REVIEW ARTICLES

Test Methods for Air-Jet Textured Yarns

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There are wide ranging quality parameters of the air-textured yarns on which depend their end use applications such as upholstery, apparels and technical applications such as sewing threads. However, the most important quality parameters of air-textured yarns are: instability; physical bulk; boiling-water shrinkage; size, form and frequency of loops; and tensile properties. A number of test methods are available for the evaluation of these properties and the present review provides a critical insight into them. The advantages and shortcomings of some of these methods have also been highlighted. The lack of standardization of the various test methods is pointed out and the need for arriving at a consensus on the test methods of the important properties of air-textured yarns is stressed.

Keywords: Air-jet texturing, Boiling-water shrinkage, Instability, Loop frequency, Loop size, Microdensitometer, Optical attenuator, Photomultiplier detector, Physical bulk, Tensile properties, Textured yarn

1 Introduction

Air-jet texturing was invented in the early 1950s. The commercial success of this process was delayed in the early stages of its introduction because of unfavourable economics and the problems with the quality of textured yarns. Sustained efforts by Du Pont and others during the last 35 years have solved many of the problems associated with air-jet texturing. Improvements in jet designs and air-jet texturing machines have resulted in the production of better quality air-textured yarns at a much lower cost.

Air-jet texturing is a purely mechanical process in which a high pressure air stream separates the overfed bundle of filaments and intermingles them, imparting a loopy and bulky structure to the final yarn. Since the process does not involve any heat, it is suitable for both thermoplastic and non-thermoplastic yarns.

The characterization of the air-jet textured yarn (hereinafter referred to as AT yarn) is important for its processing and end-uses. Some of the important properties which characterize the AT yarns are: yarn instability; physical bulk; boiling-water shrinkage; size, form and frequency of loops; and tensile properties. Various test methods are available for the evaluation of these properties and the present review provides an insight into them.

2 Measurement of Yarn Instability

The instability of AT yarns is important in further processing so that the end product will retain its spun-like aesthetics. Basically, there are two different approaches for measuring the stability of AT yarns or rather the instability of AT yarns. The term ‘stability’ of AT yarns was first introduced by the Du Pont company. However, Wray stated in 1969 that “The use of the word ‘stability’ for the values obtained by the Du Pont test is unfortunate since the lower the percentage value the more stable is the yarn. A more correct term for this measurement would have been instability”. Thus, a more direct term ‘instability’ came into use and is widely adopted by the industry today.

The two different concepts for the measurement of instability of AT yarns vary in their methods of approach. One way is to characterize the instability by measuring the permanent elongation of the yarn after removing a specific load applied for a constant time and the other is to measure the extension after the application of a constant load. Though most of the methods for the measurement of instability fall broadly under these two approaches, there are wide variations in the amount of load used, time of application of load, specimen length and its form, and the mode of application of load either by hanging it freely or by using a tensile test. Thus, no consensus exists, as
yet, on the basis for the measurement of instability and inevitably, one observes a lack of agreement between the results reported by various research workers.

The detailed descriptions of the various test methods available for the measurement of instability are given below:

2.1 Weight Hanging Methods

2.1.1 Du Pont Method

The Du Pont company recommended a simple stability tester comprising a vertical board with a toggle clamp at the top on which to hang the AT yarn. At a distance of 1 m below this clamp is a marking notch and beneath this is a centimetre scale. A weight hanger is provided for hanging the weights on the specimen. The purpose of this set-up is to measure the permanent elongation of the textured yam after applying a specific load for a constant time and then releasing it, this being an indication of the stability of the texturing effect.

The procedure is illustrated in Fig. 1 and can be explained as follows: A basic load $W_1$ of approx. 0.01 gf/den is hung at the end of the yarn and left on the specimen throughout the test. A 1 m section on the thus tensioned specimen is marked. The specimen is then subjected to a higher load $W_2$ of 0.33 gf/den for 30 s. The permanent elongation in the length of the specimen is measured 30 s after the load $W_2$ has been removed by using the 1 m mark as reference. This percentage elongation is taken as the direct measure of the stability. As per the suggestion of Du Pont, a satisfactory textured yarn must have a stability of less than 5%. Though it appears reasonable to use a 1 m specimen length to facilitate a direct percentage reading, it is not known why a load of 0.33 gf/den is applied and why it is applied for 30 s.

