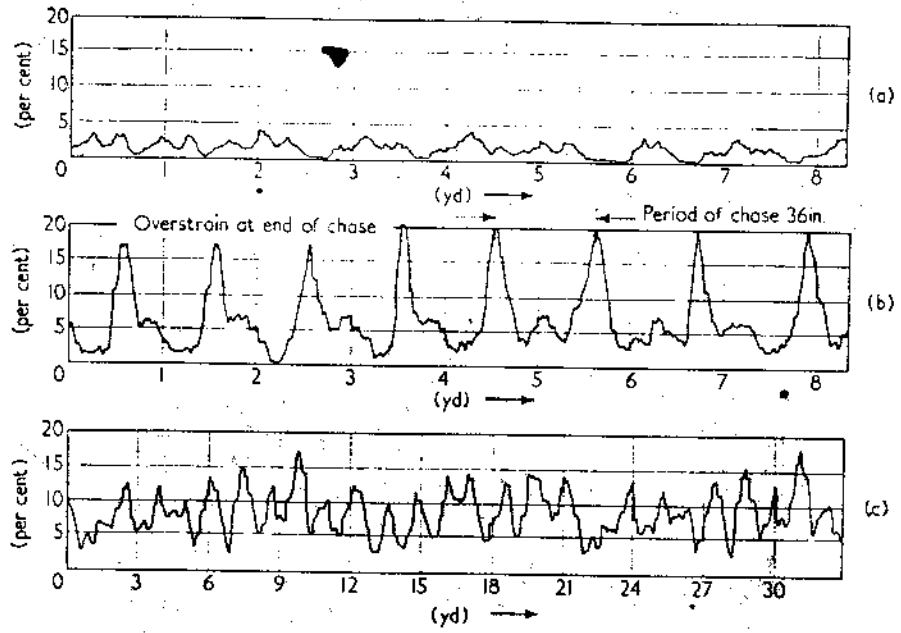


Figure 8.44. Traces obtained with the 'Strainometer': (a) 150 denier viscose yarn on cake (the variation of properties in this sample would not cause a fault in the finished material); (b) The same yarn as (a) after winding on to a pirn; (c) 1,000 denier nylon tow on cheese (each peak coincides with yarn from edge of cheese)

model there are interchangeable input heads, of fixed circumference, and, with a gear change system, a variety of elongation ratios from 0 to 1,100 per cent can be obtained.

The tension developed by the stretched yarn is measured by a three-pulley tension transducer, the load cell being a weigh beam strain gauge with a range of 0–2,000 g. The transducer output is fed to a recorder which produces a continuous trace of the tension variation. The chart can then be analysed and possible causes of faults located.

THE HYDRAULIC BURSTING TESTER

It is sometimes desirable to test a fabric by applying the load multi-directionally instead of in one direction only, as in the case of warp or weft way strip tests. The reasons for this preference may be due to the difficulties associated with other methods of test or perhaps because the material will, in use, be stressed in many directions simultaneously. Knitted fabrics are particularly tricky to test in

strip form. Figure 8.49 (page 435) shows a knitted fabric being tested in a Heal's cloth tester. The edges of the strip have curled and the specimen is generally distorted. Filter cloths, sacks, nets, and parachute cloths are examples of fabrics stressed in all directions. Fabrics without well defined 'directions' such as felts and the recently developed bonded fibre fabrics may be conveniently tested on a bursting strength tester.

The pressure in a liquid is exerted in all directions and advantage is taken of this phenomenon in the hydraulic bursting tester. Briefly, the specimen S in Figure 8.45 is clamped by a ring over a thin flexible rubber diaphragm D, which is itself clamped over a circular hole in the upper face of a reservoir. The liquid used may be water or glycerine. The hydraulic pressure is increased, by valves or screw-driven piston, and the diaphragm distends, taking with it the specimen. At some point the fabric bursts, the pressure being indicated by the gauge G. Since the rubber diaphragm requires a certain pressure to stretch it, corrections may be made either by doing a 'blank' test, i.e. noting the pressure required to distend the diaphragm the same amount without the presence of fabric, or, where an autographic device is used, pressure–distension curves for the diaphragm give the correction directly.

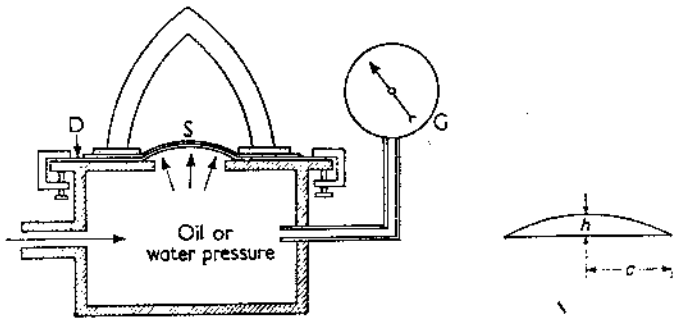


Figure 8.45. The hydraulic bursting strength tester

The height to which the specimen bulges enables the extension percentage to be calculated if required. If h is the height and c is the radius of the specimen, and assuming that the bulge is in the form of a spherical cap, then,

$$\text{Extension} = \left[\left(\frac{c^2 + h^2}{h} \right) \tan^{-1} \left(\frac{h}{c} \right) - c \right] \frac{100}{c} \text{ per cent}$$

Proof of this formula is an exercise for the reader.

The diameter of the specimen may be varied. It is considered good practice in testing to have a test length greater than the fibre length. A diameter of 1·2 in. which is used on some testers is a little on the small side for woven cotton fabrics. For knitted fabrics the length of yarn in a 1·2 in. circle is much longer, of course, because of the looped structure. The point of fibre length does not arise with filament yarns. Nevertheless, a larger specimen is preferred and used, e.g. 2 in., 4 in., and 7 in.

First thoughts on the test may suggest that the weaker threads will break first, but this is not strictly true. The extensibility of the yarns and the structure of the fabric are factors which determine the behaviour of the specimen. It is quite possible that the stronger threads, being less extensible than the weaker threads, reach their limit of stretch first and therefore break first. The crimp percentages in the warp and weft will naturally play an important role. With a high crimp percentage a large proportion of the total extension will be due to the removal of crimp, thus the yarns with low crimp will reach their limit of extension first.

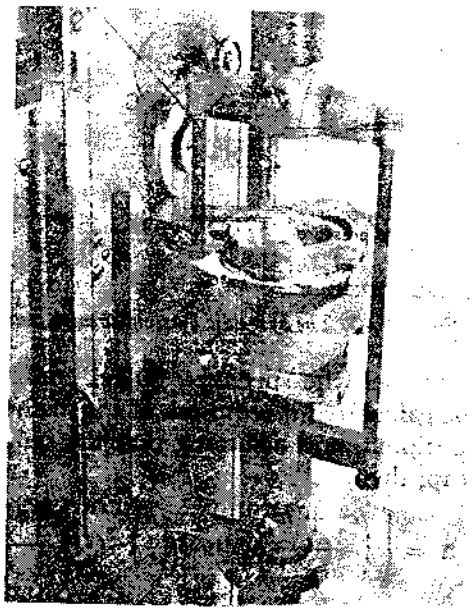


Figure 8.46. Mechanical bursting test. Steel sphere pushed through the specimen

A variation in the method of test is the 'wounded' bursting test. In this test the specimen is deliberately weakened either by cuts made with a $\frac{1}{2}$ in. chisel across either or both sets of threads or by a $\frac{1}{4}$ in. hole punched in the centre.

The testing procedure and more detailed descriptions of the instruments will be found in B.S. Handbook, No. 11. It is worth while noting that mechanical bursting testers are available in which a 1 in. steel ball is forced through the specimen clamped between a pair of rings, the force required being the measure of the bursting strength (see Garner, *Textile Laboratory Manual* (2nd Edn) p. 148, and Skinkle, J. H. *Textile Testing*, p. 170) (see also Figure 8.46).

The bursting test is really the only one that is of use with knitted fabrics. The effect of loading a knitted strip specimen has already been noted, but it is also a useful test for woven fabrics in which local tendering has occurred, e.g. with discharge printing. No doubt the bursting test will also be useful in testing bonded fibre fabrics and similar textile structures.

GENERAL REMARKS ON FIBRE STRENGTH TESTING*

The unit from which many yarns and textile structures are built is the single fibre. Naturally, a great amount of research has been devoted to the measurement of the various properties of a wide range of fibres. One of the elements which contribute to the strength of a yarn is the strength of the fibre. This property may be expressed in a number of ways. The engineer's approach would probably be to express the strength in terms of ultimate tensile stress, i.e. pounds per square inch or kilograms per square millimetre. From a textile technologist's point of view, it is more convenient to consider fibre strength in terms of either tenacity or breaking length, the former in grams per denier or grams per tex and the latter in kilometres. The reason for this can perhaps be explained by taking the cotton fibre as an example.

Consider two yarns of the same count, Yarn A spun from fine fibres, Yarn B spun from coarse fibres. Now, the breaking length of fine fibres is generally higher than that of coarse fibres. This is one of the reasons why Yarn A will be stronger than Yarn B. If the individual strengths of the two fibres had been compared, then the coarse fibres would have shown the higher strength. When breaking lengths are compared, however, the order of ranking is reversed:

*See also Morton, W. E., and Hearle, J. W. S. *Physical Properties of Textile Fibres*, Part IV.

Cotton type	*Fineness (denier)*	*Individual fibre strength (g)*	*Breaking length (km)*
St. Vincent	0·9	4·6	46
Bengals	2·9	5·8	18

In the selection of raw materials, knowledge of the comparative strengths of the available fibres is extremely useful. The problem facing the mill laboratory is how to carry out comparative strength tests. Single-fibre testing* is really a job for the research laboratory, where the instruments required receive the attention of specialists and where time, although important, is not as limited as in the mill laboratory. Reviews of the methods of single-fibre testing will be found in the Journals of the Textile Institute for May 1937 and February 1947. Further papers will be found in the references at the end of this chapter. The Cambridge Extensometer, the Instron, and the Scott Serigraph have already been described and all three can be used for single-fibre testing, the Scott requiring an accessory.

Consideration of the time and skill required for single-fibre testing has led to the development of instruments which test a composite specimen. The Pressley, the Stelometer, and the Clemson are all examples of instruments which test a flat bundle of fibres. In the early stages of this development the specimens were tested at zero gauge length, but the conclusion has been reached, after a considerable amount of investigation, that tests on a specimen length of $\frac{1}{8}$ in. give a closer agreement with subsequent yarn strength tests.

Amongst other sets of valuable data, Hertel and Craven (*Text. Res. J.* **26**, p. 479 (1956)) obtained correlation coefficients between the values of cotton fibre tenacity at zero gauge length, tenacity at $\frac{1}{8}$ in., and the skein or hank strength of yarns produced from the tested cottons. The Stelometer was used in the experimental work since the relations between the elongation values obtained from fibre bundle testing and various yarn properties were also studied. Table 8.3 is taken from Hertel and Craven's paper.

For both the long and medium staple cottons there appears to be a high correlation between the tenacity of the raw cotton at the $\frac{1}{8}$ in. gauge length and the skein strength of the resultant yarns. A high correlation between the Stelometer results and the results of single-fibre tests on the Instron tester is also reported.

*See B.S. 3411:1961. *The Tensile Properties of Individual Textile Fibres and Filaments.* B.S. Handbook No. 11, p. 62. See also p. 407 of the present volume for description of the W.I.R.A. Single Fibre Strength Meter.

Table 8.3

Number of samples (variables correlated)	*Long staple 25 (correlation coefficient)*	*Medium staple 194 (correlation coefficient)*
T_0T_1	0·96	0·44
$Y\ T_0$	0·95	0·38
$Y\ T_1$	0·96	0·86

T_0 = Tenacity in grams per grex at zero gauge length ('grex' is a count system based on grams per 10,000 m).

T_1 = Tenacity in grams per grex at ⅛in. gauge length.

Y = Skein strength of 22s carded yarn for the medium staple cotton, or 36s combed yarn for the long staple cotton.

Even though fibre bundle testing does reduce the work involved, it is still a relatively slow process since about sixteen tests per sample are required to give confidence limits of around 2 per cent.

From the above general remarks on fibre testing the inference must not be drawn that yarn properties can be predicted from either single-fibre or fibre bundle tests. The results are guides which should be used complementarily with experience; a great amount of investigation is yet to be done before such predictions can be made with a high degree of accuracy. One interesting line of inquiry may lead to the use of a punched card system; the various fibre properties are punched into the card, the card fed to a card-reading device, and the probable yarn properties derived automatically and delivered from the machine on a printed card.

The increased use of small-scale spinning tests on equipment such as the Shirley Miniature Spinning Plant will no doubt remove some of the problems of forecasting yarn character from samples of raw materials. Even so, work on the fundamental properties of the fibres will still be necessary for continued progress in textile technology.

YARN STRENGTH TESTING

The range of instruments which are available for testing the strength of yarns is quite wide—single-thread testers operating on the principles of pendulum lever, inclined plane, strain gauge, and constant-tension–hank testers of the pendulum lever or ballistic types. Some of these instruments are relatively simple, some complicated, some have recording devices, some are automatic. The choice of the best type to use is often difficult.

A general answer cannot be given here because so much depends upon the use to which the resultant information is to be put. Technical and economic points require close study. Are the test

results purely for internal use or are they quoted to outside people? What degree of accuracy is demanded? How quickly must the results be available? Is the test for routine control or for experimental work? These are just a few of the questions which arise. It would be unwise to say that instrument A is superior to B without knowing all the facts, but it is useful to compare the various methods of yarn testing from a purely technical angle.

The lea test

In many sections of the textile industry, especially the older sections of wool, cotton, and flax, the lea or hank test on a pendulum lever tester is the standard method of measuring the 'strength' of the yarn. Inverted commas are used deliberately and the reason will be gathered in the course of the following discussion.

A hank of yarn, with its starting and finishing ends knotted, is placed over the hooks of a lea tester of the type shown in Figure 8.16. As the lower hook descends, a load is imposed on the loops of yarn constituting the hank. At some point one of the threads breaks, yet the hank remains intact and capable of sustaining further loading. The hank suffers a succession of thread breaks and ultimately becomes unable to sustain any further increase in load. When this happens the pendulum stops moving and the maximum load is indicated on the dial, the 'lea strength' of that particular hank. Note here that only a fraction of the total number of threads between the hooks have actually broken. The end-point of the test is determined by the rate at which the hank unravels as the threads break. At the first few breaks the rate of unravelling is small. When the rate of unravelling equals the rate of separation of the hooks, the top hook will stop and the maximum load will have been reached.

If, instead of two hooks, the yarn had been looped round 80 pairs of frictionless pulleys, then as soon as the first thread broke the whole hank would unravel. In the normal test, therefore, it is the presence of frictional forces between thread and thread, and thread and hook, which restricts the unravelling of the hank. Hence, the indicated strength is a combination of a complex composite specimen test plus a measure of the frictional properties of yarn in hank form and yarn/hook friction. The inter-yarn friction is increased by any twist put into the hank as it is placed over the hooks or if the threads are bunched on the hooks. Personal errors are thus liable to creep in. A further point to note is that unequal tensions in the threads of the hank will result in a lowered strength because the tighter threads will break too soon.

The frictional forces present in the lea test reduce the sensitivity of the test to the detection of weak places in the yarn. A yarn which is generally weak will, of course, produce a low lea strength, but the presence of an abnormally weak place in one of the threads will escape detection. This may be demonstrated by testing a set of hanks, one thread in some hanks being cut during reeling. The resulting average lea strength is seldom so much lower than that of a set of uncut hanks that anything out of the ordinary is suspected by the operator.

Richards (*J. Text. Inst.* **49**, T131 (1958)) points out that there is no simple proportional relation between the hank breaking load and the single-thread strength, a limiting factor in the usefulness of the lea test.

Some lea testing machines have a scale which indicates the extension of the yarn but, since the elongation is partly the unravelling of the hank, it is not a satisfactory measurement.

With all this adverse criticism of the lea test, one wonders why it continues to be used at all. Therefore, the reasons for its popularity must be considered. Firstly, it is a simple test which is fairly rapid and which tests a reasonably large sample of yarn. The broken hanks can also be utilised for count testing. Secondly, the machine is robust and gives long periods of service without trouble. Thirdly, since most of the testing will be routine and of a comparative rather than an absolute nature, the lea test is adequate for the job because it is sensitive enough to detect a change in the yarn quality. An accurate determination of the degree of change may not be called for. Investigation of the cause of the change may then be made with the aid of more refined testing instruments and techniques. Finally, any test which has been in use for a long time tends to be difficult to replace. Managers and technicians build up a store of knowledge based on the data and standards associated with the established tests and there is a reluctance to scrap the old in favour of the new.

The count–strength product

When assessing the character of cotton yarns, the product of the count and the lea strength is a useful measure of the merit of the yarn from a strength point of view. The count-strength product, C.S.P., enables comparisons to be made between yarns of similar, but not necessarily identical, count. It often happens that a series of tests on a nominal, say 60s, yarn is in fact made on yarn of perhaps 59·2s or 60·8s. Corrections to the C.S.P. are therefore made and in spinning test reports the 'corrected lea count–strength product' is quoted.

Some C.S.P. values for various yarns may be read off the graph of Figure 6.9 which shows how the C.S.P. varies as the twist factor is changed. The concept of the C.S.P. may be used to derive an index by which the spinning quality of a cotton may be judged or the spinning efficiency of a particular system. Standard C.S.P. values have been chosen, 2,000 for carded and 2,250 for combed yarns.

As the count of a yarn becomes finer the C.S.P. falls, therefore at a certain count the C.S.P. will be equal to the standard. This count is then termed the 'highest standard count'. Hence, the H.S.C. for a sample of cotton is a measure of its spinning quality.

These standards have been developed by the Shirley Institute (B.C.I.R.A.) and are based on the conditions under which spinning tests are carried out there. In an excellent paper by Lord and Underwood (*Emp. Cott. Gr. Rev.* No. 1 (1958)) many aspects of fibre and yarn testing are covered and the principles of the C.S.P. and H.S.C. are discussed in detail.

Skein-breaking tenacity

In a report of the London Conference of the International Standards Organisation, Technical Committee 38, 1960, a new specimen size for yarn count testing was suggested. The skein would be 50 m long, i.e. 50 wraps on a one metre wrap reel. This skein would be tested on a strength testing machine and the breaking load measured in kilogrammes. In place of the count × strength product (C.S.P.) a measure of the yarn strength 'quality' would be the 'skein-breaking tenacity' and this would be calculated as follows:

$$\text{Skein-breaking tenacity (grammes per tex)} = \frac{\text{(Average skein-breaking load in kilogrammes)} \times 1000}{2 \times \text{wraps in skein} \times \text{average linear density of unstrained yarn, in tex}}$$

Direct comparison of this figure with single thread tenacity from single thread tests would be possible.

The ballistic test

This test on hanks of yarn has a number of desirable features:

(1) It is simple to carry out and it tests a large sample.
(2) It is rapid (faster than the lea test).
(3) It is not as liable to operator errors as the lea test.
(4) Yarn friction plays a negligible part in determining the result.
(5) Every thread breaks and contributes to the final result.
(6) The machine is robust and no power supply is needed.
(7) The broken lea may be used for a count test.

The ballistic test records the amount of energy or work required to break a hank of yarn and in effect three characteristics of the yarn are combined in one figure: breaking load, breaking extension, and work factor. Unfortunately the breaking load and the breaking extension cannot be separated. Further, a strong inextensible yarn may not be distinguished from a weaker but more extensible yarn. The spinner is concerned with the way in which current qualities of yarn vary from week to week, i.e. he is concerned with the comparison of basically similar specimens. Changes in the cotton quality, the machinery performance, etc., must be detected. The ballistic test is sensitive enough to do this job; it may in fact be more sensitive in the detection of increase in yarn irregularity than the lea test. Nevertheless, the lea test maintains its place in routine testing and has not been replaced by the ballistic test.

The single-thread test

The disadvantages of the lea test—a complex result, no measure of extension—are eliminated in the single-thread test. Testing instruments are available which produce load–elongation diagrams if required, Goodbrand, Scott, and Instron being examples. The development of automatic instruments of the calibre of the 'Uster' has removed a major disadvantage of single-thread testing, that of the time required.

For critical testing where the maximum amount of information is required, the single-thread test should be used. It must be borne in mind that the level of skill and care should be high, especially if the instrument is non-automatic, because the manner of handling the threads can affect the results. The aim is to give each individual thread identical treatment.

In the standard test procedure (B.S. Handbook, p. 135) the minimum number of 20 in. test specimens for single spun yarns is 50. Thus, the actual length tested is relatively short and must be regarded as a disadvantage of the test. The chances of spotting a weak place which may only appear once every 1,000 yd or so by testing only 1,000 in. might seem small. Even so, by calculating the coefficients of variation of the strength and the extension, a measure of the regularity of the material is obtained.

It has already been mentioned that there is no simple relation between the single-thread strength and the lea strength. The strength per thread for the lea test may be calculated by dividing the lea strength by the number of threads between the hooks, e.g. by 160 if the hank was a 120 yd hank wound in 80 revolutions of the

wrap reel. This value of strength per thread can be expressed as a percentage of the average single-thread strength. Usually, about 70 per cent is obtained but it may vary between 50 per cent and 90 per cent. In Gregory's paper (*J. Text. Inst.* **44**, T515 (1953)) the ratio of lea breaking length: single-thread breaking length is quoted for a number of experimental yarns, the ratio varying from 0·56 to 0·90.

The constant-tension winding test has been discussed earlier in this chapter and its value as a detector of weak places has been mentioned. A word of warning is necessary. The test is apparently a close approximation to actual running conditions and is therefore of an imitative nature. Like a number of such imitative tests the real conditions are exaggerated, in this case the tension level is far higher than normal running tensions. Caution must therefore be used in the interpretation of the results.

Standard single-thread strength values

The introduction of an automatic single-thread strength tester of the 'Uster' type has enabled the laboratory in an average mill to make a close study of the strength characteristics of its yarns. It is clearly a useful exercise to compare one's own products with those of other yarn producers. The manufacturers of the 'Uster' tester have therefore prepared a set of standards based on the results of tests on many yarns from different countries. The standards are for carded and combed cotton yarns spun from various raw cotton varieties and at different twist factors. A book of standards charts is published by Melliand of Heidelberg, West Germany. An extract is given in Figure 8.47.

It will be noted that the breaking strength is expressed in terms of 'breaking length', a concept discussed earlier in this chapter. Further, the count is expressed in tex, but the twist factor in the English form. A carded cotton yarn, spun from Texas cotton, $1\frac{1}{16}$ in. staple, to a count of 24s (English), with a twist factor of 4·00, should give a breaking length of about 14·25 km. Changing the 24s into tex counts, 24·6, we locate 24·6 along the horizontal scale and then move vertically to cut the 4·00 twist factor line. The point of intersection lies approximately one-quarter the distance between the thick 14 and 15 km lines. Hence, 14·25 km tolerances or limits are shown above the chart, ± 0·30 km. Converting the breaking length to breaking load in grams (14·25 × 24·6) we conclude that our 24s yarn should have a mean breaking load of about 350 g. Below the chart there is a line which indicates the degree of variation to be expected; for the yarn considered, a C.V. percentage of 10·5 is indicated.

Standards for the elongation at break are also to be found below the strength standards. These are interpreted in virtually the same way. It is stressed, of course, that the tests should be carried out on an accurate tester and under the recommended conditions of humidity and at a time of break of 20 sec, otherwise false conclusions may be drawn.

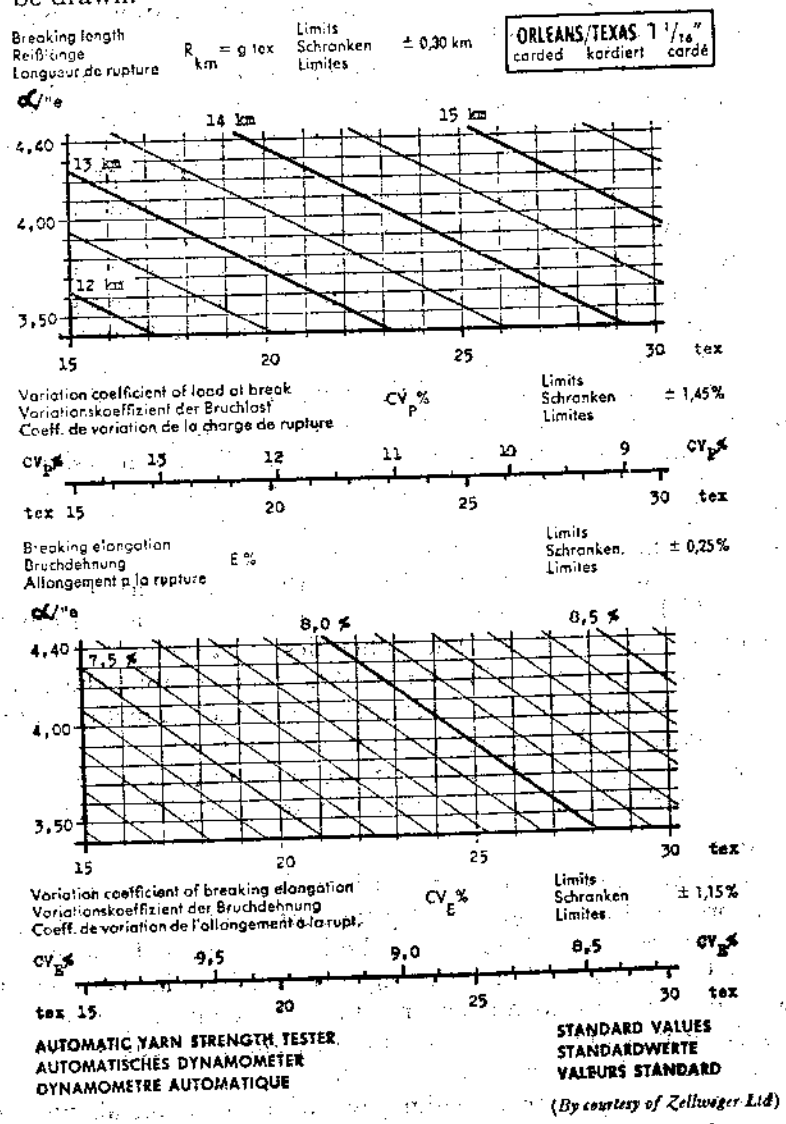


Figure 8.47. Example of an 'Uster' standard for single-thread strength

FABRIC STRENGTH TESTING

The reasons for carrying out tests on fabrics are numerous and varied, some common ones being:

(1) To check that the fabric conforms to specification.
(2) To note the effects of changes in structural details.
(3) To note the effects of physical and chemical treatment, exposure to weather, laundering, etc.
(4) To obtain some indication of probable performance in use.
(5) To investigate causes of failure and customer complaints.
(6) To help in the design of a fabric for a specific purpose.
(7) To study the interaction of fibre, yarn, and fabric properties.

The choice of the most suitable type of testing instrument will be largely governed by the information sought. There may be difficulties associated with the type of fabric, really tough industrial fabrics will require different test methods to ladies' dress goods. In some cases a suitable testing machine is not available and a special one is designed. For the general run of fabrics, however, the instrument selected will be one of the types described earlier in this chapter. These machines will be based on the pendulum lever, inclined plane, and strain gauge principles, differing in design from yarn testers in capacity and detail. Machines such as the Denison and the Instron are multi-purpose testers, and the switch from yarn testing to fabric testing is readily made.

As in the testing of yarns and fibres, the atmospheric conditions under which the tests are made should be controlled and a reliable scheme of sampling used. The difficulties of sampling from fabric have been discussed in Chapter 3. Wherever possible, the testing procedures should follow the recommended standard methods of the British Standards Institution or some other authority.

The main types of strength test are the straightforward tensile test, the tearing test, and the bursting test, each with variations.

The strip test

The specimen used in the strip test is usually a 2 in. wide piece of fabric prepared by initially cutting the material to a width of about $2\frac{1}{2}$ in. and removing threads from both edges until the width has been reduced to 2 in. The test length should be 8 in. between the jaws and so enough extra length must be allowed for gripping in the jaws. If the type of fabric is difficult to fray along the edges, then the fabric is carefully cut to the 2 in. width.

It is not a simple job to design jaws which will suit all types of fabric because different materials behave in different ways when

clamped between two surfaces. Under optimum conditions the specimen will be mounted centrally, securely gripped along the full width to prevent slipping, and the jaws aligned and parallel so that the load is applied uniformly across the full specimen width. When breaks close to the jaws occur frequently, the method of gripping the specimen should be examined critically. The use of soft packing such as felt between the specimen and the jaw faces often improves matters. The Tentative Textile Standard No. 46* (*J. Text. Inst.* **48**, P680 (1957)) refers to jaw breaks as follows: 'If a test specimen breaks within 0·25 in. (0·5 cm) of the line of contact of either of the pairs of jaws at a load substantially less than the average of normal breaks, the results shall be recorded but not used in calculating the breaking load and breaking extension. Another specimen shall be tested and the results used instead.'

When the load is applied to the strip of fabric the crimp in the direction of loading is gradually reduced and the crimp in the transverse threads increases, a process known as 'crimp interchange'. The visible effect of this is the 'waisting' of the specimen. Contraction in width is greatest in the middle and decreases towards the jaws. In the region of the jaws the stresses in the specimen are high and can be a cause of jaw breaks. Figure 8.48 shows a strip of fabric at different stages during a test.

A general equation to relate the strength of the fabric and the strengths of the component yarns will no doubt be a complex one if and when it is finally derived.† The variables which face the technologist include:

(1) Raw material characteristics.
(2) Yarn structure—count, irregularity, twist factors, doubling, etc.
(3) Fabric structure—settings, crimp percentages, weave.
(4) Fabric finish.

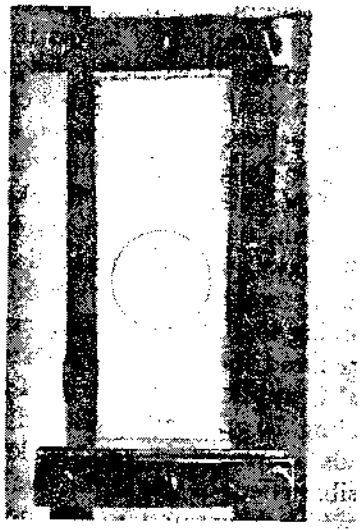
One important point is the effect of the transverse threads on the strip strength. If we calculate the ratio

$$\frac{\text{Strip strength per thread}}{\text{Single thread strength}}$$

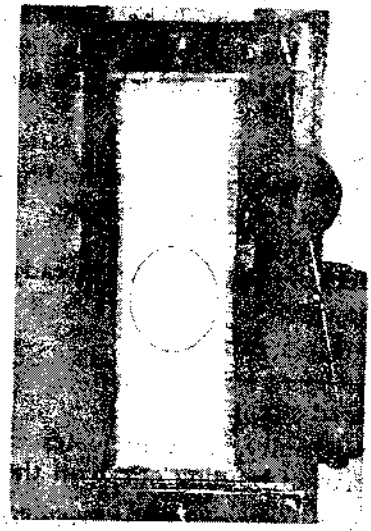
the result is usually higher than unity. This indicates that the transverse threads have some form of binding effect on the longi-

*B.S. 2576:1959. *Breaking Load and Extension of Strips of Woven Textile Fabric.* B.S. Handbook No. 11, p. 249.

†See also Chadwick, G. E., Pollitt, J., and Taylor, H. W. 'Relations between Cloth, Yarn, and Fibre Properties with Particular Reference to Blended Cloths.' *J. Text. Inst.* **54**, 126 (1963).



(a)



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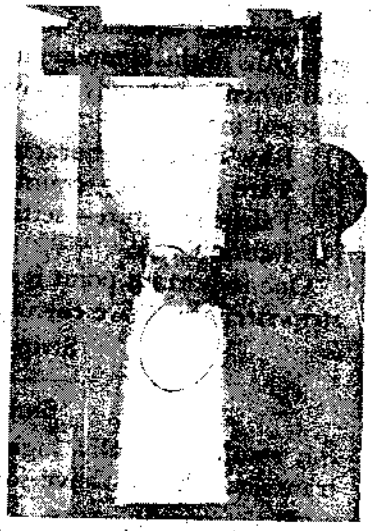


(c)

Figure 8.48. Woven fabric tested in strip form

tudinal threads, so increasing their strength. Some authorities refer to this effect as 'fabric assistance'. In some cases the ratio may be in the region of 1·8 where the number of transverse threads per inch is high.

A variation to the unidirectional strip test is described in the *Textile Research Journal* **28**, No. 5, p. 399 (1958). In this test the specimen is stressed in two directions at once. (See also Taylor, H. W., and Clulow, E. E. *J. Text. Inst.* T323 (1963).)

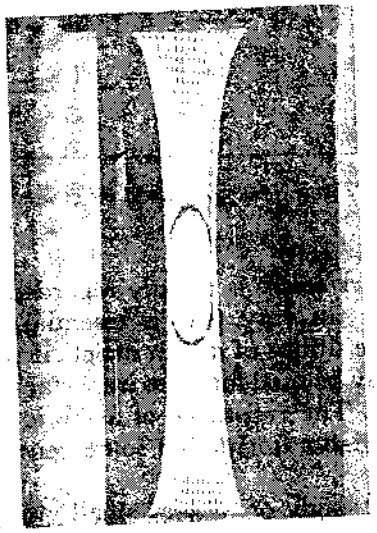


Figure 8.49. Knitted fabric tested in strip form

The grab test

Figure 8.50 illustrates the form of the grab test. The effective width of the specimen is the width of the jaws, usually 1 in. It will be appreciated that the stressed zone of fabric between the jaws will be reinforced a little by the fabric on either side. From tests made at the Shirley Institute, on a wide range of fabrics, the ratio grab strength/tensile strength per inch for a 2 in. strip varied from 1·0 to 2·0. It was also found that the ratio was correlated with the breaking extension of the fabric in the strip test. The relation was approximately:

$$\frac{\text{Grab strength}}{\text{Tensile strength per inch}} = 1 + \frac{\text{breaking extension \%}}{40}$$

Factors other than the extension are involved but the relation with breaking extension takes care of a large part of the variation in the grab/tensile ratio. One advantage of the grab test is that the preparation of the specimens is simpler. To ensure that the two jaws grip the same threads it is usual to line them up against a pencil line marked down the specimen. In the U.S.A. the grab test is commonly used for control testing, but for accurate work the strip test is preferred.

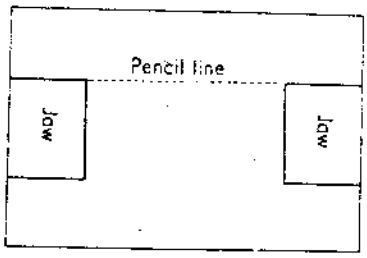


Figure 8.50. Specimen of the grab test

Tearing strength

A fabric which tears easily is usually regarded as an inferior product except where an easy tear is essential, e.g. bandages and adhesive tapes. The utility of a torn article is reduced; at best it is patched up and may be used for a less important job and at worst the article is scrapped. The resistance of a fabric to tearing has been studied by various laboratories and some general conclusions have been drawn:

(1) Threads break singly or in very small groups during the tear, therefore the single-thread strength of the component yarns is of great importance.

(2) Where the fabric characteristics allow, the threads group closer together under the force of the tearing agency and so, instead of the successive breakage of individual threads, the action becomes more of a strength test on plied yarns. This grouping of threads is made easier if the yarns are smooth and can slip over each other.

(3) Closely related to point (2) is the effect of weave. Thus, a twill or a 2/2 matt structure allows the threads to group better than a plain weave. Twills and matt weave exhibit better resistance to tearing than plain weave.

(4) High-set fabrics preclude thread movement and the assistance by thread grouping is therefore greatly reduced.

