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QUALITY CONTROL IN THE KNITTING INDUSTRY[1/]

by

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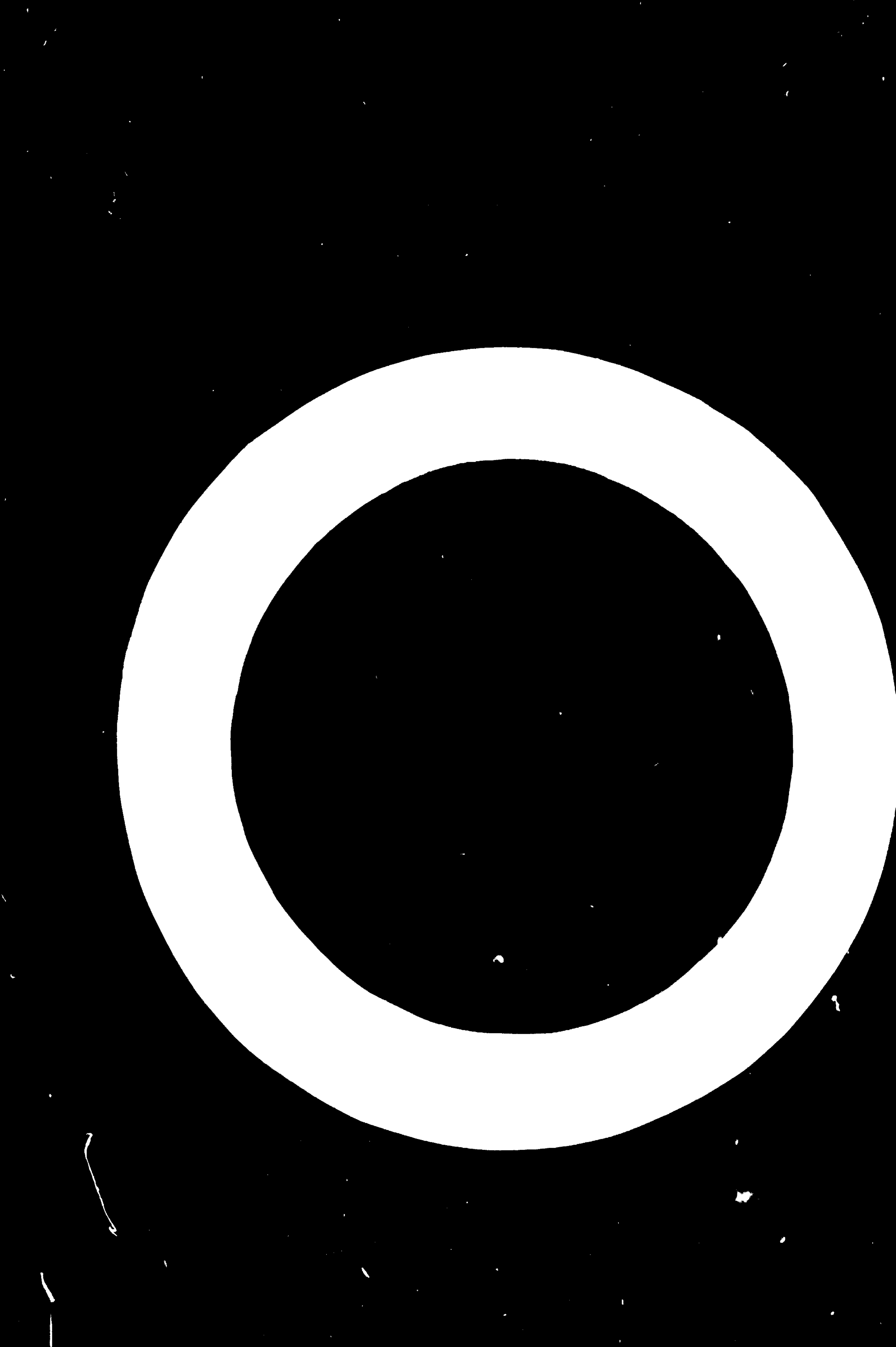

1. INTRODUCTION

Quality control can be defined as the regulation of the degree of conformity of the final product to its specification. This specification may be objective and formal but in knitted fabrics it is often subjective and difficult to define. A discussion of quality control in knitting must therefore begin with a consideration of the objective properties of the fabric which need to be controlled if both the objective and subjective specifications are to be met. The number of these properties is very large but they can be conveniently divided into three groups.

