GARMENT PERFORMANCE:
EXTENSIBILITY, SPIRALITY, COMFORT AND FIT

1. INTRODUCTION

The STARFISH system is aimed primarily at helping knitters and finishers to produce a fabric which has the required performance in terms of weight, width, and shrinkage. However, these fabrics have to be made into garments, so it is important to understand some of the fabric characteristics which are important in determining garment performance and garment fit, even if some of these characteristics can not at present be predicted by STARFISH.

An important growth area in the market is knitted garments for casual leisure wear where comfort is a key aspect of performance. There are many factors which affect the comfort of a garment, but one of the most important aspects is the fit - i.e. the relationship between the size of the garment and the body size of the wearer - and the way that the fit changes over the lifetime of the garment. This paper will outline some of the fabric characteristics which influence the performance of knitted cotton garments in respect of fit and fit retention, particularly for close fitting garments such as T-shirts, polo shirts, sports shirts, and ladies' tops.

2. BASIC CONCEPTS

The comfort of a close-fitting garment depends to a large extent on how tightly it hugs the body. These garments are designed to be close fitting but not tight. Therefore, the size of a given item has to be large enough to fit comfortably around the largest body expected in a given size range, but small enough so that the smallest member of that size range still has a close-fitting garment. In the length direction, the garment must be long enough to reach well below the waistline of the largest person in the size range but short enough to be manageable by the smallest person. These garment length and width requirements apply not only to the new garments but must continue to be met throughout the useful life of the garment.

Obviously, if a garment is to fit properly throughout its lifetime, then: -

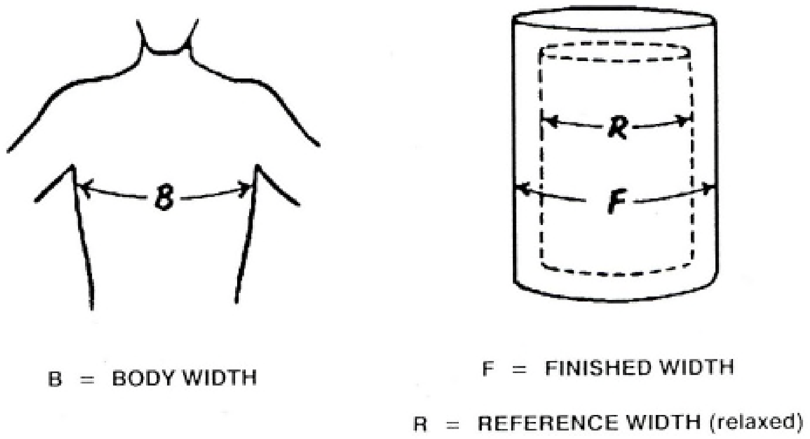
a. it must be correctly sized in the first place - in particular, the size interval must be small enough that excessive demands are not being placed on the range of body sizes which have to be accommodated

b. the shrinkages and the width extensibility of the fabric must be such that a reasonable fit is maintained for all of the people within the given size range,

In order for a garment manufacturer to be able to design a rational size range, with appropriate size intervals for a given fabric and garment style, he has to know about the relationships between the different body size parameters (e.g. chest girth vs height) and the performance of his fabric in terms of shrinkage and extensibility. A great deal of basic research in this area has been carried out by Starfish collaborators at the Swedish Textile Research Institute (TEFO), who have gathered extensive data on these relationships, have developed specialised garment testing equipment, and have established a rational garment sizing system based on these data and test equipment.

At CTI, we have developed a useful concept as an aid to rational garment sizing which we have called the “Reference Fit”. (Fig. 1) This is the ratio between the size of the garment in its *Reference State* and the body size in question; R/B in the diagram. For a close-fitting garment, the Reference Fit will be 1.00 or lower, for a loose fit it will be greater than 1.00.

Figure 1



Workers at the Swedish Textile Research Institute (TEFO) have shown that a close-fitting garment becomes uncomfortable when it exerts more than a certain level of pressure on the body. The precise comfort threshold obviously varies with different individuals (and fashions) but, after a large series of practical test measurements, TEFO found that a garment would normally be found to be comfortable when the tension developed in the fabric, when the garment is stretched over the body, is not greater than about 0.25 Newtons per centimetre of garment length. This value therefore sets one constraint upon the amount of stretching which can be allowed in the fabric width of a garment when it is being worn by an individual having the largest body in the given size range.

Obviously, in order to calculate the maximum allowable stretch, and hence the maximum comfortable size for a particular garment, we need to know something about the stress-strain characteristics of the fabric. TEFO have developed test equipment and procedures for evaluating fabrics and garments for the tension developed when they are stretched to a given body size.

Another constraint on garment size is provided by width shrinkage in the fabric as a result of home laundering procedures. Obviously if the fabric shrinks to a significant degree then, during the lifetime of the garment, its width will be reduced and hence the amount of extension which is imposed by placing the garment over its owner's body will increase. This would be expected to result in a higher level of pressure being generated by the garment on the body - the greater the shrinkage, the greater the increase in pressure of the washed garment compared to the new one. In addition, it could be expected that the stress-strain characteristics of laundered, fully relaxed fabrics would not be the same as those of the new fabric.

Shrinkage in the length direction can also not be neglected in terms of comfort. In the first place, excessive length shrinkage will cause the garment hem to rise towards the waist line which can be uncomfortable. In the second place, extension of a garment in its width direction will usually cause some contraction (i.e. shrinkage) in the length. Thus, a further consequence of excessive width shrinkage in a close-fitting garment can be additional shrinkage in the length, over and above that which may have been measured by quality control laboratories at the fabric- or garment-production stage.

Spirality in plain jersey fabrics, caused by twist liveliness in the yarn, can also be a problem if it causes the garment to twist to such an extent that the side seams are displaced around the wearer's body by a noticeable amount. Similarly, bowing and skewing of a fabric will cause the garment to become distorted after laundering. In fabrics which are also liable to spirality, bowing and skewing can accentuate seam displacement and general fabric distortion problems.

3. FABRIC EXTENSIBILITY

We have carried out a fair amount of research, in collaboration with TEFO, into the extensibility of cotton knits. Most of this work has been based on measurements made at TEFO using test equipment specially designed by them to measure extensibility under conditions which simulate those which obtain when a garment is being worn. The ultimate objective is to develop prediction equations for extensibility which can later be incorporated into the Starfish model in order to provide guide-lines for: -

- garment makers to allow them to choose appropriate sizes and size intervals for garments made from particular fabrics, or
- fabric designers in order to allow them to design a fabric which is appropriate to a particular garment style and size interval.