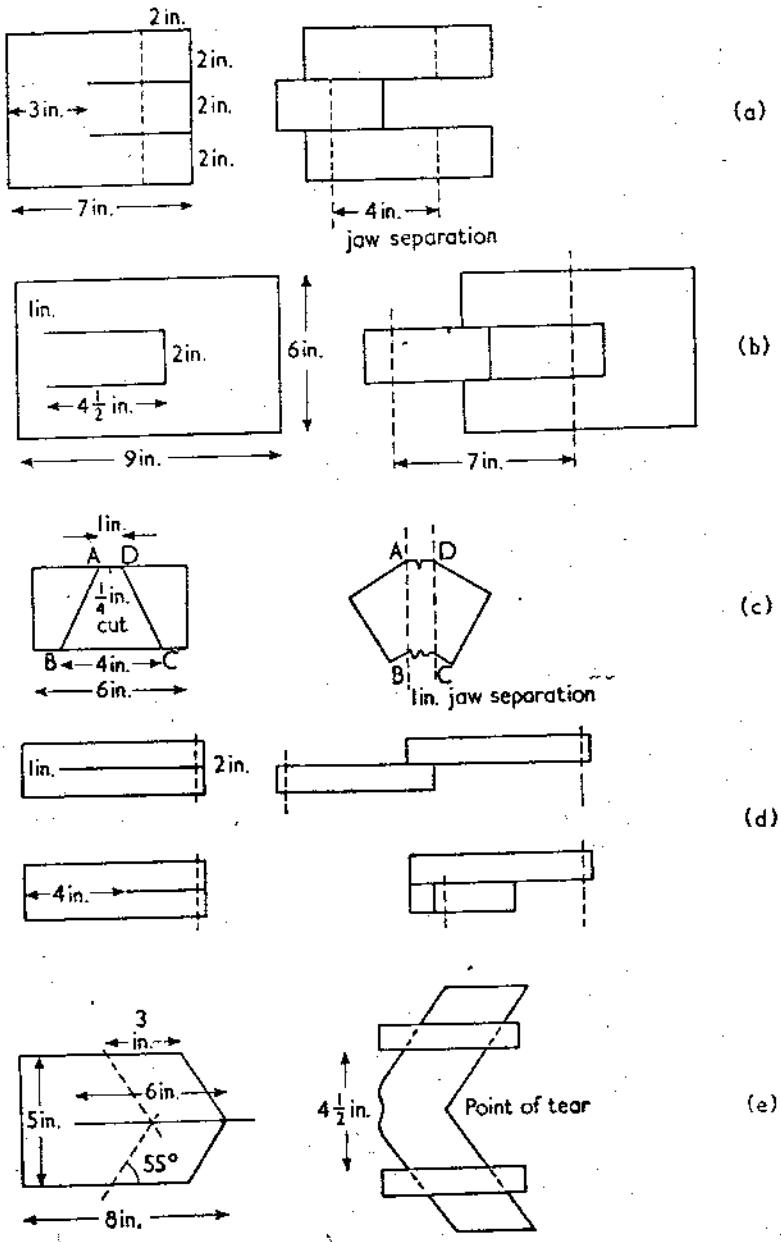


Figure 8.51. Tearing strength test specimens: (a) Tongue tear test; (b) Tongue 'double rip' tear test; (c) Trapezoid tear test; (d) Ballistic 'single rip' tear test; (e) Wing rip tear test

(5) Special fabric finishes such as drip-dry and crease-resist treatments may reduce the tearing strength. (Much work on this aspect of finishes is currently in progress and no doubt some of the adverse effects will be eliminated.)

The mechanism of tearing is discussed in the following papers: Krook and Fox (*Text. Res. J.* **15**, p. 389 (1945)), Teixiera, Platt, and Hamburger (*Text. Res. J.* **25**, p. 838 (1955)), Taylor (*J. Text. Inst.* **50**, T161 (1959)).

Methods of measuring tearing strength

For many of the tearing strength tests standard tensile strength testing machines are used; they are sometimes modified slightly but the important features of the various tests are usually the form of the test specimen, the method of securing it in the jaws, and the interpretation of the recorded strength values. Some authorities point out that many tears in practice occur suddenly and that a tearing test should be made at high speed rather than at the normal slow traverse speed of tensile tests.

Figure 8.51 illustrates some of the forms of the test specimens used for tearing tests.

The tongue tear test (B.S. Handbook, p. 165). The specimen is prepared and mounted in the jaws of the tensile strength tester, as indicated in Figure 8.52. Where a pendulum lever machine is used the pawls on the pendulum are made inoperative so that as the thread breaks the lever falls back from a peak position and rises again when the next thread is loaded. An autographic device is useful here since the peak loads are recorded on the chart, whereas a testing machine without a chart will require the operator to follow the peak loads carefully and to record them as the tear proceeds. Five tests in each direction are made. The tearing strength reported is the *median* value of the peak load values. Figure 8.53 shows the chart produced from a tearing test using the Instron tester.

The tongue 'double rip' test (B.S. Handbook, p. 167 (1956)). This test is put forward by the Linen Industry Research Association. In principle, it is similar to the previous test. Again, five tests are made in each direction but the reported tearing strength is determined from the *highest* value during each tear and the *mean* of the five highest values is calculated.

In both the tests just described it sometimes happens that the tearing occurs at right angles to the direction of the applied load. In such cases the fabric is regarded as untearable *under the test conditions* but not necessarily untearable under other conditions.

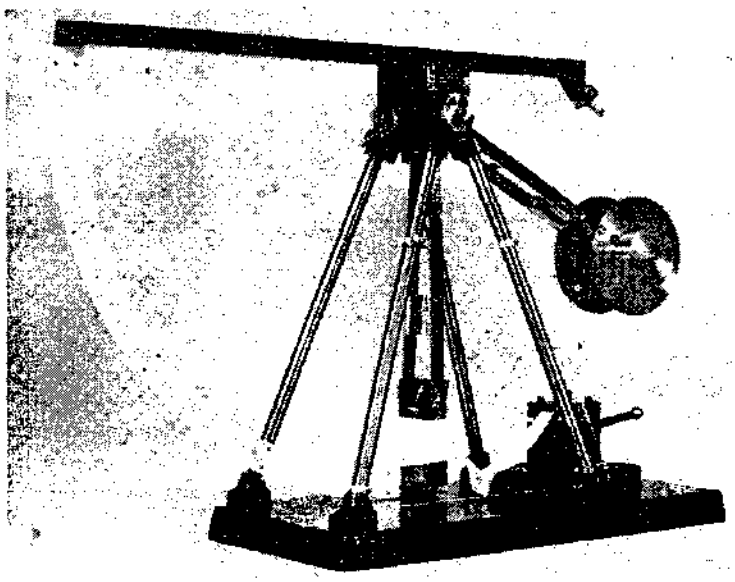


Figure 8.52. The 'Shirley' double pendulum ballistic tester (for tearing strength)

*The trapezoid tear test.** This form of tear test is a standard method of the American Society for Testing Materials. The title of the test stems from the shape of the test specimen. The specimen is clamped with the jaws along the lines AB and CD, with the edge AD taut and the edge BC in folds. As the jaws separate the fabric tears, starting from the $\frac{1}{4}$ in. cut. The average tearing strength is determined on five specimens in each direction. Here again, an autographic device on the testing machine is a useful accessory.

The wing rip tear test. The tendency for the tear to transfer in direction from the direction of the applied load can be counteracted by preparing the specimens for the wing rip test. This has been developed by LINRA and is described by Ewing (*J. Text. Inst.* **47**, T609 (1956)). An angle of 55 degrees was found to be an optimum which is suitable for a wide range of fabrics. The point of tear remains more or less in line with the jaw centres as the tear proceeds. (See B.S. Handbook No. 11, p. 255.)

*Now rescinded.

The ballistic tear test (B.S. Handbook, p. 257). The tearing tests described above are normally carried out at a slow rate of jaw separation, say 4½ in./min, but in practice tears are produced accidentally and at relatively high speeds. The rapid action of the ballistic test may therefore offer a closer approximation to the actual tearing of a fabric.

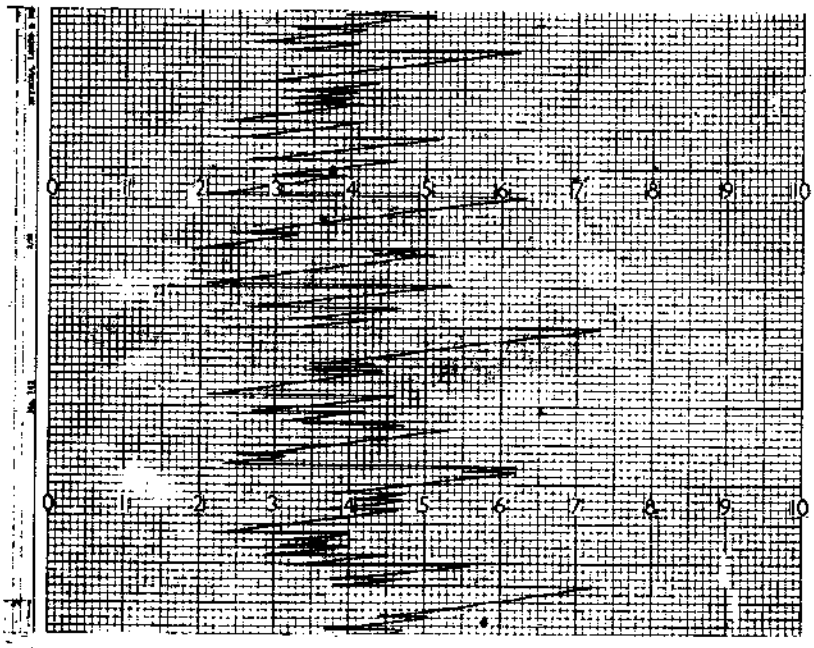


Figure 8.53. Record of tearing strength test on Instron machine.
Material: Drip-dry poplin 126 × 72, 45s × 36s cotton counts.
Median value of peak loads = 940 g, mean = 932 g

For the ballistic tear test the specimens are prepared in sets of two, five sets warp way and five weft way. The form and dimensions of the specimens are shown in Figure 8.51. The tails are clamped in the jaws of a suitable ballistic tester (Figure 8.52) and the pendulum released. It will be remembered that the ballistic tester records the energy or work absorbed by the specimen. The reason for using two specimens will be appreciated when it is realised that, in addition to tearing the fabric, part of the energy recorded is used in stretching the tails. By tearing through 1 in. of fabric with the first specimen and through 4 in. with the second, it is possible to cancel out the energy absorbed in stretching the specimen tails.

Let W_1 = mean tearing strength of five specimens torn through 1 in., and

W_4 = mean tearing strength of five specimens torn through 4 in.

$$\text{Then, Tearing strength, lb} = \frac{1}{6}(W_4 - W_1)$$

The divisor 6 must be used because, in order to tear through 3 in. of fabric, the ends of the specimen must be separated by a distance of 6 in. The scale of the ballistic tester is graduated in inch pounds. Therefore, by dividing by inches, i.e. 6 in., the result is given in pounds.

The ballistic tester has been used to measure the tearing strength of a fabric through which a nail has been driven (see Creswick, J. *J. Text. Inst.* **38**, T307 (1947)). An article by Hayes (*J. Text. Inst.* **38**, T1 (1947)) deals with a specific problem, the tearing strength of wagon covers.

The Elmendorf tearing tester

The tearing of paper is in some ways like the tearing of fabric and so it is not surprising that a testing instrument originally designed for paper testing can be adapted and used for fabric testing. In essence, the test is a single rip ballistic test having the advantages of rapidity and small samples. Figure 8.54 shows the form of the sample as punched out by a cutting die. In the test the Elmendorf continues to tear the fabric from the end of the slit to the opposite edge, a distance of 43 mm.

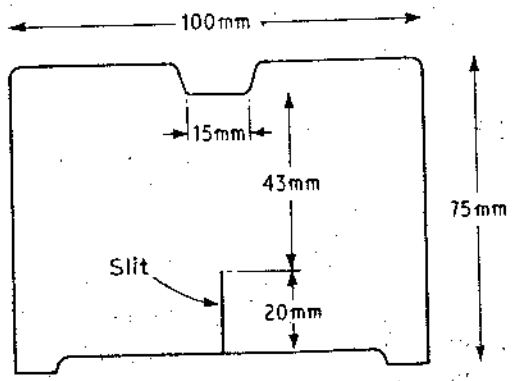


Figure 8.54. Sample for Elmendorf test

The pendulum of this instrument is sector-shaped (Figure 8.55), and mounted on it is sample clamp A. The other clamp, B, is fixed to the frame. With the pendulum in the raised position the two clamps are aligned and the sample carefully fitted and clamped tight. (For samples without a precut slit, a knife on the frame is used to make the 20 mm slit.) When the pendulum is released clamp B moves away from clamp A and the fabric tears across its width. The arc through which the pendulum swings is related to the energy consumed by tear. A pointer indicates the tearing force on a scale on the pendulum. On some models the scale is graduated in hectograms (100 g) units; on another model as a percentage of the initial potential energy of the pendulum when in the raised position. Results can be expressed in two ways: (1) the tearing force required to continue the tear, and (2) the tearing energy in in. lb/in. (or g. cm/cm). The tester capacity is in three ranges: 0–1,600 g, 0–3,200 g and 6,400 g. The two higher ranges are obtained by using additional weights on the pendulum.

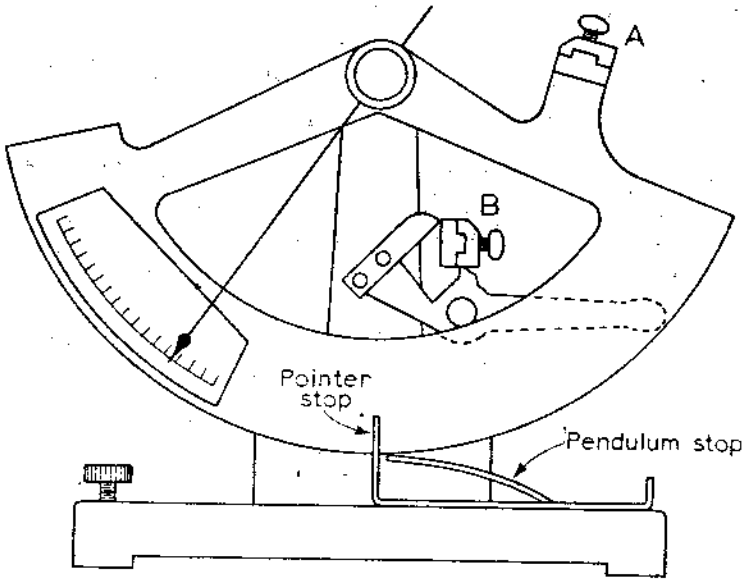


Figure 8.55. Elmendorf tearing tester

One comment on this test was made by Painter, Chu and Morgan (*Text. Res. J.* **20**, 410 (1950)). 'The force calculated (from energy values) is not the average of the maximum loads, the top peaks of the saw tooth diagram, nor of the lower loads, but somewhere in

between, and hence is not the load necessary to tear the fabric, since a higher value must be reached to get beyond the first peak. However, the energy itself is more useful in comparing the tear resistance of fabrics. Such a measure has the added advantage of avoiding any assumptions concerning tail extension or jaw separation, neither of which is determinable by the Elemendorf tester.'

The bursting test. The 'wounded' bursting test has been described earlier in the present chapter. Since it is, in effect, the continued tearing of a cut made in the test specimen, it may be regarded as a form of tearing test.

Tearing test literature

An excellent review of the literature concerned with tearing tests has been published by Harrison (*J. Text. Inst.* **51**, T91 (1960)). The review is not merely a list of references but contains comments and criticisms of the various methods used for the measurement of tear strength of fabrics.

*Seam strength**

When fabrics are made up it is usual for the component sections to be joined together by stitched seams, although other methods such as the use of special adhesives may be used. Failure at the seams leads to a reduction in serviceability even though the fabric in the rest of the article is in good condition. Investigation into seam failure has shown that the causes can be put into three main classes:

(1) The sewing thread wearing out before the fabric.

(2) Seam slippage, especially where the yarns are smooth and where the fabric has an open structure, or one in which the number of warp and weft interlacings is relatively low. Slippage can be reduced by the use of French seams instead of plain seams. Figure 8.56 shows several types of seams employed, the dotted lines indicating the stitching.

(3) The breakage of the yarns by the needle during sewing. Some of the problems associated with sewing are discussed in papers by Dorkin and Chamberlain (*J. Text. Inst.* **43**, T203 (1952)), Scott (*J. Text. Inst.* **42**, P653 (1951)), Frederick (*Text. Res. J.* **22**, p. 687 (1952)), and Sondhelm (*J. Text. Inst.* **44**, T580 (1953)).

*See B.S. 3870:1965: 'Schedule of stitches, seams and stitching.'

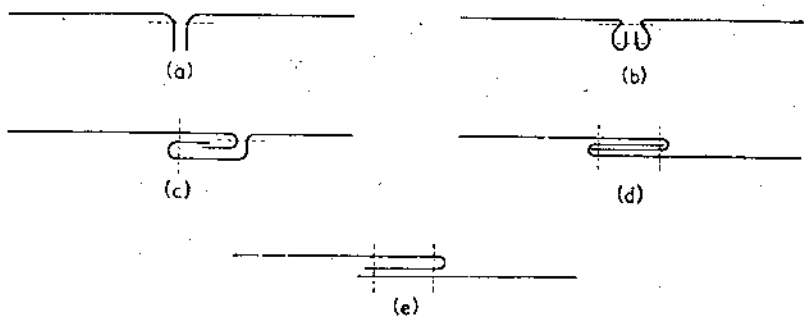


Figure 8.56. Types of seam: (a) Plain seam; (b) French seam; (c) Flat-felled or lapped seam; (d) Double-lapped felled seam; (e) Single-lapped or raised seam

At the time of writing, a Tentative Test Standard for seam strength was published (T.T.S. No. 55, 'Determination of Seam Slippage of Woven Fabrics'. *J. Text. Inst.* **50**, P688 (1959)). The methods suggested by Williams and Skinkle are given by Garner (*Textile Laboratory Manual*):

Williams:

A long strip of cloth is folded over, a seam is sewn about 1 in. from the fold, the strip is opened out and placed in a fabric strength tester, the machine is operated until a predetermined strain has been imposed, when it is stopped and the average width of the zone of slippage is measured. [Note: The T.T.S. No. 55 is based on this method.] (See B.S. 3320:1960 and B.S. Handbook No. 11, p. 189.)

Skinkle:

Skinkle determines the force across the seam per inch width necessary to produce an elongation of $\frac{1}{4}$ in. in excess of the normal stretch of the fabric under the same load. A standard grab tester of 50 lb capacity is used. Two specimens are cut, one 4 in. × 10 in., the other 4 in. × 4 in.; the smaller specimen is sewn to the longer by a standard seam $\frac{1}{2}$ in. from the end, using a needle of approximately 0·030 in. diameter, with No. 00 white mercerised cotton at 14 plain stitches to the inch. A stretch load chart is made on the long strip; then, using the same chart, on the seam. With a pair of dividers the difference between the two curves at 1 lb force is measured, the dividers are set for this distance plus $\frac{1}{4}$ in., and run along the curves until the force where the two curves are separated by this distance is found; this force minus 1 lb is the resistance to slippage of the seam. [This method is now an American Standard Test (see *A.S.T.M.* D1683-59T).]

THE MEASUREMENT OF RESISTANCE TO SLIPPAGE OF FABRICS

It is pointed out by Kendall (*J. Text. Inst.* **40**, T247 (1949)) that slight variations in the preparation of the seams may have a marked influence on the test results. In addition, there may be variations in the properties of the stitching material and a risk of needle damage. It is also noted that complaints regarding slippage and fraying are not confined to seam slippage. A test method is therefore put forward which does not require the preparation of a seam and so eliminates a source of error and variation.

Briefly, a test specimen of fabric is ravelled to 2 in. wide and one end secured in the upper jaw of the testing machine. The lower end is secured on a row of steel pins mounted in a plate which is gripped by the lower jaw. The pins pierce through the fabric along a line $\frac{1}{4}$ in. from the bottom edge of the fabric. Loading is started and the load at which slippage occurs is recorded. An autographic device is o. great value in this type of test since the load–extension curve will be serrated, the serrations corresponding to slippage points.

The number of pins and pin settings can be varied to suit different types of fabric, e.g. fine fabrics require pins at $\frac{1}{16}$ in. pitch, coarse fabrics $\frac{1}{8}$ in. pitch. Fuller details of the proposed test method will be found in the reference given.

Another test of thread slippage is described by Cowles (*J. Text. Inst.* **44**, T293 (1953)). Two sets of comb needles pass through the fabric, the distance between them about $\frac{1}{4}$ in. Separation of the combs is achieved by mounting them in special holders in a testing machine fitted with a pen recorder. Analysis of the stress–strain chart produced enables an evaluation of the resistance to thread slippage to be made.

NOTES ON JAWS AND CLAMPS FOR TENSILE TESTING

Textile specimens range from fine fibres to tyre cords, ropes, and plied fabrics; the methods used to mount the test specimen in the tensile testing instrument vary accordingly. Ideally, the gripping of the ends of the test specimen should not influence the results recorded, but in practice errors may creep in. For example, if any slip occurs it will be recorded as extension and attributed to the specimen. Again, if the pressure applied by the jaws damages the specimen, then the breaking load may be less than the true breaking load and, in addition, the load–extension properties may be affected.

Where the extension at break is not of immediate importance then a certain amount of slippage will be tolerated, of course; each case must be considered in the light of experience and the knowledge of the use to which the results are to be put.

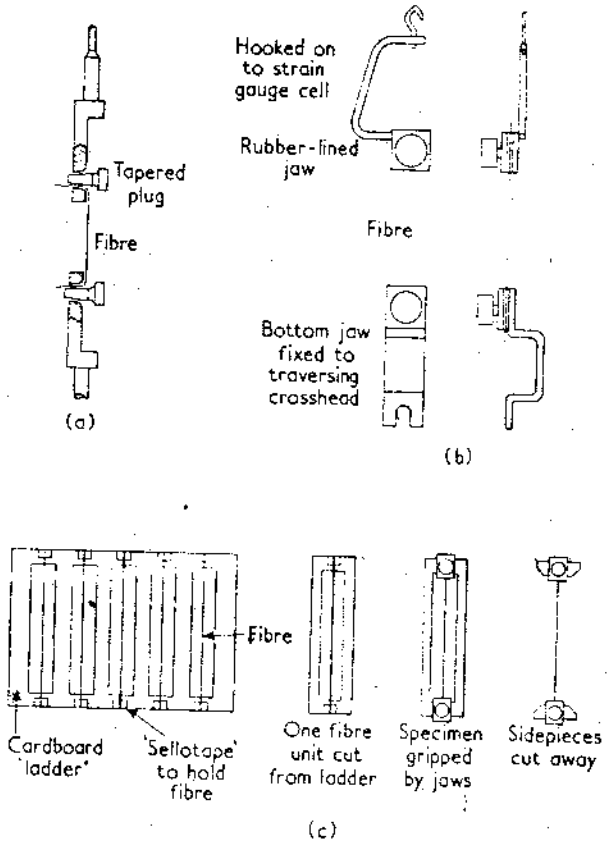


Figure 8.57. Single-fibre clamping methods: (a) The Cambridge Extensometer; (b) The Instron tester; (c) Preparation of single fibres for tensile tests

Single fibres require careful manipulation, the less handling the better.* One useful method is to mount the fibres on a 'ladder' of cardboard (see Figure 8.57(c)) and leave the fibres supported until everything is ready and the testing machine waiting to be switched on. Other fibre clamping methods are shown in Figure 8.57. Small

*See also B.S. 3411:1961. B.S. Handbook No. 11, p. 62.

rubber-faced clamps can be used in the Instron. For the Cambridge Extensometer one method is to wedge the ends of the fibre into holes by means of round tapered plugs. The fibre ends are sometimes cemented to small tags or rings, these auxiliary devices then being gripped or hooked into the testing instrument.

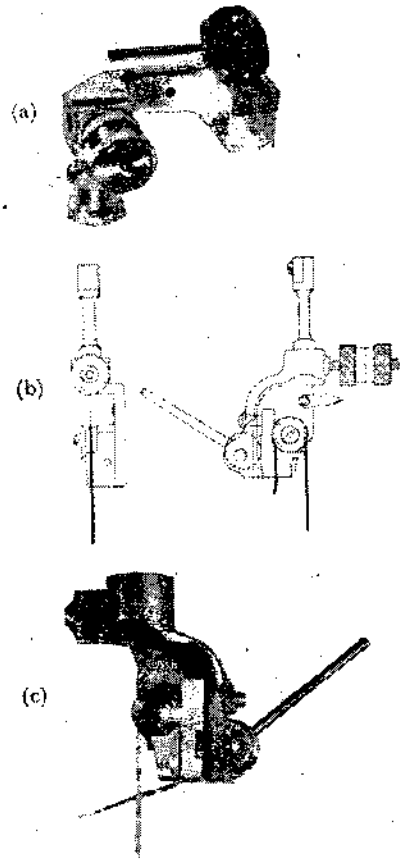
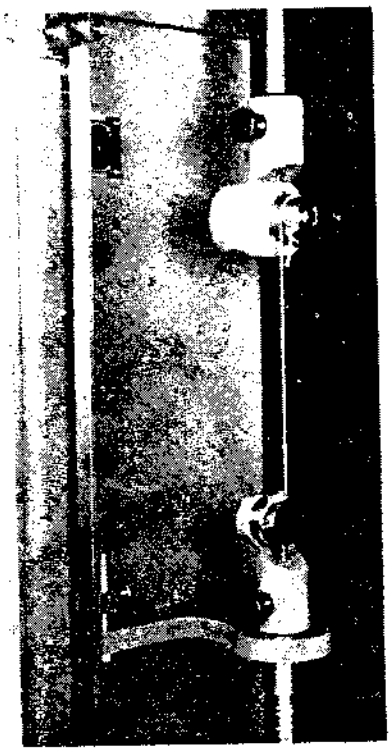


Figure 8.58. Yarn and cord clamps: (a) Quick-acting cam closing yarn grip; (b) 'Callaway' tyre cord grip; (c) Tyre cord grip



(*By courtesy of Avery Ltd*)

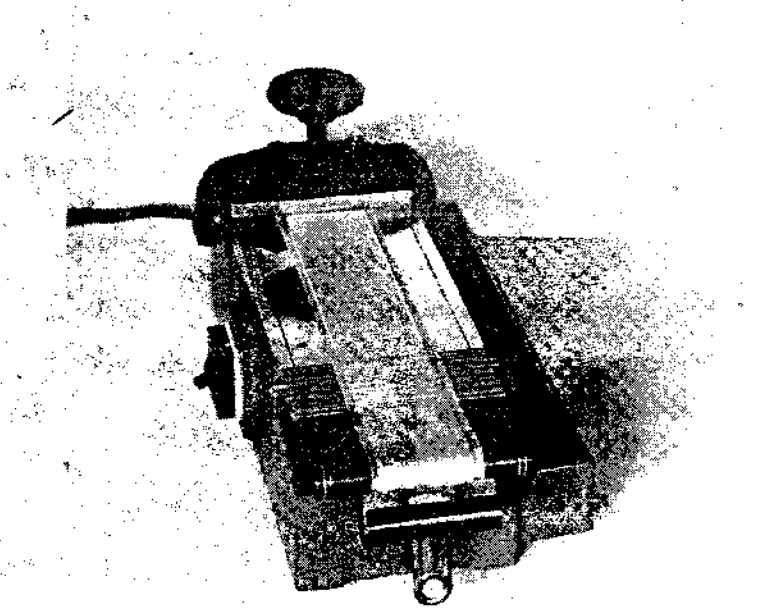
Figure 8.59. Grips for tyre cords, twines, lines, etc.

For fibre bundles the Pressley jaws seem to be favoured. A special mounting device is employed. The pressure applied is controlled by restricting the tightening of the clamp screws by means of an indicator which tells the operator when sufficient torque has been applied. The upper faces of the Pressley jaws are leather lined.

For the general run of single yarns the grips usually take the form of pairs of fibre-faced washers tightened by a screwed nut. Heavier yarns such as cabled yarns and tyre cords require special grips. Two examples are given, the 'Callaway' tyre cord grip, an American design, and the grips used on the Avery testing machine (see Figures 8.58 and 8.59).

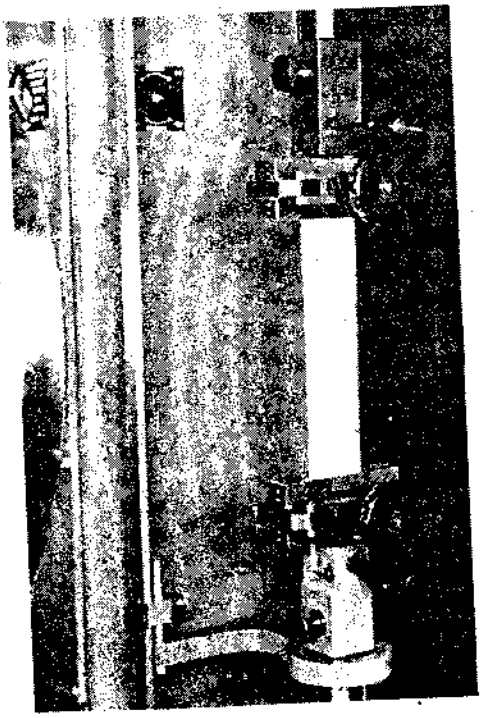
The problems associated with fabric testing have been discussed earlier in this chapter. Figures 8.60 and 8.61 show the preparation of a fabric specimen for the Avery machine. In this case a special mounting block is used and the jaw faces are corrugated.

The reader is recommended to study the catalogues of the various testing instrument makers; a wide range of jaw types, quick-acting clamps, etc., is usually illustrated.



(By courtesy of Avery Ltd)

Figure 8.60. Preparing a fabric specimen for the Avery testing machine. Note the corrugated faces of the jaws



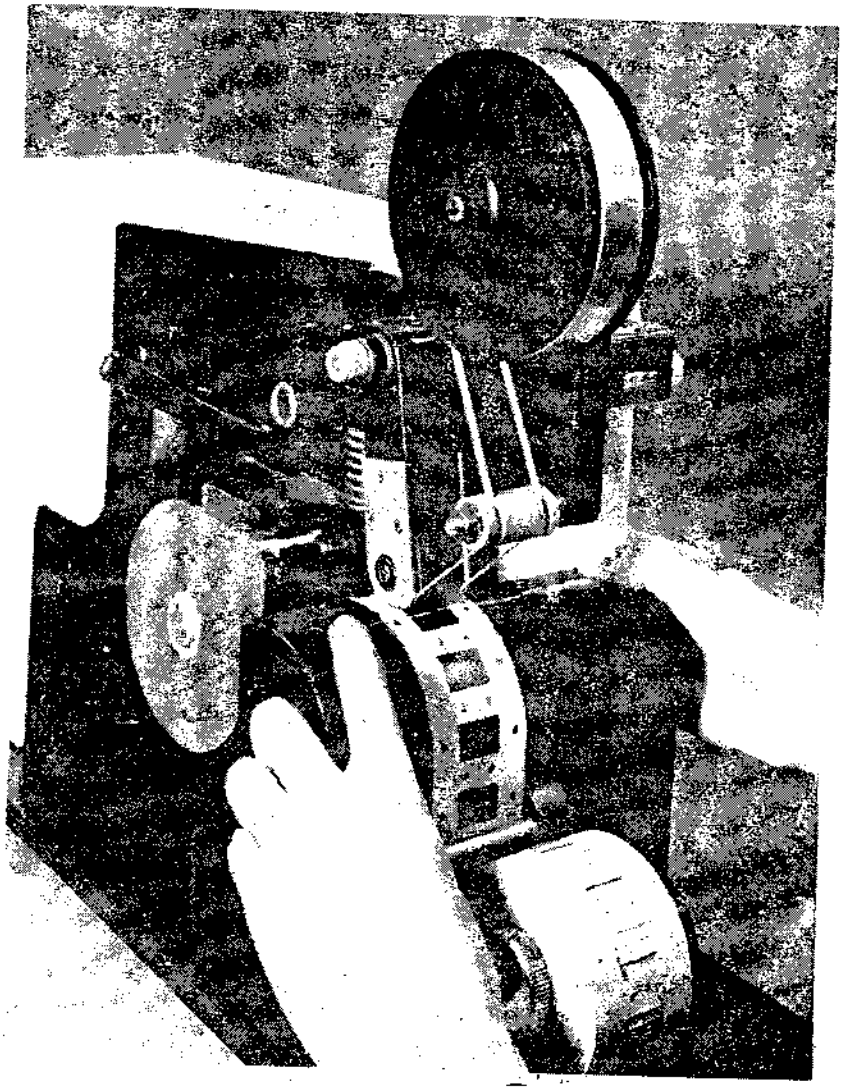
(*By courtesy of Avery Ltd*)

Figure 8.61. The prepared specimen mounted in the Avery testing machine

Filament mounting machine

Earlier in this chapter a short description of the Courtronic Type 5 filament tensile tester included a reference to the semi-automatic method of specimen mounting and loading. The makers of the system of filament testing describe the mounting device as follows.

The use of the machine (see Figure 8.62), greatly simplifies the mounting and securing of textile filaments on paper tape. The pre-punched paper roll is fed over a drum, which has a matt black finish to give a contrasting background to filaments, and which is fitted with pegs engaging in the tape to ensure positive drive. The operator selects individual filaments from a bunch on a velvet pad adjacent to the drum and lays them over the centre of each 2 cm wide 'window' in the paper tape. Depression of a foot-pedal initiates the advancement of the tape by one frame, simultaneously



(By courtesy of Courta lds Engineering Ltd)

Figure 8.62. The filament mounting machine for use with the Courtronic Type 5 filament tensile tester

securing the filament by laying a narrow band of adhesive tape over the filament projecting on each side of the 'window'. After mounting, a high pressure rolling stage ensures secure adhesion between tape and paper, and the tape passes into a detachable 'cassette'. A cutter is provided, allowing the tape to be cut on accumulation of a suitable number of mounted samples. A resettable frame counter is mounted on the front panel of the machine.

By passing the tape, with mounted filaments, directly into a cassette, which may be detached and fitted into a filament loading machine, complete protection against damage is afforded between mounting filaments and testing them. The machine ensures consistent location of each filament in the centre of each 'window', with consistent slack in each filament, combined with a high rate of mounting. The filament mounting machine is available as a separate item to the Courtronic system and can therefore be used with other types of tensile testing instruments.

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9

EVENNESS TESTING

INTRODUCTION

AN optimist talks in terms of evenness and regularity; a pessimist talks about irregularity. Whichever terminology we prefer, we are concerned with the degree of uniformity in the products of the various machines used in the formation of yarns. The task of the spinner of staple fibres, in particular natural fibres, is to transform a mass of millions of individual fibres with variable properties, tangled and containing unwanted foreign matter, into a yarn characterised by uniformity of weight per unit length, diameter, turns per inch, colour, strength, and so on. The magnitude of this task is indeed great and it is not surprising that perfectly uniform yarns are as yet a spinner's dream. Nevertheless, the efforts of many textile technologists are directed to the design of systems of fibre manipulation which will produce yarns whose regularity approaches the ideal.

The textile industry is diverse; some people specialise in the production of irregular and fancy yarns but we will not pursue their problems here. In passing it is worth remembering that one problem is to imitate the irregularity of yarns used in linen, a fabric whose character is partly dependent on the irregularity of its component yarns.

A high degree of uniformity may produce problems for the fabric manufacturer. Other yarn blemishes, e.g. knots, and the shortcomings of the loom or knitting machine may be thrown into greater prominence by the lack of the power of concealment which irregular yarns tend to possess. Those who handle filament yarns are well aware of these problems. One result is the greater precision demanded in the construction of the machinery used in the manufacture of filament yarn fabrics.

THE NATURE OF IRREGULARITY

We are aware already that some yarn properties are subject to variation, e.g. weight per unit length, twist, diameter, strength, etc., and it is therefore necessary to decide which property will be the most useful one to measure in order to derive a numerical assessment

of the irregularity. Most of the properties are related in some way and for specific purposes any one may be studied, but perhaps the most popular approach is to consider the variation in weight per unit length or thickness. Hence, not only yarns may be studied from this angle but laps, slivers, and rovings also.