(i) The geometrical properties of the fabric. This group of properties includes the average, as well as the variability in, loop shapes. The average loop shape together with the total number of loops in the various parts of the fabric determine the fabric dimensions. In addition, however, the variation of loop shape affects the fabric appearance. The colour design of the fabric can also be considered to belong to this group of properties. The retention of these properties during wear forms part of the second group of properties but their retention during wetting and drying, washing and any other water treatment is most usefully considered under this heading.

(ii) The mechanical properties of the fabric. The basic mechanical properties of the fabric, i.e. the load-extension, shear and bending properties are in themselves of no interest in the quality assessment of the fabric. These properties, however, are of importance as they play a major part in determining the subjective properties of handle, drape and sleaziness. The hysteresis of these properties also governs the retention of the geometrical properties of the fabric during mechanical handling in subsequent wear, and in particular, determine the "bagginess" of such fabrics.

(iii) The retention properties of the fabric comprise a miscellaneous group of properties relating to the ability of the fabric to retain its initial characteristics during use. The most important members of this group are the abrasion resistance, pilling resistance and colour fastness.

The simplest quality control scheme consists of testing all these properties of the final finished fabric, either on a sample from or on the totality of all the fabrics produced, and discarding all fabrics or batches of fabric whose test values lie outside predetermined limits of the specified values. Such a quality control scheme would be highly uneconomic for two reasons. Firstly because it would involve a needlessly high cost due to waste of finished product. The waste would always be lower if the control scheme was based on the control of the input raw material (acceptance testing) and the control of the processing variables. Secondly, because it involves an excessive cost in testing since it will be shown in the next section that by controlling certain important raw material and processing variables, many of these properties of the finished fabric are automatically kept within sufficiently close limits. Control of the process and raw materials produces, therefore, a large cost saving, which is of importance since an elaborate system of quality control forms a large charge on the total cost of production of knitted fabrics. Some of the fabric properties detailed above cannot, however, be controlled in this way and it is necessary, therefore to do some testing on the final product. To differentiate between the properties which can be reasonably controlled during the process and in the raw material and those which cannot, it is necessary to look briefly at the theoretical background, i.e. at our knowledge, of the way in which these various groups of properties are governed by either raw material or processing alterations.

2. THEORETICAL BACKGROUND

Doyle in a classical paper showed (1) that for a large range of plain weft-knitted fabrics the stitch density of the fabric (i.e. the number of stitches per unit area) was inversely proportional to the square of the stitch length, ℓ, i.e. the length of yarn knitted into each stitch. Munden extended this work and showed (2) that in fact there were three important geometrical constants for plain weft-knit fabrics, viz. (i) the product of the number of wales per unit length and the stitch length, (ii) the product of the number of courses per unit length and the stitch length, and (iii) the stitch density times the stitch length squared. These constants were shown to be independent of the tightness of knitting or cover factor of the fabric defined as the ratio of the square root of the linear density or Tex of the yarn to the stitch length, i.e. $\sqrt{Tex}/\ell$. The constants, however, did vary with the state of "relaxation" of the fabric and to a smaller extent, with the type of fibre used. Munden introduced the concept of the completely relaxed state of the knitted fabric, a state to which all fabrics tend to relax. Subsequent work has been devoted to (i) finding the best conditions for obtaining this relaxed state (3,4) and (ii) determining Munden's three constants for various knitted structures in this relaxed state (5,6). The most complete relaxation is apparently achieved by gentle agitation in water at 100°C followed by tumble drying at 80°C for 30 minutes. This work has shown that the average dimensional properties of all relaxed weft-knitted fabrics is dependent solely on the stitch length and the structure. Although the geometry of "grey" fabrics is slightly dependent on (i) the fabric cover factor (ii) the machine settings for complex fabrics and possibly (iii) the coefficient of friction between the yarns, the controlling parameter is still the stitch length. For set fabrics the geometry is also dependent on the setting treatment, but there is a tendency, except in a severely strained and heat-set man-made fibre fabric, for even the set fabric to approximate on wet treatment to the initial relaxed state of the fabric.

