4.3 Yarn evenness

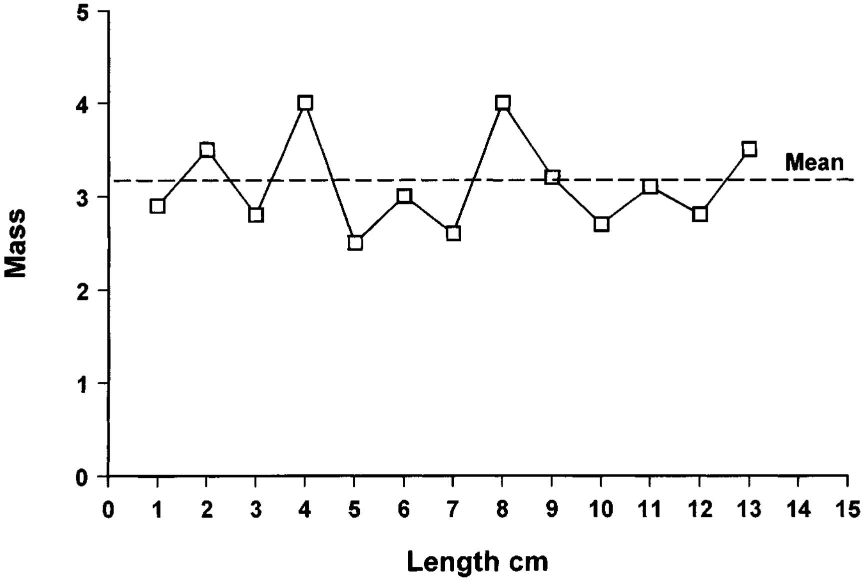
Yarn evenness can be defined as the variation in weight per unit length of the yarn or as the variation in its thickness. There are a number of different ways of assessing it.

4.3.1 Visual examination

Yarns to be examined are wrapped onto a matt black surface in equally spaced turns so as to avoid any optical illusions of irregularity. The blackboards are then examined under good lighting conditions using uniform non-directional light. Generally the examination is subjective but the yarn can be compared with a standard if one is available; the ASTM produce a series of cotton yarn appearance standards. Motorised wrapping machines are available: in these the yarn is made to traverse steadily along the board as it is rotated, thus giving a more even spacing. It is preferable to use tapered boards for wrapping the yarn if periodic faults are likely to be present. This is because the yarn may have a repeating fault of a similar spacing to that of one wrap of yarn. By chance it may be hidden behind the board on every turn with a parallel-sided board whereas with a tapered board it will at some point appear on the face.

4.3.2 Cut and weigh methods

This is the simplest way of measuring variation in mass per unit length of a yarn. The method consists of cutting consecutive lengths of the yarn and weighing them. For the method to succeed, however, an accurate way of



4.11 The variation of weight of consecutive 1 cm lengths of yarn.

cutting the yarn to exactly the same length is required. This is because a small error in measuring the length will cause an equal error in the measured weight in addition to any errors in the weighing operation. One way of achieving accurate cutting to length is to wrap the yarn around a grooved rod which has a circumference of exactly 2.5 cm and then to run a razor blade along the groove, leaving the yarn in equal 2.5 cm lengths. The lengths so produced can then be weighed on a suitable sensitive balance.

If the mass of each consecutive length of yarn is plotted on a graph as in Fig. 4.11, a line showing the mean value can then be drawn on the plot. The scatter of the points about this line will then give a visual indication of the unevenness of the yarn. The further, on average, that the individual points are from the line, the more uneven is the yarn.

A mathematical measure of the unevenness is required which will take account of the distance of the individual points from the mean line and the number of them. There are two main ways of expressing this in use:

1 The average value for all the deviations from the mean is calculated and then expressed as a percentage of the overall mean (percentage mean deviation, PMD). This is termed *U*% by the Uster company.
2 The standard deviation is calculated by squaring the deviations from the mean and this is then expressed as a percentage of the overall mean

(coefficient of variation, CV%). This measurement is in accordance with standard statistical procedures.