Suppose we had a strand of material and cut it up into short equal lengths. The weight of each consecutive length could be found and plotted on a graph in a manner similar to that shown in Figure 9.1. By joining the points a trace is produced; this shows the way in which the weight per unit length varies about a central or mean value. The deviations from the mean could be determined, the mean deviation calculated, and the percentage mean deviation derived and used as a measure of the irregularity. Alternatively, the deviations from the mean could be squared and the coefficient of variation calculated. Where the deviations from the mean are of a random nature, the percentage mean deviation (P.M.D.) and the coefficient of variation (C.V.) are related:

$$\text{C.V.} = 1{\cdot}25\ \text{P.M.D.} \qquad \ldots (9.1)$$

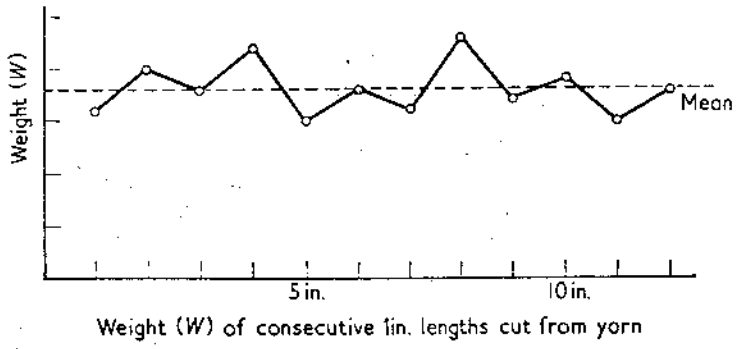


Figure 9.1. Variation in weight per inch

The cutting and weighing method is in fact one technique used in the measurement of irregularity, but it has the disadvantage of being slow and laborious. Other methods use instruments which automatically produce a trace of the variation and, at the same time, either carry out the calculations of P.M.D. or C.V. or produce figures which enable the required information to be calculated fairly rapidly.

Not all traces of the variation in weight per unit length show a random distribution of the deviations from the mean. Inspection of some traces reveals definite sequences of thick and thin places in the

strand of material. These forms of irregularity are referred to as 'periodic variations' because of their cyclical nature. To describe these periodic variations we use two terms, 'wavelength' and 'amplitude'. Figure 9.2 illustrates these two terms. The wavelength is the distance from one peak of the wave to the next, and the amplitude is a measure of the size of the 'swing' from the mean level, usually expressed as a percentage of the mean level.

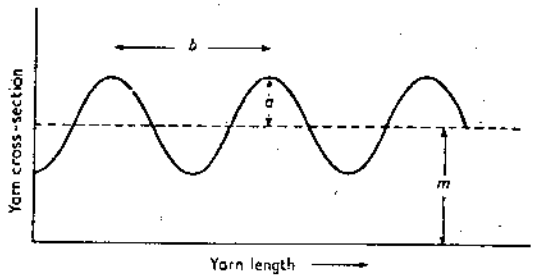


Figure 9.2. Wavelength and amplitude

m = Mean chart height
a = Amplitude of wave or variation
b = Wavelength of periodic variation
$\frac{a}{m} \times 100$ = Percentage amplitude

A selection of regularity traces are given in Figures 9.3–9.7, together with descriptive notes. Not unnaturally, the reader will want to know the reasons why one trace is less variable than another and what causes periodic variations. The subject of irregularity, both in its theoretical and practical aspects, is wide and cannot be covered adequately in one chapter. While the causes and effects will be discussed in a general way, the main object of this chapter is to describe the methods used in the testing of irregularity and the interpretation of the results obtained. It is strongly recommended that the references given should be consulted concurrently with the study of the present chapter.

SHORT TERM, MEDIUM TERM, AND LONG TERM VARIATION

Where periodic variations are present in the material being tested they may be classified according to their wavelength, using the fibre length as a length unit:

Short term variation: 1 to 10 times the fibre length
Medium term variation: 10 to 100 times the fibre length
Long term variation: 100 to 1,000 (or more) times the fibre length

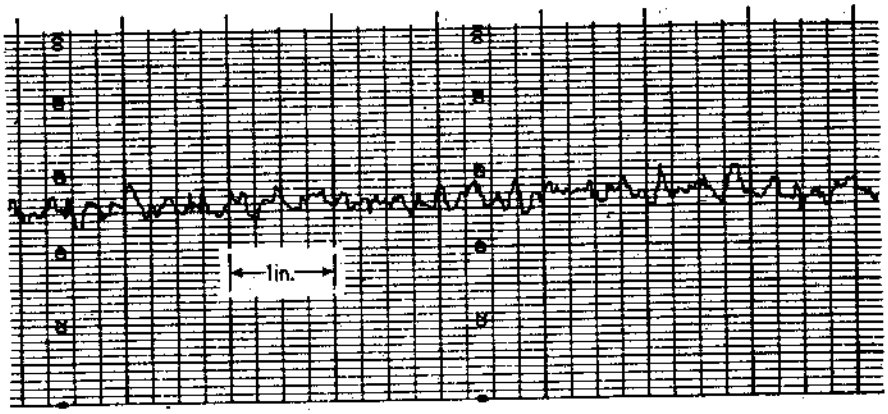


Figure 9.3. Irregularity trace of comber sliver. 58 grains/yd.
1 in. chart = 20 in. sliver. C.V. = 4·0 per cent

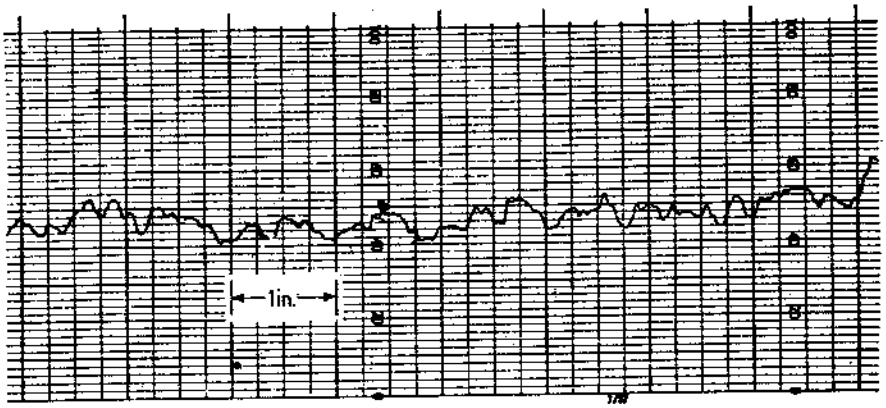


Figure 9.4. Irregularity trace of drawframe sliver. 0·2 hank.
1 in. chart = 10 in. sliver. C.V. = 6·6 per cent

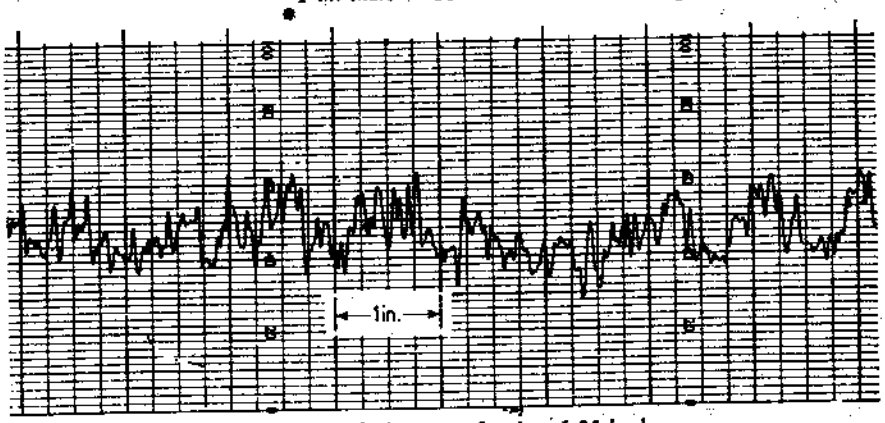


Figure 9.5. Irregularity trace of roving. 1·25 hank.
1 in. chart = 10 in. roving. C.V. = 14·0 per cent

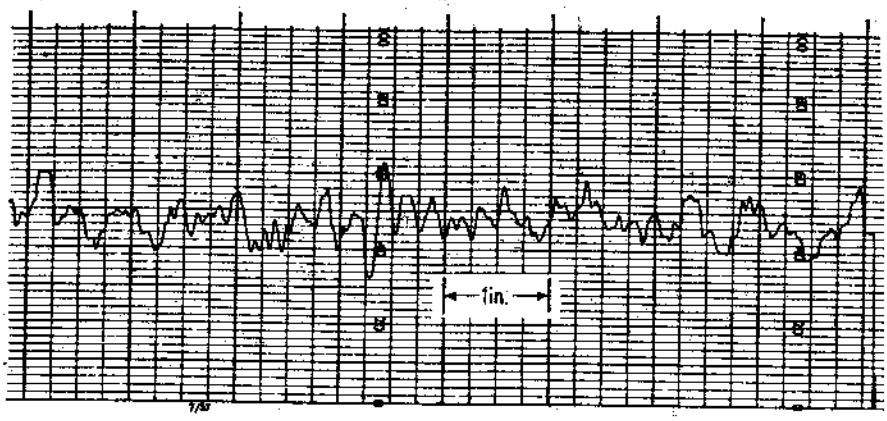


Figure 9.6. Irregularity trace of 8 hank roving.
1 in. chart = 10 in. roving. C.V. = 12·2 per cent

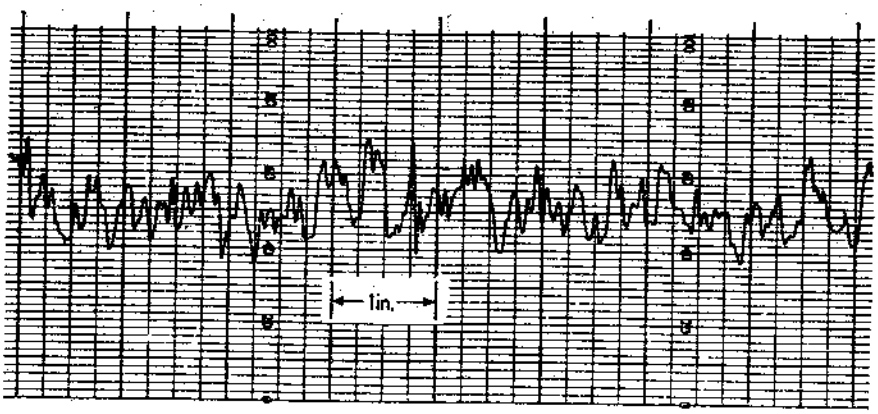


Figure 9.7. Irregularity of 18s cotton/viscose yarn.
1 in. chart = 10 in. yarn. C.V. = 11·2 per cent

The importance of the classification of the periodic variations is evident when the probable causes of faults in yarns and fabrics are being investigated. The amplitudes of short term variations are generally greater than those of the longer term variations. This is because they are usually the result of faulty processing at the last machine and they have had no chance of being reduced in amplitude by drafting and doubling. The different classes of periodic variation affect the appearance of the woven or knitted fabrics in different ways, a point which will be discussed later.

INDEX OF IRREGULARITY

Two expressions for irregularity have been given: the percentage mean deviation and the coefficient of variation. It is useful to have standards against which the products of one's own mill may be judged. Used with discretion and in the light of previous experience, such standards enable the laboratory to decide whether the products are satisfactory or not. Tables 9.1, 9.2, and 9.3 have been derived from a fuller set of Tables published by Zellweger Ltd, the Swiss firm who build the 'Uster' evenness testing equipment. It should be borne in mind that these Tables are only guides and that actual figures must be examined carefully with the details of the particular spinning conditions to hand. For example, it is possible to achieve a lower irregularity for a given count by selecting a better type of cotton than would normally be chosen, a practice known as 'spinning down'. Conversely, attempts to spin a higher count than usual for a particular type of cotton will generally result in higher irregularity than indicated in a set of standards. Further, these Tables correspond to the values produced when testing the materials under 'Uster' conditions.

Table 9.1. Standard Values of Irregularity — P.M.D. and C.V. (C.V. percentages are given on second line values)

Material	*Carded cotton*		
	Even	*Average*	*Uneven*
Drawframe (finisher)	2·8 – 3·5 3·5 – 4·4	4·5 – 5·6 5·6 – 7·0	6·7 – 8·2 8·4 – 10·4
Slubbing	4·1 – 5·8 5·1 – 7·2	5·6 – 8·0 7·7 – 10·0	7·6 – 10·8 9·6 – 13·6
Single process roving	4·4 – 6·1 5·5 – 7·6	5·8 – 8·2 7·2 – 10·2	8·0 – 11·2 10·0 – 14·0
Yarn: 12s (50s tex)	11·4 14·3	15·2 19·0	19·7 24·6
24s (24·4s)	13·5 17·0	17·3 21·7	20·6 25·8
40s (14·7s)	15·0 18·8	18·8 23·5	22·5 28·2

(Derived from Uster Standards (1957))

Other types of irregularity testers may require a slightly different set of values since the same material, tested on a range of testers, may produce differing irregularity figures. It will be appreciated, therefore, that a certain amount of experience must be gained with the particular type of testing instrument, the testing routine, and the internal spinning systems before full advantage can be taken of the test results.

Table 9.2. Standard Values of Irregularity—P.M.D. and C.V. (C.V. percentages are given on second line of values)

Material	*Combed cotton from fine fibres*		
	Even	*Average*	*Uneven*
Drawframe sliver (finisher)	2·2 2·8	3·4 4·2	4·9 6·1
Slubbing 0·8 hank	2·8 3·4	3·8 4·8	6·0 7·6
Roving 9 hank	5·9 7·4	7·4 9·2	10·3 12·9
Yarns:			
20s (29·6 tex)	9·4 11·7	12·2 15·2	15·5 19·3
40s (14·7)	11·7 14·6	14·8 18·5	18·0 22·4
60s (9·8)	13·8 17·3	16·2 20·3	19·0 23·8
100s (5·9)	15·3 19·1	18·5 23·0	21·0 26·4

(*Derived from Uster Standards (1957)*)

Limit irregularity

Martindale (*J. Text. Inst.* **36**, T35 (1945)) has shown that the most uniform strand of material which our present machines can produce is one in which the fibre ends are laid in a random order in the sliver, roving, or yarn. For such a strand of material the irregularity is given by the formula

$$V_r^2 = \frac{(100)^2}{N} + \frac{V_m^2}{N} \qquad \ldots (9.2)$$

Table 9.3 Standard Values of Irregularity — P.M.D. and C.V. (C.V. percentages are given on second line of values)

Material	Worsted spinning					
	Merino			Cross-bred		
	Even	Average	Uneven	Even	Average	Uneven
Top sliver	2·9 3·6	5·8 7·2	9·2 11·5	3·8 4·7	7·6 9·5	11·1 15·0
Finisher 4s – 6s	6·0 7·5	7·7 9·6	10·1 12·6	7·8 9·7	10·0 12·5	13·2 16·5
Yarn: 9s (100 tex)	6·8 8·5	8·7 10·9	11·2 14·0	8·9 11·1	11·3 14·1	14·6 18·2
28s (32 tex)	12·0 15·0	15·2 19·0	19·6 24·5	15·7 19·6	19·8 24·7	25·6 32·0
50s (18 tex)	16·3 20·4	20·7 25·9	26·6 33·2	– –	– –	– –
74s (12 tex)	17·4 21·8	22·1 27·6	28·4 35·5	– –	– –	– –

(Derived from Uster Standards (1957))

where V_r = coefficient of variation of weight per unit length,
N = the average number of fibres in a cross-section of the strand,

and

V_m = coefficient of variation of the fibre weight per unit length.

Thus, for a particular fibre and count of yarn, there is a limit or basic irregularity upon which our present machinery cannot improve. By calculating the limit irregularity and then measuring the actual irregularity, we have a means of judging the spinning performance.

Let V_r = the calculated limit irregularity, and
V = the actual irregularity

Then, the *Index of Irregularity* is

$$I = \frac{V}{V_r} \qquad \ldots (9.3)$$

Hence, a value of unity for this ratio corresponds to the limit irregularity, i.e. the best possible yarn; the higher the value of I the more irregular the yarn.

For cotton fibres the limit irregularity formula may be reduced to, $V_r^2 = (106)^2/N$, and for wool fibres, $(112)^2/N$. These simplified formulae allow for the variation in the linear density of cotton and the variation in fibre diameter of wool. The problem of calculating an equivalent formula for blended fibres has been discussed by Bornet (*J. Text. Inst.* **51**, 326 (1960)). One method he used produced a formula of $V_r^2 = (118{\cdot}8)^2/N$ for a 35 tex yarn, spun from a blend of 60 per cent 56s wool and 40 per cent 3 den. Terylene. The ideal yarn would have a C.V. of 14·3 per cent.

The importance of the number of fibres in the cross-section should be noted.* The higher the number the lower the basic irregularity. This bears out the well-known fact that fine fibres produce a more regular yarn for a given count than coarse fibres. More important, perhaps, is the effect of fibre fineness on the upper spinning limits. The degree of irregularity in the yarn affects the spinning performance; the higher the irregularity the higher the end-breakage rate. A point will be reached when it becomes impracticable to spin finer with the material available. A finer fibre, i.e. more fibres in the cross-section, would enable the upper limit to be pushed a little higher. Curiously enough, the formula does not include any reference to fibre length.

Tables 9.4, 9.5, and 9.6 give sets of figures for the irregularity index of various materials.

Table 9.4. Standard Values of the Irregularity Index, I, for Carded Cotton

Material	*Even*	*Average*	*Uneven*
Drawframe sliver (finisher)	5	8	12
Slubbing	4	5·5	7·5
Single process roving	3	4	5·5
Yarns:			
12s (50s tex)	2·5	3·3	4·3
24s (24·4s)	2·1	2·7	3·2
40s (14·7s)	1·8	2·25	2·7

(Derived from Uster Standards (1957))

*$N = 591000/CH$ where C is the cotton count and H is the fibre weight in milligrams per kilometre or $N = 1000T/H$ where T is the tex count.

Table 9.5. Standard Values of the Irregularity Index, I, for Combed Cotton

Material	*Even*	*Average*	*Uneven*
Drawframe sliver (finisher)	3·6	5·5	8
Slubbing 0·8 hank	2·5	3·5	5·5
Roving 9 hank	1·6	2·0	2·8
Yarns:			
20s (29·6 tex)	1·7	2·2	2·8
40s (14·7)	1·5	1·9	2·3
60s (9·8)	1·45	1·7	2·0
100s (5·9)	1·25	1·5	1·7

(Derived from Uster Standards (1957))

Table 9.6. Standard Values of the Irregularity Index, I, for Worsted Materials

Material	*Even*	*Average*	*Uneven*
Top sliver	7·0	14·0	22·5
First passage	5·3	9·8	15·0
Final passage	1·2	1·5	1·9
Yarns	1·1	1·4	1·8

(Derived from Uster Standards (1957))

Addition of irregularities

In formula (9.2) the square of the coefficient of variation is used; in this form it is known as the 'relative variance', often abbreviated to 'variance'. By using the squares of the coefficients of variation it becomes possible to add and subtract the irregularities produced at various stages in yarn preparation and spinning. Suppose the coefficient of variation of a sliver is V_1 and it is fed to a machine which adds irregularity to it during processing. Let V be the coefficient of variation of the processed sliver. Using the squares of the coefficients,

$$V^2 = V_1^2 + V_2^2 \qquad \ldots (9.4)$$

where V_2 is the coefficient of variation of the added irregularity. Hence, by knowing the value of any two of the quantities the third is easily found. Extending this idea a little further, suppose a machine which normally delivers a product whose relative variance is V_1^2 and at some stage it rises to V^2. This could indicate that a mechanical fault has developed in the machine which adds V_2^2 to the total variation.

Reduction of irregularity by doubling

One of the objects of doubling is to reduce the irregularity. If n strands of material, each having the same coefficient of variation, are doubled, then the coefficient of variation of the combined strands is given by

$$\text{C.V. of doubled strands} = \frac{\text{C.V. of individuals}}{\sqrt{n}}$$

Thus, by doubling two rovings, the coefficient of variation is divided by $\sqrt{2}$.

In practice, when slivers and rovings are doubled they are usually drafted at the same time, a process which adds to the variation. The final product will therefore have an irregularity value which depends on whether the reduction due to doubling is greater than the increase due to drafting.

Variance–length curves, variation between and within samples

Up to the present, we have considered single expressions with which to describe the irregularity, P.M.D., C.V., and I. We would be falling into a trap if we regarded two samples of yarn having identical irregularity values as being nominally similar yarns, both fit to be used for the same purpose.

The coefficient of variation indicated on the meters of an evenness tester is a measure of the overall irregularity. It is quite possible that one yarn will have a relatively large amount of short term irregularity and not very much long term irregularity, while a second yarn will have the relative amounts of short and long term irregularity reversed. The overall irregularity in terms of the coefficient of variation may be the same for both yarns, but the effect in the fabric may be quite different. How, then, can yarns be described in order to distinguish the character of the variation?

Consider a long length, T yd, of a yarn which produces a regularity trace as shown in Figure 9.8. Let the overall coefficient of variation be $C.V.(T)$; or better still, square this value and let the total variation be $V(T)$.

Now, consider the length of yarn divided into equal lengths l yd. Two determinations of variation may now be made:

(1) The weight of each length, l, is measured, and the mean weight and the coefficient of variation of the individual weights are calculated. This coefficient is referred to as the coefficient of variation *between* l yd lengths and is given the symbol $CB(l)$; the corresponding square, i.e. the variance, has the symbol $B(l)$.

(2) The coefficient of variation of each individual length l yd is determined and the mean coefficient of variation calculated. This gives the coefficient of variation *within* l yd lengths. The symbol for this is $C.V.(l)$, and for the square, $V(l)$. Thus,

$B(l)$ is the variance *between* lengths
$V(l)$ is the variance *within* lengths

The total variance, $V(T)$, is the sum of these two quantities:

$$V(T) = V(l) + B(l) \qquad \ldots (9.5)$$

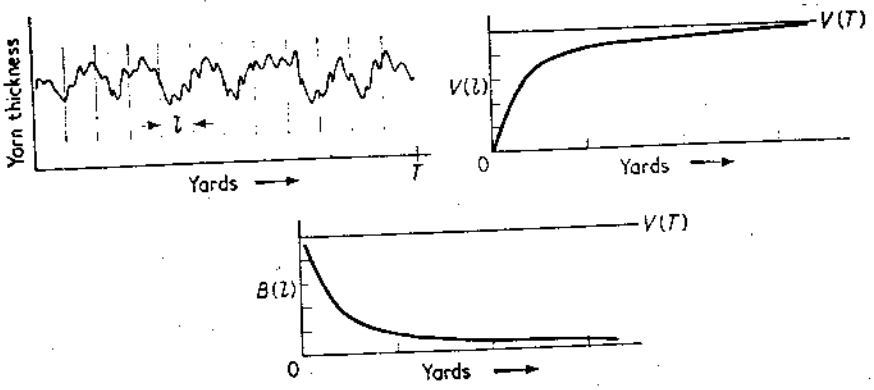


Figure 9.8. Variance–length curves

A series of tests could be carried out to determine the $V(l)$ and $B(l)$ values for different values of l. By plotting such a series of results we obtain two curves known as 'variance–length' curves. Figure 9.8 shows the types of curve which are obtained. The variance values are plotted on the vertical axis and the l values along the horizontal axis, often logarithmically.

The V(l) *curve*

This curve starts at the origin because with zero length there can be no variation. With increases in the value of l the curve rises steeply at first, flattens out, and approaches $V(T)$ very slowly. The initial rapid rise occurs because as the lengths tested become longer each individual length becomes a more representative sample of the whole, thereby including a more representative selection of the variations present in the full length. After a certain value of l has been reached, each length l has a variance approaching the total value and further increase in the value of l has little effect on $V(l)$.

The B(l) *curve*

Since $B(l) = V(T) - V(l)$, it follows that the $B(l)$ curve will be a mirror image of the $V(l)$ curve. Thus, if the total variation is known and one of the variance–length curves obtained, the second curve can be readily constructed.

Interpretation of V(l) *and* B(l) *curves*

Suppose two yarns, A and B, had the same total variation and that their respective variance–length curves were obtained (see Figure 9.9). It will be seen that the $V(l)$ curve for yarn A initially rises more steeply than the curve for yarn B. From this we deduce that yarn A has more short term irregularity than yarn B. When the yarns are compared for long term variation, yarn B has a greater degree of this type of irregularity than yarn A. By studying the shape of the variance–length curve it becomes possible to get an appreciation of the character of the variation in the yarn. As we shall see in due course, short term and long term variations have different effects on cloth appearance.

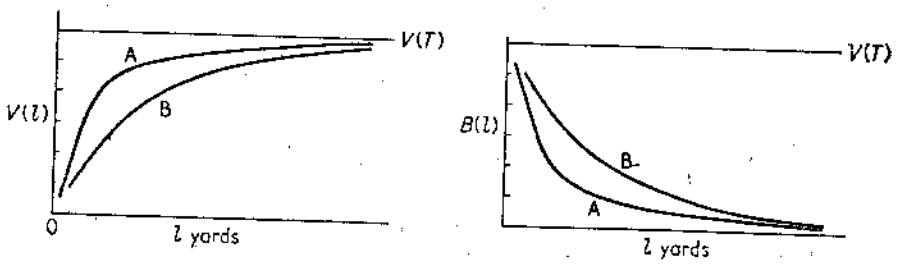


Figure 9.9. Comparison of V(l) *and* B(l) *curves for two yarns with equal total variation* V(T)

The use of variance–length curves is obviously a great help in the assessment of irregularity, but the difficulties associated with the construction of the curves prevents them from being more widely used in mill laboratories. Townsend (*J. Text. Inst.* **40**, P566 (1949)) suggests that for research purposes the quickest method of obtaining the curves is to use a combination of a continuous irregularity tester and a cutting and weighing method. The instrument is used to obtain the average value of *C.V.*(5 yd). A number of 5 yd lengths, selected at random, are conditioned and weighed, and the *C.B.*(5 yd) is calculated. These two values are then used to calculate the *C.V.*(T) value. Then, by varying l, the *C.B.*(l) for a range of l values can be determined and the corresponding *C.V.*(l) values calculated since *C.V.*(T) has already been found.

The use of variance–length curves in experimental work is well illustrated in Lund's paper on the comparison of the regularity of rayon staple yarns spun on different spinning systems (*J. Text. Inst.* **43**, T299 (1952)). Other methods of analysing irregularity will be discussed when the various testing instruments and the traces produced by them are described.

METHODS OF MEASURING AND ASSESSING IRREGULARITY*

The cost of the equipment used in the measurement of irregularity may range from nothing to £1,000 or so. The cheapest and quickest method, for yarn at least, is to make a visual examination by looking at it as a yard or so is drawn off the package by hand. At the other extreme, highly complicated electronic apparatus may be used. A short list of the more important methods available is given here. The bias is towards techniques and instruments suitable for use in mill laboratories. A more extensive list is given by Matthew et al. (*J. Text. Inst.* **41**, P486 (1950)) in an appendix to a review of testing methods.

Visual methods. Blackboards, drums, photographic devices, projection, patterning predictor, lap meter.

Cutting and weighing methods. Lap scales, lap meters, sliver tests, hank wrapping, count variation, short cut lengths.

Variation in thickness under compression. W.I.R.A. roving levelness tester, LINRA roller yarn diameter tester.

Electronic capacitance testers. Fielden-Walker, Uster.

Photoelectric testers. W.I.R.A. photoelectric tester, LINRA tester.

Miscellaneous methods. Airflow, mercury displacement, etc.

Townsend (*J. Text. Inst.* **42**, P12 (1951)) states that '. . . the most important property of a yarn is the number of fibres in a cross-section and the variation of this number along the yarn is the most fundamental measure of irregularity'. This concept should be borne in mind as the methods of measuring irregularity are considered.

VISUAL EXAMINATON

Yarns can be examined by wrapping them on to a matt black surface such as a piece of flat board. The wraps should be equally spaced to avoid optical illusions of irregularity and the blackboards examined under good lighting conditions. Some mills use a special room set aside for blackboard examination. The lighting system is designed to provide indirect illumination giving uniform non-

*See also B.S. Handbook No. 11, p. 122. *Report on Measurement of the Irregularity of Slivers, Yarns and Roving.*

directional light, plus arrangements to give edge lighting in order to throw up yarn faults such as nep into greater prominence. A particular mill may set up its own standards of judgement, but in the U.S.A. the A.S.T.M. has a series of Cotton Yarn Appearance Standards which are photographs of different counts with the appearance classified in four grades. The test yarn is wound on a blackboard approximately $9\frac{1}{2}$ in. $\times$ $5\frac{1}{2}$ in. with the correct spacing and compared directly with the corresponding standard.

The blackboard wrapping machines may wrap one yarn at a time or perhaps two yarns, one on each half of the board, for comparison. An extension of the blackboard is the wrapping drum, a cylinder with a matt black surface. The size of the drum varies, an extreme case being a large drum capable of accommodating a complete cop.

Storage and filing of blackboards is impracticable. The Vitno-Winder, a Dutch instrument marketed by Dikkers of Hengelo, Holland, is an instrument which produces a contact print of the yarn on a black background with the yarn silhouette in white. The prints may be conveniently stored or sent through the post.

Periodic variations in the yarn may cause patterns to appear on the blackboard. If such a fault is suspected, the yarn may be wrapped on a tapered board. The optical effect is almost like the grain in wood. Figure 9.10 shows this effect. At the point where the peak of the pattern occurs the board height is a multiple of the wavelength of the fault.

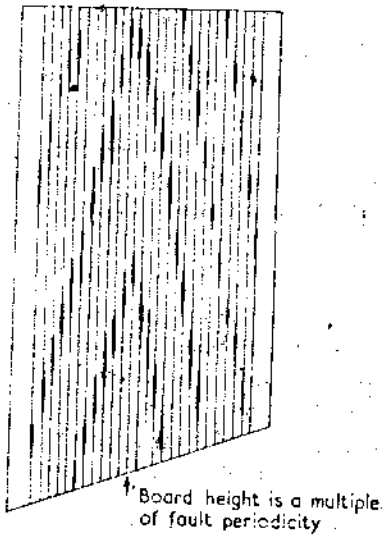


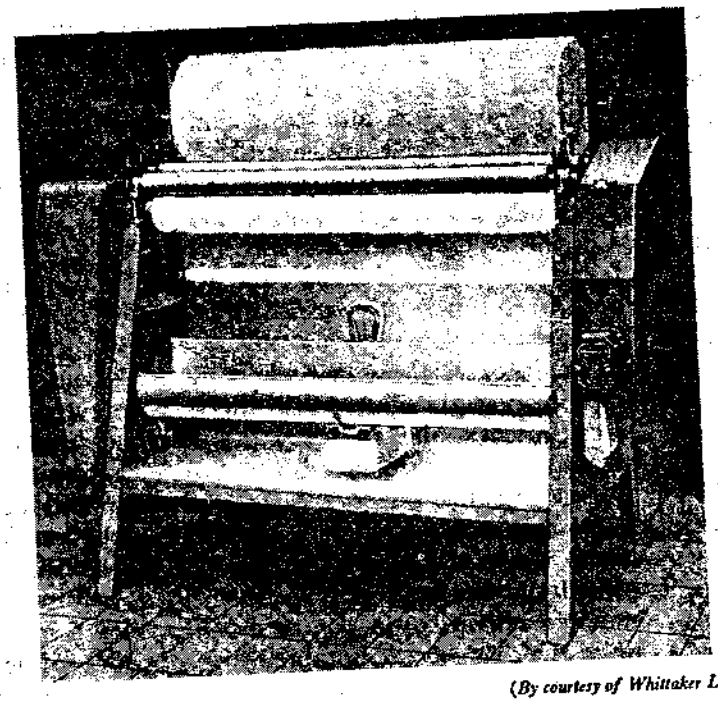
Figure 9.10. Tapered blackboard

The 'Shirley' yarn diameter projector

This instrument is described on page 117 of the B.S. Handbook. Briefly, a magnified silhouette of a short length of yarn is projected on to a ground glass scale calibrated in 1/1,000 in. The 'solid' shadow is measured, i.e. the outstanding fibres are ignored. Two hundred readings are taken at random along the yarn, say twenty from each of ten packages. From the results the mean yarn diameter and the standard deviation are calculated. Since personal judgement enters into the measurements (the decision where the 'solid' shadow ends) it is recommended that the same person always carries out such tests in the laboratory.

Examination of scutcher laps

Lap meters, such as the Whittaker (Figure 9.11), have as their main function the measurement of the yard-to-yard weight variation of the lap, but during the lap's passage from the lap holder to the



(By courtesy of Whittaker Ltd)

Figure 9.11. The Whittaker lap meter

scale pan a strip lamp behind the sheet of material allows the operator to examine visually the general uniformity of the lap. Defective operation of the lap-forming mechanism can cause the distribution of the material across the lap to be uneven enough to be readily seen. Experience with a lap meter enables trouble such as choked chimneys, wrongly adjusted dampers, etc., to be spotted.

CUTTING AND WEIGHING METHODS

The variation in the number of fibres in a cross-section of a yarn is associated with the variation in the weight per unit length. Therefore, measurement of the latter is a sound and commonly used method of assessing irregularity. Before considering small-scale fibre structures, i.e. yarns, roving, and slivers, a look at the scutcher lap is suggested.

Lap weighing

It is normal blowing room practice to weigh each lap made on the finisher scutcher, the 'cut length' in this case being the lap length. Tolerances on each side of the nominal lap weight, often plus or minus 8 oz, are allowed and laps whose weights are outside the limits are rejected. The experienced scutcher operator watches the trend of successive lap weights, and by machine adjustment prevents an excessive number of rejects. By control of the lap weight in this way the lap-to-lap weight variation is kept within bounds. Too much machine adjustment can have the opposite effect. The moisture in the material should be taken into account. It is possible for two laps to have different weights even though the actual cotton in them is the same, the difference being due to the difference in their moisture contents. Unnecessary machine adjustment may result from basing action on the results of weighing laps whose moisture contents differ rather than the dry weight of cotton in them. To prevent such incidents, an instrument which indicates the moisture regain in the laps may be used. One such device is the 'Shirley' moisture regain indicator (Figure 9.12). This consists of a sensitive but damped balance which carries a prepared cotton sample. As the humidity of the atmosphere varies the moisture regain of the cotton sample varies. The resulting change in weight is indicated, not as a weight but as a moisture regain, by a pointer moving over a scale calibrated in percentage regain. A suitable range of counterweights to be used on the lap scales can be selected, each one corresponding to an indicated regain. The regain indicator will normally be mounted

in the blowing room, where there is a free air circulation, in a position away from possible damage. In some systems the air blowing over the instrument is piped from the scutcher air currents.

(*By courtesy of B.C.I.R.A.*)

Figure 9.12. The 'Shirley' moisture regain indicator

The lap meter

The lap-to-lap weight variation is only one aspect of lap weight irregularity. By dividing a lap into yard lengths it is possible to study the yard-to-yard weight variation. The development of short processing systems, with the reduction in the number of doublings, means that a regular lap is desirable. By the routine testing of a full lap, mechanical defects in the lap-forming mechanism can be spotted before too many faulty laps have gone through into the subsequent processes.

The 'Whittaker' lap meter is a comparatively simple machine which automatically unrolls the lap, breaks off a 1 yd length, and deposits it into the pan of a scale whose dial is calibrated in ounces. The weights are recorded and plotted on a special record sheet together with all the relevant details. Figure 9.13 shows a record taken from a lap made in a condenser spinning mill when the author was asked to look at the blowing room. Incidentally, the first lap tested proved to be 39 yd long, 4 yd longer than the nominal 35. This state of affairs had apparently been unknown for at least 10 years.

The beneficial effects of a survey of the blowing room and the setting up of a system of control is well illustrated in a paper by Vaswani (*J. Text. Inst.* **45**, P16 (1954)). After the introduction of a quality control based on the results of a critical investigation of a blowing room, the card room, spinning room, and warping performances were studied and compared with their performances before the control system was operated. At every stage there was a marked improvement, e.g.

50 per cent reduction in the number of laps outside 8 oz limits.
88 per cent reduction in the number of scutcher adjustments.
Draw frame pinion changes reduced from 9 per month per machine to 1.
Ring spinning breaks/100 spindle hours reduced by approximately 35 per cent.
Warping production increased by approximately 11 per cent.