There is no similar concensus of agreement on the geometrical properties of warp-knitted fabrics (7,8), but here also the stitch length plays a larger part in determining the final geometry than any other factor. The important conclusions we can draw from all this work on fabric geometry are :

(i) The control of stitch length is essential in controlling the final dimensions of the fabric.

(ii) These final dimensions are also affected by other factors, including the manufacturing history of the fabric, but in general fabrics tend to relax to a state which is governed solely by the stitch length.

Two separate types of knitted fabrics constitute special cases of the above rules and these are felted wool fabrics and fabrics made from bulked yarns. Munden has shown that certainly in felted fabrics (9) and most probably in bulked yarn fabrics also, the geometry is still determined by the stitch length but that this length is no longer the length originally knitted into the structure but by a shorter length. This decrease in length is brought about in the first case by the felting action and in the second case by the natural tendency of the yarn structure to collapse. In a felted structure, the felted stitch length varies with the feltability of the raw material, the felting time and the cover factor of the fabric. For the bulked structure the collapsed stitch length depends on the cover factor of the fabric and the retractive properties of the yarn, i.e. the crimp rigidity of the yarn. In knitted fabrics made from bulked yarns, these two factors must also be controlled but, since for a given count of yarn the cover factor is already controlled by stitch length control, the only extra factor requiring control in bulk knit fabrics is the yarn crimp rigidity.

We have thus far considered only the average overall properties of the stitch geometry. There are, however, other more detailed properties which need to be considered. Spirality of knitting is defined as the angle between the line of the courses and a line at right angles to the wale line. In a flat bed fabric this angle is normally zero but if the fabric is made of twist lively yarn the angle of spirality can be as large as 20°. If the angle is greater than about 5° the fabric is considered to be defective and the use of twist relaxed, twist balanced or S and Z twist yarns in alternate courses must be considered. Circular knitted fabrics have a natural spirality which is usually not noticeable but if the feeders on the knitting machine are too close to each other, this may also result in a degree of spirality which is unacceptable.

In addition, the appearance of the individual loops is affected by the spacing of individual needles on the machine and the variation in yarn count and twist from one loop to the next. The effect of the needle spacing and imperfections decreases as the fabric is relaxed but for yarns which are plastically deformed during knitting the loop appearance may be permanently affected by the initial needle spacing.

As the stitch length is of such importance, a brief resume of the processing variables which affect the stitch length is also needed. When using a positive yarn feed the stitch length is determined by the ratio of the rates at which yarn is fed to the machine to the rate at which loops or stitches are being formed. The yarn feed, however, depends not only on the speed of the yarn but also on the tension at which it is being fed into the machine. For the same yarn speed but at varying feed tensions, the effective feed rate will be lower for the higher tension since, due to the yarn extensibility, effectively less yarn will be fed into the machine. For normal low extensibility yarns this effect is normally negligible, but with elastomeric yarns, for example, the control of input tension as well as yarn speed is an integral part of stitch length control using a positive feed mechanism. With bulked yarns the positive feed can only be run effectively when the tension is sufficiently [illegible] at [illegible] [illegible] tive feed control [illegible]. [illegible] warp knitting [illegible] [illegible] weft-knitting machines. [illegible] possible positive feeds are [illegible] for jacquard circular [illegible] [illegible] addition, operatives do not like positive feeds on weft-knitting machines due to the difficulty [illegible] during [illegible] a yarn break. [illegible] usually [illegible] that the positive [illegible]. As a result of [illegible] two [illegible], [illegible] advantages, are [illegible]

[illegible] yarn is drawn [illegible] the yarn package [illegible] from [illegible] ve just been forme[illegible] fraction [illegible] [illegible] depends on the build-u[illegible] the knitting point and from [illegible] ting point [illegible] when a negative [illegible] on :

(i) The average yarn [illegible] at the feed point;

(ii) The cam position [illegible]

(iii) The coefficient [illegible] between yarn and needles and sinkers;

(iv) Needle timing on dial and cylinder machines;

(v) The yarn acceleration;

(vi) The yarn linear density;

(vii) The length of yarn from package to feed point.