2.1.2 Heberlein Method

The Heberlein company of Switzerland uses a hank of textured yarn instead of a single yarn specimen in its weight hanging test method for the measurement of instability. On a reel of 1 m circumference, the yarn is wrapped to form a small hank of approx. 2500 dtex, the number of wraps being

Number of wraps

to the nearest whole number

As illustrated in Fig. 2, the hank is pretensioned with a basic load of 0.01 cN/dtex for 60 s and length $a$ is measured. Then a higher load of 0.5 cN/dtex is substituted for the above basic load and applied for 60 s and the length $b$ is measured. After 60 s, the higher load is removed and the basic load is again applied to the hank and after 60 s the length $c$ is measured. Two instability values are then calculated.

Instability I ($\%) = \left(\frac{b-a}{a}\right) \times 100$

Instability II ($\%) = \left(\frac{c-a}{a}\right) \times 100$

Instability I measures the percentage elongation of the yarn under a specified load and instability II measures the permanent elongation of the yarn, similar to the Du Pont method. However, it is not made clear why both the values of instability are suggested by Heberlein.

2.2 Instron Methods

2.2.1 Wray's Methods

In the early days of air-jet texturing, when pre-twisted yams were used as feed material, Wray suggested a method for measuring instability by using the Instron constant rate-of-extension tensile tester, which did not suffer from losing yarn twist during testing. From the load extension curve (Fig. 3), he defined the instability of the yarn as follows:

Instability ($\%) = e_r - e_p$

![Fig. 1—Du Pont stability test method [ref. 1]](image1)

![Fig. 2—Heberlein instability test method [ref. 4]](image2)

![Fig. 3—Wray's instability concept [ref. 2]](image3)
where $e_p$ and $e_t$ are the percentage elongations of the supply and textured yarns respectively at a constant load $W$ of 0.33 gf/den corresponding to the higher load used in the Du Pont test.

In this method, an attempt has been made to eliminate the elongation of straight load-carrying filaments of the textured yarn since it was implied that the elongation of textured yarn under an applied load also included the elastic deformation of the constituent filaments. Though it is true that the straight, parallel load-bearing filaments will elongate under applied loads whereas the loop-forming filaments will not; the extents of contribution by the pulling out of loops and the elongation of straight, parallel filaments to the total elongation of the textured yarn are not known. Thus, it is questionable whether the measurements obtained by this method reflect the permanent elongation of the textured yarn.

Sengupta et al.\(^5\) criticised the above method as conceptually incorrect because of the inherent assumption that the extensibility of the textured yarn is a measure of its structural integrity.

Wray\(^2\) also devised a quicker method for the measurement of instability by using a strainometer, which is in principle similar to the Instron method. By using the strainometer, a 5% constant strain is imposed on the yarn as it passes continuously over two rollers and a third roller between these two acts as a sensor to measure the tensions in the yarns, which enables one to calculate the yarn instability.

### 2.2.2 Acar's Method

Acar et al.\(^6\) suggested the use of the load-elongation curves from a tensile testing machine of the Instron type in instability measurements of AT yarns. They used a basic load of 0.01 cN/dtex and a higher load of 0.5 cN/dtex, corresponding to the loads used in the Heberlein tests, and measured the percentage elongation, which is taken as a measure of the yarn instability (Fig. 4). As suggested in their method,

\[
\text{Instability (\%) } = \frac{\text{Elongation between higher and basic load } (\Delta l)}{\text{Specimen length } (l_0)} \times 100
\]

Acar et al.\(^6\) suggested that the elongation of textured yarn under applied loads should be taken as a measure of yarn instability rather than the difference of elongations of the textured and supply yarns, as suggested by Wray earlier, because the extent of contribution of the extension of load-bearing straight and parallel filaments of the textured yarn to the overall elongation is difficult to account for.