Of course, not all mills will have the same amount of room for improvement, but the importance of lap regularity is obvious.

Not all technologists subscribe to the view that the yard-to-yard irregularity (or, for that matter, the inch-to-inch irregularity) in scutcher laps is of much importance. It is suggested that 'the importance of short term regularity within laps can be overemphasised' and that 'after two passages of drawing, the sliver produced from a regular lap will be no better in long term variation than that from a lap showing ±50 per cent yard-by-yard irregularity (Nutter. *Text. Manuf.* p. 404 (Aug., 1958)).

Even if disagreement exists between technologists about the relative importance of short term lap weight variations, it is generally agreed that long term variations are of great importance. By long term we mean, for example, variations in the average lap weight between shifts or half days. It is advisable to introduce a sound lap weight control system in the blowing room in order to reduce the amount of corrective action necessary in the card room at the draw

frames. Checking in the blowing room is continuous since every lap is weighed, whereas the draw frames may only be checked twice or three times a day and in the interval between checks faulty material may be produced.

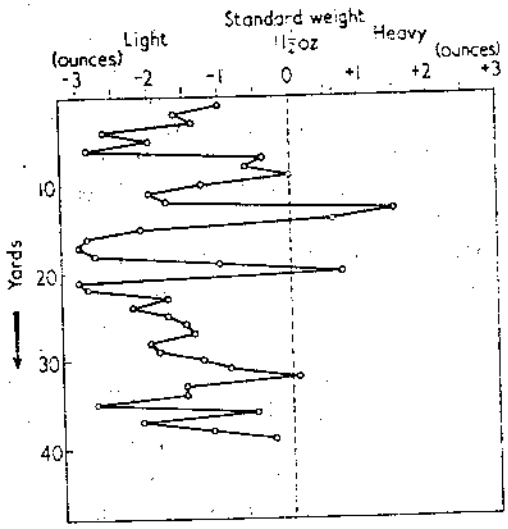


Figure 9.13. Yard-to-yard lap weight variation in a faulty lap. Nominal lap length is 35 yd, but in fact the lap length was 39 yd. Hence, even though total lap weight was correct, the weight per yard was too light. The variation was excessive in any case

Slivers and rovings

Many mills operate quality control systems in the card room or in the processes preparatory to spinning. The hank of a material is checked at specified intervals by measuring off a test length and weighing it on an accurate balance. Control charts may be employed to enable the necessary machine adjustments to be made. The test length varies from machine to machine, for instance, the ribbon lap machine may have a 1 yd length, the draw frame 3 yd, and the roving frame 30 yd. These remarks refer to the cotton spinning system of course, other systems of spinning such as woollen and worsted, condenser, or flax will have their own particular test points and test lengths. The basic principle remains the same, a given length of material is weighed and compared against a nominal weight and tolerance limit, action being taken if required.

The methods of taking the samples from the various machines will naturally vary, so also will the methods of measuring out the

required length.* The guiding principles in all cases should be accuracy of length, accuracy in weighing, and a note taken of the moisture regain of the sample.

For research purposes slivers and rovings may be cut into short lengths by means of special templates or folding the material into marked paper and cutting through the paper and the material, but such methods are not normally used in mill routines.

An interesting study of roving variation is found when the products of the condenser card are examined. The hank of the rovings varies 'across the card', the pattern of the variation being remarkably persistent for a particular card. This type of variation is discussed in the W.I.R.A. book *Testing and Control* in connection with woollen cards. Figure 9.14 shows a picture of the variation across a ring doffer condenser card in a cotton condenser spinning plant. The result of such variation is much 'bobbin-to-bobbin' variation because there is no chance of a reduction by doubling; the card roving is merely given a very low draft and twisted into a yarn by the condenser mule or ring frame.

Most of the preceding remarks have been concerned with the type of cutting and weighing methods used for control purposes rather than for the investigation of sliver and roving irregularity along the strand, and the measurement of the coefficients of varia-

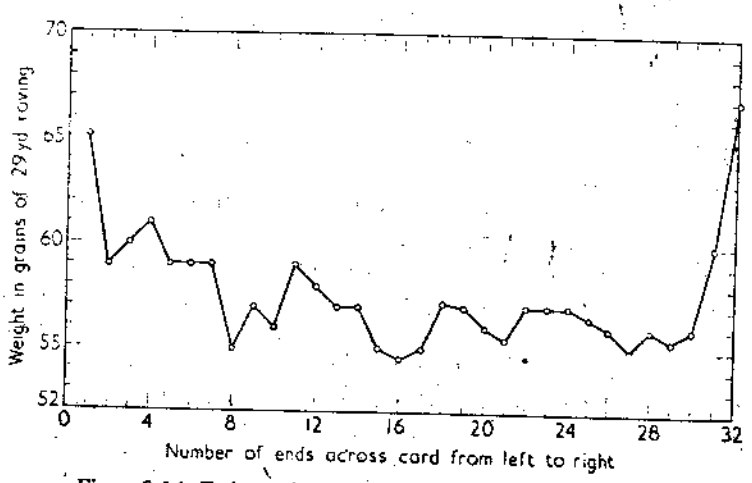


Figure 9.14. End-to-end variation across a cotton condenser card

*The accurate length measuring devices of modern machines may be used. A full can of drawframe sliver may be weighed and the decision to change pinions or not based on this result.

tion. In general, compression or electronic methods are to be preferred for such investigations.

Yarns

The wrapping of yarn for count determination is perhaps the most common test. A suitable length, 120 or 80 yd for example, is accurately wrapped on a reel and is then weighed. The estimates of irregularity which are made from a series of count tests provide a general picture of the yarn variation, but more refined methods are required for the detailed study of yarn irregularity.

Variance–length curves have been discussed earlier in this chapter. The $B(l)$ curve can be obtained by cutting short lengths of yarn, using suitable cutting methods, and weighing them on a torsion balance. The specimen length is varied in order to obtain the necessary values of $B(l)$ for plotting the curve. These techniques are too slow for mill purposes but are used in research. The reader will find accounts of the work done by several technologists in this field in the references (Townsend, Martindale, Grosberg and Palmer, Anderson, Caveney, Foster and Gregory).

The B.S. Handbook describes two methods of measuring yarn irregularity by cutting 1 in. lengths. The first method is used when faulty cloth is examined. A strip of the fabric is cut in such a way that when the short transverse threads are removed and straightened out their average length will be 1 in. The length of the strip should be sufficient to contain at least 200 transverse threads. Forceps are used to extract the threads one at a time and to place them on the torsion or microbalance. Two hundred readings are made and from them the irregularity calculated.

Yarn on packages may be tested by knotting together pieces of yarn about 12 in. in length, taken at random intervals of about 2 yd. The knotted length is wound on to a rod whose circumference is 1 in. A groove along the rod enables a razor blade to slice the yarn into 1 in. lengths; a velvet pad placed against the underside of the rod retains these lengths in position for ease of handling. The weighing and calculation is similar to the first method:

(1) Calculate the mean weight from the 200 readings.
(2) Calculate the mean range from the ranges in groups of 10.
(3) The percentage irregularity is given by

$$\frac{\text{Mean range}}{\text{Mean weight} \times 3{\cdot}03} \times 100$$

VARIATION IN THICKNESS UNDER COMPRESSION

Suppose a sliver or other relatively soft strand of material is confined in a rectangular groove, G, Figure 9.15, and compressed by a close-fitting loaded shoe, S. The height, h, of the compressed sliver will be proportional to the number of fibres in the cross-section. By taking a series of measurements of h at points along the sliver, the irregularity can be determined. The principle is used on a number of irregularity testers. Strictly speaking, the height measured is not the height of a cross-section of zero length but the mean height of a very short length, somewhere in the region of about 0·05 in. for roving and 0·10 in. for slivers. (In passing, it is worth noting that the 'Uster' staple diagram apparatus uses a groove and loaded shoe to obtain a measurement proportional to the number of fibres at points along a prepared tuft of cotton.) The thickness of the sliver may be measured at different points along the strand, i.e. in a non-continuous manner. Indeed, some instruments operate in this way but the tendency today is to demand a continuous record from the testing instrument so that the trace may be analysed for possible periodic variation, etc. An excellent example of a modern irregularity tester based on the compression principle has been developed by the Wool Industries Research Association.

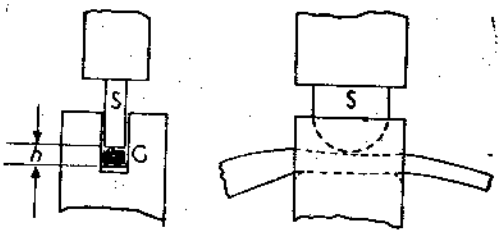


Figure 9.15. Groove and shoe principle

The W.I.R.A. roving levelness tester, manufactured by Messrs. H. A. Gaydon and Co. Ltd, uses a pair of matched rollers in place of a fixed groove and shoe. A line diagram, Figure 9.16, shows the main features of the instrument. The motor-driven lower roller R_1 has a rectangular groove into which the centrally positioned flange of the top roller R_2 just fits. R_2 is mounted on the lever or arm which is pivoted at P. The vertical movement of the top roller caused by the variation in the thickness of the tested material is mechanically magnified, the final movement being given to the recording pen. In order to accommodate different types of material, several pairs of

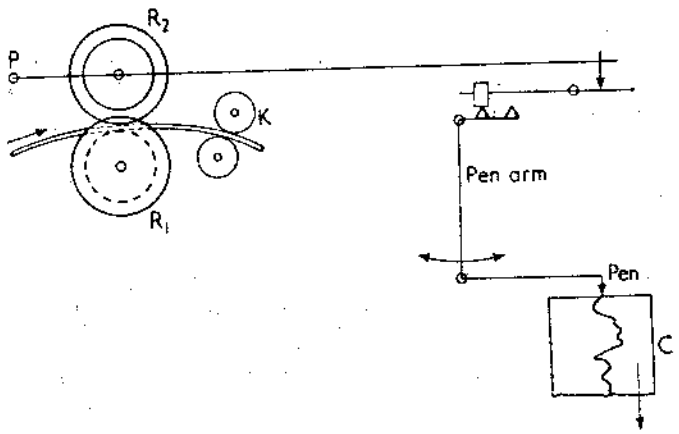


Figure 9.16. W.I.R.A. roving levelness tester (not to scale)

rollers are available with groove widths of $\frac{1}{32}$ in., $\frac{1}{16}$ in., $\frac{1}{8}$ in., and $\frac{1}{4}$ in. In addition to this, the magnification of the lever system is adjustable. Thus, the pen movement may be from 20 to 400 times the top roller movement and it is considered that a pen oscillation of about $1\frac{1}{2}$ in. is suitable for the production of a trace which can be studied conveniently. The chart C, on which the trace is drawn, is driven from the lower roller via a gearbox which enables the material : chart speed ratio to be varied so that 1 in. of chart may represent from 2 in. to 100 in. of material.

The irregularity trace

Figure 9.17 shows the trace of a sample of drawframe sliver. The actual zero line is 'off the chart', but in the initial setting up of the

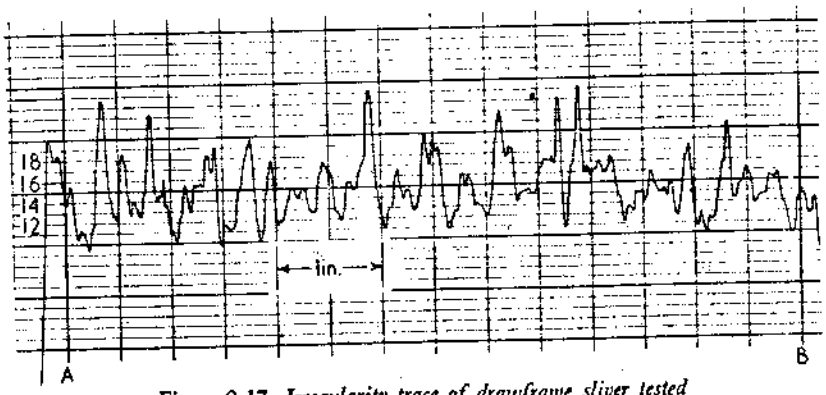


Figure 9.17. Irregularity trace of drawframe sliver tested on the W.I.R.A. compression-type instrument

tester the position of the zero line relative to the chart zero is noted from the instrument settings. It would be possible to derive the coefficient of variation by measuring the height of the chart at a large number of points and carrying out the usual statistical calculation. This method, although sound and is used, is rather laborious, and so advantage is taken of the fact that as a general rule the variations in thickness follow a normal distribution.

The use of probability paper

The irregularity trace shown in Figure 9.17 is recorded on chart paper having thirty divisions, each division $\frac{1}{10}$ in. wide. It will be seen that the trace is centred approximately on the fifteenth line. The standard deviation and coefficient of variation can be determined by carrying out the following procedure:

Step 1. Make a rough estimate of the mean chart height. Line 15 is chosen here.

Step 2. Select two lines on each side of this mean. Lines 18, 16, 14, and 12 are selected here.

Step 3. Sum the distances *a*, *b*, *c*, etc., which lie along the upper line. Figure 9.18 shows how this is done by using the edge of a piece of plain paper and marking off the lengths *a*, *b*, *c*, etc., so that they add themselves up, so to speak. These lengths are those *above* which the trace projects.

Step 4. Record the sum of the lengths in a suitable Table (see Table 9.7). For line 18 the sum was 0·88 in.

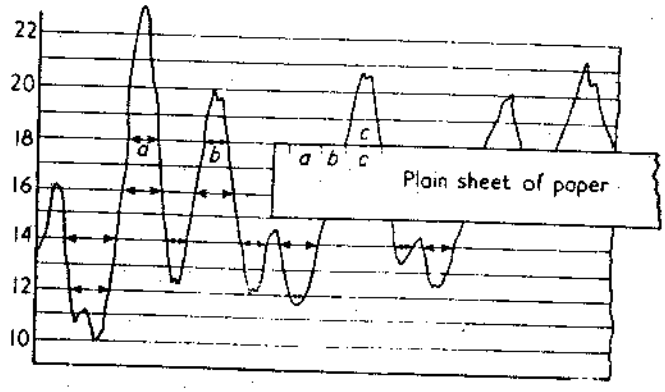


Figure 9.18. The use of the edge of a sheet of plain paper to sum up the distances a, b, c, *etc.*

Table 9.7. The Use of Probability Paper

Line	*Length above line (in.)*	*Length below line (in.)*	*Length (%)*	*Length (%) plotted*
18	0·88		12·6	87·4
16	2·10		30·0	70·0
14		2·86	40·9	40·9
12		1·10	15·6	15·6

Notes Percentages based on 7 in., the total trace length. Length percentage values plotted for length above Lines 18 and 16 obtained by subtraction from 100 per cent.

Step 5. Repeat Steps 3 and 4 for the other lines.
Note carefully that for the lines below the mean, the lengths are those *below* which the trace projects.

Step 6. Complete the Table as indicated, basing percentage values on the length of the trace examined. In this example only 7 in. of trace is examined, equivalent to only 70 in. of sliver; in practice, a longer length of chart would be analysed to give better sampling.

Step 7. Prepare a sheet of probability paper by marking off the vertical scale to cover the range corresponding to the selected lines (Figure 9.19). Here the scale is marked off from 12 to 18. The horizontal scale is specially graduated in percentages with a non-linear scale.

Step 8. Plot the length percentage values on the selected lines, using the lower horizontal scale.

Step 9. Draw the best straight line through the plotted points.

Step 10. From the straight line note the ordinates of the values 50 per cent, 15·9 per cent, and 84·1 per cent. In this example the ordinates are 14·72, 11·95, and 17·47.

Step 11. The standard deviation is given by the difference between the 84·1 and 15·9 per cent values divided by 2. In this example:

$$\text{Standard deviation} \frac{17{\cdot}47 - 11{\cdot}95}{2} = 2{\cdot}76$$

Step 12. Determine the true mean chart height. The mean trace height on the chart paper is the ordinate corresponding to the 50 per cent value. To this must be added the amount by which the true zero has been shifted when the evenness tester is initially set to test the sample. Testing machine constants and settings enable the zero shift to be calculated simply. In this example the mean trace height is 14·72 and the calculated zero shift was 32 (i.e. 32 divisions). Thus, the true mean chart height is 14·72 + 32 = 46·72.

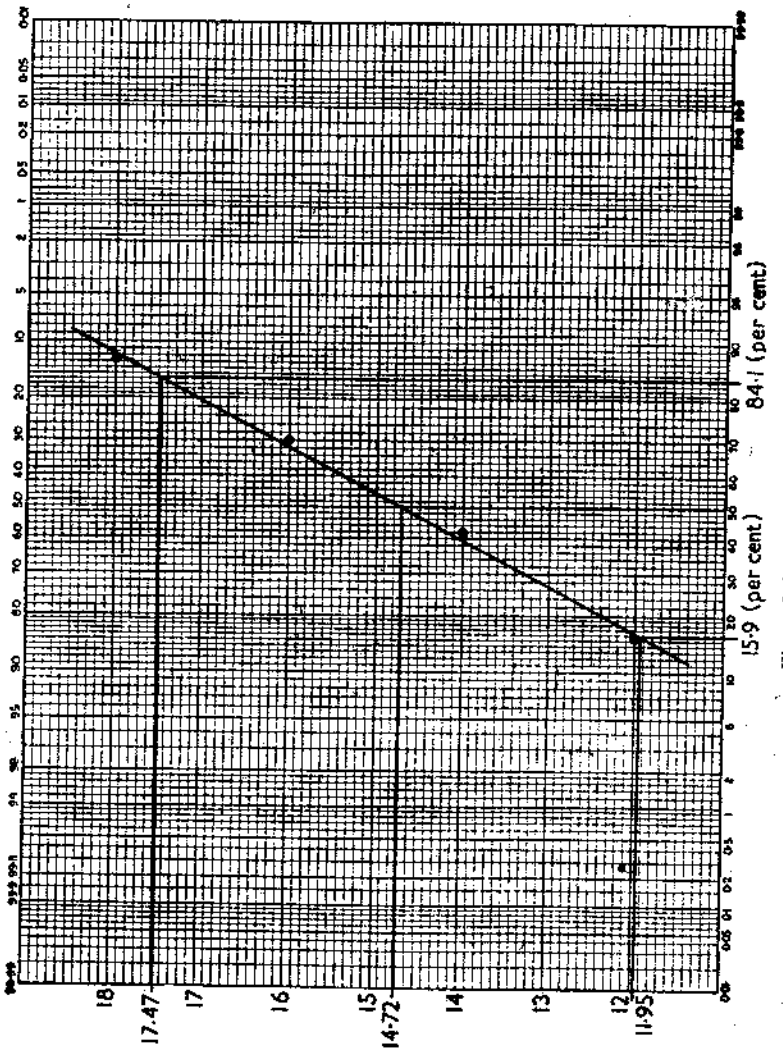


Figure 9.19. Probability paper

Step 13. The coefficient of variation is calculated:

$$\text{C.V.} = \frac{\text{Standard deviation}}{\text{Mean chart height}} \times 100 \text{ per cent}$$

In our example,

$$\text{C.V.} = \frac{2{\cdot}76}{46{\cdot}72} \times 100 = 5{\cdot}9 \text{ per cent}$$

This procedure does, at first reading, appear to be lengthy, but in practice a result can be obtained in 10 min or so. It must be noted that the method is really based upon the assumption that the variations about the mean are random and form a normal distribution; if strong periodical variations exist, the distribution is no longer normal and this method must not be employed.

The automatic computer

Even with the use of probability paper, the time taken to work out the results may be considered too long. Therefore, a method of automatic computation has been added to the W.I.R.A. machine. The purpose of the computer is to measure the height of the trace at a hundred equally spaced intervals along the chart as the material is running through the tester. The measurements are fed to a unit which automatically handles the data and furnishes quantities which enable the coefficient of variation to be calculated quickly.

The height measurements are made by a unit consisting of a 'brush' fixed on the pen arm which moves over a 'bank' of thirty contacts insulated from each other (Figure 9.20). To each contact a 'memory' relay is connected, the relays being housed in the separate computer unit. When the machine is running, a microswitch is operated by a cam at approximately 2 sec intervals. At the instant that the microswitch is closed, current flows through the brush and through the contact which the brush is touching at that moment, thus energising the corresponding relay.

Now, if $y_1, y_2, \ldots y_n$ are the values of n heights or ordinates measured from an arbitrary zero which is a distance Y above the true zero, then the mean chart height is given by

$$\text{M.C.H.} = Y + \frac{\Sigma y}{n}$$

and the standard deviation is given by

$$\sigma^2 = \frac{\Sigma y^2}{n} - \left(\frac{\Sigma y}{n}\right)^2$$

The computing unit displays the quantities n, Σy, and Σy^2 in 'bank units', i.e. the distance from one contact to the next.

It will be seen that because of the geometry of the pen arm–brush–pen system, one 'bank unit' of measurement is directly related to the units in which the actual chart is measured, i.e. tenths of an inch. The exact relationship is determined for each machine and incorporated into the arithmetic of the calculation of the coefficient of variation.

The coefficient of variation obtained by this method of testing will be a measure of the variation *within* the length of material tested.

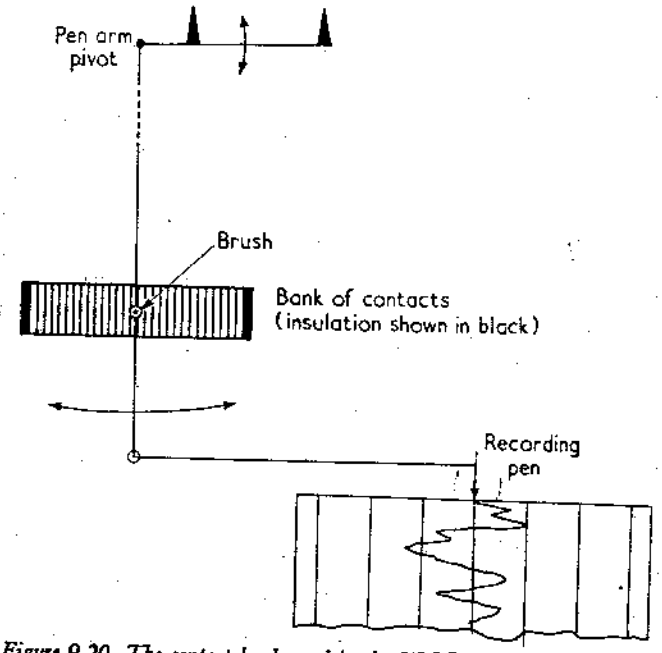


Figure 9.20. The contact bank used in the W.I.R.A. tester when the automatic computer is added

Details of the circuit are described in a paper by Hogley 'An Instrument to Measure and Compute the Mean and Standard Deviation of the Oscillations of a Recording Arm' (*J. Sci. Instrum.* **29**, p. 76 (1952)).

Yarn testing by compression methods

Slivers and rovings are soft enough to conform to the rectangular shape of the groove through which they run, but the twist in yarns causes them to be too hard for this purpose. A yarn tester described by Anderson et al. (*J. Text. Inst.* **36**, T191 (1945)), overcomes this difficulty by using a very lightly loaded radiused shoe resting on the yarn, with the yarn running over a flat anvil (see Figure 9.21). Only 2·5 g pressure is applied to the yarn. It has been found that with a light pressure the measurements of yarn thickness are closely correlated with the weight per unit length. The recording of the yarn thickness variation takes the form of an optical arrangement in which a beam of light is reflected from a small mirror on to a moving strip of photographic paper. In this way the movement of the shoe may be magnified 200 to 500 times, and a permanent record of the variation obtained.

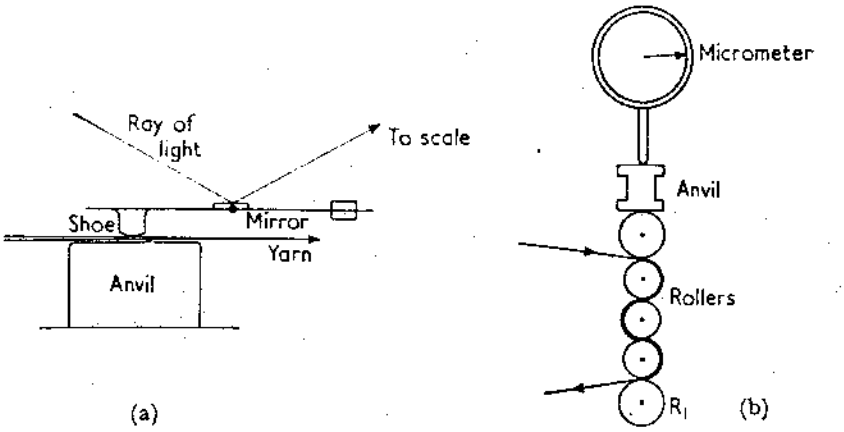


Figure 9.21. Yarn testing by compression: (a) Anderson yarn tester; (b) The LINRA roller yarn diameter tester

An instrument developed by the Linen Industry Research Association is described in detail elsewhere (*J. Text. Inst.* **41**, P486 (1950)). Briefly, the yarn passes round a series of rollers so that it lies between four nips, the pressure being about 5 g. The four thicknesses so measured are equally spaced within 1 in. The top roller supports a small anvil on which the plunger of the micrometer rests. Hence, a series of measurements may be taken along the yarn. Modifications to such an apparatus can convert it from a hand-operated instrument with intermittent measurement to a continuous tester with the movement of the top roller being used to actuate mechanical or electrical pen recorders.

Experience has shown that this instrument works satisfactorily with coarse and medium flax yarns up to about 60s lea (27·5 tex) and on rayon staple yarns with twist factors of 1·5 or more.

The two yarn testers mentioned above test one strand of yarn at a time, but it has been shown that it is possible to test a bundle of yarns on the W.I.R.A. roving levelness tester. The chart obtained can be treated in the usual way to obtain the coefficient of variation for the bundle. By assuming that all the yarns are equally variable, the coefficient of variation for the single yarn may be derived from the following relation:

$$\text{C.V. (yarn)} = \text{C.V. (bundle)} \times \sqrt{n}$$

where n is the number of strands in the bundle (see *J. Text. Inst.* **41**, P480 (1950)).

ELECTRONIC CAPACITANCE TESTERS

The measuring device of an electronic capacitance tester is a parallel-plate air capacitor. (The tuning capacitors of radio sets are of this type.) Under certain conditions, the effect of introducing a non-conducting material such as a sliver or yarn into the space between the plates is to change the capacity of the capacitor, the change being proportional to the weight of material present. If, therefore, the material is drawn through the capacitor continuously, the changes in the capacity will follow the variation in the weight per unit length of the strand, the unit length being the length of the capacitor. It is necessary to detect the changes in capacity and to translate them electronically into meter readings which indicate the coefficient of variation. At the same time a trace of the variation should be made on a pen recorder if required.

The design of the capacitors and the associated electronic circuits is a subject in itself and really beyond the scope of this chapter. Those readers who wish to gain a more detailed knowledge of such matters should consult the papers of Walker (*J. Text. Inst.* **41**, P446 (1950)) and Mack (*J. Text. Inst.* **46**, T500 (1955)).

Some of the design problems should be appreciated and will be mentioned now before the actual instruments are described. Firstly, so that the changes in capacity are linearly related to the weight of material present, the material thickness should not exceed 40 per cent of the distance between the capacitor plates. Hence, to accommodate a range of materials from slivers to fine yarns a series of interchangeable capacitors are necessary.

Secondly, the length of the capacitor should be as short as possible so that the variations in weight are measured over short lengths. In the Fielden–Walker tester this length is 1 cm, and in the 'Uster' it varies from 20 mm (for coarse materials) to 8 mm.

Thirdly, the shape of the cross-section of the tested strand affects the change in capacity. It is essential that the strand maintains its shape during its passage through the capacitor. Where soft materials are tested, guides are used which slightly compress the strand into a suitable form just before it enters the capacitor. For spun yarns the twist keeps the cross-section approximately circular. Filament yarns with low twist require extra twist and so a special twist tube, something like a false twister, is used (see Walker, P. H. *J. Text Inst.* **45**, P678 (1954)).

Fourthly, the moisture in the material affects the magnitude of the change in capacity, a higher moisture content giving a greater change in capacity. A nice point arises here. If the whole of the length of material tested has the same moisture content, the level of the change of capacity will not affect the coefficient of variation because the thick and thin places will have the same moisture content. In the laboratory, therefore, it is more important to ensure that the moisture content is the same throughout the sample rather than it be a particular value. In general, samples which have been in the laboratory for ½ hr or more will be fit to test. Foster (*J. Text. Inst.* **48**, T108 (1957)) shows that for rovings the outer layers, i.e. the layers which will be tested, will be reasonably conditioned in this time because the diffusion of the moisture into the first few layers of a roving bobbin is fairly rapid. When slivers in cans are tested it is recommended that the top layers are removed just prior to testing. Foster's paper goes into these problems of moisture in more detail.

The Fielden–Walker yarn evenness recorder

Most of the main features of this British electronic capacitance type tester can be seen in Figure 9.22:

(1) The measuring capacitor. Four sizes are available to accommodate a range of materials from slivers to fine yarns.
(2) The guides. These lead the material across the air gap in the correct position and, where necessary, give it the right shape of cross-section.
(3) The creel to hold the material and allow smooth withdrawal from the package.
(4) The take-up rollers to pull the material through the capacitor. These rollers operate at two speeds, 5 ft/min and 50 ft/min.

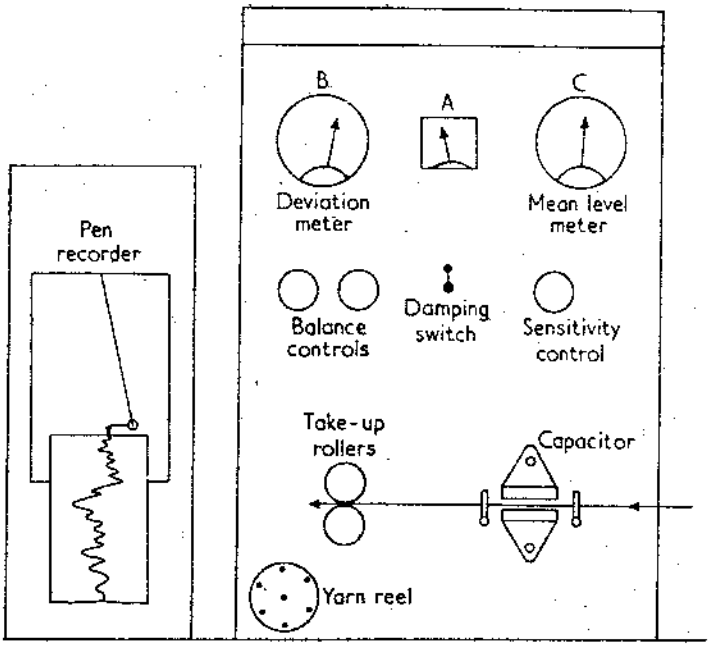


Figure 9.22. The Fielden–Walker evenness tester

(5) The yarn reel to collect tested yarn.
(6) Meter A, which indicates the momentary variation of the material.
(7) Meter B, which indicates the deviation from the mean level.
(8) Meter C, which indicates the mean level.
(9) The balance and sensitivity controls to adjust the instrument.
(10) The damping switch. When in operation, the pen of the recorder follows a smoother course.
(11) The pen recorder. The pen follows the movement of the pointer of meter A; the chart speed can be varied by change wheels to give a range of chart contractions.

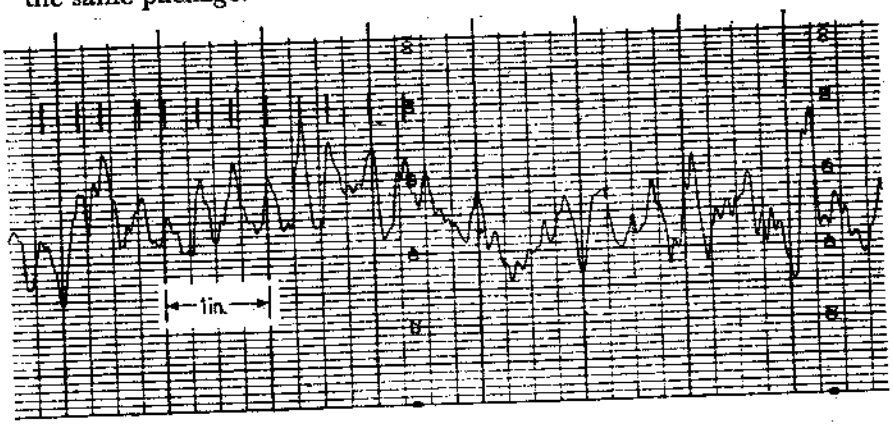
Outline of operation. The instrument is switched on and allowed to warm up before being balanced to zero by means of the controls, with no material between the plates of the selected capacitor. When the main unit is balanced to zero, the pen of the recorder should be on the chart zero; if not, it can be adjusted to zero. The material to be tested is threaded through the guides, capacitor, and take-up rollers, and the traverse switched on at the selected speed. In order to bring the pen into the centre of the chart, the sensitivity control is

adjusted until both the pen and the pointer of Meter A oscillate about a position approximately in the centre of their respective scales. The chart is then switched on and a trace of the irregularity produced.

Four different types of chart presentation can be obtained by using the two traverse speeds and the damping switch:

(1) A chart showing full detail of variation; use traverse of 5 ft/min and no damping.
(2) A chart showing basic forms of variation; use traverse of 5 ft/min and the damping switch closed.
(3) A chart showing irregularity over long lengths; use traverse of 50 ft/min and no damping.
(4) A chart showing long term trends; use traverse of 50 ft/min and the damping switch closed.

Figures 9.23–9.26 show all four types of trace for yarn taken from the same package.



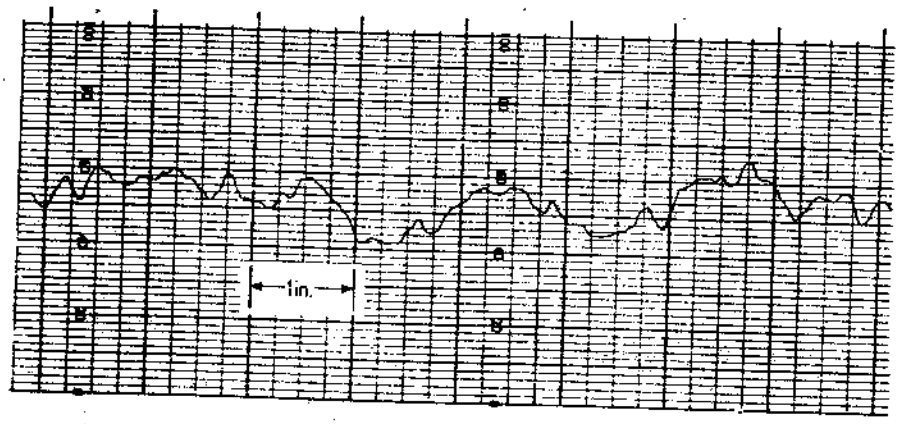
Yarn speed = 5 ft/min P.M.D. = 14·4 per cent
1 in. chart = 10 in. of yarn

Figure 9.23. Irregularity trace (undamped) of a 40s Terylene spun yarn (1½ denier, 1½ in.) using the Fielden–Walker evenness tester

The meter readings. Different forms of irregularity are shown in a simplified set of traces in Figure 9.27. Figure 9.27(a) shows the short term variation about a steady mean level. Such a yarn would give a constant reading on the deviation Meter B since the amplitude or deviation about the mean level is constant. The mean level reading on Meter C will also be constant for obvious reasons. By multiplying the two meter readings the percentage mean deviation, P.M.D., is obtained. The coefficient of variation would then be given by

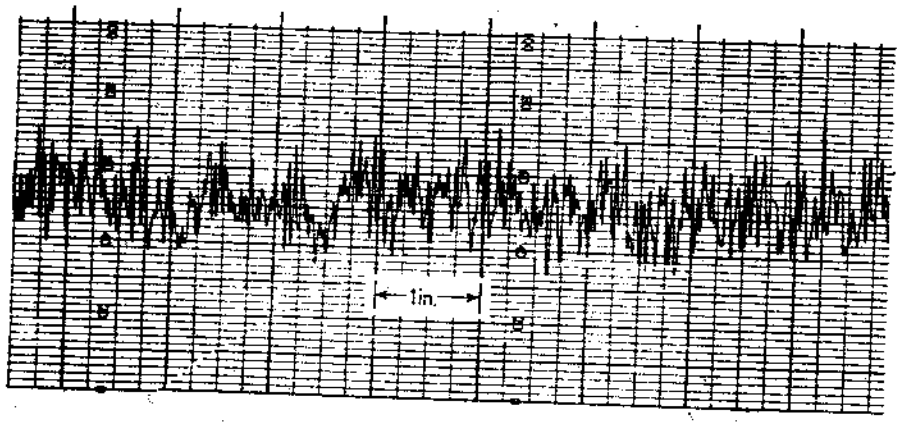
P.M.D. × 1·25. The single figure, P.M.D. or C.V. would therefore give a complete measure of the irregularity present in the material (see Table 9.8).