The second tension build-up is, in addition, determined by :

(viii) The cloth take-down tension;

(ix) The yarn fabric coefficient of friction.

These factors cannot all be readily controlled as, for example, they are affected by the humidity and temperature of the air in the knitting shed. It is common practice, therefore, to determine the yarn speed by use of a yarn speed meter and the stitch length is then controlled by adjusting the cam height position. The yarn speed meter is only suitable for stationary cam box, circular weft-knitting machines, but a yarn length counter can be used for rotating cam box circular machines and for flat bed knitting machines. In certain cases where the stitch length varies across the fabric it is possible to measure the stitch length non-distructively in the knitted fabric by extending a known number of courses or wales to their maximum extension and then measuring their width or height as the case might be - a typical instrument for such a purpose is the Hosextender. The knitting machine can then be brought back to correct operation by once more adjusting the cam positions after any of the above measurements of stitch length have been carried out.

In addition to controlling the stitch length it is also desirable to keep the maximum tension during knitting under relatively course control as excessive tension will produce excessive press-offs or broken loops. The above-mentioned analysis shows that this tension is mainly determined by the input tension, the coefficient of friction of the yarn against the needles or sinkers, and the stitch length. The input tension on a negative feed machine can be controlled by a tensioner, while on a positive feed machine it can be controlled by adjusting the cam height. The importance of measuring the remaining variable, the yarn friction, will be referred to again in the next section.

Our knowledge of the mechanical properties of knitted fabrics is much more limited. The load-extension behaviour of rib fabrics (1.) and warp-knit fabrics (13) has been studied and surveys of the bending properties of warp-knit fabrics have been carried out, but no published work has as yet appeared on the shear behaviour of knitted fabrics. However, it has been shown (14) that for all the fabrics studied, the mechanical properties are controlled by the bending and shear properties of the yarn and the stitch length of the fabric. For example, the load-extension properties in the wale direction are governed by the ratio of yarn bending modulus, B, to the stitch length cubed, i.e. it is a function of B/ℓ^3. Similarly the coursewise stretching modulus of rib fabrics is a function of G/ℓ^3, where G is the shear modulus of the yarn. It is [illegible] that all the elastic properties [illegible] extensively studied, are determined [illegible] the bending and shear moduli of the yarn and the [illegible] length.

[illegible] frictional component [illegible] the [illegible] [illegible]eable part in the hysteresis properties [illegible] frictional component [illegible] adversely affect the recovery properties [illegible] however, difficult to [illegible] or control the component [illegible] knitted fabrics, as it [illegible]ed by both the internal [illegible] in the initial and in the [illegible] fabric and the coefficients of friction between yarns [illegible].

The long-term retention properties have been investigated in considerable detail by many authors but these studies have shown that these properties are determined by so many raw material, fabric structure and processing - especially finishing - variables that the only practical method of ensuring that the final result has been achieved is by the testing and discarding, when necessary, of the final product. One obvious exception is the colour fastness of yarn dyed fabrics where the colour fastness can be checked by acceptance testing of the raw material.

Colour fastness control is such a common textile problem that it will not be considered any further in this specialised study. While abrasion resistance is very largely a question of fabric structure and raw material specification, it is also affected by finishing treatments and cannot usefully be checked except in the finished fabric. It has been shown that pilling (15) resistance is related to the cover factor of the fabric but it also depends on both the fibre properties and the finishing routine. Beside routine maintenance of the cover factor, which is required for many other purposes, pilling can also be checked only in the final finished fabric.

A difficult practical problem is the control of the dimensional stability of the knitted fabric. It has already been seen that grey fabrics will always tend to shrink to a relaxed condition; this involves an area shrinkage of some 12 - 15% and can result in many customer complaints. The dimensional stability, especially after the fabrics have been set, is dependent on many factors in their previous processing history and the only sensible method of control will be based once more on the testing of the final finished product.