In a recent survey, Demir et al.\(^7\) have exhaustively reported on the two methodologies used in the assessment of yarn instability as well as on the effects of test load and duration of application, effects of specimen type and length, and simulation of the weight hanging instability methods, using a tensile tester. They have shown that relaxing the yarn under an applied load for a certain period has an insignificant contribution to the elongation of the yarn (Fig. 5) and on the basis of this, they have simulated the weight hanging methods for yarn instability by using a tensile testing machine of the Instron type. They set the tensile testing machine in such a way so as to extend the yarn until it reaches the required load, the action being immediately reversed when the load is reached so that the conditions revert to zero loading. The permanent elongation of the yarn was measured as shown in Fig. 6, which is obtained from an Instron tensile tester. The results of such a test using the loads specified in the Herberlein tests are compared with the results of other test methods in Fig. 7. The authors claim that the advantage of the
simulation using the tensile testing machine is that it is accurate, faster and relatively easier to perform than the weight-hanging methods. It has also been reported that the test duration and the varying specimen length have an insignificant effect on yarn instability (Figs 8 and 9). The forms of the specimens used for instability tests are also discussed. Their conclusion is that the single yarn specimen is more suitable than skeins and bundles because it is easier to handle and the question of a non-uniformly distributed load through the skeins and bundles does not arise. They overrule the argument of the longer specimen length giving a better overall representation of the yarn characteristics on the basis of the insignificant effect of the specimen length on yarn instability. They also argue that the loads used for the Heberlein and Du Pont tests cannot both be representative of the applied tensions during further processing into fabrics and hence stress the need for further investigation to decide upon a representative standard load based on practical fabric forming process conditions.

Based on their work and above analysis, the authors recommend an improved test method for yarn instability, which is as follows: (a) prepare the tensile testing machine with the following recommended test conditions: distance between pneumatic jaws (i.e. specimen length), 30 cm; crosshead speed, 2 cm/min; chart speed, 10 cm/min; (b) take approx. 50 cm length of textured yarn from a representative package, taking care not to damage the yarn during its removal from the package; (c) clamp both the ends of the yarn in the pneumatic jaws, taking care not to over-tension the specimen during clamping; (d) operate the machine and record the elongation up to a value slightly greater than the load corresponding to 0.5 cN/dtex based on the untextured yarn linear density; (e) from the recorded load-elongation chart, calculate the percentage elongation between 0.01 cN/dtex and 0.5 cN/dtex loads. This percentage elongation gives the instability of the yarn. The above procedure should be repeated on randomly selected samples from different packages and from different places of the same package to obtain reliable and representative test results.

As shown in Fig. 10, the authors have given the test results of various instability test methods for comparison. Though they all yield different results because of the differences in the concepts and assumed parameters on which they are based, they
all show the same basic trend, i.e., increased instability with increasing values of air pressure used for texturing.

Some more possible ways of judging the instability of AT yarns are also reported. One of them is to measure the thread tensile force in the stabilizing zone of the texturing machine on a running yarn. With constant draw ratio, the firmer the loops are tied into the yarn the higher will be the resulting tensile force. Instability value and thread tensile force are inversely proportional in a first approximation.

Another method is to scan the yarn in an optical scanning device which uses photodiode cells prior to and after the tensile stressing and to study the loop size and configuration from which information may be obtained about the stability of texturing effect.

3 Measurement of Physical Bulk

The physical bulk of the AT yarn plays a decisive role in its end-use requirements. For example, bulk requirement for carpet and upholstery applications is highest while for technical applications, such as sewing threads, it is lowest. Apparels need moderate to high levels of bulk depending on their types. Thus, the measurement of bulk and its control within specific limits is important in optimizing the end-use requirements.

One of the simplest methods of measuring bulk is to determine the increase in the diameter of yarn after texturing by using a projection microscope. However, this method is very tedious and prone to many subjective errors. Also, any stretch or tension in the yarn shrinks the loops and gives varied diameters.

Another method of measuring bulk, as suggested by the Du Pont Company, is a simple ratio comparison of package densities of yarn before and after texturing. A length of parent yarn weighing 3 oz (85 g) is wound onto a package and a volumetrically similar package of textured yarn is then wound at the same tension. The ratio of their weights is an assessment of physical bulk.