Figs. 2 and 3 show the effect of yarn count and stitch length on the extensibility of dyed and finished 14g 1x1 rib fabrics at applied loads of 0.15 and 0.30 N/cm respectively i.e. at loads which straddle the average comfort threshold.

For a given load, these data can be adequately modelled by expressions of the type

$$E = a + b.\,S^2 / Tex \qquad [1]$$

where

E is the percent extension at the given load,
S is the stitch length,
a, b are coefficients whose generalised application (across yarn types, fabric types, and wet processes) has yet to be elucidated.

Since the square root of tex divided by the stitch length is known as the Tightness Factor, K, equation [1] can be written as

$$Ext\% = a + b / K^2 \qquad [2]$$

Figure 2
Width Extension of 1x1 Rib : Load = 0.15 N/cm

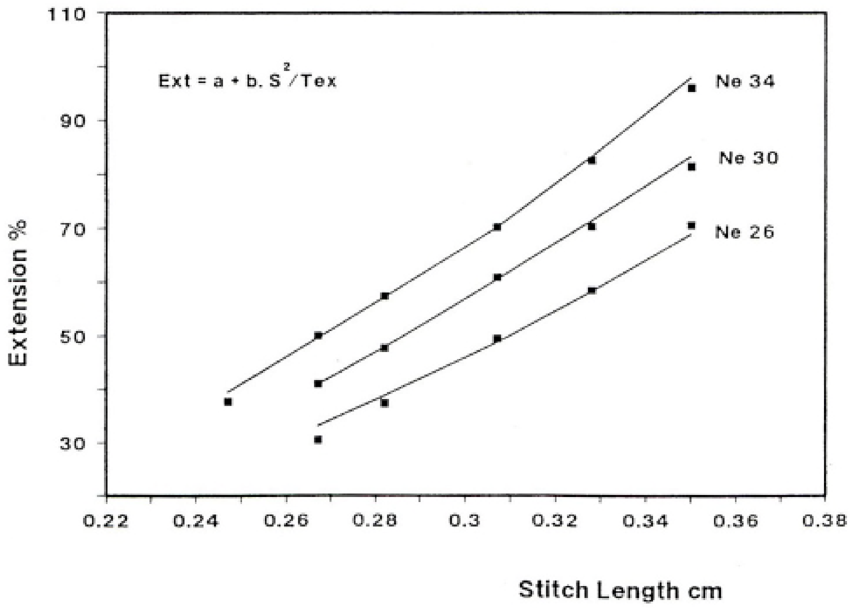


Figure 3
Width Extension of 1x1 Rib : Load = 0.30 N/cm

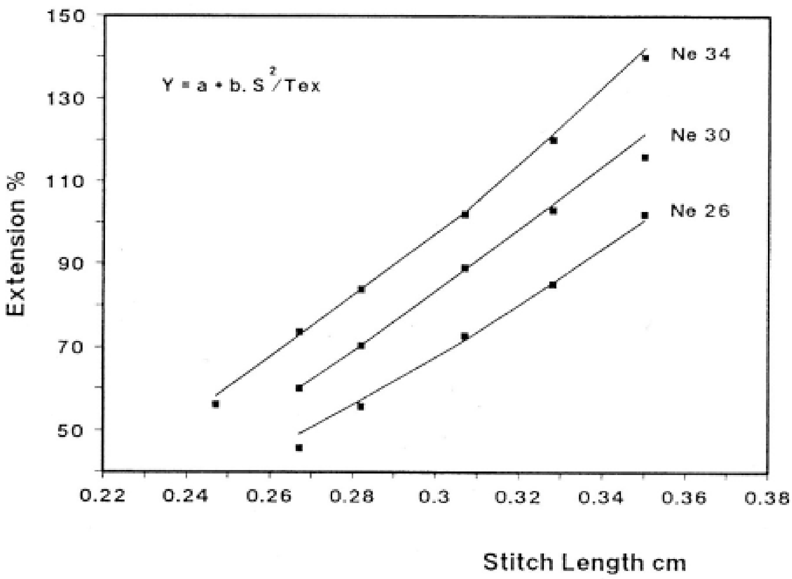
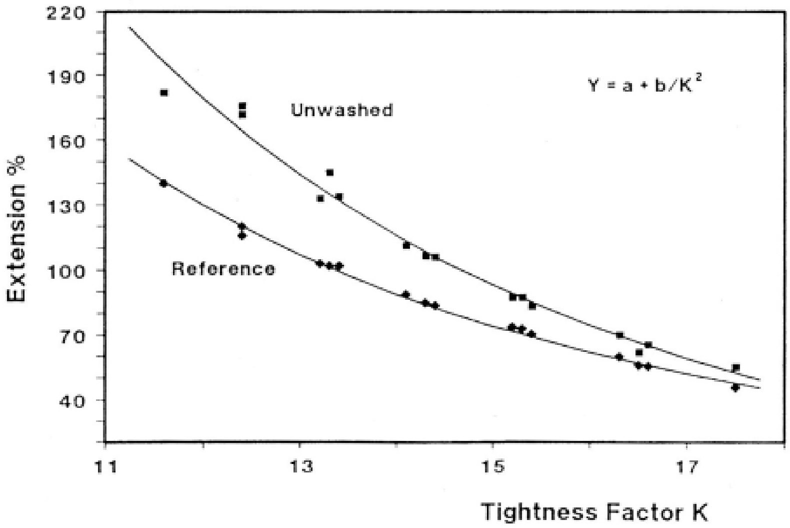


Fig. 4 shows a plot of the extensibility at a load of 0.3 N/cm as a function of the tightness factor which confirms the strong influence of this parameter and also shows that the fully shrunk fabric does not extend as far as the unwashed material at a given load. Therefore, it is important to measure the extensibility of garments in the reference state in order to be sure that they will still be comfortable when they are stretched back to their original width.

Figure 4
Width Extension: 1x1 Rib



Similar behaviour has been found for other levels of loading, for other fabric types, and for fabrics which have had other wet processing treatments. Within a fabric type, the extensibility behaviour does not seem to be greatly affected by the wet process route, provided that they are not too dissimilar and provided that the reference tex and stitch length are used as the input parameters. Different fabric types obviously give different levels of extensibility although the general shape of the curves is the same.

There is an influence of the relaxation treatment. Fabrics which have not been fully relaxed, or fabrics which have been treated with softening agents give different values from those which have not. The effect of resin finishing treatments has not yet been investigated, but a few experiments with fabrics finished with a resin/silicone elastomer treatment have shown that the extensibility of such fabrics is markedly increased.