3. CHOICE OF FACTORS TO TEST

It is proposed to use the above information to construct a reasonable overall testing programme for a knitting factory ignoring the economics of quality control. In view of our lack of knowledge of these economic factors in the quality control of knitted fabrics it is then only possible to indicate in outline how this programme would be modified by such considerations.

The testing programme is summarised in the Table below :

(a) Yarn Tests	(b) Process Control	(c) Fabric Tests
(i) Count and count irregularity	(i) Stitch length	(i) Abrasion resistance
(ii) Crimp rigidity	(ii) Input tension	(ii) Pilling
(iii) Strength, extensibility & hysteresis	(iii) Fabric design	(iii) Dimensional stability to washing
(iv) Twist and twist liveliness		(iv) Colour fastness
(v) Friction		(v) Irregularity of stitch formation
(vi) Bending modulus		

Let us briefly consider each of these tests in turn, mentioning their purpose, methods of test, probable relative frequency of testing required, and relative cost.

a(i). Yarn count and count irregularity. There are many standard methods for measuring yarn counts (16) and a proportion of knitting mills employ such methods for routine quality control. It is clear from the previous section that, taken in conjunction with stitch length control, it provides a very simple means for controlling fabric cover factor. However, for commercial reasons it is highly desirable to maintain a closer control on count than would be justified by the need to maintain a constant cover factor. Yarn is purchased by weight while the knitted garment is sold on the basis of fabric area. If, for example, the yarn is 5% heavy the manufacturer will effectively increase his raw material costs by 5% (as it is never practical to alter the fabric specification for each batch of yarn to match the average yarn count). Count determinations are therefore used not only to maintain quality but also as a basis for claiming compensation from the yarn producer.

While the determination of yarn count is standardised and relatively simple, the number of possible methods and derived statistical values for yarn irregularity determinations is large and there is no universal agreement as to the most suitable test method. Inter-laboratory trials have tended to show that the variance of weight of 10 cm and 1 metre lengths are the most desirable and these values can be readily determined on electronic irregularity testers (17). In addition, some check on the number of slubs, knots and thin places is desirable to maintain efficient production (18).

a(ii). Due to the effect of crimp rigidity on the effective stitch length in fabrics, made from bulked yarns, it is essential to check the uniformity of the crimp rigidity of the yarns supplied; otherwise streaks will be produced in the final fabric. Standard methods of test have been devised for measuring the crimp rigidity (19). These have, however, been criticised as not being well correlated with the actual retraction behaviour of bulked yarns in knitted fabrics. An alternative scheme of test (20) has been suggested which consists of taking a skein of yarn, relaxing it on the bed of a Hoffman press, and steaming it for two minutes. The skein length is then determined under a load of 0.1 g/den (ℓ_1) after one minute and then after the load has been reduced to 0.002 g/den (ℓ_2) for a further minute. The crimp rigidity is defined as $100(\ell_1 - \ell_2)/\ell_2$. This method, however, has not been extensively tested and for comparative purposes the standard methods of determining crimp rigidity are known to be satisfactory and consequently preferred, until further testing has taken place. However, in this connection, see also section 4 of this paper.

a(iii). To prevent press-offs and broken loops it is as well to check the yarn strength. This, however, is much more important for yarns of relatively low strength, e.g. wool yarns, than for yarns of relatively high strength, e.g. bulked nylon yarns. A knowledge of the maximum breaking strength and the variability of the maximum strength is required. Several automatic instruments are available for this purpose.

The yarn extensibility is of importance in the specialised knitting of elastomeric covered yarns, but in other circumstances there is some disagreement on the importance of this parameter. The fibre extensibility and diameter are important in deciding whether the yarn can withstand the sharp bends produced by the knitting actions. It is desirable to test yarns during the development stage for this reason but it is unlikely that the fibre properties will change markedly from their specified values and it is unnecessary, therefore, to carry out routine yarn extensibility testing for this reason. However, it has been suggested that the dynamic extensibility of the yarn has an effect on the uniformity of the loop shape and where this is important, e.g. in stocking manufacture, such tests may need to be considered. This test is discussed further in Section 4.