Another variation of the above method is to compare directly the package densities of parent and textured yarns. In this instance the physical bulk of the textured yarn is given by

\[
\text{Physical bulk (\%) = } \frac{\text{Net weight of parent yarn package}}{\text{Net weight of textured yarn package}} \times 100
\]

where package density is defined as

\[
\text{Package density} = \frac{(M_{p+y} - M_b)}{\pi L (R_{b+y}^2 - R_b^2)} \quad (\text{g/cm}^3)
\]

where \(M_{p+y}\) is the total weight of bobbin and yarn; \(M_b\), the weight of bobbin alone; \(L\), the length of yarn package; \(R_{b+y}\), the radius of bobbin with yarn; and \(R_b\), the radius of bobbin alone.

This method is useful for identically wound packages only since the amount of air entrapped varies for different types of packages which can play a decisive role in the physical bulk. For the same reason, the winding tension must also be kept constant.

Wray reported a method for measuring the bulk of the AT yarns based on woven fabrics made with them. Here, with parent and textured yarns as weft, woven fabric samples of similar construction are prepared. The percentage physical bulk is given by:

\[
\text{Density of parent yarn fabric} \times \frac{100}{\text{Density of bulked yarn fabric}} = \frac{W_p}{T_p} \frac{T_i}{W_i} \times 100
\]

where \(W_t\) and \(T_t\) are the weight per unit area and thickness respectively of fabrics woven with textured continuous filament yarns as weft, and \(W_p\) and \(T_p\) are the corresponding measures for the fabrics woven with the parent yarns as weft.

Wray et al. also reported a refined version of the Du Pont test, which incorporates a more accurate measurement of the various diameters. Accordingly,

\[
\text{Physical bulk (\%) = } \frac{W_p}{(D_i^2 - D_f^2)} \times \frac{(D_i^2 - D_{i,b}^2)}{W_b} \times 100
\]

where \(W\) is the net weight of yarn wound on the package in grams; \(D_p\), the outside diameter of the final package in inches; \(D_b\), the outside diameter of empty package in inches; and the subscripts p and
b indicate the parent and bulked yarns respectively.

Wray et al.\textsuperscript{10} also devised a water absorption test for the measurement of physical bulk of air-jet type bulked yarns. The apparatus for the water absorption test method is shown in Fig. 11. The procedure for the test is as follows:

The water bath is weighed when it is filled with water. A length of 400 yd (366 m) of yarn is allowed to pass through the bath at a speed of 40 yd/min (36.6 m/min) under a 0.1 gf/den (0.9 gf/tex) tension measured at the output. The water bath is again weighed to ascertain the amount of water absorbed by the yarn. The same method is used for both the parent and bulked yarns. The percentage increase in water absorption is given by

\[
\left[ \frac{W_b - W_p}{W_p} \right] \times 100
\]

where \(W_b\) is the weight of water absorbed by the bulked yarn in grams; and \(W_p\) the weight of water absorbed by the parent yarn in grams.

Figs 12 and 13 compare the two sets of typical test results obtained by the water absorption test method and the Du Pont test method as given by the authors for a 107 den/34 filaments Nylon 6.6 parent yarn with a pre-twist of 16.5 (Z) turns/in. Since this method was devised in the early stages of the development of air-jet texturing process, a pre-twisted yarn is used here, which is no longer used for the present-day process. The results in Figs 12 and 13 are for the yarns of air-jet type, which were produced by the method that the authors devised for simulating the air-jet action by a mechanical means\textsuperscript{11}. In Fig. 12, the dependent variable is \% overfeed and in Fig. 13, the overfeed is maintained constant at 11.1 \%, the variable being the linear density per filament of the parent yarn. The figures show that the water absorption test method gives assessments of yarn bulk comparable to those obtained by the Du Pont package density test method, though the values are greatly magnified because the former method is based on a measure of the weight of water absorbed by the yarn. The authors also ascertain from the figures that more experimental scatter is present with the package density test results, despite the accuracy with which the package diameters are measured.