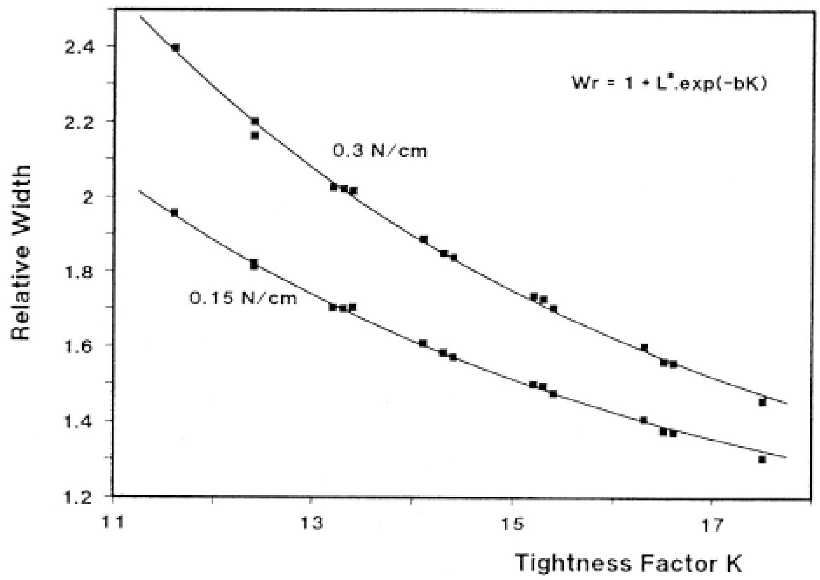
If such data are transposed so that extensibility is expressed in terms of relative width, Wr, (ie the extended width divided by the reference width), and all of the data for different fabric constructions and loading levels are included in the analysis, then expressions of the following form are found to model the data pretty well (Fig. 5).

$$Wr = 1 + L^a . \exp(-bK) \qquad [3]$$

Where

K is the tightness factor
L is the load in N/cm
a, b are coefficients whose values depend mainly on the fabric type and the degree of relaxation of the fabric.

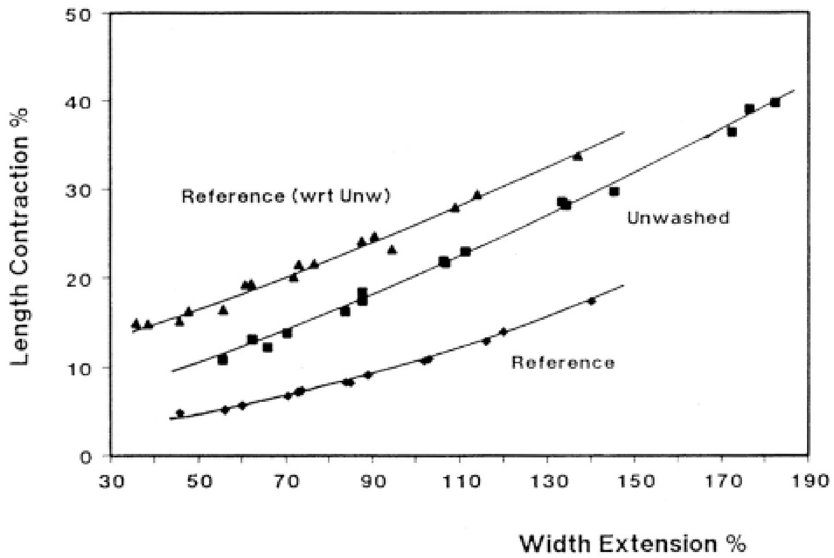
Figure 5
Relative Width: 1x1 Rib



4. LENGTH CONTRACTION

Fig. 6 shows the relationship between width extension and length contraction under a load of 0.3 N/cm for a range of 1x1 rib fabrics.

Figure 6
Length Contraction: 1x1 Rib

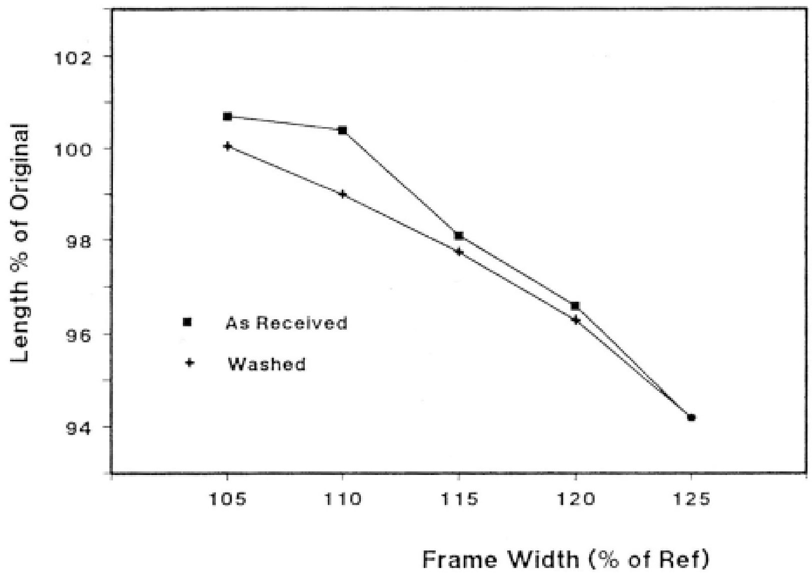


Results are given for the unwashed fabrics and for the fully relaxed, reference state materials. In the latter case, two curves are shown. In the upper curve, the width extensions and length contractions are expressed on the basis of the original, unwashed dimensions. Thus, in this case the contractions in length recorded for the relaxed fabrics include both those due to shrinkage and those due to the extension in the width. The average shrinkages in the fabrics were about 10% in both length and width directions (although there was considerable variation over the range). In the lower curve, the extensions and contractions are based on the relaxed dimensions. Thus, in this case the contraction in length is caused only by extension in width.

In each of these data sets, it is quite remarkable how closely the data follow a single trend line, which appears to be a simple exponential function, even though a wide range of constructions and shrinkage levels are present.

Fig. 7 shows the relationship between length and width for a series of single jersey T-shirts when they were stretched over a rectangular frame according to a test procedure developed by Marks and Spencer (based on the TEFO static garment test equipment). In this graph, both length and width are expressed as a percentage of the reference dimensions. The data for the washed garments are averages from several sets of specimens which had been subjected to different methods of laundering. With T-shirts, it is not uncommon for the washed garment to be called upon to stretch by 15 to 20% in order to fit over the largest body in a given size range. For the garments in this data set, the consequence would be an additional length shrinkage of up to 4%.