Figure 9.27(b) shows that the material has a constant short term variation about a mean level which has a long term variation. In this case the deviation Meter B would give a constant reading, but the mean level reading of Meter C would fluctuate. Hence, in order to obtain a measure of the long term mean level variations a series of



Yarn speed = 5 ft/min

Figure 9.24. Damped trace of yarn from same package as in Figure 9.23



Yarn speed = 50 ft/min P.M.D. = 13·8 per cent
1 in. chart = 100 in. of yarn

Figure 9.25. Undamped trace of yarn from same package as in Figure 9.23 but with speed of testing increased

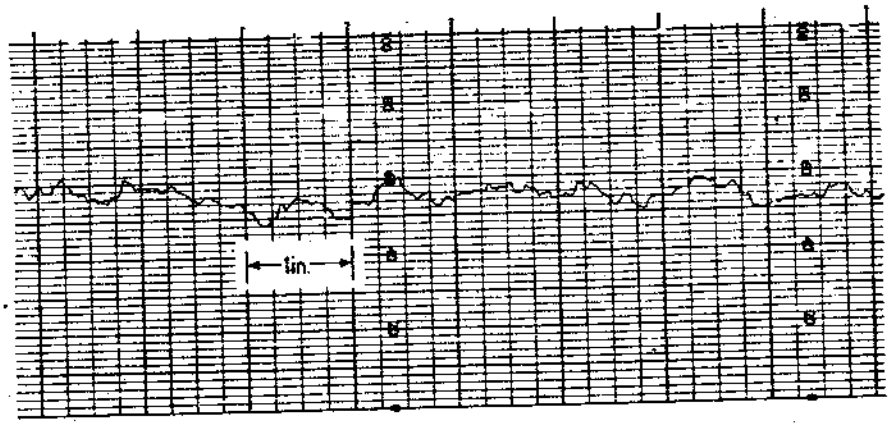


Figure 9.26. Damped trace of yarn from same package as in Figure 9.23. Testing speed increased and damping switch in use

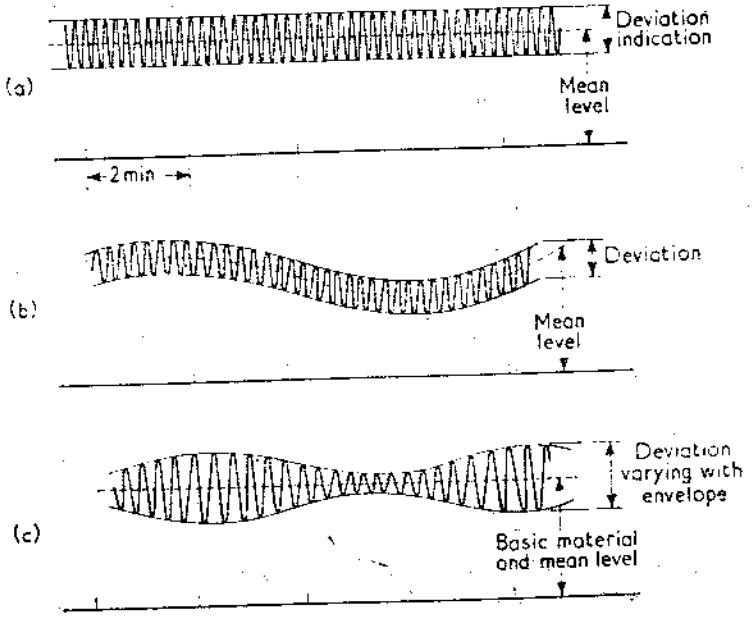


Figure 9.27. Three forms of yarn irregularity

Table 9.8. A Set of Meter Readings to Illustrate Yarn Irregularity Having a Pattern Similar to Figure 9.27(a)

Deviation	*Mean level*
11·6	0·97
11·7	0·97
11·6	0·98
11·7	0·99
11·6	0·97
11·8	0·98
11·7	0·97
Total: 81·7	Total: 6·83
Average: 11·67	Average: 0·976
Percentage mean deviation = 11·67 × 0·976 = 11·4	

Table 9.9. A Set of Meter Readings to Illustrate Yarn Irregularity Having a Pattern Similar to Figure 9.27(b)

Deviation	*Mean level*
11·6	1·1
11·7	1·2
11·7	1·3
11·6	1·2
11·7	1·0
11·8	1·2
11·6	1·3
11·6	1·4
11·7	1·2
11·7	1·2
11·6	1·1
11·8	1·2
11·7	1·3
11·6	1·2
11·7	1·1
Total: 175·1	Total: 18·0
Average: 11·67	Average: 1·2
Percentage mean deviation = 11·67 × 1·2 = 14·0	

readings must be taken over a period long enough to be a representative set of mean level measurements. The average of these mean level readings then becomes the mean level which, when multiplied by the deviation, produces the P.M.D. of the short term variation (see Table 9.9).

No deviation figure departs seriously from the average but the mean level figures range from 1·0 to 1·4; 14·0 per cent will be an accurate statement of the short term irregularity but ignores the long term variation of the weight per unit length. This can be obtained by listing the departures from the average of the mean level readings. Table 9.10 shows this operation.

Table 9.10. Calculation of Long Term Variation in Weight Per Unit Length from the Data in Table 9.9

Mean level	*Difference from average 1·2*
1·1	0·1
1·2	0·0
1·3	0·1
1·2	0·0
1·0	0·2
1·2	0·0
1·3	0·1
1·4	0·2
1·2	0·0
1·2	0·0
1·1	0·1
1·2	0·0
1·3	0·1
1·2	0·0
1·1	0·1
Total: 1·0	
Average: 0·067	

Percentage mean deviation of long term variation of weight per unit length

$$= \frac{0{\cdot}067 \times 100}{1{\cdot}2} = 5{\cdot}6 \text{ per cent}$$

To obtain a measure of the long term variation of the mean level, the differences between the individual mean level readings and the average mean level are calculated. The differences are then averaged, and the average is expressed as a percentage of the average mean level. This operation is given in Table 9.10.

Conclusions from Tables 9.9 and 9.10: The yarn has a short term irregularity of 14·0 per cent together with 5·6 per cent wander of the weight of lengths of yarn passed in 30 sec. (Note: the meter readings are logged at 30 sec intervals.)

A third form of variation is shown in Figure 9.27(c). Here the mean level reading will be constant but the deviation will vary since the amplitude of the short term variation is not consistent. Table 9.11 gives the method of treating the data. The long term variation in the amplitude of the short term variation is calculated in Table 9.12.

Table 9.11. A Set of Meter Readings to Illustrate Yarn Irregularity of the Type Shown in Figure 9.27(c)

Deviation		*Mean level*	
13·1		1·1	
12·2		1·1	
11·7		1·05	
12·3		1·1	
13·3		1·15	
12·9		1·1	
12·1		1·1	
11·3		1·1	
12·2		1·15	
13·7		1·1	
13·9		1·1	
12·3		1·05	
11·2		1·05	
11·9		1·1	
13·6		1·1	
Total:	187·7	Total:	16·45
Average:	12·5	Average:	1·1

Short term percentage mean deviation = 12·5 × 1·1 = 13·75

The long term variation on weight per unit length is small but there is a pronounced long term variation of the deviation, i.e. of the short term irregularity. This can be evaluated by the difference from average procedure shown in Table 9.12.

Conclusions: This yarn has a short term irregularity of 13·75 per cent which varies over a longer period, in this case about 3 min, by 0·79 per cent of the basic material weight.

The readings should start after 2 min running and thereafter at 30 sec intervals. At a traverse of 5 ft/min, 30 sec represents 2½ ft of material and so 'short term' at this speed means variations up to 2½ ft. Similarly, at 50 ft/min 'short term' means variations up to 25 ft.

Table 9.12. Calculation of the Long Term Variation in the Short Term Irregularity

Deviation	*Difference from average 12·5*
13·1	0·6
12·2	0·3
11·7	0·8
12·3	0·2
13·3	0·8
12·9	0·4
12·1	0·4
11·3	1·2
12·2	0·3
13·7	1·2
13·9	1·4
12·3	0·2
11·2	1·3
11·9	0·6
13·6	1·1
Total:	10·8
Average:	0·72

The percentage mean deviation of the long term variation of the short term irregularity = 0·72 × 1·1 = 0·79

In routine testing it is recommended that the higher speed is used with the pen recorder switched out. The longer lengths so tested mean that the sampling is better. For investigation of materials which show periodic variations, the slow speed may be used in conjunction with the pen recorder. The analysis of such traces will be dealt with later.

In actual practice, the various types of variation will appear in the yarn simultaneously. One set of readings are therefore taken and from them the three measures of irregularity calculated:

(1) Short term irregularity.
(2) Long term variation of the short-term irregularity.
(3) Long term variation of weight per unit length.

The 'Uster' evenness tester

A schematic diagram of this Swiss evenness tester is shown in Figure 9.28. Two oscillators A and B have equal frequencies when there is no material in the measuring capacitor C. When the two frequencies are superimposed the difference in frequency is zero.

The presence of material in the capacitor causes its capacity to change and so alter the frequency of the oscillator A. There will then be a difference between the two frequencies which varies according to the amount of material between the capacitor plates. Suitable circuits D translate these frequency differences into signals which (1) are indicated on the meter M, (2) drive the pen of the recorder, and (3) are fed into the integrator which indicates the average irregularity either as percentage mean deviation or coefficient of variation according to the model used.

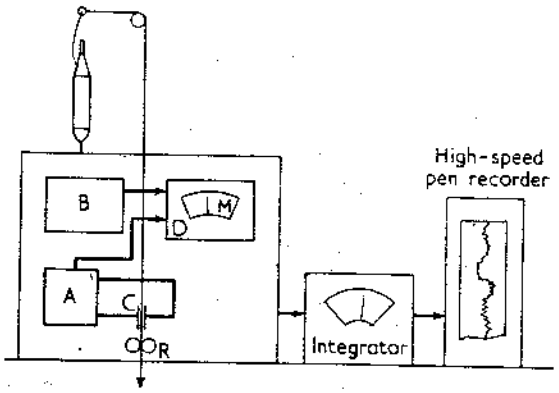
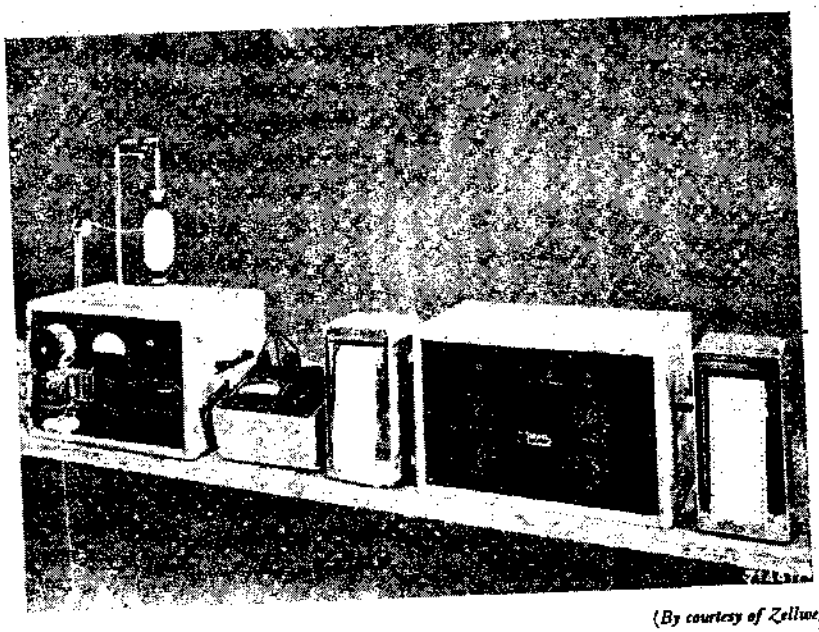


Figure 9.28. Schematic diagram of the 'Uster' evenness tester

The actual tester is illustrated in Figure 9.29 which shows the following external features:

(1) The 'comb' of eight measuring capacitors of different sizes.
(2) The creel and guides to control the material.
(3) The traverse rollers which can control the material speed over a range from 2 to 100 yd/min.
(4) The control switches.
(5) The meter on the main unit which indicates the momentary variations in the material.
(6) The integrator which indicates the P.M.D. or C.V.
(7) The high-speed pen recorder whose chart speed can be varied between 1 and 40 in./min.

As in the case of the Fielden–Walker instrument, the 'Uster' is adjusted and balanced after a preliminary warming-up period. The detailed procedure for adjustment and testing will not be discussed here but several points should be noted.



(By courtesy of Zellweger)

Figure 9.29. The 'Uster' evenness tester and 'Spectrograph'

Material speed. In yarns, the drafting wave variations have the highest amplitude and have a wavelength of about 2 to 2·5 times the mean fibre length. The speed of testing must be chosen so that the frequency of these fluctuations lies within the capacity of the recording pen to follow them. For example, with a yarn speed of 50 yd/min and a drafting wavelength of about 3 in., the pen must be capable of responding accurately to 10 fluctuations per second. The recorder of the 'Uster' is a high-speed instrument which can cope with a yarn speed of 100 yd/min.

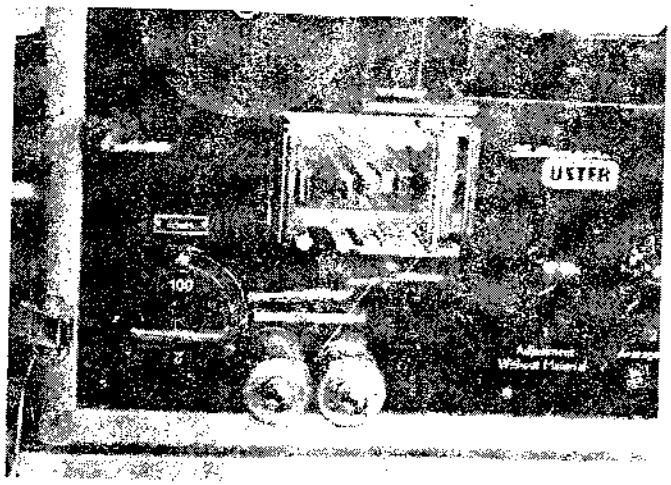
Chart speed and chart contraction. The yarn speed: chart speed ratio, i.e. the chart contraction, is chosen to suit the type of variation being examined.

For short term variation a ratio of 8 to 20 is recommended.
For medium term variation a ratio of 40 to 160 is recommended.
For long term variation a ratio of 200 to 1,000 is recommended.

Choice of measuring capacitor

Earlier in this chapter we learnt that in order to achieve a change in capacity which is linearly related to the amount of material

between the capacitor plates, the thickness of the material relative to the size of the capacitor must not exceed certain limits. In the 'Uster' instruction manual a Table states which capacitor in the 'comb' must be used for the different hanks and counts.



(*By courtesy of Zellweger*)

Figure 9.30. Close-up of the 'comb' of measuring capacitors of the 'Uster' evenness tester

'Normal' and 'inert' testing

When the 'Uster' is used with a control switch set to 'normal', the trace records all the variation, short, medium, and long term. A special filter circuit comes into action when the switch is set to 'inert'. In effect, the short term variation is separated from the medium and long term variations. The integrator and the recorder, then, deal only with the medium and long term irregularity. The results are similar to those obtained by cutting and weighing; therefore by 'inert' testing we achieve an electrical equivalent of measuring the irregularity *between* cuts of equal lengths. These 'electrical cut lengths' depend upon the speed of testing:

2 yd/min is equivalent to 5 in. cut lengths (approx.)
8 yd/min is equivalent to 20 in. cut lengths (approx.)
25 yd/min is equivalent to 60 in. cut lengths (approx.)
100 yd/min is equivalent to 225 in. cut lengths (approx.)

It may occur to the reader that a possible method of obtaining a $B(l)$ curve presents itself. This can, in fact, be done on the 'Uster' by employing special testing procedures.

Associated 'Uster' equipment

Since the introduction of the basic testing units a number of new units have been developed which increases the usefulness and versatility of the original evenness tester. The 'Spectrograph' is a piece of equipment which is used in the analysis of irregularity and will be described later.

The 'imperfection indicator'

The introduction of the imperfection indicator in place of the 'Hy-Lo' indicator (described in the Second Edition) offers the quality control department greater opportunities for detailed analysis of faults in yarns. Signals from the main unit are fed to the imperfection indicator which simultaneously measures neps, thick places and thin places. A count of all three types of fault is made and the results shown on separate counters. It is possible to adjust the sensitivity of the system so that a chosen size of fault is counted and smaller faults ignored. In 1964, a new set of 'Uster' yarn standards were introduced, the yarn parameters considered being evenness, neps, thick places and thin places. It was therefore necessary to define the meanings of the last three terms.

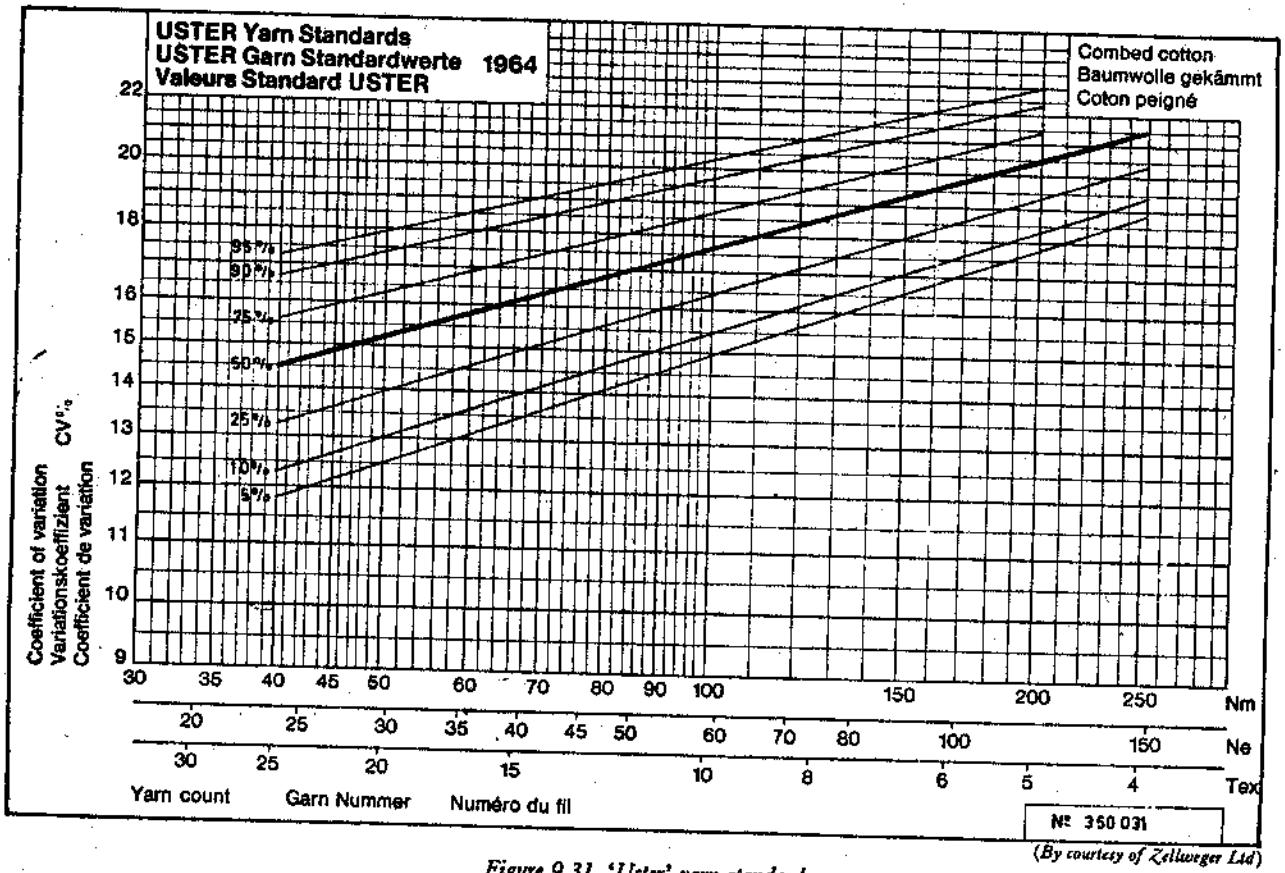
Neps—a fault length of 1 mm having a cross-section 200 per cent of the average value. This corresponded to a sensitivity setting of 3 on the 'neps' knob of the imperfection indicator.

Thick Places—a fault length of approximately the fibre staple length; having a cross-section of 50 per cent increase over the average value. 'Thick places' knob set to 3.

Thin Places—a fault length of approximately the fibre staple length, having a cross-section approx. 50 per cent less than the average value. The 'thin place' knob set to 50 per cent.

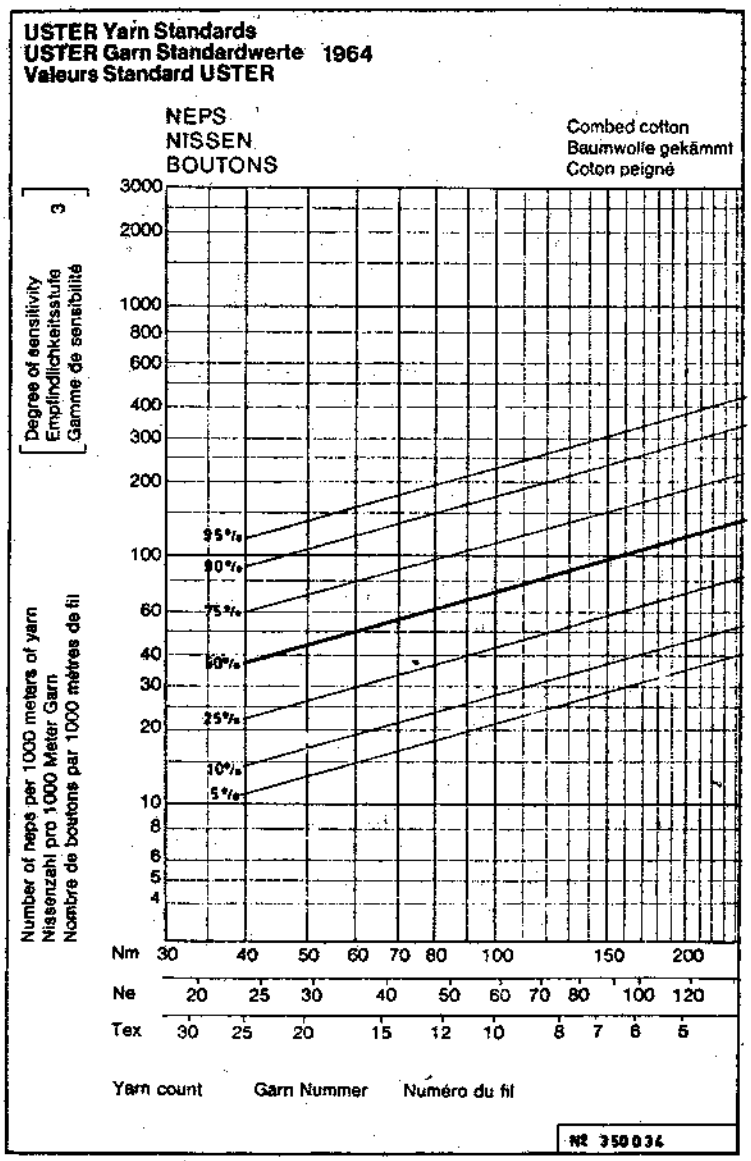
'Uster' yarn standards

The standards of evenness described earlier in this chapter were based on the results of testing the products of the machinery and techniques in use at the time. Advances in spinning technology since then, and improvements in quality control systems, have demanded a fresh appraisal of the standards. It was decided to base the standards on the quality of the yarns rather than the characteristics of the intermediate products. Yarns from all over the world were sampled and tested, the results analysed and the standards prepared. The presentation of the standards is in graphical form. Charts for combed and carded cotton, blends and worsted-spun yarns are available, but for the purposes of explanation we shall consider the charts for combed cotton yarns.



(By courtesy of Zellweger Ltd)

Figure 9.31. 'Uster' yarn standards



(By courtesy of Zellweger Ltd)

Figure 9.32. 'Uster' yarn standards

In Figure 9.31 the yarn count is on the logarithmic horizontal scale and the C.V. percentage on the vertical scale. Suppose the yarn being considered is a 40s (15 tex). Locating the 40 position on

the count scale we travel vertically until we meet the 50 per cent line; reading across to the vertical scale we read off the value C.V. 16·2 per cent. This means that of all the 40s combed yarns spun, 50 per cent of them will have a C.V., of 16·2 or worse, and 50 per cent of them better (lower) than 16·2 per cent. The spinning technologist can therefore compare his own product with the products of other spinners. If our own 40s combed yarn has a C.V. of 13·2 per cent we would be amongst the spinners of good quality yarns as the intercept on the 5 per cent line corresponds to a C.V. of 13·5 per cent. In other words, only one spinner in twenty spins 40s combed as evenly as ourselves.

Standards charts for thick and thin places, and neps, are similarly constructed, the example shown in Figure 9.32 being the nep count chart. For our 40s combed cotton yarn the number of neps per 1,000 m, for the 50 per cent line, is 54. (On the carded yarn chart the corresponding value for 40s is about 600.)

Extreme imperfections

With the selector switch set to 'Extreme Imperfections' the thick places, which are more than double the average cross-section, can be counted. For worsted spinners two limits have been fixed, + 33 per cent and + 100 per cent, and the two counters register the number of times that these limits have been exceeded.

The 'Varimeter' and 'Varisignal'

This equipment brings a further refinement to the testing of scutcher laps. A mechanical lap meter of the 'Whittaker' or 'Saco-Lowell' type provides for the measurement of the yard-to-yard variations in lap weight, whereas the 'Varimeter' measures the inch-to-inch variation. The merit of such refinement has been

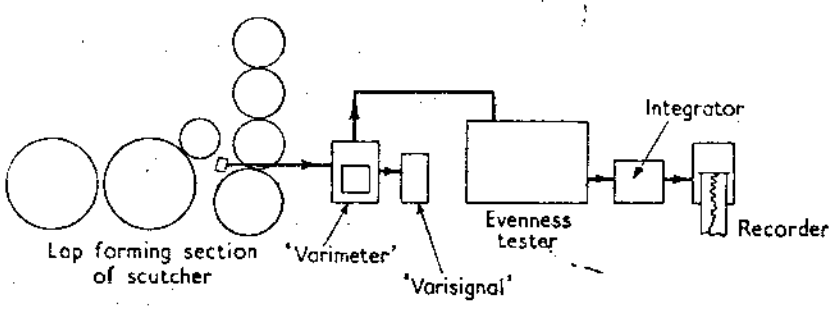
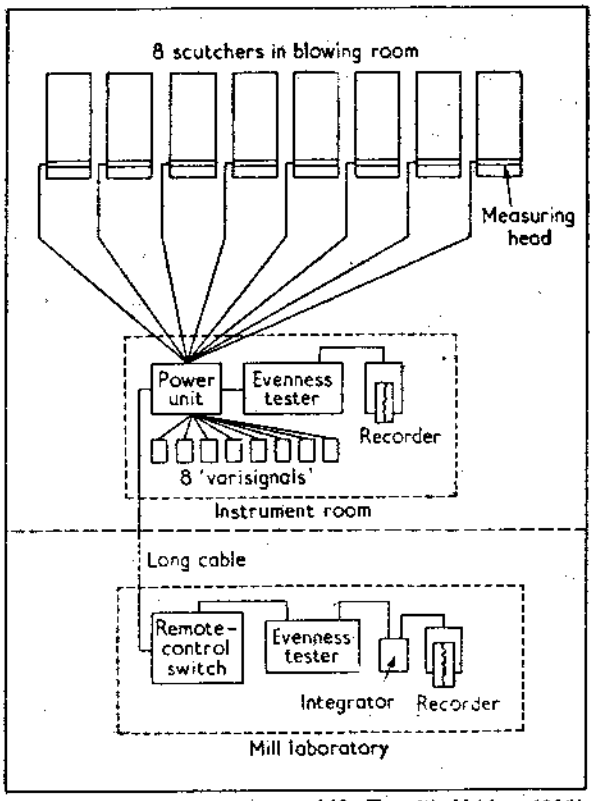


Figure 9.33. Single scutcher control by the 'Varimeter'

questioned (indirectly) by Foster who, in his book, points out that the variation within scutcher laps has a relatively small effect on the count variation of the yarn. Nevertheless, there are mills which use the 'Varimeter' system of lap testing and find that it serves a useful purpose in the control of quality (see *Text. World* (Aug., 1954)). As the spinning processes becomes shorter the inference is that the early materials will of necessity have to be more regular.

The measuring capacitor covers the full width of the lap and may either be mounted on a mechanical lap tester or be fixed in the scutcher between the bottom pair of calender rollers and the lap winding rollers (see Figure 9.33). An adapter unit converts the variations caused by the lap irregularity into low-frequency voltage variations which are then fed to the evenness tester. The 'Varisignal' is an additional unit which registers the number of times that chosen limits have been exceeded.



(*After* Text. World (*Aug., 1954*))

Figure 9.34. Multi-control of scutcher lap variation

For one measuring capacitor unit the evenness tester can supply the power, but in installations where a number of units are fitted into a range of scutchers a centralised power supply unit is used. A block diagram of a system used by an American mill is shown in Figure 9.34. Note that at any time the laboratory personnel can select a particular scutcher and obtain an irregularity trace on the pen recorder in the laboratory. By analysis of any periodic variations which may appear, it is possible to locate the likely source of the trouble (see *Text. World* (Aug., Oct., Nov., 1954)).

PHOTOELECTRIC TESTERS

When a beam of light is directed on to a photoelectric cell an electric current is produced. The magnitude of the current is directly proportional to the intensity of the light falling on the light-sensitive part of the cell. If part of the light is cut off by a yarn passing between its source and the photoelectric cell, the current flowing will vary as the thickness of the yarn varies. Irregularity testers based on this principle usually consist of the following parts (see Figure 9.35):

(1) A stabilised source of light (A).
(2) An optical system to control the light (B).
(3) A slit of variable width through which the yarn passes (C).
(4) A photoelectric cell (D).
(5) Suitable meters and recording instruments to measure the current variations and produce an irregularity trace (E).
(6) A yarn-control device.

Photoelectric testers built by research laboratories are described

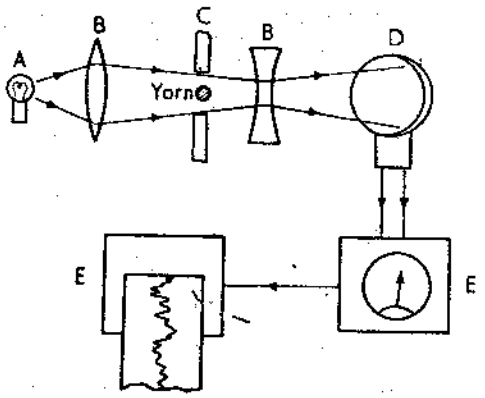


Figure 9.35. Schematic diagram of a photoelectric evenness tester (not to scale)

by Onions et al. (*J. Text. Inst.* **41**, P480 (1950)), Matthew et al. (*J. Text. Inst.* **41**, P486 (1950)) and in the W.I.R.A. handbook *Testing and Control*, p. 87.

The coefficient of variation measured by photoelectric methods does not give a measure of the variation of weight per unit length. In the papers referred to, the coefficients of variation obtained by photoelectric testers and the cutting and weighing of 1 in. lengths have been compared for a number of yarns. The conclusions reached by Onions and his colleagues are that yarns of comparable count and construction are graded by a photoelectric tester in the same order as by cutting and weighing 1 in. lengths, and that the numerical value of the coefficient of variation measured optically is greater than that of short term weight variation.

It is pointed out by Matthew that a photoelectric tester is unaffected by moisture, a useful advantage when yarns such as wet-spun flax yarns are taken directly from the spinning frame.

THE CAUSES AND EFFECTS OF IRREGULARITY

A knowledge of the mechanism and functioning of the various types of irregularity testing instruments is important, but perhaps more important is a clear understanding of the reasons why these techniques are used, how the results are interpreted, and how irregularity testing can best serve the spinner, the manufacturer, and the customer. Apart from its value in research and development, irregularity testing may be looked at from two angles: firstly, to answer the question 'What has caused this fault?' and secondly, 'How can such faults be prevented?' Chronologically, the cause comes before the effect, but often a yarn fault remains undiscovered until the fabric is made and sometimes until it has been dyed or finished. The technologist, then, has to work backwards, retracing the history of the faulty yarn and using the testing methods at his disposal to track down the probable cause of the trouble. He must therefore have a sound understanding of the processes of spinning and fabric manufacture. Even so, the help of the mill technician is often invaluable since he has an intimate knowledge of the machinery under his supervision. For this reason it is essential that the relations between the laboratory and the machine rooms should be cordial, a state of affairs to be encouraged but not, unfortunately, always found. When causes of faults have been found it is logical to design control systems which will prevent them from occurring again, or at least reduce the chances of repeat faults.

The diversity of the textile industry precludes the possibility of discussing all the causes and effects of irregularity. In the remarks which follow, attention will be given to one or two important points; but in the main the treatment will be of a general rather than a detailed nature. Further, the irregularity considered will be mainly the variation in weight per unit length even though other types of irregularity such as twist variation and dye affinity may be of equal importance in the final analysis.

EFFECTS OF IRREGULARITY IN WEIGHT PER UNIT LENGTH

Strength

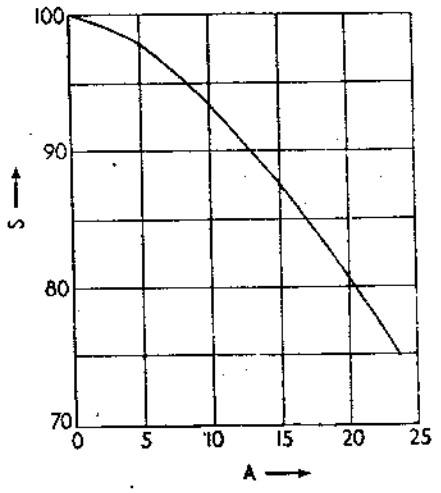
Thin places, whether in slivers, rovings, or yarns, will be weak places. Therefore, in any process where the strand has to support itself during its passage from one point to another, the more irregular it is the greater will be the chance of a break. In addition to a lower machine efficiency, the repair of breaks usually means the introduction of other faults, e.g. thicker sliver or roving at the piecing or knots in yarn.

In yarns the relation between irregularity and strength is not as straightforward as one might expect because the distribution of twist has an effect. It is well known that twist tends to 'run into the thin places'. The extra twist will tend to counteract loss in strength which would otherwise occur. Foster and Tyson (*J. Text. Inst.* **47**, T385 (1956)) investigated the relation between the amplitude of periodic variations due to eccentric top drafting rollers and the lea strength of a cotton yarn. One of the graphs appearing in their paper is shown in Figure 9.36.

Fabric appearance

With spun yarns a certain amount of irregularity is inevitable and the fabrics produced from them will possess irregularity in appearance. In some ways this variation in surface gives 'character' to a fabric, but excess of variation will produce a fabric with an objectionable appearance. The effect of the yarn irregularity will depend on several factors, including the type of variation (periodic or non-periodic), the fabric structure, the fabric dimensions, use of yarn (e.g. as warp or weft), and fabric finish. Yarns free from strong periodic variations but with a high degree of general irregularity will tend to produce patchy fabric, whereas under certain conditions yarns with periodic thick and thin places will cause the fabric to exhibit an unwanted pattern. The key words of the last sentence are

perhaps 'under certain conditions'. An odd bobbin of yarn wound on to a warping package will not cause a pattern even if it has a periodic variation because it will be hidden to some extent by adjacent warp threads and the picks of weft. Excessive warp irregularity can, however, give the cloth a streaky appearance. Where a weft yarn contains a periodic fault, fabric faults known as 'diamond bars' and 'block bars' can arise.