When the deviations have a normal distribution about the mean the two values are related by the following equation:

$$CV = 1.25\,PMD$$

4.3.3 Uster evenness tester

The Uster evenness tester measures the thickness variation of a yarn by measuring capacitance [8–10]. The yarn to be assessed is passed through two parallel plates of a capacitor whose value is continuously measured electronically. The presence of the yarn between the plates changes the capacitance of the system which is governed by the mass of material between the plates and its relative permittivity (dielectric constant). If the relative permittivity remains the same then the measurements are directly related to the mass of material between the plates. For the relative permittivity of a yarn to remain the same it must consist of the same type of fibre and its moisture content must be uniform throughout its length. The presence of water in varying amounts or an uneven blend of two or more fibres will alter the relative permittivity in parts of the yarn and hence appear as unevenness.

The unevenness is always expressed as between successive lengths and over a total length. If the successive lengths are short the value is sometimes referred to as the short-term unevenness. The measurements made by the Uster instrument are equivalent to weighing successive 1 cm lengths of the yarn.

The measured unevenness arises from various components, the main ones being [11]:

1. The variation in the number of fibres in the yarn cross-section. This is by far the most influential cause of unevenness.
2. In a yarn made from natural fibres the fineness of the fibres themselves is variable leading to a difference in yarn thickness even when the number of fibres in the cross-section remains the same.
3. The inclination of the fibres to the yarn axis can vary. This has the effect of presenting an increased fibre cross-section to the measuring apparatus. The steeper the angle of inclination of the fibre, the longer is the length that is contained within a fixed length measuring slot.

The Uster tester, besides measuring an overall value of unevenness, also presents a number of other factors derived from the basic measurement of the change in mass along the length of the yarn.

Diagram

A diagram should be plotted of the actual variations in mass per unit length along the length of the yarn.

CV or *U*

The percentage CV or *U* value gives an overall number for yarn irregularity and hence is the most widely used of the measurements that the instrument makes. The *U* value was the only value calculated by the older Uster equipment and is equal to percentage mean deviation. The upper limit of CV which is acceptable for a yarn varies with the different types of yarn. Different spinning systems, counts and end uses have different upper limits and knowledge of these can only be gained from experience of what is acceptable in a given application. Uster produces a volume of 'statistics' which lists the measured values of unevenness for the main types of yarn and for a range of counts for each type, so that measured values can be compared with expected values.

Index of irregularity

There is a natural limit to the evenness that can be achieved in a staple yarn. To produce a completely regular yarn there would need to be exactly the same number of fibres in each cross-section through the yarn. This would mean that the end of one fibre would have to connect with the beginning of the following fibre. No available spinning process can produce such assemblies. The best that can be achieved is complete randomness of the position of individual fibres. On the assumption that all the fibres have the same diameter the theoretical limit to evenness has been calculated as:

$$\mathrm{CV}_{\mathrm{lim}} = \frac{100}{\sqrt{n}}\%$$

where n = mean number of fibres in the cross-section.

In the case of yarns produced from wool the variations in fibre diameter have also to be taken into account, so that the limiting CV becomes:

$$\mathrm{CV}_{\mathrm{lim}} = \frac{3.58\, d_{\mathrm{f}}}{\sqrt{T}}$$

where T is the yarn count in tex and d_{f} is the mean fibre diameter in micrometers. This formula assumes that the coefficient of variation of the wool fibre diameter is 25%.

The formula shows that the finer the count of a yarn, the higher will be its irregularity. This is because when there are only a few fibres in the yarn cross-section the presence or absence of a single fibre makes a bigger difference than if there were a large number of fibres making up the yarn. It is possible to calculate an index of irregularity, I, for any yarn by comparing its measured CV with the theoretical limiting CV.

$$I = \frac{\mathrm{CV}_{\mathrm{meas}}}{\mathrm{CV}_{\mathrm{lim}}}$$

To be able to calculate the limiting CV the number of fibres in the cross section of the yarn needs to be known. This number can be calculated from the count of the yarn and the fibre fineness if they are both expressed in the same units. The following formula gives the index of irregularity in terms of the measured CV, the yarn count and fibre fineness.

$$I = \frac{\mathrm{CV}_{\mathrm{meas}}\sqrt{T}}{100\sqrt{T_{\mathrm{f}}}}$$

where T is the yarn count in tex and T_{f} is the fibre fineness in tex.