Figure 7
Garment Length on the M&S Frame

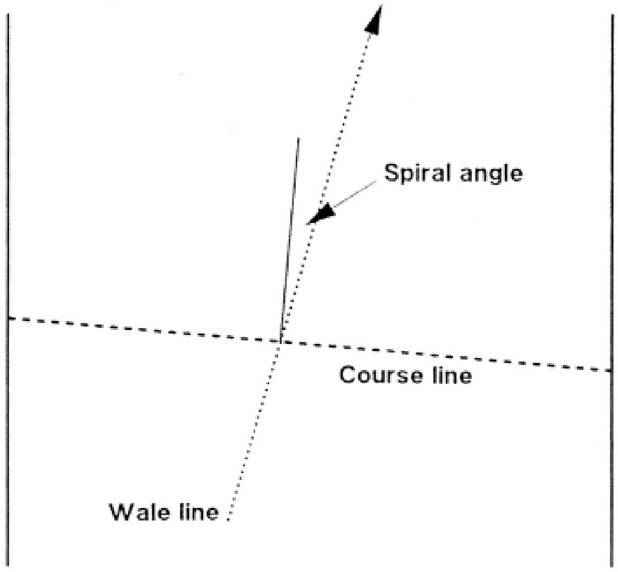


5. SPIRALITY

Spirality is defined as the angle made between the wales and a line drawn perpendicular to the courses. (Fig. 8) Positive spirality, or Z spirality indicates that the wale line is displaced to the right, or clockwise. It is caused by the use of Z twist yarns. Negative, S spirality has the wales displaced to the left or anti-clockwise and results from the use of S twist yarns.

This distortion is most noticeable in plain single jersey fabrics and is a source of problems in finishing, in making up, and in garment appearance. Therefore we have studied the causes and the extent of spirality with the ultimate objective of providing prediction model equations for future versions of starfish.

Figure 8
Spirality Definition



Spirality in the Reference State has three basic sources :-

1. The number of feeders at the knitting machine,
2. Twist liveliness in the yarn,
3. The geometry of the fabric.

Effect of Number of Feeders

Spirality caused by the number of feeders is a relatively small effect and its magnitude can easily be calculated from the number of feeders, the width of the fabric and the number of courses per unit length. The larger the number of feeders, the fewer the courses per cm, and the wider the fabric, the greater will be the spirality from this cause.

The direction of the feeder spirality depends on the direction of rotation of the knitting machine. Z spirality is produced by machines which rotate anti-clockwise, S spirality is produced on machines which rotate clockwise.

If the spiral angle caused by the feeders is denoted as Sf, then the tangent of this angle is given by the ratio of the distance between successive courses from the same feeder (the drop), D, and the fabric width, W: -

$$\tan (Sf) = D/W$$

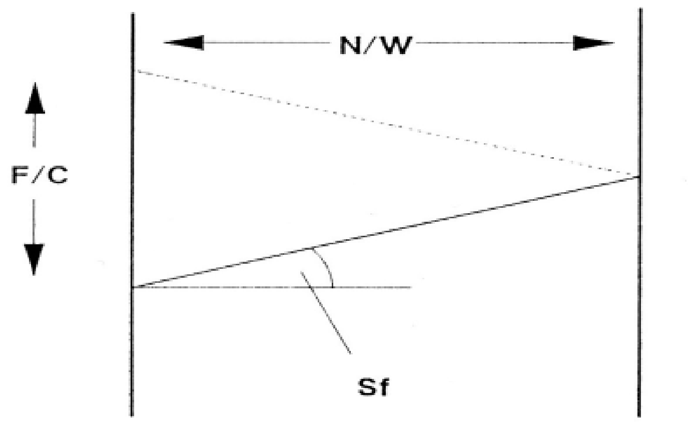
But D is given by the ratio of the number of feeders, F and the number of courses per cm, C, whereas W is given by the ratio of the number of needles, N and the width. (Fig. 9). Therefore

$$\tan (Sf) = F.W/C.N$$

Figure 9
Effect of Number of Feeders on Spirality

Drop = Feeders/Courses per cm

Width = Needles/Wales per cm



tan(Sf) = F.W/C.N

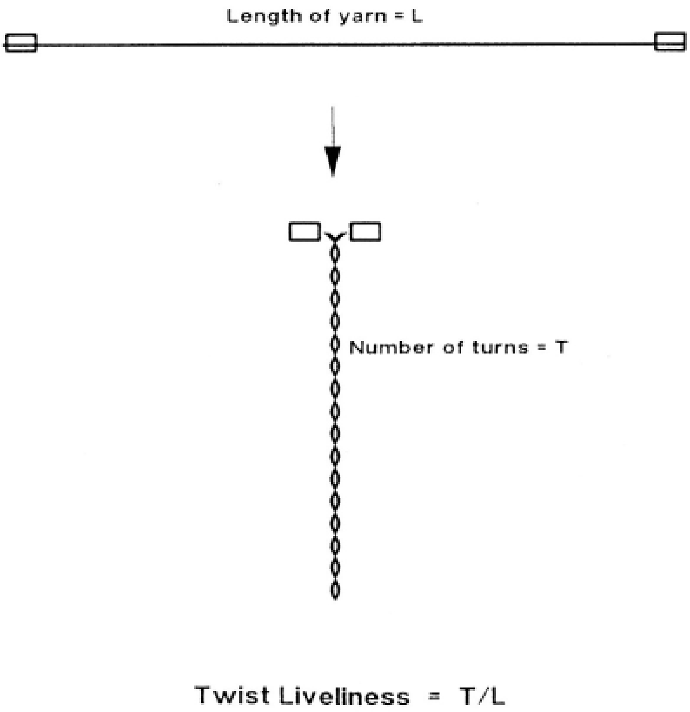
The number of feeders and the number of needles are both known, and the course and wale densities can be calculated using Starfish. Therefore, the contribution to spirality made by the feeder effect can be calculated for any combination of fabric structure and knitting machine.

Effect of Twist Liveliness

The twist in a singles yarn causes torsional forces to develop in the fibres which tend to make the yarn try to untwist. If a piece of singles yarn is held at each end and the ends are slowly brought together, the yarn will twist up upon itself. (Fig. 10). This effect is called snarling and the torque in the yarn which causes it is called twist liveliness. When the yarn is knitted into a fabric, the consequence of twist liveliness is that the loop twists and bends out of shape. Its twisted shape is such that spirality is generated in the fabric. The higher the number of turns per cm in the yarn, the greater the twist liveliness and the greater the spirality.