(After Foster, G. R. A., and Tyson A. J. Text. Inst. **47**, *T.385 (1956))*

Figure 9.36. Percentage lea strength (S) plotted against percentage amplitude (A) of wave

Diamond bars

The conditions which result in the production of the 'diamond bar' fault have been defined by Catling (*J. Text. Inst.* **49**, T232 (1958)).

Let W = the effective cloth width, i.e. the length of yarn per pick,
λ = the wavelength of the periodic variation in the weft yarn,
R = an integral multiple of $\frac{1}{2}$, and
x = a value less than $\frac{1}{4}$, positive or negative.

Then, $$W = (R + x)\lambda$$

This is a mathematical way of saying that to cause diamond barring a weft must have a periodic variation whose wavelength is less than twice the pick length.

Suppose the pick length or effective cloth width of a certain fabric is 39 in. and that the weft has a periodic variation whose wavelength is 40 in. For the sake of the discussion we will assume that the

weft yarn is composed of 20 in. sections of thick and thin places. The diagram in Figure 9.37 is a representation of the way in which the weft would position itself in the fabric (the warp is absent). Features of the effect are full diamonds in the body of the fabric with half diamonds at the selvedges. In this example only one row of full diamonds is produced, but changes in the effective cloth width and the wavelength of the periodic variation can produce several rows. The actual number will be $2R-1$, R being defined above.

In the diagram the pick spacing is wide for the sake of clarity, but in cloth the 'diamonds' will be flatter, of course. A paper by Foster (*J. Text. Inst.* **43**, P742 (1952)) goes deeper into the problems of patterning and is worthy of close study.

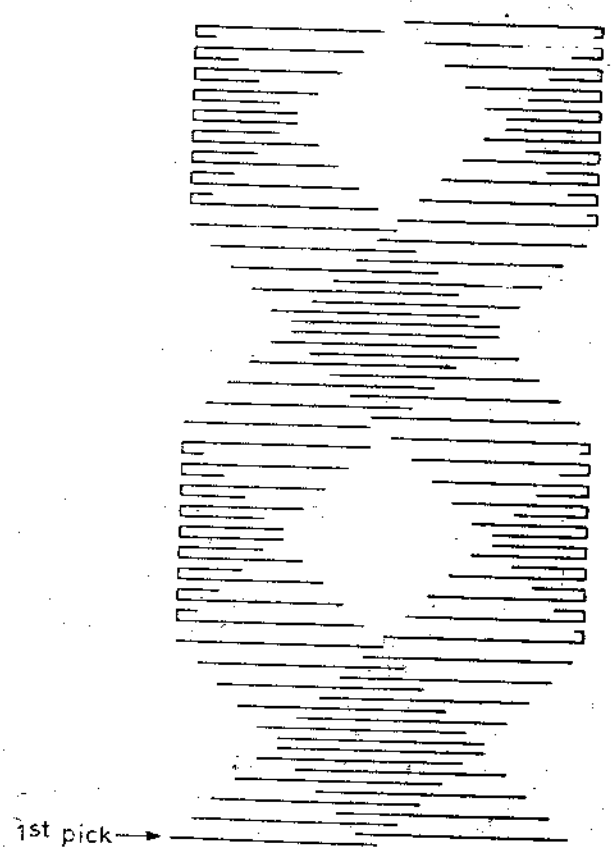


Figure 9.37. Diamond barring. Cloth width = 39 in. Wavelength of variation = 40 in., i.e. 20 in. thick yarn followed by 20 in. thin yarn

The B.R.R.A. yarn patterning predictor

We have just seen how periodic faults in weft may result in 'patterning' across the woven fabric. The prediction of the type of pattern which a given yarn may produce is made possible by the use of the Yarn Patterning Predictor, an instrument developed in the laboratories of the British Rayon Research Association. The weft yarn is passed through the measuring electrode of an electronic evenness tester, such as the Fielden–Walker, which produces an electrical signal proportional to the thickness of the material between the plates of the measuring head. This signal is fed into an amplifier and the amplified signal fed into a picture recorder of the type used in picture transmission systems for the reproduction of photographs in newspapers.

The recording apparatus draws an inked line across a chart and the thickness or density of this line is proportional to the size of the input signal. Thus, if a line represents one pick, then a thin part of the line represents a thin place in the yarn; similarly, a thick place in the yarn is represented by a thick section of the line. A succession of lines is then equivalent to a hypothetical piece of woven cloth.

Adjustments to the apparatus enable the 'width' of the hypothetical fabric to be altered. Therefore, the effects of a periodic variation in yarn thickness can be studied in relation to cloth width which, as we have noted earlier, is a major factor in patterning troubles.

A fuller description of this apparatus is given by Butler and Cowhig (*Skinner's Silk Ray. Rec.* pp. 1178–1181 (Nov., 1954)). This article is issued also as a Technological Reprint by the B.R.R.A.

Weft bars or block bars

Where the thick and thin places in the weft extend over a length several times the effective cloth width, it follows that a number of consecutive picks of thick yarn will be followed by a number of thin picks. Weft bars or block bars across the full width of the fabric result. It has been found that with very long wavelengths, e.g. fifty times the pick length, the change in count is so gradual that the 'bar' effect becomes subdued and ceases to be objectionable. Pirn-to-pirn differences in count will, if great enough, produce weft bars; the change from one thickness to another at the pirn change will be sudden. Sudden changes in most things are more noticeable than gradual changes. Some of the problems of weft mixing to counteract such undesirable effects are dealt with in a paper by Snowden and Sidi (*J. Text. Inst.* **41**, P507 (1950)).

Stripy knitted goods

In some ways the weaver fares a little better than the knitter because the irregularity in one set of threads may be partially concealed by the other set. In a weft knitting machine the weft must stand on its own feet, as it were. Knitting machines are set to produce a given quality of fabric from a known count of yarn. When the count varies from cone to cone, or where one cone contains yarn of differing count, the result is stripy fabric (see Walker, E. M., and Sleath, C. E. *J. Text. Inst.* P559 (1950)).

Dyeing and finishing faults

One effect of yarn irregularity on the dyeing process is mentioned by Fargher et al. (*J. Text. Inst.* **41**, P590 (1950)). The thicker and softer parts of the yarn take up more size than the thinner and harder regions; after the desizing process prior to dyeing, the distribution of the residual size may be uneven and cause difficulty in achieving a level dyeing.

CAUSES OF IRREGULARITY

A broad classification of the causes of yarn irregularity has been given by Martindale (*J. Text. Inst.* **41**, P340 (1950)):

(1) Properties of raw materials.
(2) Inherent shortcomings in yarn making and preparatory machinery.
(3) Mechanically defective machinery.
(4) External causes due to working conditions and inefficient operation.

Properties of raw materials

The design and adjustment of spinning machinery is in effect a compromise which aims at processing at an optimum efficiency the majority of fibres in a particular mixing. Natural fibres have variable properties and set the spinner a variety of problems. A major variable is the fibre length, of course. However, other variables such as surface character, fineness, shape of cross-section, maturity, crimp, etc., have some effect on the yarn properties. Much work remains to be done before the individual parts played by the different variables can be isolated. The old spinners' dream of fibres of uniform length, fineness, etc., has come to pass but the modern spinner of staple rayons still has his problems of irregularity.

Inherent shortcomings of machinery

In many engineering processes the units from which the final product is assembled are positively controlled by hand or machine and positioned with only a few thousandths of an inch tolerance. In spinning it is surprising how often the individual fibres are only negatively controlled—at times they are carried forward by air currents or jostled along by surrounding fibres, or they are held in position by friction and twist.

Fibre manipulation by rollers, aprons, gills, and other machine parts is hampered by fibre variation, and the machines can only be set to give the best results within the limitations imposed by the material.

The 'drafting wave' is one example of irregularity due to the inability of a drafting system to control each fibre. Where roller drafting is used, the distance from one nip to the other is greater than the length of the shorter fibres. These short fibres 'float' in the drafting zone and move forward in an irregular but cyclical manner which results in the drafted strand having thick and thin places. The wavelength of this type of irregularity is about 2·5 times the mean fibre length but it is not necessarily constant for a particular strand. In addition to a varying wavelength, the amplitude of the drafting wave is also variable. Spinning students in particular are recommended to read Foster's book *The Principles of Roller Drafting*, where an excellent account of the drafting wave mechanism is given in Chapter 4.

Not all spinning systems use drafting rollers. In condenser spinning, for example, the key machines are the cards. The roving produced by the cards is converted to yarn on the mule or ring frame without any doubling, and only a small draft is used. Thus, drafting waves do not arise but other variations peculiar to the system are found. For example, there is usually bobbin-to-bobbin variation due to uneven splitting of the card web by the tapes and the variation in web density across the card.

Mechanically defective machinery

Since machines even in good condition produce irregular yarns, it is reasonable to assume that defective machinery will increase the amount of irregularity. The implementation of an efficient maintenance system is essential if the level of irregularity is to be kept within bounds. Machines drift out of adjustment, bearings become worn, components get damaged, lubrication systems clog, and dirt works its way into the mechanism.

Many spinning machine mechanisms are based on rollers and their associated drives. Faulty rollers and gear wheels usually produce periodic variation, a fact which helps the technologist to track down the probable cause by analysis of the traces made on the evenness tester. The methods of analysis will be dealt with shortly.

External causes

A mill is not merely a building containing machinery and materials—men and women are necessary to 'keep the wheels turning'. To achieve a first-class product, a first-class team of managers, technicians, and operatives is essential. Schemes of maintenance and quality control which look good on paper will soon become second-rate if the men and women who operate them neglect their duties. Operatives, too, can spoil yarn by poor piecings, careless oiling and cleaning, and general slack work; sound training can help a great deal in the spinning of good yarns.

In modern mills it is usual to have control over the atmospheric conditions of the various sections of the spinning plant. Optimum temperature and relative humidity limits can be established both for the process and the operatives. Also, good lighting and an accent on cleanliness encourage good work.

THE INTERPRETATION OF THE RESULTS OF IRREGULARITY TESTS

One or two methods of extracting information from the irregularity charts and meters of testing instruments have already been mentioned in the descriptions of these machines. For example, with the W.I.R.A. mechanical compression-type machine, the use of probability paper and the special computer has been dealt with. Again, in the case of the Fielden–Walker tester the methods of handling the meter readings have been covered. In the notes which follow we shall consider the interpretation of test results in more detail and see how the information obtained may be used to improve yarn quality and to locate sources of trouble.

The examination of charts

The judgement of blackboard wrappings is a well established method of assessing yarn quality. A parallel technique may be employed where irregularity charts are concerned. Essentially, the observer must be competent enough to examine an irregularity

chart by eye and decide whether it represents a good, an average, or an inferior material. A mill laboratory may build up its own 'library' of typical charts and these may be used to help in the assessment of the routine test charts; but even so, a fair amount of experience is demanded. The nature of the judgement is subjective and as such precludes a precise description of the irregularity. An estimate of the coefficient of variation may be attempted but its accuracy will probably be suspect.

A convenient chart contraction has been found to be 10:1, i.e. 1 in. of chart represents 10 in. of material, and a 2 ft length of chart from each package examined. Longer lengths of chart and higher ratios may be used if long term variations are thought to be present. Examination for periodical variation will be dealt with shortly.

An important point to bear in mind when charts are being compared is the fact that the testing instrument settings can alter the chart appearance. For example, if the magnification factors used in two tests on similar materials differ, then the size of the swings above and below the mean will differ. One yarn will apparently be more irregular than the other, whereas in fact they are both of equal irregularity. Care must be taken to ensure that fair comparisons are being made and testing machine settings checked.

Incidentally, it is worth remembering that the packages tested are samples which represent bulk production, and that the assessment of the irregularity of the sample is an assessment of the irregularity of the bulk. By chance, of course, a package from a single faulty spindle may be included in a sample of packages and the cause of the fault require investigation. However, in general, routine testing of irregularity is a check on the quality of the bulk production.

Percentage mean deviation and coefficient of variation

By chart measurement or by electronic integrators, a single-figure expression is obtained which describes the irregularity of the tested material numerically. Two expressions are used, the percentage mean deviation (P.M.D.) and the coefficient of variation (C.V.). Provided the variations in the material are random, these two values are simply related:

$$\text{C.V.} = \text{P.M.D.} \times 1{\cdot}25$$

Different testing instruments may give slightly different values even though the same material is tested. This is due to differences in mechanical and electronic design but since, in general, a mill laboratory will make the routine tests on one instrument, this point is not of major importance.

The test value may be compared with standard values. The latter may be based on past experience with the type of raw material being processed and the system of preparation and spinning used. The various research associations publish figures which can be used as guides. In addition, the manufacturers of the testing instruments publish Tables of standards and include them in the relevant manual. Extracts from such Tables have been given in Tables 9.1–9.4.

When variance–length curves were discussed it was pointed out that different coefficient of variation values are obtained when the test length is varied. If a length, l yd, is run through an evenness tester, the value determined will be the $C.V.(l)$, i.e. the C.V. *within* l yd. For most materials, however, the $C.V.(l)$ value for a test length of 10 yd or so will be quite close to the overall C.V., the $C.V.(T)$. Moreover, the latter is really only the theoretical concept of the variation within an infinite length of material. For practical purposes, therefore, the determination of the C.V. over about 10 yd will be sufficient when a mechanical tester is used. With electronic testers, better sampling is ensured by running the material through at the higher speeds, e.g. 50 ft/min on the Fielden–Walker and 8 yd or more per minute on the Uster. The meter readings are then taken over, say, 5 min.

Again referring to the variance–length curves, it was noted that two yarns could have the same overall variation figure but that the character of the irregularities present in each yarn could be quite different. One yarn could produce satisfactory fabric but the other may possess a periodic variation which would produce a fabric with an unsatisfactory appearance. Hence, a single-figure expression is not a completely satisfactory method of reporting irregularity, especially when the figure is given to the man in charge of the processing machinery, because it does not give him any indication where to find the source of excessive variation. In most cases, the greater part of the total coefficient of variation figure is due to the short term variation and a relatively small part to the medium and long term variations, which are usually the variations which give rise to objectionable fabric appearance.

Suppose a yarn is being used as weft and when free from periodic variation has a coefficient of variation of 16 per cent. Imagine that some mechanical defect in the spinning process introduces a periodic variation with an amplitude of 6 per cent. (Amplitude is the maximum deviation from the mean level expressed as a percentage of the mean level.) For a given amplitude we can calculate the corresponding coefficient of variation using the assumption that the wave

form of the variation is of a simple shape, as in Figure 9.2. Thus,

$$\text{C.V.} = \text{Amplitude} \div \sqrt{2} \text{ (per cent)}$$

Hence, the corresponding coefficient of variation to a variation with an amplitude of 6 per cent is $6/\sqrt{2}$ per cent.

We can now calculate the coefficient of variation of the faulty yarn by combining the two coefficients of variation, 16 per cent and $6/\sqrt{2}$ per cent. To do this we square both values, i.e. we obtain the two variances, add them, and then take the square root of their sum:

$$\text{Variance of faulty yarn} = 16^2 + \left(\frac{6}{\sqrt{2}}\right)^2$$
$$= 256 + 18$$
$$= 274$$

Therefore,

$$\text{C.V. of faulty yarn} = \sqrt{274}$$
$$= 16{\cdot}6 \text{ per cent}$$

The difference between 16 per cent and 16·6 per cent is not particularly striking and is no greater than the inter-package differences of even yarns. From a set of results the faulty yarn would probably be overlooked and no action taken. This calculation illustrates one weakness of reporting single-figure values of irregularity and it also shows the advisability of producing a chart as a routine procedure when testing for irregularity. Examination of the charts together with a perusal of the P.M.D. or C.V. percentages offers a much better chance of detecting faulty material.

THE DETERMINATION OF PERIODIC VARIATION

Several methods of detecting periodic variation are available, including:

(1) Blackboard wrapping on a tapered board—useful for wavelengths shorter than 12 in. but only applicable to yarns.
(2) Correlogram techniques—research methods described in several papers (Cox, D. R., and Townsend, P. P. *J. Text. Inst.* P145 (1951); Onions, W. J., and Selwood, A. (*J. Text. Inst.* T127 (1956); T603 (1956)).
(3) Yarn period analyser (Catling, H. *J. Text. Inst.* T232 (1958)).
(4) Examination and measurement of the chart.
(5) The use of the irregularity spectrum.

Methods (4) and (5) will be considered here.

Examination and measurement of the chart

The irregularity chart of a material which is free from periodic variation follows a course which swings at random from side to side above and below the mean level. When a strong periodic variation is present, the chart assumes a pattern which can be detected by the eye. Weaker periodic variations tend to be masked by the general random variation and so become difficult to pick out; they may in fact be missed altogether. Figure 9.23 is the irregularity chart of a Terylene yarn spun from 1½ denier fibre with a 1½ in. staple length. The traverse speed of the yarn through the measuring electrode was 5 ft/min and the chart speed 6 in./min. Hence, the chart contraction is 10:1, therefore 1 in. of chart represents 10 in. of yarn. Fairly well defined peaks will be seen on the chart and these have been marked by short vertical lines. Eleven waves extend over a chart distance of 3·45 in. and so the average distance from peak to peak is approximately 0·31 in. With a chart contraction of 10:1 the wavelength of the variation in the yarn will therefore be about 3·1 in.

A feature of spun yarns is a drafting wave with a wavelength of two to three times the staple length of the fibre; with staple rayons the effect is greater than with cotton fibres whose individual fibre lengths vary so much. Since this particular yarn has been spun from 1½ in. staple it is quite probable that the periodic variation with a wavelength of 3·1 in. is in fact the drafting wave. Note also that the distance from one peak to another is not exactly equal, another characteristic of the drafting wave.

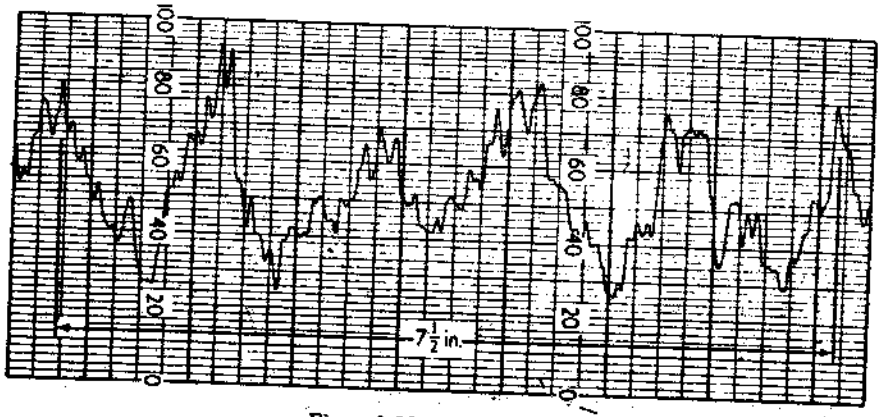


Figure 9.38. 32s spun yarn
1 in. chart = 10 in. yarn
Wavelength on chart = 7½ in. ÷ 5 = 1½ in.
Wavelength in yarn = 1½ × 10 = 15 in.

The variation just described has a short wavelength. Figures 9.38 and 9.39 show examples of a periodic variation with a longer wavelength. Five waves occupy 7·5 in. of chart; with a chart contraction of 10:1 the wavelength will be 7·5/5 × 10, i.e. 15 in.

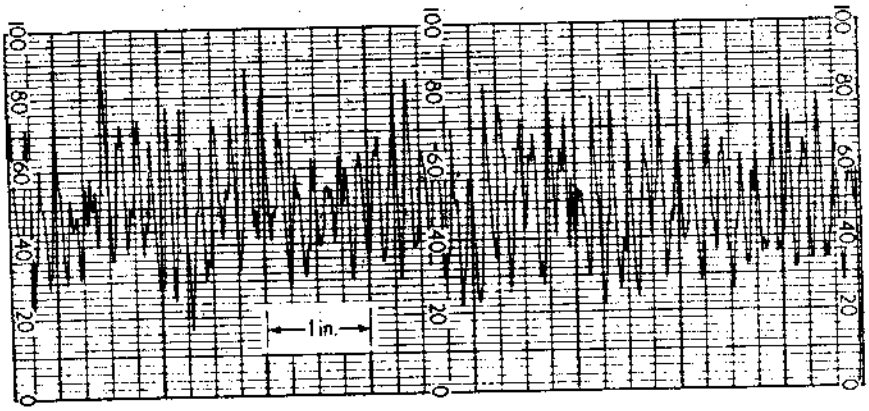


Figure 9.39. Same yarn as in Figure 9.38

1 in. chart = 100 in. yarn

Both the examples above show very definite periodic faults. When the variation is not so self-evident, especially when the wavelength is fairly long, help can be obtained on electronic testing instruments by the use of special controls. On the Fielden–Walker this control is the 'Damping Switch' and on the Uster the selector is switched to 'Inert'. The effect of these controls is to bring into action special circuits which filter out the shorter wavelength variations which tend to swamp other types; the pen recorder traces out a chart which follows the course of the variations with the longer wavelengths. (The effect of the damping is shown in Figure 9.24.) The damped chart may then be examined and measured as before.

When operated with the filter circuits in action, the meter readings on the integrators indicate the P.M.D. or C.V. of the long wave irregularities.

The use of the irregularity spectrum

An irregularity spectrum is a curve obtained by plotting the amplitude of irregularity against wavelength. Figure 9.40(a) shows the type of graph paper used for this purpose. The vertical scale is linear and the ordinates represent the amplitude of the irregularity; curved lines are used to accommodate the sweep of the recording

pen used with the Uster equipment. The horizontal scale is logarithmic, covering a range of wavelengths from $\frac{1}{2}$ in. to 20 yd.

Suppose a yarn contained only periodic variation, i.e. no random variation, and that three periodic faults were present with wavelengths of, say, 3 in., 8 in., and $1\frac{1}{2}$ yd, respectively. By constructing ordinates whose heights were proportional to the amplitudes, the irregularity spectrum of this hypothetical yarn would appear something like the one shown in Figure 9.40(b). From this spectrum we would gather that the periodic variation with a wavelength of

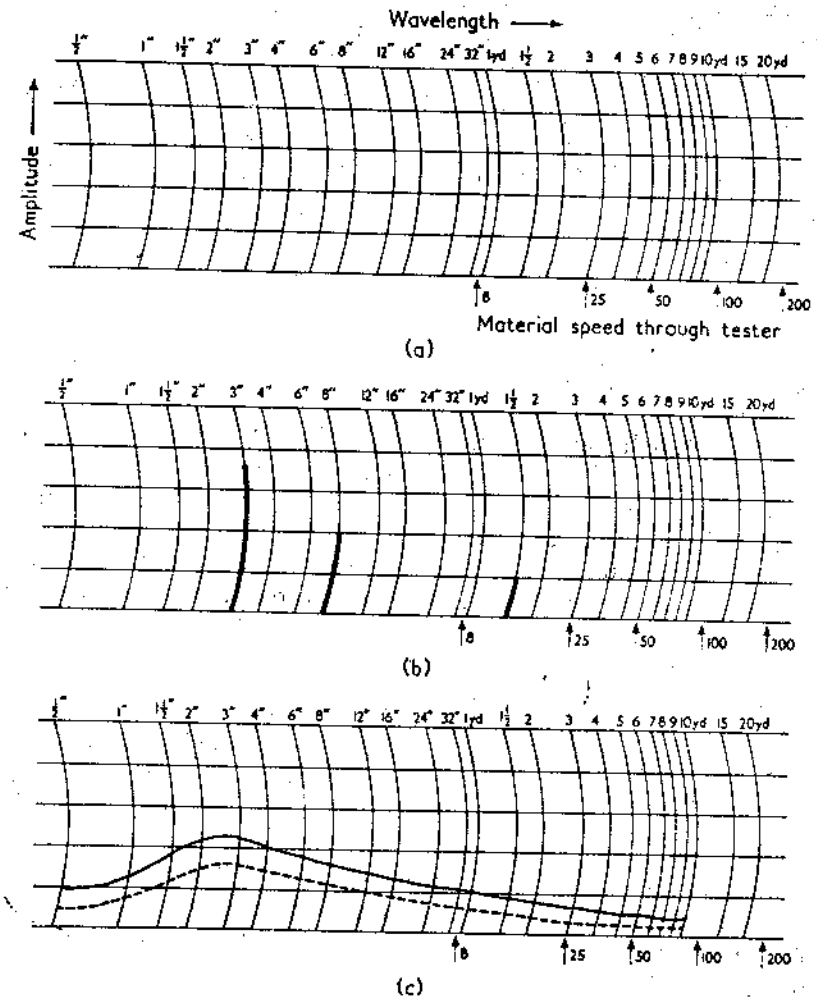


Figure 9.40

3 in. had the greatest amplitude. In practice, a strand of textile material such as roving or yarn has a whole series of irregularities with different wavelengths, and if they were all plotted a continuous curve would be produced—the irregularity spectrum. For a very even cotton yarn such a curve would be as shown in Figure 9.40(c), with a hump around 3 in. or so and falling as the wavelength increases. The dotted line indicates the curve for an ideal yarn, one in which the irregularity is that due only to the random distribution

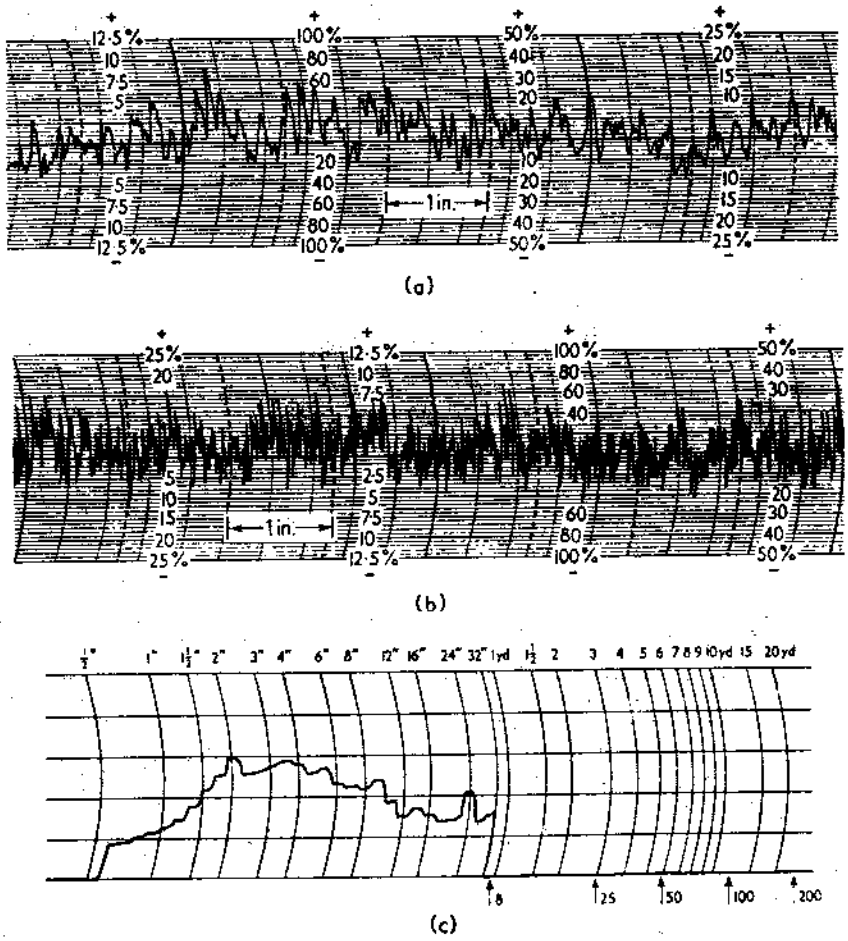


Figure 9.41. Irregularity charts and spectrogram of a reasonably even 70s cotton yarn

(*a*) 70s cotton yarn, ring spun
1 in. chart = 18 in. yarn
C.V. = 19 per cent
(*b*) 1 in. chart = 72 in. yarn
(*c*) Spectrogram of yarn in (*b*)

of the fibres (refer to Martindale's formula on page 462).

The Uster Spectrograph is an electromechanical unit which is operated in conjunction with the associated Uster evenness tester; its function is to produce an irregularity spectrum of material tested in the evenness tester. During a test, signals from the evenness tester are fed into the spectrograph and are analysed by a special circuit. The data are stored until, after 5 or 10 min testing, a button is pressed and the pen recorder produces the irregularity spectrum or

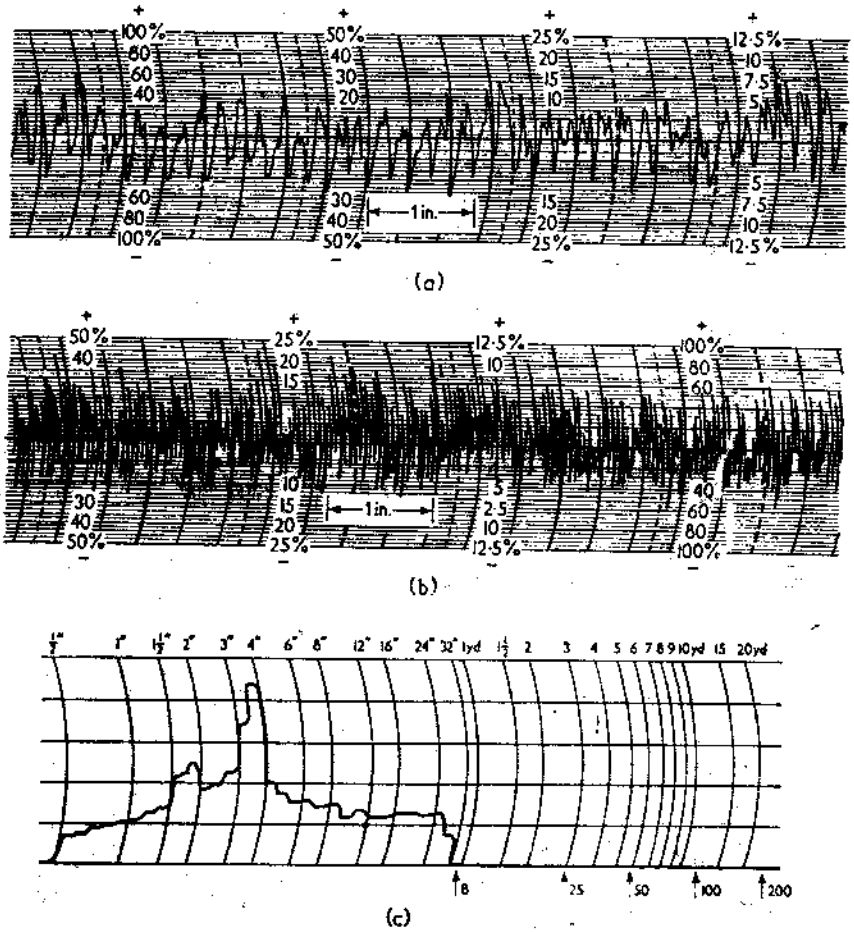


Figure 9.42. (*a*) *70s cotton yarn, ring spun*
(*b*) *Same yarn as* (*a*) *but with a different chart contraction*
(*c*) *Spectrogram of yarn in* (*b*)
1 in. chart = 18 in. yarn
C.V. = 25 per cent
1 in. chart = 72 in. yarn

'spectrogram'. Figure 9.41 (c) shows the spectrogram of a reasonably even yarn. The stepped outline of the curve will be noted. This arises because the wavelength range is split up into thirty narrow bands or channels, each approximately 15 per cent wide, i.e. the next channel to the right has a wavelength 15 per cent longer. At a testing speed of 8 yd/min the wavelength range covered is from $\frac{1}{2}$ in. to 32 in.; with a material speed of 100 yd/min the range covered by the resulting spectrogram is from 7 in. to 400 in. Hence, to get complete coverage two spectrograms should be made.

The spectrogram of the even yarn, Figure 9.41(c), shows a hump around 3·5 in. This corresponds to the drafting wave present; since we learnt earlier that the wavelength of a drafting wave is not constant, it is not surprising to find that the drafting wave effect is spread over several channels. However, when a periodic variation is present and it has a constant wavelength, a well defined peak is produced in the spectrogram in one or perhaps two channels and the corresponding wavelength is readily observed. Figure 9.42 illustrates this point.

If more than one periodic fault is present the spectrogram will exhibit a peak for each one. In this way the problem of picking out a number of faults from an irregularity chart alone is solved. Inspection of the spectrogram enables the observer to note the presence, wavelength, and amplitude of periodic variations immediately without the need to analyse charts which are often confusing. For the purposes of explanation, illustrations have been restricted to cotton yarns, but spectrograms of all types of strands of material, sliver, roving, etc., can be made and for all types of natural and synthetic fibres. The critical assessment of spectrograms is really a study in itself, and for a fuller account of some of the methods of analysis the references must be consulted. The main point to note here is that we have a powerful tool with which the textile technologist can detect periodic faults and, armed with information about their wavelength and character, locate their source.

The Uster spectrogram can also be used in conjunction with the Courtronic yarn irregularity tester Type 2, an instrument developed by the Engineering Development Department of Courtaulds. The instrument is based on the capacitance principle and is of special interest to users of filament yarns. A new model, Type 3, is to be introduced, built from solid-state modular units. Type 2 deals with a denier range from 10 to 200, whereas the Type 3, by the use of extra plug-in measuring heads, will extend the range from 10 to 6,000 denier.

THE LOCATION OF THE SOURCES OF PERIODIC FAULTS

Periodic variations may be ascribed to two main causes, firstly to imperfect fibre control leading to drafting waves, and secondly to mechanical defects in the processing machinery. The major clue in the detection of the source of the trouble is the wavelength of the variation. This does not mean that the trouble spot is immediately recognised because, in addition to this information, the technologist must also be in possession of such details as raw material characteristics, machine settings, gearing plans, roller dimensions, drafts at each process, and so on. He must also be conversant with the practical aspects of fibre processing and be aware of such points as roller vibration, eccentricity, roller slip, the effects of worn bearings, broken gears, and the many other potential trouble makers.

Considerations of space do not permit a comprehensive survey of the many sources of variation, but a few examples will illustrate how the underlying principles of trouble shooting are applied.

Example 1. The spectrogram of a cotton yarn shows a hump spreading over several channels with the maximum amplitude corresponding to a wavelength of approximately 48 in. This is in addition to the usual drafting wave around 3 in. The draft at the spinning frame is 20.

The spread of the hump over a few channels suggests that a drafting wave is present and the wavelength of 48 in. indicates that its origin is probably in the machine which supplies the frame with roving. Dividing the wavelength of the variation by the draft at the spinning frame, we get

$$\frac{\text{Wavelength of variation}}{\text{Draft at the spinning frame}} = \frac{48}{20} = 2{\cdot}4 \text{ in.}$$

This value of 2·4 in. corresponds to the wavelength of a drafting wave introduced by the roving frame. A confirmation check on the roving bobbins could be made if considered necessary.

Example 2. (From a publication by Fielden Electronics Ltd.). A ring yarn of 21s cotton count produced an irregularity chart which exhibited a pronounced periodic variation with a wavelength of 1,200 in. Clearly the source of the fault is at some process farther back in the production line than the ring frame. The yarn was spun from 1·25 hank slubbing and a check on this material revealed a periodic variation with a wavelength of 72 in. We again conclude that the fault must lie farther back in the line and transfer our attention to the drawframe.

The drawframe sliver was 0·2 hank and hence the draft at the slubber was 1·25/0·2, 6·25. An estimate of the wavelength of the fault in the sliver is obtained by dividing the wavelength of the slubbing fault by the slubber draft:

$$\frac{72}{6{\cdot}25} = 11{\cdot}5 \text{ in.}$$

An irregularity chart of the drawframe sliver shows a periodic variation with a wavelength of 11·25 in., confirming the estimate. (Note: the arithmetic in this type of calculation is often only approximate since the measurement of charts is not always a precise operation.)