According to a patented method\textsuperscript{12}, the bulk can be obtained by determining the volume for a definite weight of yarn while under pressure. It has been claimed that the method will be useful in assessing the bulk which the yarn will have when fabricated into carpet or other fabrics and the results correlate very well with the subjective assessments. The method involves taking a crimped...
sample in the untwisted state, i.e. with less than 1 turn/in, giving a hot water relaxation treatment to develop maximum bulk and drying and conditioning at 70°F and 65% RH. Weighed samples of exactly 2.0 g are then cut into 1/2-3/4 in. pieces. The cut pieces are then dropped into a hollow stainless steel cylinder of 1.008 in. inside diameter and a round stainless steel piston of 1 in. diameter is slowly lowered in such a way that a final pressure of 3.1 lb/sq. in. is exerted on the yarn sample. The pressure is maintained for 100s and the volume of the compressed yarn is measured. The volume (cm³) divided by the weight (g) of the yarn gives the specific volume (cc/g). Specific volumes of 7-14 cc/g for jet crimped yarns and 3-7 cc/g for others have been reported.

Another method is to wind the same weight of textured and untextured yarns under constant tension on two different cheeses and measuring the percentage increase in the thickness of the package, which gives a measure of bulk. As per this method,

\[
\text{Physical bulk} \% = \left( \frac{\text{Diam. of textured} - \text{Diam. of parent}}{\text{yarn package} - \text{yarn package}} \right) \times 100
\]

Another possible way of measuring bulk is to measure the air permeability of a certain mass of yarn in a constant volume. This method is almost the same as that of micronaire testing of fibres in a sheffield micronaire instrument. The air permeability level can be correlated to an index of physical bulk as that of the micronaire value.

4 Determination of Boiling-Water Shrinkage

Boiling-water shrinkage is the change in length as a percentage of original length of yarn after immersion in boiling water for a specific time. This is one of the very important properties of AT yarns because this determines their dimensional stability during subsequent processing stages and in fabrics. Also, the shrinkage process in the heater zone causes the yarn core to be compressed and long loops to be drawn into the yarn axis whereby the stability of the yarn improves and ‘velcro’ effect is reduced. Many factors, such as heater temperature, processing speed, length of the heater, overdraft to the heater zone, temperature of the draw pin, and the draw ratio in the drawing zone, affect the shrinkage properties of the final yarn and effect of these factors on yarn shrinkage has been studied.

According to Piller the shrinkage of thread structures may be defined as irreversible length change of a thread structure, expressed as the percentage of its shortening, and is the ratio between the difference of the original length and the length after shrinkage \( (L_a - L_s) \) and the original length \( L_a \).

\[
\text{Shrinkage} \% = \left( \frac{L_a - L_s}{L_a} \right) \times 100
\]

where \( L_a \) is the original length; and \( L_s \), the length after shrinkage.

One of the methods in use is to prepare skeins of yarn on a standard denier reel of circumference 1.125m. The number of revolutions of the denier reel is selected as follows:

- 7-29 denier—800 revolutions
- 30-50 denier—400 revolutions
- 51 denier and above—20 revolutions

The skeins are then straightened by hanging them on 1/2 in. diam. horizontal rod and attaching a 4.68 lb (2.12 kg) weight onto them. The weight is then raised 6 in. vertically and allowed to fall freely. Raising and dropping of the weight is repeated until a constant skein length \( L_1 \) is obtained. The skeins are then wrapped in cheese cloth, 8 skeins to a bundle, and placed in a boil-off pot at 100°C for 70 min. This is followed by a 5 min spin cycle in a commercial washing machine. The skeins are conditioned at 74°F (23.3°C) and 72% RH for 24 h after which the skein length \( L_2 \) after boil-off is measured in a manner similar to that of \( L_1 \). The percentage boil-off shrinkage is given by

\[
% \text{Boil-off shrinkage} = \left( \frac{L_1 - L_2}{L_1} \right) \times 100
\]

Another method consists in first applying a 0.1 gf/den load on a skein of yarn and measuring its length \( L_0 \). Then the weight is replaced by a lighter weight of 0.005 gf/den and the loaded yarn is immersed in boiling water for 30 min. Then the yarn is removed, air-dried, loaded again with the original weight of 0.1 gf/den and the new length \( L_i \) is recorded. The percentage shrinkage is given by

\[
% \text{Boil-off shrinkage} = \left( \frac{L_0 - L_i}{L_0} \right) \times 100
\]

A method has been used in which the yarns are mounted on a special frame which allows the yarn to shrink but does not allow the yarn to rotate or lose twist. The entire frame is then immersed in a constant temperature bath at 90°C for 60 min. The change in length is expressed as a percentage of original length to obtain yarn shrinkage.