Different types of yarn, made from different qualities of fibre can exhibit different degrees of twist liveliness. In the early days of open-end rotor spinning, it was generally found that rotor yarns were more twist lively than the corresponding ring yarns. However, the modern rotor yarns tend to be significantly less twist lively. In principle, finer fibre qualities should be expected to give lower levels of twist liveliness, for a given number of turns per metre, than coarse fibre types but this aspect has not been thoroughly investigated.

Figure 10
Twist Liveliness



With twofold yarns which are perfectly balanced, there will be no twist liveliness and hence no spirality. If the twofold yarn is not perfectly balanced, then spirality will be generated in direct proportion to the magnitude and the direction of the net residual twist.

If a fabric is knitted with alternate Z twist and S twist yarns, then the net effect on the magnitude and direction of spirality is similar to the case where a twofold yarn is used, although of course the fabric appearance and dimensions will be quite different, and the influence of the direction of machine rotation on the net residual twist of the two yarns may need to be allowed for.

Wet processing treatments tend to produce stress release in the yarns with a consequent reduction in twist liveliness and hence in spirality. (Fig. 11, 12). However, it is sometimes found that a wet processing treatment can upset the balance of twist in a twofold yarn so that spirality may actually be increased. In reducing twist liveliness, wet processing alters the shape of the loop and this effect may an important source of differences in reference state dimensions caused by different wet processing treatments.

Figure 11
Twist Liveliness of Yarn Taken from Finished fabric

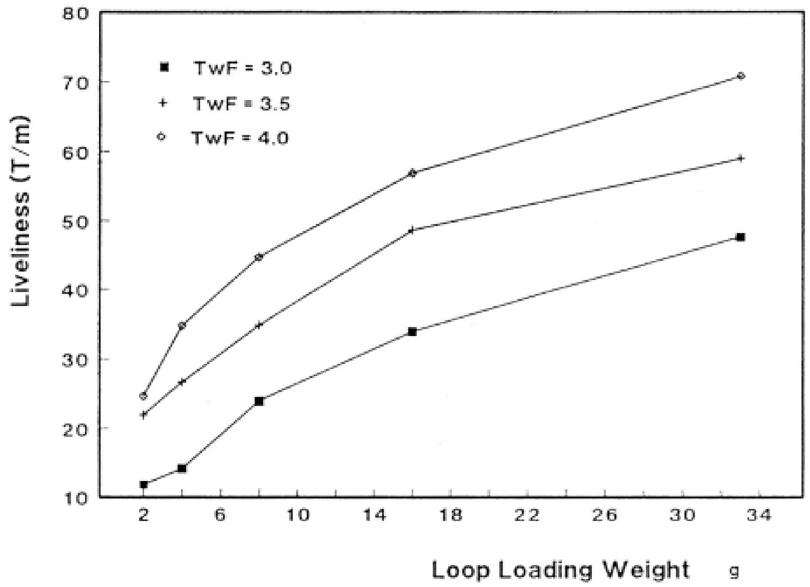
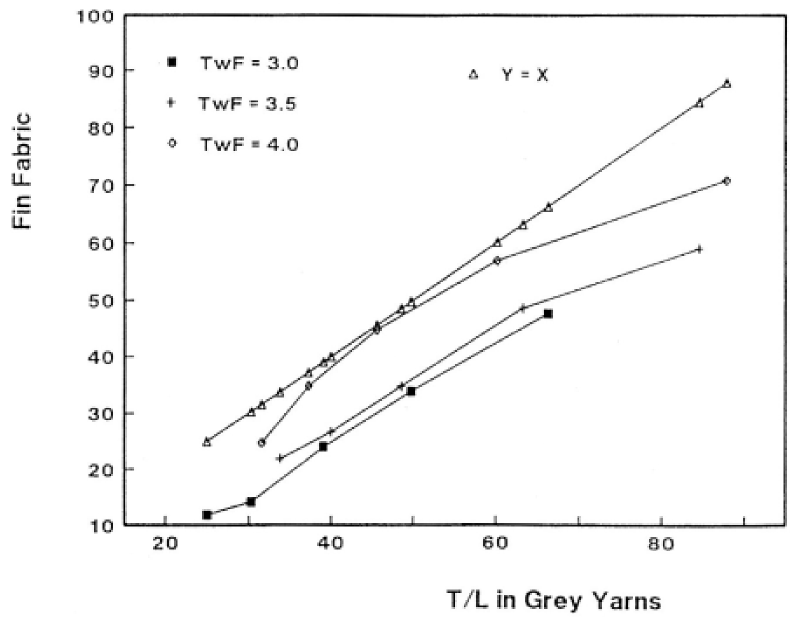


Figure 12
Reduction of Twist Liveliness Caused by Finishing



Effect of Fabric Geometry

Fabric geometry affects spirality in two ways, much in the same way as it affects shrinkage. In other words, we have to consider the spirality in the fabric before relaxation and after relaxation. The amount of spirality which will be measured in the finished fabric, as delivered, is critically dependent on the deformation and relaxation history of the fabric. Therefore, once again we have to define the reference spirality as that which is found in the *Reference State*, and relate this to the actual dimensions of the fabric.

However, in the case of spirality, there is one further complication which is that deformation of the fabric can be not only in length and width but also in twisting. Indeed, most finishers will attempt to twist the fabric so that spirality is at a minimum when the cloth is delivered. This is a purely temporary deformation which will not affect the reference spirality. It can not be calculated in advance but has to be assumed as a finishing target.

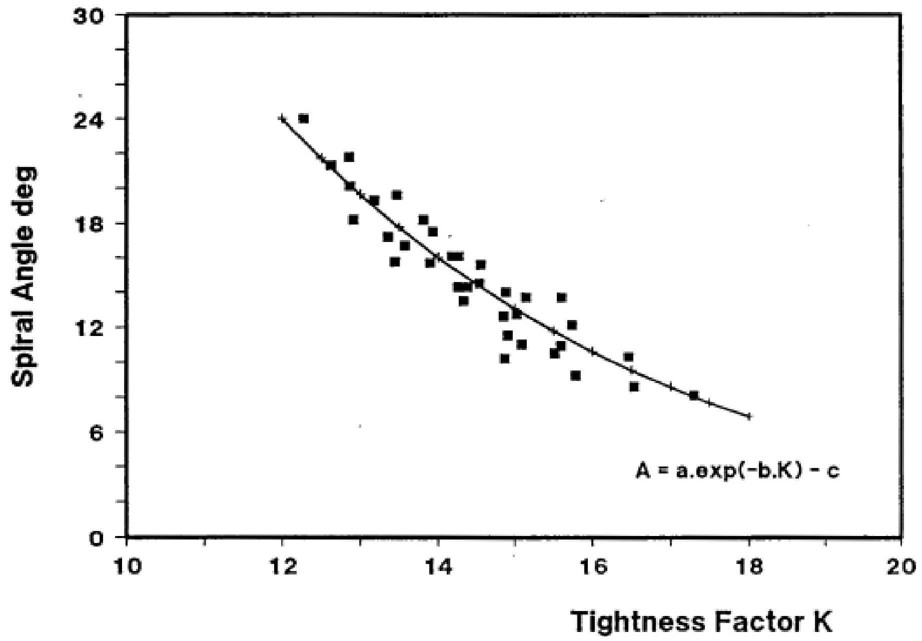
The reference spirality can be examined in the same way as we examine the reference courses and wales, and a few results from our research work are given below.