Addition of irregularities

Each machine in the process that produces yarn from fibre adds to the irregularity of the finished yarn. If the irregularities introduced by processes A and B are CV_{A} and CV_{B} then the total irregularity can be calculated as follows:

$$\mathrm{CV}_{\mathrm{tot}} = \sqrt{\left(\mathrm{CV}_{\mathrm{A}}^{2} + \mathrm{CV}_{\mathrm{B}}^{2}\right)}$$

Imperfections

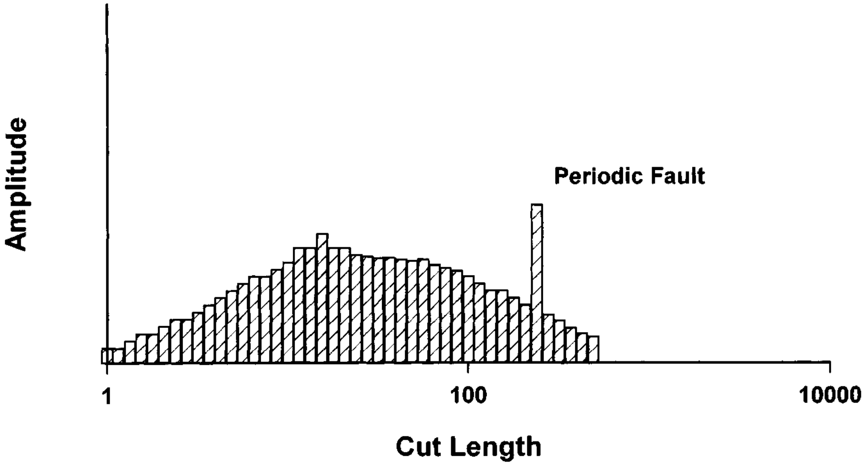
In addition to measuring the overall variability of yarn thickness the Uster tester also counts the larger short-term deviations from the mean thickness. These are known as imperfections and they comprise thin places, thick places and neps.

The sensitivity of the eye to thick and thin places in a yarn is such that around a 30% change from the mean thickness is needed for a thick or thin place to be visible. In the instrument, therefore, only thick and thin places above these levels are counted. Neps are considered to be those thick places that are shorter than 4 mm whereas areas counted as thick places are the ones that are longer than 4 mm. The total volume of the nep is considered in the assessment but for the purposes of counting they are all assumed to have the same length of 1 mm so that any variation in size is registered as a variation in thickness. Neps are counted at sensitivities of +140%, +200%, +280% and +400% above the mean thickness. For the purpose of the instrument thick and thin places generally have a length equal to the mean fibre length; any places longer than this are considered to be part of the general yarn diameter variation. In general it has been found that the number of imperfections at any one level is related to the imperfections at all other levels so that for comparison purposes it is not important which particular levels are chosen to be recorded.

Spectrogram

An important type of thickness variation is the regular appearance of a thick or thin place at equal intervals along the yarn length. This type of unevenness can give rise to visual effects such as stripiness or moiré patterns in the finished knitted or woven fabric depending on how the repeat length of the fault compares with the fabric width or course length. A level of unevenness which would not be apparent if it was random is much more objectionable if it comes from a regular fault as the eye is very sensitive to pattern.