A useful formula relates wavelength, draft, and the diameter of the roller producing the fault:

$$\text{Wavelength of fault} = D \times \pi \times \text{Draft between the faulty roller and the front roller}$$

where D is the diameter of the faulty roller.

Inspection of the drawframe showed that the second roller was the source of the trouble. The roller diameter was $1\frac{1}{8}$ in. and the draft between the second and front rollers of the drawframe was 3·18. Substituting in the formula

$$D = \frac{\text{Wavelength}}{\pi \times 3{\cdot}18} = \frac{11{\cdot}25}{\pi \times 3{\cdot}18} = 1{\cdot}125 \text{ in.}$$

The value of 1·125 in. confirmed the conclusion that the second roller was defective.

Example 3. An alternative method of locating a faulty roller is based upon the formula

$$\text{Wavelength of variation} = \text{Delivery speed of the front roller in inches per minute} \div \text{rev/min of the faulty roller}$$

Hence, if we know the wavelength of the periodic fault and the delivery speed, we can deduce that the cause of the fault is a roller or machine part which rotates at the calculated rev/min. The faulty roller or machine part may then be located either by direct measurement of speeds with a tachometer or by studying the gearing plan of the machine and calculating the rev/min of the various parts. The tachometer is preferable, both because it is quick and because gearing plans are often out of date, the wheels on the machine being different to those shown on the diagram supplied with the machine.

In Example 2 the wavelength of the fault was 11·25 in. Suppose the delivery speed is measured and found to be 30 yd/min. Applying the formula

$$11{\cdot}25 \text{ in.} = \frac{30 \times 36}{\text{rev/min}}$$

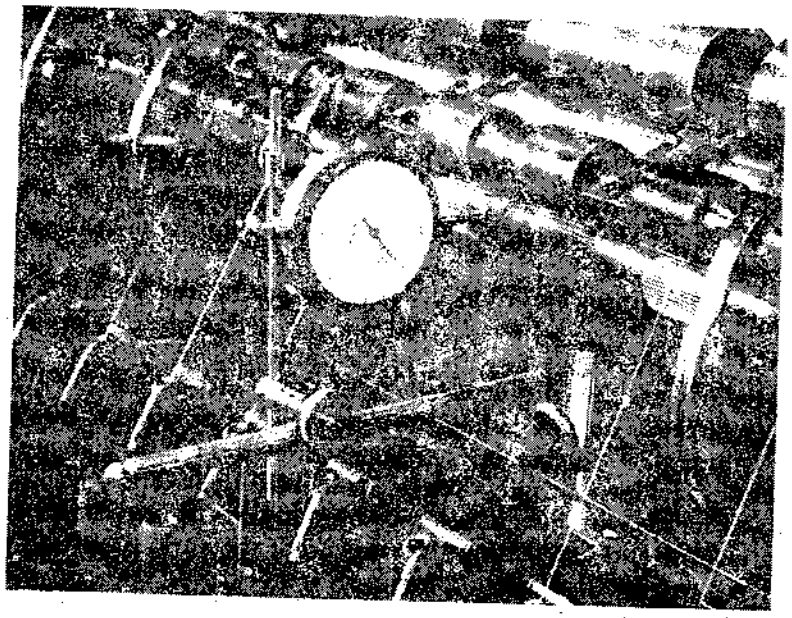
Hence,

$$\text{rev/min} = \frac{30 \times 36}{11{\cdot}25} = 96$$

The next step is to locate a roller whose revolutions per minute are 96. In this example it would be the second roller.

OTHER EQUIPMENT USED IN FAULT LOCATION

The use of a tachometer has already been mentioned. Other useful items are roller eccentricity testers. The 'Shirley' models are shown in Figures 9.43 and 9.44, separate devices being used for top and and bottom rollers. Note the special magnetic base on which the bottom roller tester is mounted.

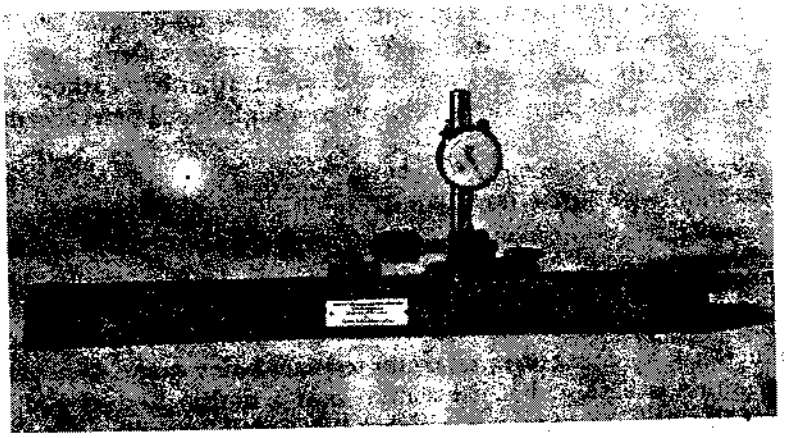


(By courtesy of B.C.I.R.A.)

Figure 9.43. The 'Shirley' bottom roller eccentricity tester

The British Cotton Industry Research Association has developed a simple instrument with which to detect roller vibration, a mechanical fault which is liable to occur where the roller has a low speed and is relatively 'whippy'. In *Principles of Roller Drafting* (published by the Textile Institute) Foster discusses roller vibration in detail and describes the use of the Shirley Roller Vibration Detector as follows:

> The instrument consists of a metal case containing eight reeds, each tuned to a different frequency. A rubber-tyred driving wheel, not visible in the Figure [Figure 9.45] protrudes from the bottom of the case. To test for roller vibration the instrument is held with the wheel in contact with the top or bottom roller (although the vibrations originate in the bottom roller, they are transmitted to the top roller). The driving wheel transmits the vibrations to the reeds, and if the roller is vibrating, the reed which is in tune with the vibration itself vibrates with a large amplitude; in the photograph the third reed from the left is doing so. The number of the strongly vibrating reed gives, from a Table supplied with the instrument, the frequency of the roller vibration.'
>
> Having thus observed the frequency, we can calculate the wavelength in the roving delivered by the front rollers. If the frequency is f vibrations per second, the time for one vibration is $1/f$ sec; if the front roller speed is v inches per second, the length of roving delivered during one vibration is v/f in. This is the wavelength; therefore,
>
> $$\text{Wavelength} = v/f$$
>
> If this wavelength is multiplied by the draft at the next frame, the result is the wavelength at that frame, and this can be checked against the wavelength observed in a regularity trace of the product of that frame.



(By courtesy of B.C.I.R.A.)

Figure 9.44. The 'Shirley' top roller eccentricity tester

(By courtesy of B.C.I.R.A.)

Figure 9.45. The 'Shirley' roller vibration detector

Another instrument used in the detection of roller vibration and its measurement has been designed by the British Rayon Research Association. In place of the usual tachometer a tacho-generator is used, i.e. the rotation of the shaft of the instrument generates an electric current proportional to its speed. Variations in speed produce variations in current. The output of the tacho-generator is fed to a circuit and a meter indicates the percentage roller vibration. The output of the tacho-generator could be fed either to a cathode ray oscilloscope or, for permanent records, to a high-speed pen recorder.

Irregularity testing programmes

In common with other testing instruments, irregularity testers and their associated equipment must be used methodically and systematically in order to obtain maximum benefit from their use. One cannot lay down a programme to suit all mills of course, but key machines should be checked daily, e.g. drawframes. Spinning frame products can be checked when count tests are being made. Whatever programme is designed it is essential that a faulty product can be identified with the machine which produced it; sample collection and testing must be carefully controlled. Where one package or

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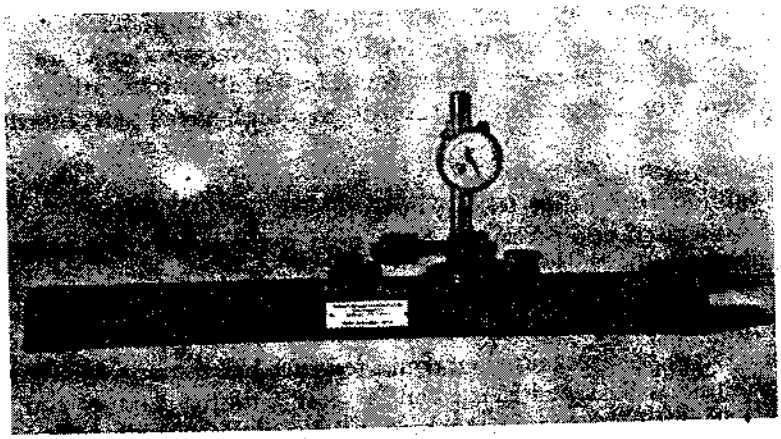
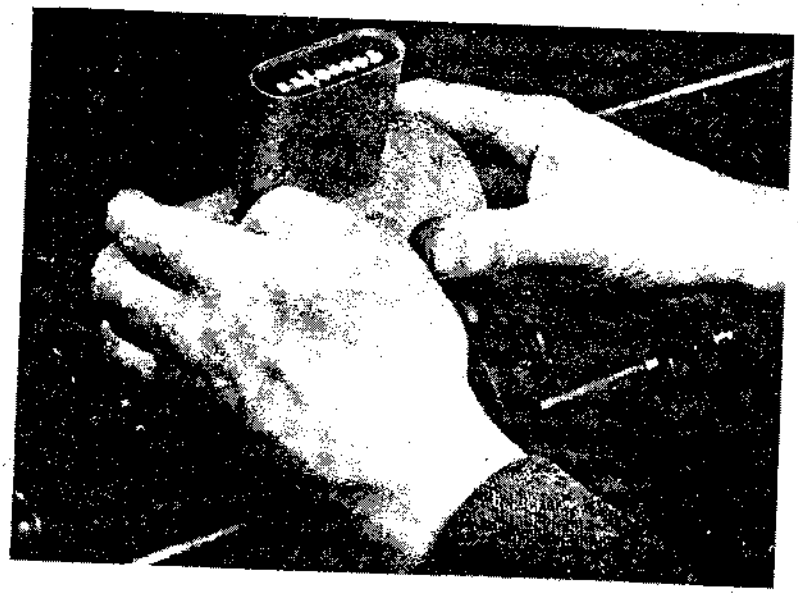


(By courtesy of B.C.I.R.A.)

Figure 9.44. The 'Shirley' top roller eccentricity tester



(By courtesy of B.C.I.R.A.)

Figure 9.45. The 'Shirley' roller vibration detector

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sliver represents a machine producing many similar packages it is necessary to check the other deliveries when a periodical fault is discovered; this confirms whether the fault is restricted to a particular delivery or spindle, or whether all the machine products are faulty.

In all systems a first-class method of communicating the findings of the testing room staff to the mechanics servicing the machinery is a 'must'. The laboratory offers a service to the production lines and the best results are achieved when the laboratory staff and the machinery supervisors form a friendly team.

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10

MISCELLANEOUS TESTING INSTRUMENTS

INTRODUCTION

MEMBERS of the staff of a mill testing laboratory are often called upon to help in technical investigations outside the normal testing routines. The objects of such investigations may be the assessment of a machine's performance, the behaviour of a new accessory, or the location of a source of trouble in the finished product. This aspect of testing in its wider sense often requires special instruments which cannot be readily classified. In the notes which follow the reader is given a brief description of several of the more useful instruments. Sources of information on other special devices will be found in the references.

TENSION METERS

Tension is applied to yarns in process for a variety of reasons. During the preparation of yarns for weaving and knitting it is usually necessary to transfer yarn from the spinner's primary package to a secondary package of a more suitable shape and size. For example, the yarn on a ring bobbin may be wound on to a cone and used as a supply package for a pirn winding unit or a knitting machine. The application of tension at this stage does two jobs: firstly, weak places in the yarn are detected and broken out; secondly, a stable cone is produced. In the later stages of yarn preparation, e.g. winding from cone to pirn, the stability of the wound package is of prime importance. It would be impracticable to attempt to weave a fabric without tension in the warp threads. Weft tension, too, plays an important part in the successful production of a well woven cloth.

It is not sufficient to think only in terms of applying tension but to consider the control of the tension applied. The control of tension is a problem which has confronted textile men for many years and has led to the invention of literally hundreds of warp let-off motions, yarn tensioning devices, etc. The introduction of more accurate tension meters has enabled the performance of such devices to be investigated, especially in cases where the tension fluctuates rapidly, as, for instance, in pirn winding.

The measurement of tension is made by tensometers or tension meters; these may vary in cost from a few pounds to several hundreds. The difference lies in the fact that some instruments are capable of recording accurately variations in tension which occur at high speeds, and to accomplish this the measuring head must be precision engineered and its output fed to electronic amplifiers which in turn feed high-speed pen recorders. The three-pulley system is commonly used and its basic principle is shown in Figure 10.1. P_1 and P_2 are freely running pulleys on fixed centres, whereas P_3 is capable of movement at right angles to a line joining the pivots of P_1 and P_2. With a tension T in the yarn the centre pulley assumes an equilibrium position where the resultant of two forces T acting at an angle θ is balanced by a restraining device linked to the pulley P_3. The resultant force R is given by $R = 2T\cos\frac{1}{2}\theta$.

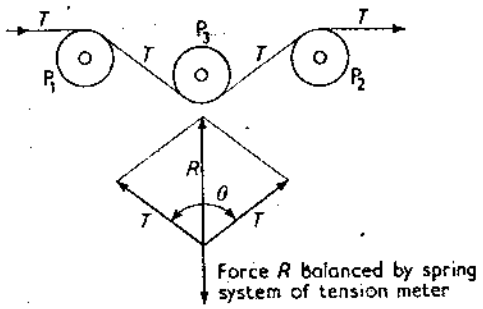


Figure 10.1. The three-pulley tension meter principle

The movement of the centre pulley is thus related to the size of the tension in the thread. In some simple tension meters the centre pulley moves against the pull of a spring, and a pointer connected to the centre pulley moves over a scale to give a direct indication of the tension. Such 'direct reading' tension meters have their uses where tension fluctuation is low. In order to give a well spaced dial the movement of the centre pulley is fairly large. When rapid fluctuations are present the inertia of the moving parts is too great to allow the meter to follow them. Further, the oscillations of the pointer make the reading of the meter difficult.

In the Zellweger 'Uster' thread-tension gauge the pointer is coupled to the centre pulley through a spiral spring, an arrangement which prevents the rapid thread-tension variations from being transmitted to the pointer. An air vane fixed to the pointer provides

some additional pneumatic damping and the net effect is that the pointer indicates the mean thread tension. The measurement of mean tensions is useful of course, but the cause of trouble is often sudden peak tensions. In order to measure these a Zellweger 'Uster' model is available whose pointer has a very quick response to increase in tension but a slow return. Hence, a succession of peak tensions keeps the pointer very close to the maximum readings.

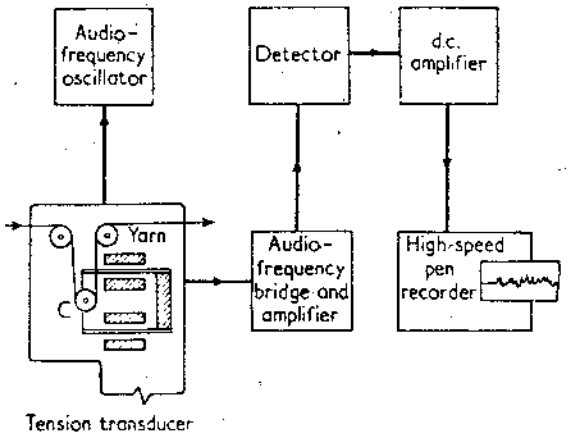


Figure 10.2. Schematic diagram of the B.R.R.A. tension transducer and associated equipment

For detailed practical investigation and for research, a recording tension meter is necessary. One such instrument has been developed by the British Rayon Research Association and described by Butler and Morris in Technological Reprint No. 6. The instrument, Figure 10.2, consists of the usual three-pulley system; the centre pulley C is mounted on a cantilever spring system. The small deflections of the centre pulley cause the flat springs to move between the plates of a capacitor system. In this way variation in tension differentially varies the capacity of the system. The movement is damped by completely enclosing it in oil. The 'transducer', as the measuring head is termed, converts yarn tension into electrical capacitance and can be used in conjunction with any suitable electronic unit capable of producing an electrical signal proportional to capacitance. The signal can subsequently be indicated or recorded by means of an oscilloscope or any other high-speed recording device.

Another type of electronic tension meter is described in *Rayon Review* (Dec., 1958). In this model the centre pulley is mounted on a

pair of flat springs to which strain gauges are bonded. Deflections of the cantilever springs result in changes in the resistance values of the strain gauges. Suitable electronic circuits convert the changes into pen movement on a high-speed pen recorder.

Some of the problems of tension meter design are discussed in greater detail in the references.

FRICTION AND FRICTION MEASUREMENT

In a preface to *Friction in Textiles* the authors state: 'To a large extent, interfibre friction determines the behaviour of drafting assemblies, the strength of yarns, the wear of guides in textile machinery, the tensions developed in fibre- and yarn-handling equipment, the possibility of felting and shrinkage, and even the feel or handle of the finished fabric.'

The importance of friction need not be stressed further. In the present chapter the measurement of the friction between running yarns and solid materials is briefly discussed because of its relevance to the previous notes on yarn tension.

In the study of mechanics, the reader will have no doubt made calculations in which the equation $T_2/T_1 = \exp(\mu\theta)$ is used. Power transmission by belt drive is often the subject of such calculations.

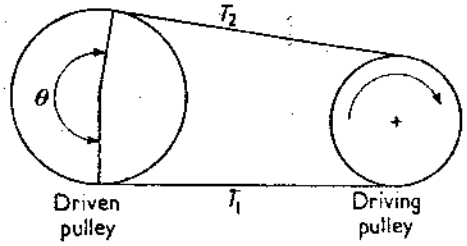


Figure 10.3. Basic coil friction principle applied to belt drive

$$\frac{\text{Tension in tight side}}{\text{Tension in slack side}} = \frac{T_2}{T_1} = \exp(\mu\theta)$$

In the equation, T_1 is the tension in the slack side, T_2 is the tension in the tight side, θ is the angle of contact or lap, and μ is the coefficient of friction between the pulley and the belt (see Figure 10.3). In many instances in textile processes, yarns pass at various speeds over surfaces of steel, chromium, ceramic, plastic, and so on. Under running conditions, the relatively simple relationship between the input and output tensions does not strictly apply because research has shown that the coefficient of friction is influenced by

such factors as the size of the input tension (T_1), the radius of the curved surface, the yarn speed, the temperature, and the atmospheric conditions. Nevertheless, the basic equation may be used to solve many problems even if some precision and accuracy is sacrificed.

A number of instruments designed to measure the coefficient of friction between yarns and solid surfaces are described in the literature on the subject, and an excellent survey is provided in *Friction and Textiles* (1959). Two meters developed by the British Cotton Industry Research Association are described in the B.S. Handbook, but for the sake of completeness the principles on which they are based will be considered here; the actual testing procedures can be obtained by consulting the B.S. Handbook.

Kinetic friction of yarn against steel

In the original instrument, designed by Morrow, the pulley system was mounted vertically, but the modern version is used in a horizontal position (see Figure 10.4). The yarn is led round a loose pulley B after passing through a tensioning drag, round the eccentrically mounted steel ring C, round the loose pulley D, through a guide eye, and on to a take-up drum which can wind the yarn on at 60 yd/min. Under running conditions the steel ring C is displaced through an angle α whose value will depend upon the coefficient of friction μ. The geometry of the system is such that the angle of lap is virtually 180 degrees, π radians. Let the system be in equilibrium with the yarn running through the instrument. Then,

$$\frac{T_2}{T_1} = \exp(\mu\pi)$$

Taking moments about P,

$$T_1 \times (r + \mathrm{OS}) = T_2 \times (r - \mathrm{OS})$$

Since $\mathrm{OS} = \mathrm{OP} \sin \alpha$,

$$T_1 \times (r + \mathrm{OP} \sin \alpha) = T_2 \times (r - \mathrm{OP} \sin \alpha)$$

Therefore,

$$\frac{T_2}{T_1} = \frac{r + \mathrm{OP} \sin \alpha}{r - \mathrm{OP} \sin \alpha}$$

Dividing by r,

$$\frac{T_2}{T_1} = \frac{1 + \mathrm{OP}/r \sin \alpha}{1 - \mathrm{OP}/r \sin \alpha}$$

For a given instrument, OP and r are constants and therefore OP/r will be constant. Let OP/r be N.

Hence,

$$\frac{T_2}{T_1} = \frac{1 + N \sin \alpha}{1 - N \sin \alpha}$$

Therefore,

$$\exp(\mu\pi) = \frac{1 + N \sin \alpha}{1 - N \sin \alpha}$$

Thus, the coefficient of friction μ can be calculated by reading the value of the angle α. In the actual instrument, calculation is eliminated by causing the angular deflection to be recorded by a pen on a circular chart on which a closed circle is traced. The radius of this circle is directly related to the angle of deflection and thus to the value of μ. A transparent calibration scale, on which circles corresponding to various values of μ are marked, is placed over the chart and the value of the coefficient of friction between the yarn and the stainless steel surface is read off directly.

Before a test is carried out, clean and scoured cotton yarn is run through in order to remove any traces of grease from the apparatus because this would affect the results obtained.

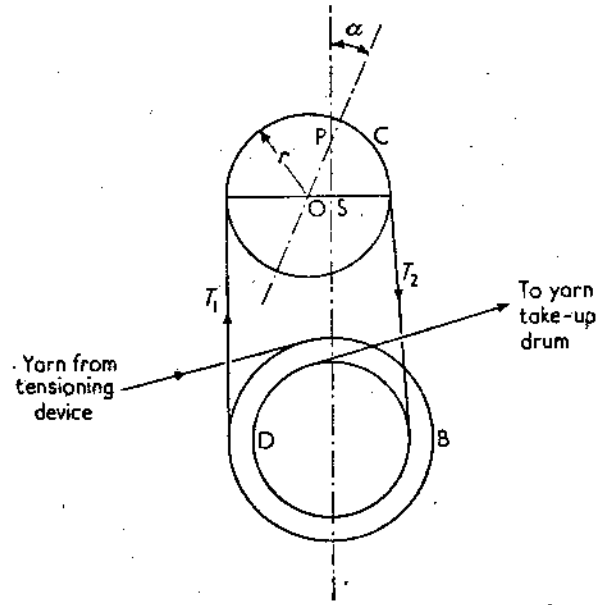


Figure 10.4. Kinetic yarn friction meter (Morrow)

Kinetic friction of yarn against any solid material

The instrument just described does not enable the operator to substitute a range of solid materials for the steel surface. Buckle and Pollitt designed a direct-reading instrument in which the test conditions of friction surface, tension, and speed can be readily varied (Figure 10.5). After passing through a tensioning device, the yarn is led round the lower of two small pulleys at B, round the freely running pulley C_1, round the friction surface at F, round pulley C_2, round the upper small pulley at B, and from there to a winding drum. The pulleys C_1 and C_2 are mounted on unequal arms at an angle, the lever system being pivoted so that under running conditions it will assume some position giving an angle ϕ between the arm of the lever and the line through the centre of the friction cylinder F and the lever system pivot.

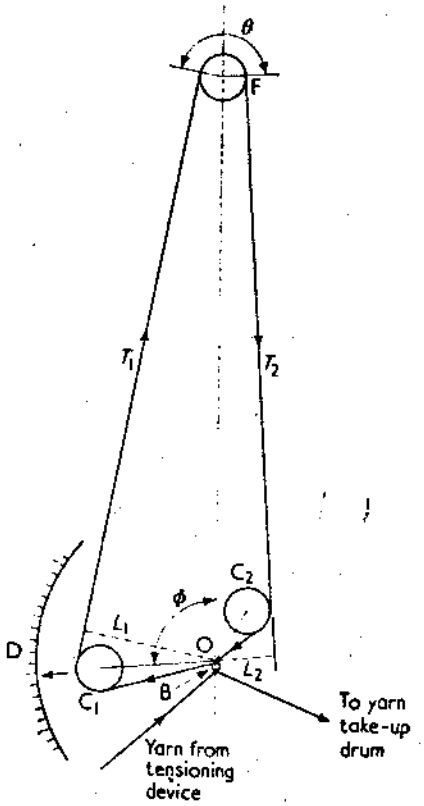


Figure 10.5. Kinetic yarn friction meter (Buckle and Pollitt)

Let θ be the angle of lap.

Then,
$$\frac{T_2}{T_1} = \exp(\mu\theta)$$

Taking moments about the pivot,
$$T_1 \times L_1 = T_2 \times L_2$$

Hence,
$$\frac{T_2}{T_1} = \frac{L_1}{L_2} = \exp(\mu\theta)$$

From the geometry of the instrument it will be seen that L_1/L_2 is dependent on the angle ϕ. In mathematical terms we say that ϕ is a function of μ,
$$\phi = f(\mu)$$

In practice, it is not necessary to measure the angle ϕ and then calculate μ from a formula. Instead, a pointer is attached to the longer arm of the lever and the value of μ is read off directly from a calibrated scale D. The dimensions of the friction cylinder may vary, e.g. the value of μ for rods of various materials and of different diameters may be required. The instrument is calibrated for a cylinder of 1 in. diameter, but a Table of corrections is supplied with the instrument to cover objects of very small radius to those with a 2 in diameter.

Since the coefficient of friction is sensitive to the input tension and to the speed of testing, it is necessary to report these values when quoting the results. Here again, the instrument should be thoroughly cleaned by running through some scoured yarn prior to testing.

THE STROBOSCOPE

A stroboscope is a device by which a rotating, vibrating, or reciprocating body is made either to appear stationary or to move very slowly. Such a device is obviously useful when rapidly moving machine parts and mechanisms must be observed under running conditions. In addition to observation of the moving part, it is also possible to measure the frequency of the movement, e.g. the revolutions per minute of a spindle or the traverses per minute of, say, a pirn winder. Mechanical stroboscopes have been used but modern instruments are usually based on the flashing-lamp principle and the notes which follow are concerned with these modern stroboscopes.

Suppose a disk marked with an arrow as in Figure 10.6 is rotated at high speed. The phenomenon known as persistence of vision, by which an image is retained for approximately $\frac{1}{10}$ sec, would cause the observer to see a blur instead of a clear picture of the arrow. If, however, the disk is illuminated by an intense light which is of very short duration and which occurs when the arrow is in one particular position, then the eye retains this picture and the disk is 'frozen', i.e. it appears to be stationary. This frozen picture would also occur if the flashes of light happened only every third or fourth revolution of the disk; in other words, if the number of revolutions of the disk per minute was a whole number multiple of the frequency of the flash.

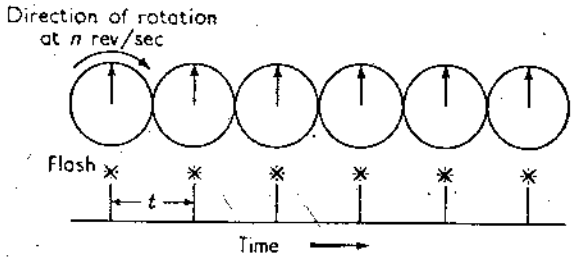


Figure 10.6. The stroboscope principle. An intense illumination of the rotating disk at intervals of t *sec, where* t = 1/n *sec, causes the arrow on the disk to appear stationary. The duration of the flash must be very short in order to obtain a clear picture*

When the rate of flashing and the rate of rotation do not coincide an interesting thing results—the moving part appears to rotate slowly either backwards or forwards. The reason for this will be understood by studying Figure 10.7.

Ordinary filament lamps cannot be used because they take time both to heat up and cool off. Instead, gas discharge lamps are used, and these are triggered off electronically by a circuit which controls the flashing rate. The duration of the flash is measured in microseconds and may be of the order 10 to 40 microseconds with a flashing rate up to 15,000 flashes per minute. The control knob of the triggering unit can therefore move over a scale calibrated in cycles or frequency per minute. For instance, if the lamp is directed on to a rotating wheel and 'frozen', the revolutions per minute will be indicated directly on the scale. It could happen, of course, that the shaft was actually rotating twice or three times as fast as the scale indicated but, in general, the observer would know roughly the expected value and mentally correct the indicated value.

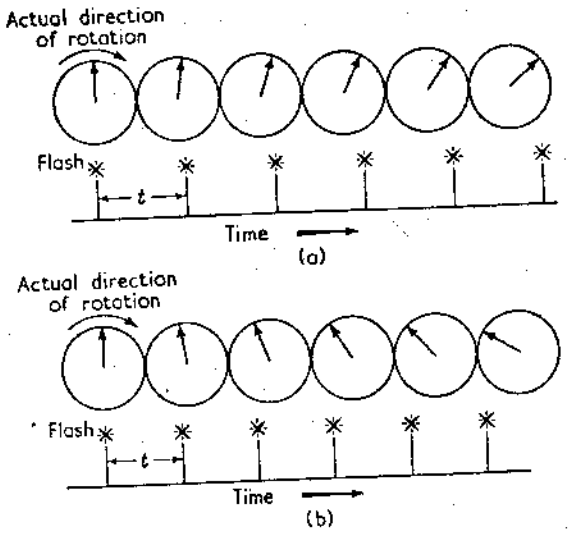


Figure 10.7. The results of using flashing rates which differ slightly from the operating cycle rates: (a) Disk rotates at n *rev/sec in a clockwise direction. 1 rev = 1/*n *sec. Time interval between flashes =* t *sec and is slightly greater than 1/*n*. Result—Disk appears to rotate slowly in a clockwise direction; (b) Disk rotates at* n *rev/sec in a clockwise direction. Time interval between flashes,* t *sec, is slightly less than 1/*n *sec. Result—Disk appears to rotate slowly in an anti-clockwise direction*

It is often very useful to trigger off the flashing lamp from the machine observed. In loom study, for example, the Dawes 'Stroboloom' can be triggered from the crankshaft and the timing adjusted so that the flash occurs at any selected point in the weaving cycle. In this way the flash rate is accurately locked to the event being observed, e.g. the checking of the shuttle in the shuttle box.

The measurement of yarn speeds is often useful in textile mills in order to check machine performance from efficiency and production points of view. An excellent example of the use of the stroboscope principle is seen in the Briggs–B.R.R.A. 'Speedotex'. This instrument is in two parts, the lamp unit and the control unit. The lamp unit is conveniently small and of light weight so that it can be held in the hand without causing fatigue. The Neostron valve which produces the flashing light is housed in a rectangular box (Figure 10.8). The yarn is led over the pulleys A and B; it is not necessary to break the yarn in order to do this. Pulley A has a slot near its rim and the light from the Neostron can be seen flashing through this hole at a frequency controlled by a knob on the control unit. With

the yarn running through the instrument the frequency of the flash is adjusted until the hole in pulley A appears to be stopped. This will occur when the number of revolutions per second of the pulley is equal to the flashes per second of the Neostron. (It will also appear stationary if the pulley speed is a multiple of the flashing speed.)

Suppose the flashing rate is n per second and that the radius of pulley A is r in. In order to rotate pulley A at n rev/sec the yarn speed, v, in yards per minute, assuming no slip between the yarn and the pulley, will be given by

$$v = \frac{2\pi rn \times 60}{36} \text{ yd/min}$$

For example, let n be 70 flashes per second and r be 0·5 in. Then the yarn speed will be

$$v = \frac{2 \times 22 \times 0{\cdot}5 \times 70 \times 60}{7 \times 36} = 367 \text{ yd/min}$$

This speed will be read directly on a scale beneath the pointer-type control knob.

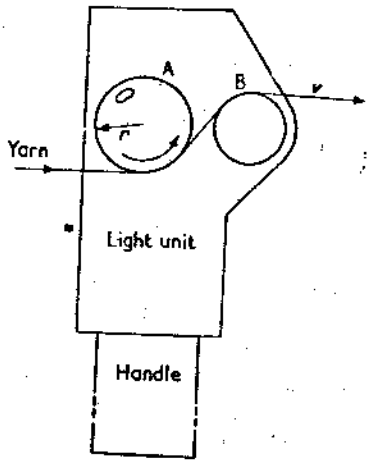


Figure 10.8. The Briggs–B.R.R.A. 'Speedotex' yarn speed indicator

Where the yarn speed is constant a clear image of the hole will be seen, but in many instances the yarn speed varies, e.g. in pirn winding and in cone winding. Instead of a hole a well defined arc of light is observed. Nevertheless, the mean yarn speed is then obtained.

At this point it is of interest to note that the winding rate of a yarn being put on to a package is not merely related to the surface speed of the package but also to the traverse speed. In Figure 10.9 the net winding rate can be considered as the resultant of two velocities at right angles to each other. Thus, the net winding rate V_n is the resultant of the surface velocity V_s and the traverse velocity V_t. The angle θ is therefore the coil angle. On a parallel-sided package the surface velocity will remain constant, but where the wound package has a conical profile, e.g. cones and pirn chases, the surface velocity changes from base to nose. We see in Figure 10.10, therefore, that the net winding rates V_{na} and V_{nb} differ and also the coil angles θ_a and θ_b.

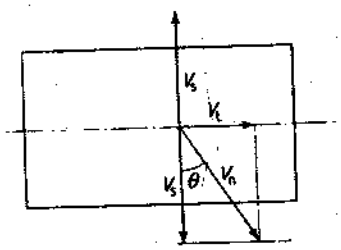


Figure 10.9. The net winding rate on a parallel-sided package

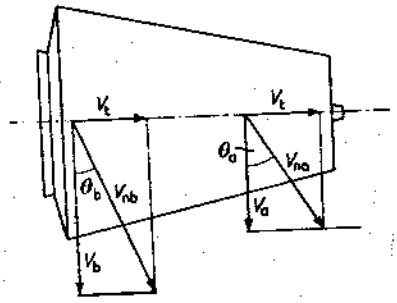


Figure 10.10. The effect on the net winding rate of a conical package

The 'Speedotex' may be used as a straightforward stroboscope as well as a yarn speed indicator. On the opposite side of the lamp unit an aperture allows the flash to be directed on to moving parts. A lens of about 1 in. focal length is mounted in this aperture to produce a focused beam. The compact dimensions of the lamp unit enable it to be brought close up to the machine part to be observed. Like other stroboscopes based on the flashing lamp principle, the 'Speedotex' can measure speeds without needing a mechanical connection to the machine, therefore eliminating errors caused by the added load of a mechanical device of the tachometer type. Further, the need for a convenient connection point or shaft is absent.

THE TACHOMETER

A tachometer is an instrument designed to measure speeds of various types, e.g. rotational speeds of rollers and gears, linear speeds of running yarns and fabrics, and surface speeds of rollers, etc. Hand tachometers of a mechanical design may be based on centrifugal principles. The displacement of flyweights on the rotated shaft against the resistance of a spring is approximately proportional to the square of the speed. To give steady readings the pointer movement is damped; a high-quality instrument usually incorporates protection against sudden accelerations and speeds beyond its range. Range switches enable one instrument to operate over various speed ranges, e.g. 0–500, 0–5,000, and 0–50,000 rev/min.

Rotational speeds can be measured directly by pressing the shaft of the tachometer on to the shaft or spindle of the rotating part. Surface speeds, e.g. the peripheral speeds of rollers, can be measured by fitting a disk to the shaft of the tachometer and pressing the edge of the disk against the moving surface. The diameter of the disk is such that the surface speed in feet per minute is obtained by dividing the indication on the dial by some simple factor such as 2 or 10.

Electric tachometers

An electric generator with a constant permanent magnetic field and loaded with a high-resistance voltmeter provides an output voltage which is nearly proportional to speed. A direct-current type requires a commutator; this is a disadvantage because commutators are subject to wear and the brushes may have variable contact resistance. Modern electric tachometers employ an alternating-current generator which operates in conjunction with a rectifier and a moving-coil voltmeter. An example of a self-contained instrument is the 'Smiths' yarn speed indicator which is designed to measure the yarn speeds of knitting machines.

Where required, the generating unit and the speed indicating unit can be separated by considerable distances and linked by screened cable. In addition, since the instrument produces an electric current it is possible to feed the output to suitable pen recorders and to obtain permanent records of speed variations. This possibility has been exploited by the British Rayon Research Association for investigations into yarn irregularity caused by faulty roller movement. The output from a small tachogenerator is fed to an amplifier which in turn feeds a sensitive pen recorder. Examination of the traces of speed variation enables trouble such as roller vibration to be detected and located.