The yarn hysteresis characteristics are important in that they affect the "bagginess" etc. of the fabric but suitable tests for the complete range of yarns used in knitting are not available nor is it certain that they are necessary for routine quality control testing. A test procedure for power net fabrics is available (21) but modifications to this test have been suggested recently (22).

a(iv). A simple examination of the yarn for twist liveliness, based on a visual assessment of its tendency to snarl, is quite sufficient to prevent fabric faults from this cause. The measurement of the actual twist and twist variability is of importance only with staple fibre yarns and even for such yarns only spot checks are required to ensure that the yarn quality is being reasonably well maintained.

a(v) The measurement and control of yarn friction. As was noted above, the yarn friction affects both the maximum knitting tension - and hence the tendency of the yarn to break during knitting - as well as the stitch length in machines using negative feeds. Though the stitch length should be controlled using a yarn speed meter, or similar device, it is still desirable to maintain some check on the yarn friction to ensure efficient production and to check the quality of the anti-friction dressing applied to the yarn. It is essential that yarn friction be tested under dynamic conditions as in the Shirley yarn friction tester (23).

a(vi). The direct determination of the yarn bending modulus is difficult and the methods available are only suitable for use in a research laboratory. The bending modulus, however, is unlikely to vary to any extent for yarns made from fibres of constant denier. As the denier of man-made fibres does not vary greatly, it follows that for this purpose it is sufficient to check the fibre diameter of staple fibre yarns made from natural fibres. Such a check is common practice (24) especially for woollen yarns. The yarn bending modulus is dependent on the number of fibres in the yarn and the bending modulus of the individual yarns. As the fibre bending modulus depends on the fibre diameter and as the number of fibres in a yarn of given count also depends solely on the fibre diameter, a check on the fibre diameter is usually a sufficient check on the yarn bending modulus.

b. The stitch length and yarn input tension are the two critical processing parameters that need to be controlled. Some form of yarn speed meter is essential even when using a positive feed to provide a calibration for the settings on the positive feed. Methods of checking the yarn speed meter are discussed later under fabric testing. There are two forms of stitch length meter. The yarn speed meter which determines the rate at which yarn is fed in, and the yarn length counter which finds the total length of yarn fed in from the moment the instrument is activated until the feed is stopped. The yarn speed meter is suitable for circular machines with stationary cam boxes. The yarn length counter can be used on rotating cam box machines by clamping the instrument to the rotatable feed mechanism and then noting the change in reading after the machine has made a known number of revolutions. It can also be used on a flat bed machine by finding the yarn length fed in for one passage of the knitting cam or slurcock across the knitting bed. To convert this reading to stitch length it is necessary to know how many needles are actually knitting during the test.

A fair number of industrial instruments are available for yarn tension measurements, from small hand operated mechanical instruments to complex electronic instruments. None of these are very effective for determining the absolute value of the yarn tension but all give reasonably good comparative values suitable for quality control purposes. It is, however, desirable that the same type of instrument should always be used for checking yarn tension, as different types of instruments give different absolute readings.

The yarn tension and stitch length should be checked frequently. The frequency depends on the number of product and raw material changes but it should also be based on the experience gained from previous determinations of yarn stitch length or the likely rate of drift in such measurements. As a guide, however, such checks should be made at least once a day. During such a determination a routine visual inspection of the design, if any, should be made on the material coming off the machine to check the working of the pattern selector.

Where the direct measurement of the stitch length is not practical, the measurement of the fully stretched length of a known number of courses or wales can be substituted for such a direct measurement, but the time honoured practice of the measurement of the courses per inch as knitted on the machine is both unreliable and often misleading. This common practice results in many difficulties in many existing quality control schemes in the knitting industry.

c. Although there are doubts whether any of the standard tests for abrasion and pilling resistance are very closely correlated with wear trials, their use in the maintenance of quality control standards has been justified by experience. The dimensional stability of fabrics is usually determined by measuring the shrinkage after washing the sample, using a specified procedure, in a standard home washing machine. For warp-knitted fabrics one standard procedure is to measure the shrinkage after immersion in boiling water for [illegible] minutes (24). The standard relaxation procedure described in section [illegible] would probably be more suitable but it is not, as yet, a standard approved by any consumer organisation and it will probably be some time before this more scientifically justified procedure becomes universal practice.