Fig. 13 shows the angle of Spirality, A, measured in the reference state on a series of dyed and finished plain jersey fabrics made from Ne16 to Ne40 yarns, all with similar twist factors (3.6 to 3.8), plotted as a function of the fabric tightness factor. These data can be modelled approximately by a simple exponential function of the form,

$$A = a.\,exp(-bK) - c \qquad [4]$$

where a and b depend mainly on the twist liveliness of the yarn and the way that this is modified by the wet processing.

Figure 13
Spirality vs Tightness factor



Twist liveliness in ring yarns is directly related to the number of turns per metre in singles yarn or the difference between singles and folding twist in twofold yarns. Twist liveliness in singles yarn is invariably reduced by wet processing, but in twofold yarns it can be significantly increased by a drastic wet process, such as mercerising.

Although equation [4] is an adequate model for practical purposes, the data can actually be more satisfactorily modelled by using more complex equations which take explicit account of the twist level and the probable boundary conditions for spirality.

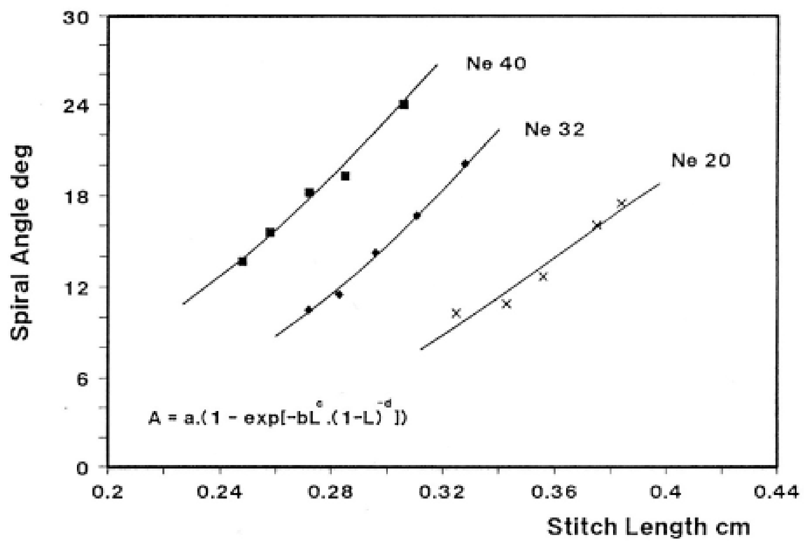
Fig. 14 shows spirality plotted against the stitch length for three of the seven yarns. The models which are being investigated for such data have the following form.

$$A = a\{ 1 - exp [-b.L^c . (1-L)^d] \} \qquad [5]$$

where

A	is the spiral angle,
L	is the stitch length,
a	is a simple function of the yarn twist whose coefficients depend on the yarn type and the wet process route,
b	is a coefficient which seems to be a simple function of the yarn tex,
c, d	are probably constants.

Figure 14
Spirality: Plain Jersey Jet Dyed

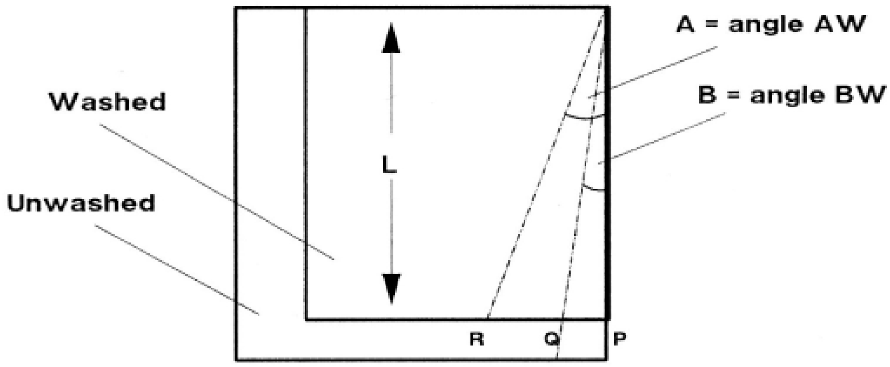


6. SEAM DISPLACEMENT

The relationship between spirality and the amount of garment twisting or seam displacement (SD) which can develop in a garment after laundering is a simple geometrical one which can be derived from the spiral angle (B) in the new garment, the spiral angle (A) in the laundered garment, and the length (Lf) of that part of the garment which is free to twist. (Fig. 15). It is given approximately by: -

$$SD = Lf\,(tan\,A - tan\,B) \qquad [6]$$

Figure 15
Dependence of Seam Displacement on Garment Length and Spirality



Seam Disp = QR = (PR–QP)

PR = L.tan(A)

QP = L.tan(B)

therefore SD = L.(tanA – tanB)

For most garments, the free length is significantly less than the total garment length. For T-shirts it seems to correspond roughly to the distance from the hem to the underside of the arm. For practical purposes, equation [6] can be simplified further since, for the small angles which are normally encountered in fabric spirality, (tan A - tan B) is given approximately by