In yet another method yarn hanks are exposed...
to air at 180°C for 5 min, suspended for 15 min in boiling (95°C) distilled water and finally air-dried at 50°C in a drying cabinet. The shrinkage index (A) is given by \( [(a-b)/a] \times 100 \).

where \( a \) is the yarn length prior to shrinking treatment; and \( b \), the yarn length after shrinking treatment.

Thus, in principle, the methods are all similar where shrinkage is expressed as per cent change in length from original length after hot water/air treatments.

5 Determination of Size, Form and Frequency of Loops

Smaller size and larger frequency of loops yield a better covering power in the fabric and reduced velcro effect. The configurations of loops also play an important role in the warmth and comfort properties of the final product.

Wray\(^2\) suggested an optical test for the characterization of Taslan textured yarns as shown in Fig. 14. Here, from the optically magnified image of the textured yarn, overall diameter \( (D) \) and core diameter \( (d) \) are measured to determine the loop size of a textured yarn, loop size being equal to \( (D-d)/2 \). This is of course a measure of the maximum loop size rather than an average size. In this microscopic method, specimens of 50 mm length are mounted on a microscopic slide in a tensionless state and viewed at a magnification \( \times 25 \). On a section of 0.6 mm width in this specimen, overall and core diameters are measured and loop sizes are computed. To measure loop frequency, the specimens are sandwiched between two microscopic slides to flatten the projecting loops into a single plane and on a characteristic section of 2.5 mm the number of loops is counted to determine the loop frequency. Even though this method is much simpler and adequately signifies the yarn structure, it is extremely tedious and prone to many subjective errors.

Wray\(^21\) devised an improved version of this test method, wherein he used a microprojector instead of a microscope and mounted the yarn by means of a clamp and a weight. On the movable stage of the microprojector there is an open slot and the yarn is pulled through and brought over this slot after which the toggle is closed. The free end of the yarn is taken over a guide at the opposite end of the slot and tensioned lightly by means of a small weight. Thus, the yarn is now ready for observation and a portion of this yarn can be viewed through the open slot.

Piller and Lesykova\(^22\) listed the key geometrical characteristics of AT yarns as the type, orientation, form, frequency and dimensions of the arcs and loops. To characterize these geometrical parameters they defined the structure of an idealized AT yarn as shown in Fig. 15. On this basis, the loop structure of the AT yarn may be divided into four parts: a distinct yarn core \( (d) \), a uniform base mass of loops of two layers \( (d_1) \) and \( (d_2) \) in which the geometry of these layers is determined by the loop length \( (l) \) and loop height \( (h) \); a less uniform, more extended and predominantly elliptical shaped loops of layer \( (d_3) \) which are mainly responsible for the surface make up of the AT yarn; and the diameter of the filament yarn. However, the authors admit that the structure of an actual AT yarn differs considerably from that of an idealized yarn and for this reason determining the cited characteristics is a very complex and sometimes impossible task.

Bock\(^8\) described an opto-electronic instrument, devised by the Institute fur Textiltechnik of RWTH, Aachen, for assessing the loop size and frequency. Here the shadow of the loop yarn is projected on to a line of 256 photodiodes. The light impingement on the individual diodes is evaluated electronically yielding a corresponding video signal. This may be recorded analogously as the yarn diameter and evaluated statistically by a computer. One possible evaluation is to record the fre-
quency of loops exceeding a predetermined size. The author used a loop size of 1 mm as the threshold for the yarns examined.