The above checks on the final product are useful, not only to prevent the sale of sub-standard merchandise, but also to enable the quality control department to provide advice to the processing section on the limits of the processing variables within which satisfactory material can be produced. As an example, it is not possible to predict the limits of the stenter stretching to which a knitted fabric can be subjected and still produce a reasonably satisfactory product. A quality control division which has available data on the stitch length, relaxed state, stretching conditions and final stability of the companies products is in a position to provide advice on future practice.

Final inspection of the fabric or garment for irregular stitches, dropped stitches and rough checks on the dimensions (especially for garments) are routine tests in all knitting plants. These checks are important but the practice in some mills of relying solely on such checks for their quality control is a result of a lack of understanding of the basic geometrical properties of knitted fabrics. Such rough dimensional checks may be meaningless if performed on an unrelaxed fabric and will result in needless confusion if the fabric is later returned because of dimensional instability. When final checking is, however, combined with a thorough programme of quality control it provides essential information for checking plant operation.

A further desirable check is the occasional direct determination of the fabric stitch length. This is carried out by unroving a known number of stitches from the fabric and then measuring the fully stretched length of the unroved yarn (at a load of 0.2 g/den.) Such tests enable the quality control laboratory to keep a check on the processing control of this important parameter (25).

4. GENERAL DISCUSSION

As was mentioned previously in the introduction, such a quality control scheme cannot be considered purely on its ability to maintain a high quality product. The cost of the scheme and its benefits must be considered together. The scheme outlined above is more detailed than any existing quality control scheme known to the author. The reason for the relatively small expenditure usually allocated to quality lies in the relatively low added value of many knitted products and the consequent necessity for keeping costs to a bare minimum. Knitting mills rarely conduct acceptance tests for their yarns because of economy. In many instances this has been justified by the fact that there is an excess of yarn spinning capacity so that the knitter can rely on the spinner to keep his yarns up to specification otherwise he will lose future orders. Even where such conditions operate it is as well to check the yarn count because of the large effect deviations in the yarn count can have on the profitability of the knitting operation.

A minimal quality control scheme would consist of the routine testing of yarn count, processing controls as outlined in section 3b, and the final inspection of the fabric. In addition, occasional spot checks on the dimensional stability and colour fastness of the finished fabric are also required. Between such a minimal scheme and the complete scheme outlined in section 3 lie many intermediate schemes, the choice of any scheme depending on the type of fabric or garment made, the added value of the product, and the state of the industry.

In recent years two further acceptance tests for knitting yarns have been suggested : (i) The determination of the dynamic modulus and (ii) the determination of the "knittability" of the yarn based on the Lawson testing machine. The Lawson machine consists of a single cylinder knitting machine on which the yarn can be knitted with or without a positive feed. The yarn feed tension can also be controlled by means of automatically controlled cams. The torque required to rotate the machine under controlled conditions is then measured. The theoretical connection between the parameters measured in both of these test methods and the yarn behaviour during knitting is, as yet, only partially understood, and the use of these instruments depends very largely on empirical correlations. Both instruments have thus far only been used for development work on yarns for the knitting industry and certainly at the present time their use for routine acceptability testing of yarns is not in general justified. An exception is the use of the Lawson tester for knitting samples from new batches of yarn. As the machine has such a close control of stitch length and yarn tension, the presence of streaks in the sample is a very good indication of excessive variation in the yarn bulk rigidity. The Lawson tester is used extensively for this purpose.

This very brief survey of quality control has specifically excluded any topic of general interest to all sections of the textile industry, e.g. the statistical methods for setting quality control specifications, the control of colour fastness, etc., since the discussion of such topics, important as they are, would have needlessly condensed the discussion of topics of particular interest to the knitting industry.

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