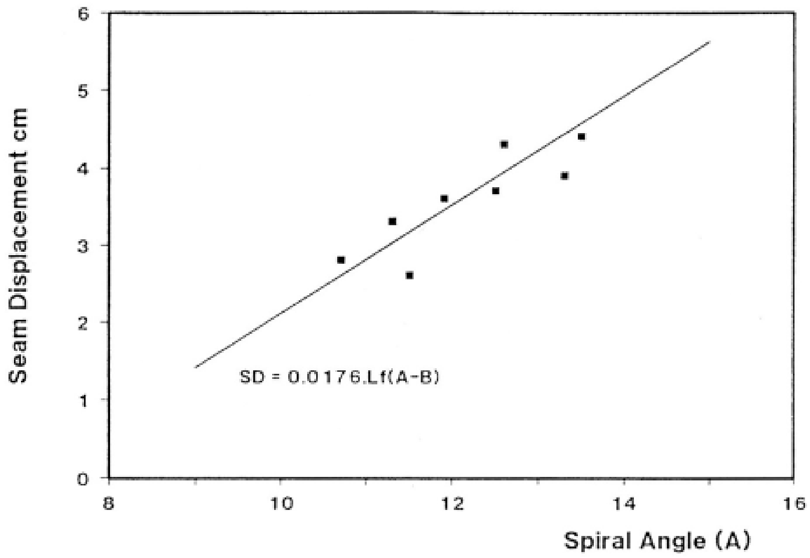
$$\tan A / A \,.\, (A-B)$$

But tanA/A is approximately equal to 0.0176, so the following equation can be used with negligible loss in accuracy to predict the seam displacement in laundered garments.

$$SD = 0.0176\, L_f\, (A-B) \qquad [7]$$

Fig. 16 shows the results of some measurements of seam displacement made on a series of plain jersey T-shirts compared to those predicted by equation [7].

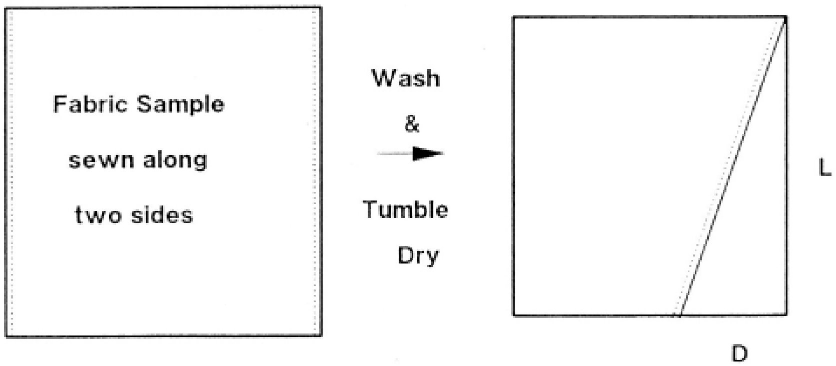
Figure 16
Seam Displacement vs Spirality



A practical test for seam displacement is carried out by taking a rectangular sample of fabric, whose length is double its width, and sewing it into a bag - a kind of simulated garment. (Fig.17). The bag is then given the standard wash and tumble dry shrinkage test laundering. The amount of seam displacement can then fairly easily be measured. The amount of seam displacement is then expressed as a percentage of the seam length. If D is the displacement, and L is the length, then:-

$$\%SD = 100. D/L$$

Figure 17
Percentage Seam Displacement



The percentage seam displacement can be related to seam displacement, as described earlier, by means of the following facts.

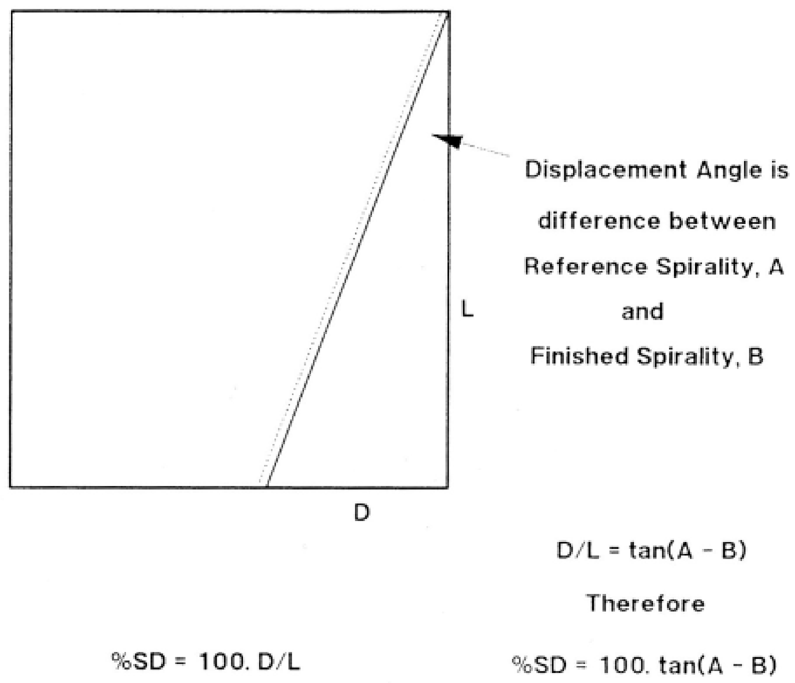
The displacement angle must be the difference between the after-wash spirality, A, and the before-wash spirality, B (Fig 15).

D/L is equal to the tangent of the displacement angle. (Fig. 18)

Therefore,

$$\%SD = 100. D/L = 100. \tan(A - B)$$

Figure 18
Percentage Seam Displacement and Spirality



If the Reference spirality, for a given quality, is established by calibration trials, then it is a simple matter to work out what will be the percentage seam displacement for any proposed spirality which can be delivered in the finished fabric. The actual displacement is obtained by multiplying by the effective garment length.

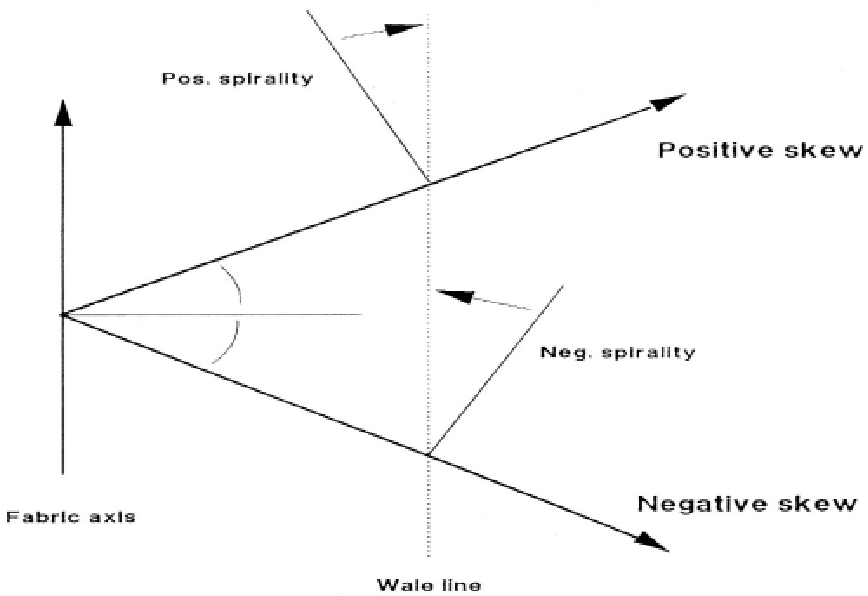
7. SPIRALITY AND BOW OR SKEW

During wet processing, fabric can become distorted by bowing or skewing of the courses. One of the most common causes of such fabric distortions is poor alignment of sewings when the grey pieces are assembled for processing or, in extreme cases, the practice of tying grey pieces together instead of sewing. The distortion can extend for ten metres or more into the pieces, on each side of the ties, and there is a strong temptation for the garment maker to include some of this distorted fabric into his garments in order to avoid making a large quantity of waste. The inevitable consequence is that the garment will become more or less heavily distorted after laundering, as the fabric recovers its natural alignment of courses and wales.