The spectrogram measures the periodic mass variations in a yarn by analysing the frequencies at which faults occur electronically. From the speed at which the yarn is running the frequencies are converted to wavelengths and slotted into a finite number of discrete wavelength steps. The result is a histogram as shown in Fig. 4.12 where the amplitude is a measure of the number of times a fault of that repeat length occurs. Owing to the fibre length having an effect on the distribution of repeats around that



4.12 Spectrogram.

length the background level of the spectrogram is not flat but a periodically repeating fault will show a level much greater than the background as is shown in the figure. As a general rule the height of a peak in the spectrogram should not be more than 50% of the basic spectrogram height at that wavelength.

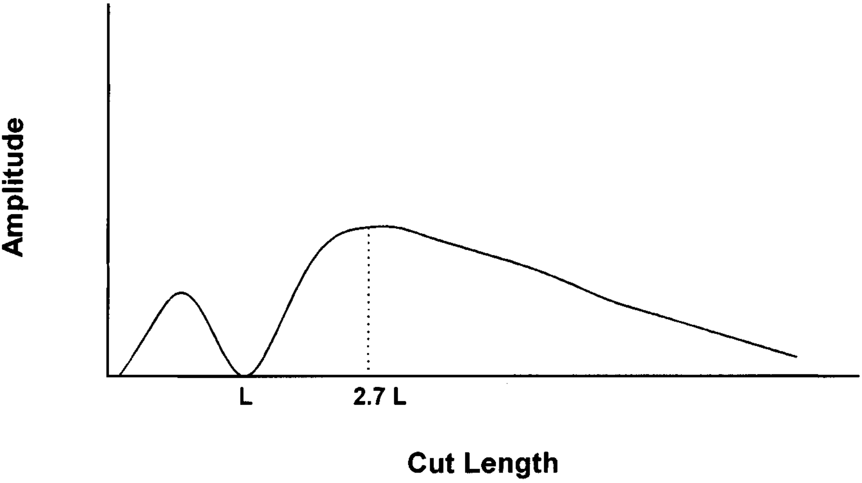
Theoretical spectrogram

If the CV of a yarn were zero then the spectrogram would consist of a straight line. However, if the yarn has a completely random distribution of staple fibres, as in the case of the limiting CV value, then the staple length *L* has an effect on the spectrogram.

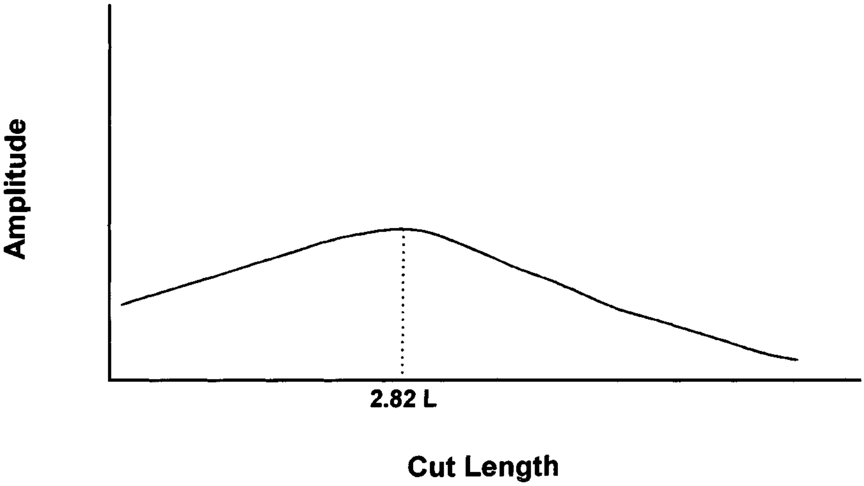
In the case that all the fibres have the same length then the spectrogram would appear as in Fig. 4.13 with a zero point corresponding to the staple length and a maximum value at 2.7 times the staple length. A diagram of this shape is hardly ever found in practice even in a yarn made from synthetic fibres of constant cut length staple.

In the case of yarns made from natural fibres there is the added complication that the staple length varies quite widely. If L_w is the mean fibre length calculated from the fibre weight staple diagram, the spectrogram then appears similar to that shown in Fig. 4.14 with a less well-defined peak situated at 2.82 times L_w.