THE ULTRA-VIOLET LAMP

In his 'emission' or 'corpuscular' theory of light, Sir Isaac Newton suggested that a luminous object emitted small particles which travelled in straight lines. This theory was proved to be invalid and Huyghens (1678) put forward the 'wave' theory of light. Light is a form of radiation and as such has the characteristics of wavelength and amplitude. The electro-magnetic spectrum, of which the visible spectrum is part, ranges from the gamma- and X-rays with very short wavelengths to radio waves of long wavelength. Short wavelengths may be expressed in Ångström units, where 1 Å $= 10^{-8}$ cm. Thus, the visible spectrum extends from about 4,000 Å, the violet end, to about 7,500 Å, the red end. In 1801, Ritter located the ultra-violet rays beyond the violet end of the visible spectrum. Nearly all substances absorb ultra-violet energy readily and many important photochemical effects are produced, some of which are extremely useful to the textile technologist in charge of a testing laboratory.

A source of ultra-violet radiation is the mercury vapour lamp, in which an electric current is passed through mercury vapour contained in a quartz tube. Since the visible light rays are not required when materials are being examined by an ultra-violet lamp, they are cut off by a special filter which transmits ultra-violet rays but not visible light.

Luminescence, fluorescence, and phosphorescence

Fluorescence and phosphorescence are two effects concerned with the result of subjecting materials to light. Other effects include chemical degradation, e.g. tendering and fading of dyes. It is of interest to note also that the wavelength of the light is important since the ability of the radiation to produce chemical change increases as the wavelength decreases. The short wavelength ultra-violet rays, therefore, have a greater effect than the light rays of the visible spectrum. Householders know to their cost of the fading of carpets and furnishings in rooms into which strong sunlight shines, sunlight containing not only visible light but ultra-violet (and infra-red) radiation.

When light energy is absorbed by many materials energy is emitted again, usually with a longer wavelength. Hence, it is found that ultra-violet energy is absorbed and emitted in the form of visible light. A material is said to 'fluoresce' in ultra-violet light if the emission of visible light continues as long as the ultra-violet rays fall

on it but stops as soon as the ultra-violet rays are cut off. If the emission of visible light continues even when the ultra-violet rays are cut off, then the material is said to 'phosphoresce'. Both effects come under the more general heading of 'luminescence'. Fluorescent powders are now commonly used in washing powders and on posters; luminous paint containing calcium sulphide will phosphoresce for hours in the dark after exposure to strong sunlight.

Examination of materials in ultra-violet light

The ultra-violet lamp is often used in the early stages of investigations into the cause of stains and stripes in woven and knitted fabrics. Stains are often the result of contamination by metals and oil. If the stained fabric is examined under an ultra-violet lamp and the discoloured part appears rather duller than the rest, the possibility of metallic contamination should be considered and the appropriate chemical tests made. When one considers how often yarns and fabrics are manipulated and handled by machinery it is, perhaps, not surprising that now and again minute quantities of metallic foreign matter get into them. In the 'wet' end of the processing, faulty pipes, water supplies, and becks, etc., are sources of trouble. For example, 'rusty' drips of water can be a source of iron contamination; the soldered joints of tanks and becks may be the cause of contamination by lead.

A stain which fluoresces could indicate the presence of oil. Generally speaking, the vegetable oils do not fluoresce to any great extent but the mineral oils do, particularly the less well refined types. Since most lubricating oils used for the machinery are mineral, it is evident that oil stains will usually fluoresce strongly under the ultra-violet lamp.

Under suitable conditions textile material may be subjected to mildew attack. A region suffering from mildew will fluoresce quite strongly. The fibres should be examined further by microscopical and chemical methods for confirmation of the possibility of mildew.

Increasing use is being made of the so-called 'optical bleach', in which a 'colourless dye' is applied to the material in order to heighten the brilliance of the finished goods, e.g. a white garment will almost glow with whiteness. The fluorescent agent applied may become degraded and lead to the discoloration of a white material or a change in shade of a coloured one. Under the ultra-violet lamp the faulty part will be dull compared with the strongly fluorescent regions of the rest of the fabric.

Other applications of ultra-violet light

The fastness to light of dyed materials may be tested by exposing them to sunlight, but it is a slow process and therefore special laboratory apparatus has been developed to speed up fastness tests. The lamps used in the various instruments must naturally produce light which is similar in quality to natural sunlight and therefore they are designed to emit light containing an appropriate amount of ultra-violet radiation.

In his book *Fibre Microscopy* Stoves discusses the use of ultra-violet light in microscopy techniques.

Garner (*Text. Lab. Man.*, p. 267) mentions the use of the ultra-violet lamp in the identification of fabric finishes containing resins. It is pointed out that some confusion could arise if quantities of strongly fluorescent non-resins are present.

YARN TESTING

The increasing demand by fabric producers for high quality yarn has resulted in greater attention being paid to the design of yarn clearing devices for fault removal at the winding processes preparing yarns for warps or weft. At the same time improvements and new items of equipment have been developed by the makers of electronic testing equipment. It is now possible to fit electronic slub catchers to winding frames and thus exploit the principles of irregularity measuring devices in a very practical way. In place of a mechanical clearer of the slit or comb type, a measuring electrode based on the capacitance principle or in some types photo-electric cells, is fitted. A central power supply and control box may maintain say 120 units. The sensitivity of the clearing unit is adjustable and therefore the severity of clearing can be controlled. When a slub passes through the clearing unit the signal is translated into a mechanical motion and the yarn is cut.

When testing yarn in the laboratory for irregularity the incidence of a slub is, to use a statistical term, a rare event. Nevertheless, these rare events are the type of fault which reduces the quality of the finished product and the efficiency of the production units. In order to collect sufficient data about slubs and other faults it is necessary to examine long lengths of yarn, a slow process with standard irregularity testers. By mounting electronic clearers on a small six or ten spindle cone winding machine it is now possible to carry out a winding test in the laboratory and examine the necessary amount

of material. Since the yarn is wound on to cones it can be processed in the normal way and wasted yarn avoided.

The test yarn is wound with the sensitivity of the clearing unit set to detect the smallest faults which are considered by the mill management to be of importance. As the faults appear they are mounted on cards, examined, classified, and graded. The grading can be made against photographic standards. The results are recorded on suitable test sheets and over a period of time quality standards can be agreed on. This type of laboratory test on yarn quality can clearly be useful in the investigation of complaints by the fabric producer.

In the 'Qualitester' the winding units, power supply, and grading unit are all mounted in one console. For each gauging condenser there is a four channel counter which records the number of faults classified into four degrees of size.

NEP COUNTING

Neps may be considered as small tight balls of tangled fibres which can lead to the downgrading of the fabric. For cotton, five classes of nep have been identified: (1) process nep, commonly produced by faulty carding; (2) mixed nep, fibres tangled around a foreign nucleus, e.g. grit; (3) immature nep, generated by the processing of immature fibre; (4) homogeneous dead nep, a tangle of nearly all dead fibre; (5) fuzz nep, a tuft of short fuzz fibres. A fuller description of these types will be found in Lord's textbook, *The Characteristics of Raw Cotton* (Textile Institute and Butterworths).

Some of the neps may be removed during carding and at the same time more nep created. The comber is, of course, a machine process subsequent to carding where neps can be removed. Even so, more nep can be produced in the drafting zones of later machines and the resultant yarn contains nep. It would be uneconomical to remove nep by an efficient yarn clearing device during winding since the small nep would then be replaced by another fault, the small knot. The nepping potential of raw cotton is indicated to some degree by the Micronaire test. Low values for a particular cotton show immaturity, and the immature, flabby fibres are prone to process nepping. In blended yarns the proportions of the blend in the nep may not match the proportions in the base yarn and subsequent dyeing may cause them to become more prominent and objectionable.

Counting neps at the card

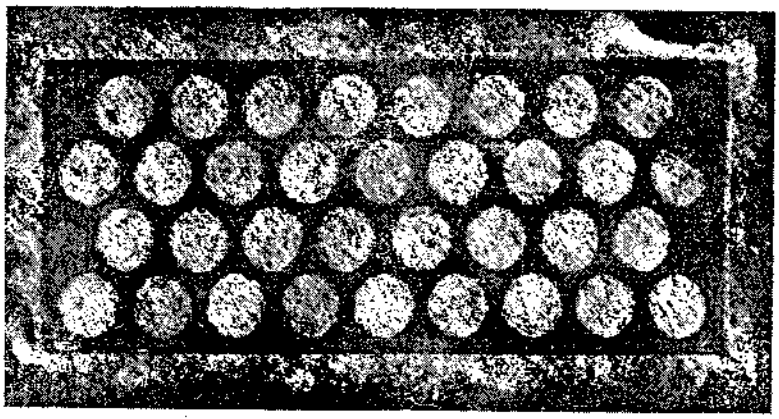
The neppiness of a card web is expressed as follows:

Nep count is the number of neps per 100 in^2 of card web, forming a standard hank of sliver of 0·12 on a card 40 in. wide. At a first inspection it would seem necessary to collect a web from the card, on a black board 10 in. × 10 in., count the neps and correct the number obtained to account for any difference in hank and card width. In practice, the task is not so simple. It is often difficult for the observer to decide whether a speck in the web is a nep or not. Repeated counts by the same observer may result in different nep counts. Investigation of the problem by the Shirley Institute led to the development of a simplified technique of nep counting. A fuller treatment of the test is described by Linnert (*J. Text. Inst.* **52**, P289 (1961)) from whose article the present notes are largely derived.

(By courtesy of the British Cotton Industry Research Association)

Figure 10.11(a). Collection of card web sample

From each side and the middle of the card samples of web are collected on black boards, $11\frac{1}{2}$ in. $\times$ 5 in., and over the top of each web sample a counting template is placed (see Figure 10.11(b)). This is a black painted metal plate, $11\frac{1}{2}$ in. $\times$ 5 in. $\times \frac{1}{8}$ in., with 34 round holes in it, each hole or cell being 1 in^2 in area. During the collection of samples the card continues to run.



(By courtesy of the British Cotton Industry Research Association)

Figure 10.11(b). Counting template placed over card web sample

The number of neps in each cell is not counted. We do not, therefore, obtain the mean number of neps per square inch in that way. Instead, we employ a method based on the statistical characteristics of the Poisson distribution. In each cell there may be none, one, two, three, etc., neps. The frequency distribution of these 'events' or 'successes' is of the Poisson form, the neps being randomly occurring events. Therefore, if $\mathcal{N}$ cells are observed, the number of cells in which no neps occur, i.e. no successes, will be given by the first term of the series, $\mathcal{N}\exp(-m)$. (See Chapter 2.)

If the number of cells containing one or more neps is x, then $\mathcal{N} - x = \mathcal{N}\exp(-m)$.

In the test, the number of cells containing one or more neps is counted, thus giving the value, x. We can now determine, m, the mean number of neps per cell.

$$m = \frac{\log_{10}\mathcal{N} - \log_{10}(\mathcal{N} - x)}{\log_{10} e}$$

The Shirley template has 34 cells in it, hence N is 34. We have

$$m = \frac{\log_{10} 34 - \log_{10} (34 - x)}{\log_{10} e}$$

Therefore,

$$m = \frac{1{\cdot}531 - \log_{10} (34 - x)}{0{\cdot}434}$$

Having derived the mean number of neps per square inch, i.e. per cell, multiplying by 100 provides the nep count, n, for the card web sample. The labour of calculation is avoided by consulting a Table from which n is obtained when x, the number of cells with one or more neps, has been counted.

The nep count, $\mathcal{N}$, has been defined as the number of neps per 100 in^2 of card web forming a standard hank sliver of 0·12 on a card 40 in. wide. If the sample web does not conform to this standard the nep count is given by:

$$\mathcal{N} = n \times \frac{\text{hank sliver}}{0{\cdot}12} \times \frac{\text{card width in inches}}{40}$$

$$\text{or } \mathcal{N} = \frac{21 \times n \times \text{hank sliver} \times \text{card width in inches}}{100}$$

Even with the aid of the Shirley templates the test still depends on subjective observations, and therefore in order to obtain reproducible results a set of standard nep boards are available against which the observer can be checked and trained. It is recommended that the same observer be used for particular comparisons and that sample boards are examined in random order and preferably all counted on the same day.

The principle of nep counting just described has been extended to nep counting of the combed web (see Basu, *J. Text. Inst.* **52**, P295 (1961)).

Nepping potential

It has already been mentioned that the Micronaire value gives an indication of the nepping potential of raw cotton. At the North Carolina State College School of Textiles an instrument called the 'nepotometer' was developed in order to grade raw cotton with respect to nepping potential. The instrument is basically a miniature

card with three small rollers clothed with metallic wire. A sample of about 25 gr is first hand carded into a 5 in. × 5 in. pad and then fed to the nepotometer. After 4 min treatment the web is removed and collected on to a black velveteen-covered board, 4 in. × 9 in. Its neppiness is graded against a set of photographic standards. As in the case of the Shirley test it is preferable to have a standard web weight for judgement. Tests showed that the sample weight fed to the nepotometer could be calculated from a knowledge of either the Micronaire value or the upper half mean fibre length as determined by the fibrograph.

Sample weight in grains = 30 − (2 × Micronaire reading)

or $10 \times (1 + \text{Upper half mean length})$

This sample weight then produces a reasonably standard web weight. The testing atmosphere has to be controlled since low humidities give high web weights and fewer neps. Further information on the nepotometer will be found in the references. Also in the references are articles which describe a photoelectric/electronic technique of nep counting. (See Barella, *Text. Res. J.* **34**, P675 (1964)).

Neps in spun yarns

Equipment associated with the Zellweger 'Uster' range of testing instruments can be used to count the number of neps in yarn passing through the electrode of the evenness tester. The yarn imperfection meter has one counter which indicates neps. In this connection a yarn nep is defined as a yarn fault of approximately 1 mm length and having a cross-section of 200 per cent of the average value. (See also Douglas, *J. Text. Inst.* **53**, P252 (1962) and 'Uster' News Bulletin No. 7 (Dec., 1965).)

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11

CONCLUSION

IN the previous chapters we have examined a variety of textile testing instruments and have studied the principles upon which they operate, some in detail and others in outline. A laboratory equipped with a full complement of such instruments can look impressive, but even more impressive is concrete evidence to prove that each instrument is being put to work and earning its keep. Such evidence is provided by control charts with the daily points hugging the nominal, reduced waste in the mill, increased production, fewer complaints from customers, and more repeat orders. It is therefore important not only to understand how the testing instruments function but also to know how to use them in the most effective way and how to interpret the results produced by them. An appreciation of the limitations of testing is also of value. It is not intended to cover these last few points even in a general way, one or two more volumes would be required rather than paragraphs. Instead, the reader's attention is directed to 'quality control', a management function in which testing plays an important part. Since each branch of textile production has its own peculiarities and problems, it is obviously impracticable to attempt to set out schemes of quality control to serve them all. The subject is therefore treated in a broad fashion and for detailed information the reader must study the references given.

QUALITY CONTROL

In the *Shorter Oxford English Dictionary* we see:

Quality: 'An attribute, property, special feature'
or, 'The nature, kind, or character (*of* something); hence, the degree or grade of excellence, etc. possessed by a thing.'

Control: 'To check or verify, and hence to regulate'.

We may now try to define quality control as, say, 'quality control is the checking, verification, and regulation of the degree of excellence of an attribute or property of something'.

The two meanings of the word 'quality' should be noted and clearly understood. For example, the 'property' of a yarn being

checked may be its regularity, whereas its 'degree of excellence' may be expressed in terms of its coefficient of variation. Thus, in textile testing for control of quality we select some attribute of a product, measure it, and then make the necessary regulations to the machinery if the measured attribute is below the desired degree of excellence. Sometimes the measurement and regulation are reasonably straightforward; bobbins from a ring frame are tested for count and, where necessary, the draft change wheel is replaced in order to bring the count closer to nominal. In other cases neither the measurement nor regulation is simple: How does one measure fabric appearance? Can fabric appearance be controlled by a set of change wheels? Clearly, the approach to quality control is governed largely by the subject of control and different techniques will be required by different conditions.

It is of interest to note other definitions of quality and quality control: 'Quality in the textile trades might perhaps be defined as the degree of conformity to a specification, the specification itself having been drawn up with the object of providing an article which has suitability for an end-use.' (Kenyon. *Text. Manuf.* (June, 1956).)

'Quality control is a wide subject and covers all those factors which help to ensure that the product produced is of the desired quality.' (Newbery. *Text. Wkly.* (Feb. 21, 1958).)

Newbery's definition emphasises the fact that many factors are concerned in the production of the desired quality, and from Kenyon's definition it can be inferred that the desired quality is not always achieved and that deviations from the specification can be expected. The task of drawing up specifications to ensure that the article 'has suitability for an end-use' is often a formidable one and in some intances the form of the specification is loose and vague, an indication that the person responsible for it admits defeat (see Alexander and Munden, Collins, and Bayes).

It has often been stated that quality and the control of quality are governed by the three 'M's: Men, Materials, and Machines. The order in which these three are placed is not intended to be significant; it is left to the reader to decide for himself whether it is possible to rank them in order of importance.

Men. One of the functions of top management is the co-ordination of the activities of the complete labour force, administrative, technical, supervisory, and operative. A member of the technical staff, often the head of the testing laboratory, is nominally given the job of Quality Controller. One says 'nominally' because the control

of quality is in the hands of many persons including those who clean, oil, run, and maintain the machinery. The selection and training of operatives is of great importance and is a specialised art (or science) in itself. The quality of the available labour is, of course, outside the control of the mill; because of this there is a constant challenge to the Personnel, Training, and Work-study departments to develop the abilities of each individual both to the mill's and the operative's advantage. Training in the best methods of doing a job is essential to quality; quality in yarn and fabric is not only measured in lea strength and tearing strength but in such matters as good piecings, freedom from oil, neat weaver's knots, and imperceptible starting places after 'unweaving'.

Of even greater importance perhaps is the selection and training of supervisors and foremen. Those who lead must possess the enthusiasm and self-discipline required in the maintenance of standards and must be able to communicate these virtues to the operatives by setting a good example. In the testing laboratory, too, great care should be taken to choose the right type of assistants and to train them to be scrupulously honest in recording test results and conscientious in carrying out the tests. Judicious 'cooking' of results is not altogether unknown.

Materials. The selection of the raw materials is a key factor in the success or failure of the product, hence the importance attached to the results of tests from which a decision on the choice of fibre or yarn has to be made. Knowledge of the properties of alternative materials is very useful when the preferred type is either not available or too expensive; substitution may then be made without seriously impairing the 'degree of excellence' of the product. Selection of raw materials on the basis of test results is one example of the application of textile testing. The methods of testing have been discussed in the earlier chapters but the application and interpretation has often been mentioned only in passing. Yet from the point of view of the mill management it is more important to know exactly what the test results mean and how they can be used than to understand how the instrument works or what testing procedure has been followed.

When testing raw materials (i.e. fibres for the spinner, yarns for the weaver, fabric for the finisher) it is assumed that the properties tested are in fact related to the desired characteristics of the subsequent product. A cotton spinner producing combed yarns will not want a variety of cotton which has a high percentage of short fibre, he will therefore be interested in the results of comb sorter tests on

the types of cotton available. This is an example of a fairly straightforward and logical test but not all problems of testing for choice of raw material are simple or logical. For example, a manufacturer wishing to produce a warm fabric might think that the fibre for the job would be the one with the lowest thermal conductivity value, a reasonable deduction but unwise because the thermal conductivity of the fibre plays only a minor role in the warmth properties of a fabric.

The structures of many standard yarns and fabrics which are made from natural fibres are the result of evolution over the years, a process of trial and error producing the desired product characteristics. These structures were developed before the introduction of man-made fibres and the question now arises, 'If we wish to use man-made fibres in the place of natural fibres in traditional structures, should we try to copy the properties of the natural fibres or should we examine the purpose for which the structure is intended and design something fresh in the light of our new knowledge of the relationships between the properties of the fibres and the properties of the yarns and fabrics built from those fibres?' The author would prefer the latter approach, but as yet our knowledge of the complex relationship between fibres and fibre structure is not complete. At the moment we are in a transitional stage where we must take advantage of the experience of past technologists but at the same time try to put into practice the theories of such investigators as Peirce, Gregory, and Hamburger.

Machines. The selection of the types of machine best suited to the production of high-quality goods is not easy. The machine which may be best from a technical viewpoint may not be an economical proposition when the class of market or the state of trade is considered. The labour force available can influence the decisions. Where highly trained teams of technicians and operatives are available, the more refined and complex (and expensive) machines may be chosen, whereas in parts of the world where technical skills and know-how are not yet fully developed the choice may be for the simpler and more easily maintained machines.

A first-class system of maintenance is essential in any scheme of quality control. It is not sufficient that a programme of maintenance schedules is drawn up on paper; it is necessary to see that the jobs are carried out properly. Once again we meet the men with the oil cans, gauges, and spanners, very important people forming one section of the large team of administrators, technicians, and operatives concerned in the control of quality.

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APPENDIX

A new edition of the British Standards Handbook No. 11 was published in 1974. Many of the standards referred to in the present edition of *Principles of Textile Testing* have been modified and some new ones have appeared. The following table gives the 1974 equivalents of the 1963 British Standards. (N.B. some entries are not yet standards.)

Page	*Topic*	*BS Handbook 1963*	page	*BS Handbook 1974*	page
85	Fibre sampling	2545:1954	21	2545:1965	2/1
86	Fibre sampling	2545:1954	20	2545:1965	2/1
86	Fibre sampling for length	—	90	3994:1966	2/60
88	Squaring technique	2545:1954	24	2545:1965	2/6
89	Comb sorter	—	33	4044:1966	2/13
92	Dye sampling	—	23	deleted	
95	Yarn count	2010:1953	109	2010:1963	3/12
95	Yarn count (sampling)	2010:1953	113	2010:1963	3/14
96	Twist testing	2085:1954	114	2085:1973	3/16
100	Humidity	1339:1946	4	1339:1965	1/1
110	Conditioning	—	10	1051:1972	1/12
114	Correct invoice mass	—	11	4784:1973	1/15
140	Fibre length	—	29	3697:1963	2/10
141	Comb sorter	—	33	4044:1966	2/13
159	Wool fibre length	—	87	3994:1966	2/60
167	Flax fibre length	—	37	deleted	
169	Fibre linear density	2016:1961	40	2011:1961	2/20
172	Wool fineness	2043:1953	57	2043:1968	2/31
179	Air flow (wool)	3183:1959	51	3183:1968	2/27
176	Air flow (cotton)	3181:1959	44	3181:1968	2/23

191	Cotton immaturity	3085:1959	69	3085:1968	2/44
200	Trash content	2889:1957	73	2889:1967	2/48
209	Yarn diameter	—	117	—	3/19
214	Yarn count systems	947:1959	98	947:1970	3/8
217	Yarn linear density	—	109	2010:1963	3/12
230	Twist direction	946:1952	103	946:1970	3/1
236	Curl in fabrics	2888:1957	186	2888:1967	4/19
237	Twist in yarn	2085:1954	114	2085:1973	3/16
249	Yarn structure	—	103	946:1970	3/1
250	Crimp rigidity	—	—	—	3/21
255	Fabric length	1931:1953	163	1931:1968	4/3
257	Fabric width	1930:1953	165	1930:1968	4/6
258	Fabric thickness	2544:1954	174	2544:1967	4/14
261	Floor covering thickness	—	180	4051:1972	4/51
—	Floor covering thickness	—	—	4052:1972	4/53
263	Fabric weight/unit area	2471:1954	167	2471:1971	4/8
263	Threads per unit length	2862:1957	222	2862:1972	4/88
268	Crimp measurement	2863:1957	230	2863:1972	4/94
277	Air permeability	3217:1960	303	—	4/169
277	Pore size	3321:1960	313	3321:1969	4/177
277	WIRA Permeameter	—	308	—	4/171
284	Fabric stiffness	3356:1961	194	3356:1961	4/26
287	Fabric drape	—	—	5058:1973	4/29
291	Crease recovery	3086:1959	198	3086:1972	4/35
298	Abrasion resistance	—	555	—	4/49
315	Flammability	2963:1958	264	deleted	
324	Wetting time test	—	337	—	4/211
325	Spray test	—	330	3702:1964	4/201
325	Wettability (cotton fabric)	—	334	4554:1970	4/204
328	Shower test (WIRA)	—	317	5066:1974	4/192
331	Hydrastatic head test	2823:1957	324	2823:1968	4/186
—	Static immersion	3449:1961	327	3449:1961	4/189

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Page	*Topic*	*BS Handbook 1963*		*BS Handbook 1974*	
334	Cold water immersion	—	276	4736:1971	4/153
336	Abrasion of carpets	—	—	—	4/70
341	Carpet thickness	—	—	4051:1972	4/51
340	Carpet soiling	—	—	—	4/80
340	Carpet appearance retention	—	—	—	4/74
343	Carpets—dynamic loading	—	—	4052:1972	4/53
368	Tensile test time	1932:1953	135	1932:1965	3/32
369	Conditioning	—	10	1051:1972	1/12
429	Single thread strength	1932:1953	135	1932:1965	3/32
433	Fabric strength test	2576:1959	249	2576:1967	4/107
440	Ballistic tear	—	257	4253:1967	4/114
438	Double rip	—	—	—	4/118
438	Tongue tear test	—	253	deleted	
439	Wing rip test	—	255	4303:1968	4/110
443	Seam slippage	3320:1960	189	3320:1970	4/22
446	Clamps and jaws	3411:1961	62	3411:1971	2/38
471	Yarn diameter	—	117	—	3/19
477	Yarn irregularity	—	119	—	3/25
536	Yarn friction	—	148	—	3/46
538	Yarn friction	—	150	—	3/48
549	Nep counting (Card web)	—	—	—	2/63

Metrication and SI Units in Textile Testing

One of the problems of communication between countries is that of language. An additional problem facing the technologist is that of units. In the United Kingdom a textile man may use an odd system of linear measurement in which the basic unit of length is the yard. For cotton count testing he may use the hank, a length unit 840 times the yard. To carry out a count test he will probably take one seventh of the hank, i.e. a lea. When measuring fabric properties it may be more convenient to use the inch, one thirty-sixth of the basic yard—thread spacing may be indicated as the number of threads per inch. Yet another sub-division of the yard may be used for fabric thickness, the thousandth of an inch or the thirty-sixth thousandth of the yard. A curious mixture of multiples and sub-multiples of the base unit is evident. Even if the yard remained the basic unit, calculations would be easier if the multiples and sub-multiples were in powers of 10. In the metric system the basic length unit is the metre but for long lengths the kilometre, the metre $\times 10^3$, is more convenient, and for very short lengths the millimetre, the metre $\times 10^{-3}$, may be preferred.

A technical article using metric units may be more easily appreciated by someone used to Imperial units if all the metric values are first converted. The arithmetic may be simple but there is always the danger of error when converting from one system to another. The time taken for conversion is non-productive. The concept of an internationally accepted system of units is clearly attractive. In 1960 the General Conference of Weights and Measures recommended the 'Système Internationale d'Unités' to be used universally. The SI system is a version of the metric system and has seven basic units plus two supplementary units for angular measure. The quantities, units and symbols are given in Table 1 and their definitions are given below.

Basic SI Units

metre The metre is the length equal to 1 650 763·73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom.

kilogram The kilogram is the unit of mass and is equal to the mass of the international prototype of the kilogram (kept at Sèvres).

second	The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.
ampere	The ampere is that constant current, which, if maintained in two straight parallel conductors of infinite length of negligible circular cross section and placed one metre apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.
kelvin	The kelvin unit of thermodynamic temperature is the fraction 1/273·16 of the thermodynamic temperature of the triple point of water.
candela	The candela is the luminous intensity in the perpendicular direction of a surface of 1/600 000 square metre of a black body at the temperature of freezing platinum under a pressure of 101 325 newtons per square metre.
mole	The mole is the amount of substance which contains as many elementary units as there are atoms in 0·012 kilogram of carbon-12. The elementary unit must be specified and may be an atom, a molecule, an ion, an electron, a photon, etc., or a given group of such entities.
radian	The angle subtended at the centre of a circle by an arc of the circle equal in length to the radius of the circle.
steradian	The solid angle subtended at the centre of a sphere by an area on the surface of the sphere equal in magnitude to the area of a square having sides equal in length to the radius of the sphere.

Derived units

Many quantities in technology are defined in terms of the basic units and are referred to as 'derived' units. Velocity is an example where the magnitude may be 25 metres per second, the unit in this case being the metre per second. This unit of velocity has no special

name but many derived units are given special names, very often the name of a scientist as a tribute to the contribution to science that he has made. For example the unit of force is the newton, after Sir Isaac Newton. The unit of work is the joule, and power, the rate of working, is expressed in watts.

Multiples and sub-multiples

We have already mentioned the kilogram and the milligram, the prefixes kilo and milli meaning one thousand times and one thousandth respectively. Other multiplying and dividing values may be convenient at times and a list of prefixes is given in Table 2. In the SI system the preferred prefixes are those which raise the basic unit by powers of 10 in steps of three, e.g. 10^3, 10^6, 10^{-3}, 10^{-6} and so on. It may be difficult to discard the centimetre as a length unit because it is so convenient practically.

The SI system and coherence

The units in the SI system illustrate what is termed a 'coherent' set of units. For example, one watt is a rate of working of one joule per one second. Again, the newton is that force which would give an acceleration of one metre per one second per one second to an unrestrained mass of one kilogram. The stress is on the factor 1·0. A derived unit from basic units is itself unity.

Units in textiles

Many SI Units will be common to the various sciences and technologies but for each special technology a set of units will be necessary to cope with its peculiar problems. This specialised set will have to be acceptable internationally in the same way as the basic SI Units, otherwise a technologist in France will still have to convert the units used by a technologist in Australia. A selection of SI Units recommended for use in the field of textile technology is given in Table 3. It has been pointed out by Hearle (*Text. Inst. Ind.*, June 1971) that for some purposes, e.g. in programs for computers, the use of multiples and sub-multiples is disadvantageous and that all quantities in such cases should be given in basic units (consistent units). The results may then be converted into practical units (see Table 3).

Conversion to SI Units

Even when the SI Units are in general use many references will still be in older unit systems and a common calculation will be the

conversion of data to SI Units. The conversion may be carried out from first principles as in the following example.

Example. A terry towelling has an areal density of 8·5 ounces per square yard. What is the areal density in grams per square metre?

From conversion tables it is noted that to convert ounces to grams we multiply by 28·3495 and that the factor to change square yards to square metres is 0·8361.

The areal density in grams per square metre is therefore:

$$\text{mass in ounces per square yard} \times \frac{28{\cdot}3495}{0{\cdot}8361} = 8{\cdot}5 \times \frac{28{\cdot}3495}{0{\cdot}8361}$$

$$= 288{\cdot}2 \text{ g/m}^2$$

(using logs)

Another set of conversion tables reduces the labour of calculating the value of 28·3495/0·8361. Such a table gives the conversion factor for changing ounces per square yard to grams per square metre, i.e. 33·9057. Thus:

$$8{\cdot}5 \times 33{\cdot}9057 = 288{\cdot}198\,45 \text{ g/m}^2$$

$$= 288{\cdot}2 \text{ g/m}^2 \quad \text{(to one decimal place)}$$

A third approach is to use a table which converts ounces per square yard directly into grams per square metre. From such a table it is noted that 85 oz/yd^2 equals 2881·98 g/m^2, and so dividing by 10 we obtain 288·198 or 288·2 g/m^2.

No doubt in due course special conversion tables for textiles will be published to permit direct conversion to SI Units of properties such as linear density, tenacity, twist factor, cover factor, etc. Table 3 offers a number of conversion factors. Thus a tenacity of 4·2 gf/den is converted to millinewtons per tex by multiplying by 88·3, i.e. 370·86 mN/tex.

Other conversion aids may be in the form of special slide rules designed for textile users. The Shirley Institute has recently provided the Shirley Metric Converter.

Table 1 The Basic SI Units

Quantity	*Name of Unit*	*Unit Symbol*
Mass	kilogram	kg
Length	metre	m
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Luminous intensity	candela	cd
Amount of substance	mole	mol

Table 2 Multiples and Sub-multiples

Units multiplying factor	*Prefix*	*Symbol*
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h *
10^{1}	deca	da*
10^{-1}	deci	d *
10^{-2}	centi	c *
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

*The preferred multiplying factors are powers of ten which are multiples of +3 or −3, but there may be special circumstances where the preferred multiplying factors are inconvenient.

Table 3 Units in the SI System Recommended for use in Textile Technology
(From *Textile Institute and Industry*, July 1973)

Property	*SI Unit*		*Abbreviation*		*To convert to SI Units, multiply value in unit given by factor below*	
Length	millimetre		mm		inch	25·4
	metre		m		yard	0·914
	centimetre		cm		inch	2·54
Width	millimetre		mm		inch	25·4
	centimetre		cm		inch	2·54
Test or gauge length	millimetre		mm		inch	25·4
Thickness	millimetre		mm		inch	25·4
Linear density	tex		tex		Reference should be made to BS 947: 1970	
	millitex		mtex			
	decitex		dtex			
	kilotex		ktex			
Diameter	micrometre (micron)		μm		$\frac{1}{1000}$ inch (mil)	25·4
	millimetre		mm		inch	25·4
Threads in cloth:						
length	number per centimetre		picks/cm		picks/inch	0·394
width	number per centimetre		ends/cm		ends/inch	0·394
Warp threads in loom	number per centimetre		ends/cm		ends/inch	0·394
Stitch length	millimetre		mm		inch	25·4
Courses per unit length	number per centimetre		courses/cm		courses/inch	0·394
Wales per unit length	number per centimetre		wales/cm		wales/inch	0·394
Cover factor (woven fabrics)	(threads per centimetre)	$\sqrt{\text{tex}} \times 10^{-1}$	(threads/cm)	$\sqrt{\text{tex}} \times 10^{-1}$	$\frac{\text{(threads/inch)}}{\sqrt{\text{cotton count}}}$	0·957

Mass per unit area	grams per square metre	g/m^2	oz/yd^2	33·9
Twist	turns per metre	turns/m	turns/inch	39·4
	turns per centimetre	turns/cm	turns/inch	0·394
Twist factor (or multiplier)	(turns per centimetre) $\sqrt{\text{tex}}$	(turns/cm) $\sqrt{\text{tex}}$	$\frac{\text{(turns/inch)}}{\sqrt{\text{cotton count}}}$	9·57
			$\frac{\text{(turns/inch)}}{\sqrt{\text{worsted count}}}$	11·70
Breaking load	millinewton	mN	gf	9·81
	newton	N	kgf	9·81
Tearing strength	newton	N	lbf	4·45
Tenacity	millinewtons per tex	mN/tex	gf/den	88·3
Specific stress	millinewtons per tex	mN/tex	gf/den	88·3
Bursting pressure	kilonewtons per square metre	kN/m^2	lbf/in^2	6·89
Bending rigidity	millinewtons square millimetres	mN mm^2	gf mm^2	9·81

Conversion Factors for Use of Consistent Units

Property	*Consistent SI Units*	*Practical SI Units*	*To convert to practical units, multiply value in consistent units by**
Length, etc.	m	μm	10^6
		mm	1000
		cm	100
Linear density	kg/m	tex	10^6
Twist, thread-spacing, etc.	m^{-1}	turns/m	1
		ends/cm, etc.	0·01
		turns/cm	0·01
Areal density	kg/m^2	g/m^2	10^{-3}
Cover factor	$kg^{\frac{1}{2}}/m^{3/2}$	(threads/cm) $\sqrt{tex} \times 10^{-1}$	1
Twist factor	$kg^{\frac{1}{2}}/m^{3/2}$	(turns/cm) $\sqrt{tex}$	10
Force, etc.	N	mN	1000
Specific stress, tenacity, specific work of rupture, etc.	Pa m^3/kg (equivalent to Nm/kg, J/kg, m^2/s^2)	mN/tex	10^{-3}
		N/tex	10^{-6}

*In order to change an equation from consistent to practical units, multiply each parameter by the reciprocals of these numbers.

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