The practical effect of fabric skew is either to accentuate or to reduce the twisting, or seam displacement of the garment which occurs during laundering as a result of spirality. Skew is defined as the angle between the courses and a line drawn perpendicular to the fabric edges (i.e. perpendicular to the length axis). Positive, or Z skew results in a positive spirality in the fabric, negative, or S skew results in a negative spirality. If the wales are disposed parallel to the length axis, then the skew angle is equal to the spirality angle, but opposite in sign. (Fig. 19)

If the natural spirality is positive, then a negative skew will reduce spirality, and vice versa. This effect is sometimes used by finishers (especially in open width finishing on a stenter) to reduce the amount of seam displacement in garments. However, the technique can not be pressed too far otherwise a different type of garment distortion will be introduced. Spirality should first be contained by appropriate choice of yarn and fabric construction. Only then may a controlled amount of skew be used to effect a partial compensation for the fabric twisting caused by spirality.

Figure 19
Effect of Skew on Spirality

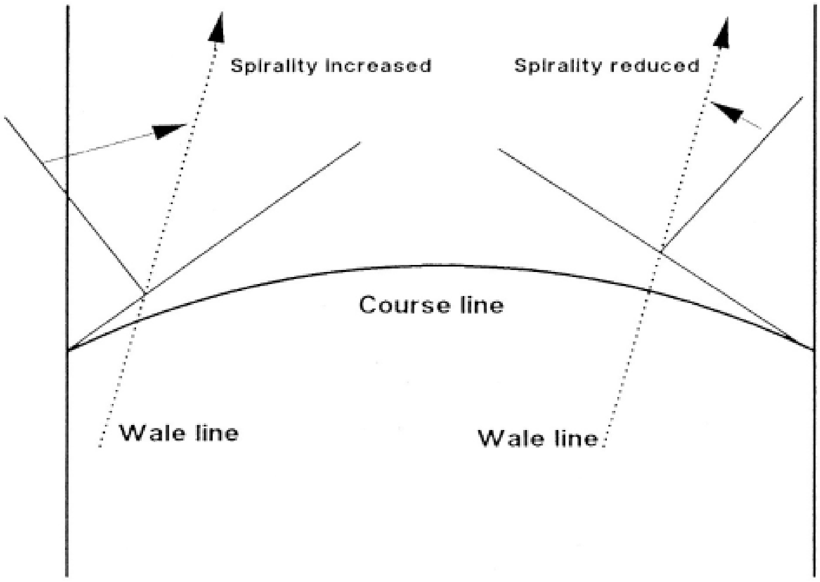


Note that the Reference spirality is not affected by skew. The effect of introducing negative skew is to change the spirality of the finished fabric, so that the difference between finished and Reference spiralities is lower. It is this difference which is responsible for fabric and garment twisting.

After laundering, any part of the skew angle which is not due to the natural drop in the course line caused by the feeder effect will disappear, and only the “natural” skew of the fabric will remain. If a garment has been made up from heavily skewed fabric, then it will develop a skewed and possibly buckled shape after laundering.

In fabrics which have horizontal stripes, the finisher will naturally attempt to deliver the fabric with the stripes going straight across the fabric. The best way to do this is for him to slit the fabric and resew it with the stripes matching at the sewn edge to eliminate the feeder drop. Special equipment is available for this operation. However, if the fabric is not cut and resewn, then the finisher is simply delivering the fabric with an angle of skew which is equal and opposite to the feeder drop. This “artificial” skew will be removed in laundering and the natural feeder drop will reappear.

Figure 20
Effect of Bow on Spirality



Bow is when the angle of skew changes over the width of the fabric. (Fig. 20) In the simplest case, the angle is positive at the left side of the fabric, decreases to zero at the centre, and then decreases further to negative skew of equal magnitude at the right side. In such cases, spirality will be reduced at the left side of the fabric, will be unchanged at the centre, and will be increased at the right side. Garments made up from pieces cut from such fabrics can display quite serious and complicated patterns of distortion after laundering, depending on exactly where in the fabric the main garment components have been cut.

The effects of bow and skew can be analysed quantitatively, by simple trigonometry, but this is hardly worthwhile because the clear lesson of the qualitative analysis is that bow and skew must be avoided.

8. SPIRALITY AND SHRINKAGE

In the standard Starfish testing procedures, courses are counted along a wale and wales are counted in a direction perpendicular to the wales. In addition, the shrinkage template is laid down on the fabric for marking with its edge along a wale line. These rules are laid down so that the course and wale measurements will be compatible with the shrinkage measurements and therefore calculations of shrinkages based on the changes in the values of course and wale densities will be valid.

However, it has to be recognised that, when a fabric shows significant spirality, the length and width shrinkages measured by the Starfish method may not correspond exactly to changes in the length and width directions of a piece of fabric or a garment because the original square shape of the test piece has been distorted into a parallelogram after washing. This can be important when assessing length changes in garments because the garment hem will rise by slightly more than the amount expected from the measured length shrinkage, and the width will be slightly greater.

The extent of this error can be calculated by examining the geometry of the test piece and the changes brought about by the development of spirality. It depends on the magnitude of the Reference spirality and the difference between the spirality before washing and that after washing. To a first approximation it can be said that the difference between the measured shrinkage and the actual change in length of a garment will not exceed about 3 percentage points, for the maximum levels of spirality which are normally encountered in practice.

9. SUMMARY

For a rational design of garments, so far as comfort and fit are concerned, STARFISH will have to be capable of predicting not only the length and width shrinkages but also the extensibility and spirality characteristics of fabrics.

So far, the necessary prediction equations are not sufficiently well developed for them to be incorporated into the STARFISH computer program.

Nevertheless, the general information given in this paper is enough to allow manufacturers of cotton knitted fabrics and garments to effect significant improvements in the performance of their products.