The wavelength of the fault gives an indication of its cause and therefore allows it to be traced to such mechanical problems as drafting waves, eccentric or oval rollers in the spinning plant or in earlier preparation stages. The



4.13 A theoretical spectrogram for yarn with its staple fibre all the same length *L*.



4.14 A theoretical spectrogram for yarn with a variable fibre length; in this case *L* is the mean fibre length.

wavelength can also correspond to the diameter of the yarn package, in which case it will vary between the full and empty package. The wavelength of a fault that occurs before the drafting in the spinning process will be multiplied by the drafting ratio.

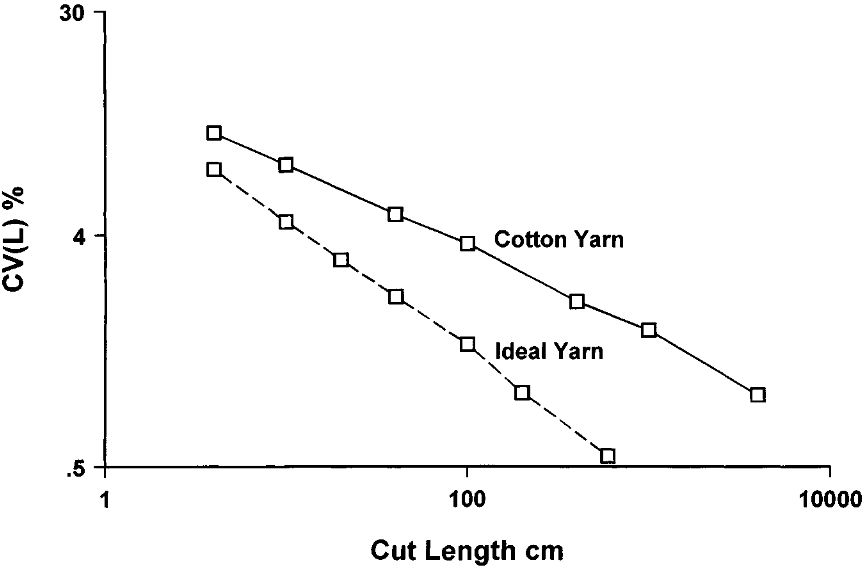
Variance length curve

The variance length curve is produced by calculating the CV for different cut lengths and plotting it against the cut length on log–log paper. A perfect yarn would produce a straight line plot. The curve is a useful tool for examining long-term non-periodic variations in a yarn. The better is the evenness of the yarn the lower is the curve and the steeper is the angle it makes to the cut length axis. This is shown in Fig. 4.15 where the variance length curve for an actual cotton yarn is compared with a curve for an ideal yarn.

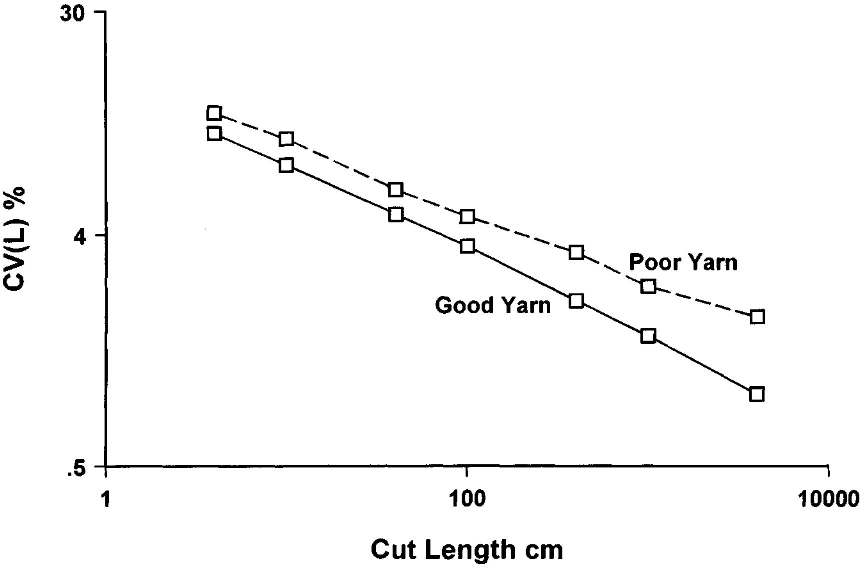
The measured curve deviates from the theoretical curve in the region where there is long-term variation in the yarn. The variance length curve of a poor fibre assembly lies above the curve of a good fibre assembly as is shown in Fig. 4.16 where the poor yarn diverges from the good yarn at the longer cut lengths.