Kollu used a microdensitometer to determine the surface characteristics of AT yarns. The optical system of the microdensitometer consists of a double beam, an optical attenuator and a photomultiplier detector. The microdensitometer operates on the principle of a true double beam light system, in which two beams from a single light source are switched alternately to a single photomultiplier. If there is a difference in the intensity of the two beams a signal is produced by the photomultiplier, which in the amplified state causes a servo motor to move an attenuator which is made to record the density of the specimen at any particular part. The specimens used here are the negative photographic films of the AT yarns and the maximum area that can be scanned is 240 mm x 115 mm. As shown in Fig. 16, when the negative is scanned at various distances from the core along the length of the yarn, each fibre end results in a peak owing to the difference between the image density and the background density. Thus, it is possible to determine the number of fibre ends at different radial positions relative to the core. This method is used graphically to assess the overall and core diameter and thereby to obtain an estimate of the loop size. Another possibility is that the number of loops can also be estimated. However, this method is tedious and time consuming, requiring a microdensitometer which is not a standard piece of equipment in textile testing. Also, the yarn itself cannot be used as a specimen and the scanning length is very limited.

Recently Acar et al. have devised an instrument interfaced with a microcomputer for the rapid analysis of textured yarn sample over a representative length. The device consists of a line scan sensor positioned at right angles to the axis of the yarn and placed at the focal plane of a SLR camera, which facilitates the use of various lenses, and a bellows unit for variable optical magnification. Yarn is moved at a steady speed, within a range of 10 m/min, by a yarn handling device, which applies a slight tension to the yarn. A light source casts the shadow of the yarn onto the sensor and as the yarn moves relatively to the sensor, the latter progressively scans the shadow of the yarn so as to build up data providing an image of a representative length of yarn.

The shadow of the yarn cast onto the sensors alters the state of the signal from background level to maximum. By setting up a suitable threshold level these signals can be identified as low or high and hence an image of the yarn can be built by progressive scanning. The cumulative data for each individual sensor will produce a distribution of signals that are high or low (Fig. 17). The distribution of the acquired data shows that the core of the yarn is very distinct and hence determining the core diameter is relatively simple. By statistically analyzing the amplitude and spatial distribution of the image data, criteria such as the yarn mean diameter, loop size and frequency can be derived, and the quality of the textured yarn can be rapidly ascertained.

6 Determination of Tensile Properties

The tensile properties are of particular importance in any yarn to withstand the stress and strain during further processing. Generally, AT yarns are inelastic and have lower tensile strength and ex-

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Fig. 16—Illustration of the microdensitometer technique [ref. 23]

Fig. 17—Histogram obtained from sensor signals [ref. 24]
tension at break than their feed materials. The reduced mechanical properties are clearly due to the yarn structure of the AT yarns.

Piller\textsuperscript{26} explained the force elongation curve of AT yarns as follows: “At first a short section of the curve agrees with the elasticity modulus of the material. When the adhesive friction is overcome, the individual loops begin to shift with respect to one another and become shorter. The force-elongation curve becomes flatter, the denier is significantly reduced. At the same time the bulk of the yarn is observed to decrease. The yarn elongation continues to a certain limit at which the yarn breaks. But this does not mean that the loops are completely pulled from the yarn at the moment of break”. He also stated that the force-elongation diagrams of AT yarns approximate to those of spun yarns.

Reporting on the tenacity and elongation of AT yarns, Piller\textsuperscript{22,26} claimed that the total strength of AT yarns is principally made up by those elementary filaments that do not form distinct loops and arcs. In the conventional AT yarns, elementary filaments make up a fifth to a quarter of all filaments. During texturization, tenacity drops by 40-50\% in the case of regenerated cellulose fibres\textsuperscript{22}. He also ascertained that the tenacity of AT yarns satisfies the requirements for knitting and weaving machinery and today tenacity is by no means considered to be a sufficiently objective quality criterion, although standards and test instrument technology keep it alive in laboratories.

With regard to the elongation of AT yarns, Piller\textsuperscript{22,26} reported that it is determined by the mean elongation of that portion of the elementary filaments that forms the yarn core. So, as in the case of breaking tenacity, the breaking elongation of AT yarns is determined by the average breaking elongation of the elementary filaments making up the basic yarn. He also stated that the AT filament yarns may be regarded as low-stretch yarns, whose elongation properties approximate those of staple yarns.

7 Conclusion

The evaluation of various test methods for the properties of AT yarns shows that there is a lack of standardization of the methods for the important properties such as bulk and instability.

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