4.3.4 Zweigle G580

This instrument measures yarn evenness by a fundamentally different method from the mass measuring system of the Uster instrument. Instead

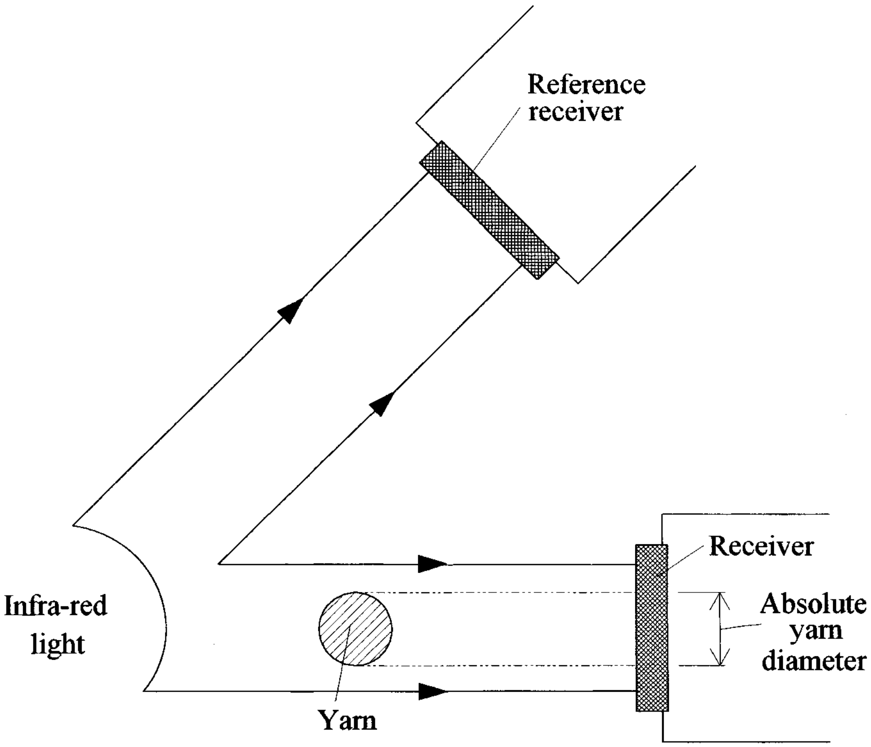


4.15 Variance length curves for cotton and ideal yarns.



4.16 Variance length curves for poor and good yarns.

of capacitance measurements it uses an optical method of determining the yarn diameter and its variation. In the instrument an infra-red transmitter and two identical receivers are arranged as shown in Fig. 4.17. The yarn passes at speed through one of the beams, blocking a portion of the light



4.17 Zweigle optical evenness.

to the measuring receiver. The intensity of this beam is compared with that measured by the reference receiver and from the difference in intensities a measure of yarn diameter is obtained.

The optical method measures the variations in diameter of a yarn and not in its mass. For a constant level of twist in the yarn the mass of a given length is related to its diameter by the equation:

$$\text{Mass} = CD^2$$

where C = constant,
D = diameter of yarn.

However, in practice the twist level throughout a yarn is not constant [3]. Therefore the imperfections recorded by this instrument differ in nature from those recorded by instruments that measure mass variation. However, the optical system is claimed to be nearer to the human eye in the way that it sees faults. Because of the way yarn evenness is measured, this method is not affected by moisture content or fibre blend variations in the yarn.