Introduction

The common view in the industry is that it is the Dyer and Finisher who has the ultimate control over shrinkage and, consequently, if a fabric has a high level of shrinkage, then the finisher is always to blame. The biggest problem that most dyers and finishers have is that they also believe in this fallacy, and they encourage their customers to believe it. Under some special circumstances, it can be true that the finisher is in control but in the modern industry the practical situation is very often exactly opposite.

It is important to make the clear distinction between the dimensions of the fabric as it is delivered to the customer, on the one hand, and the Reference Dimensions on the other. The potential shrinkage in any fabric is simply the difference between the "as delivered" dimensions and those of the Reference State. Therefore, if the finisher is to be in control of the shrinkage then he must have full control over either the delivered dimensions or the Reference Dimensions or both.

The Reference Dimensions are determined primarily by the key knitting variables – yarn quality and stitch length – and the specific type of Wet Processing route that is used. There is a small potential additional effect of the drying stage but, unless a chemical finish is being applied, the influence of the finishing operations on the Reference Dimensions is negligible by comparison.

In any given dyeing and finishing plant there will be only a limited number of wet processing options available, and the choice of which to use for a given product type will be constrained by practical considerations of capacity and economy as well as technical requirements. This is true also of the final finishing machinery.

Thus, the dyer and finisher has very little influence over the effect of Wet Processing (and final finishing) on the Reference Dimensions. The effect will be whatever his particular range of equipment delivers. For all practical purposes, therefore it is the knitter who determines the Reference Dimensions.

So far as the delivered dimensions are concerned the finisher is often no better off. This is because the delivered dimensions are usually fixed by the customer's specification in the form of his requirements for the weight, width and levels of residual shrinkage in the finished fabric.

A specific width is generally demanded in order to minimise waste in the garment cutting operation. A particular weight is usually demanded in order to fix the cost. In addition, there is usually a specification for the maximum level of shrinkage that will be accepted in order to satisfy consumer expectations.

But if the finisher has essentially no control over the Reference Dimensions, and no flexibility in the dimensions that he may deliver to the customer, then he virtually has no control over the performance of the product that he is delivering.

This should be an unacceptable situation for any manufacturer and the only defence that the finisher can have is knowledge. It is only when the finisher truly understands what are his limitations that he can begin to develop the systems and the know-how that will allow him to gain some control over his operations.

- For every quality that he is asked to produce the finisher must know the Reference Dimensions.
- For every customer specification that he is asked to meet the finisher must be able to check its validity.
- For every wet processing and finishing route that he has available in his factory the finisher must know what is its effect on the Reference Dimensions.

Without this knowledge, the finisher is powerless and often has to take the blame for poor shrinkage performance, which in fact has been imposed on him by an unreasonable or unattainable specification.

With this knowledge, he becomes a full and equal partner in the discussions that are necessary for the setting of proper targets and he is free to apply the specialised expertise and equipment that he has at his disposal for the common benefit.

Finishing Control Targets

To establish a useful Quality Control system for processing a knitted cotton fabric, the first thing that must be done is to establish the correct Finishing Control Targets for each finished fabric quality.

Control Targets for quality control and process control purposes have to be distinguished from general **Performance Targets**. Control Targets are fixed by the dyer and finisher to control his production. Performance Targets are fixed by the customer in his demands for a particular weight and width, and maximum levels for shrinkage.

Finishing Control Targets

Finishing Control Targets are those specific Fabric Properties that the dyer and finisher attempts to control, in order to guarantee that the customer's Performance Targets shall be met. Specifically they are the smallest number of fabric properties which, if held constant, will guarantee constant values for all of the Performance Targets.

In addition, Control Targets must be fabric properties that can be measured and controlled directly, on-line. It is not necessary that the Control Targets have to correspond to any of the fabric properties that are named among the Performance Targets. All that is necessary is that, if the Control Targets are hit, then the Performance Targets are guaranteed.

At this point, it is important to note that the basic knitted fabric must have been correctly engineered for the required performance. This means that, when the required fabric Weight and the required fabric Width are delivered then the Length and Width Shrinkage Values are within the given tolerances. If the basic fabric has not been correctly engineered, then the dyer and finisher may choose either to deliver the correct Weight and Width, or the correct Shrinkage; he cannot do both.

Thus, the first responsibility of the dyer and finisher is to confirm that the fabric has been correctly engineered.

For most purposes, only two Control Targets are required: one that controls the fabric Width and one that controls the fabric Length. If the Knitting Quality is reliable, and if the wet processing is constant, then a constant fabric length and a constant fabric width will guarantee that all fabric dimensional properties, including shrinkage, will be constant.

Failure to distinguish Control Targets from Performance Targets causes many dyers and finishers to attempt to control all of the Performance Targets simultaneously. This is a serious error because the control situation will be unstable and unresponsive. This is true even if the basic fabric quality has been correctly engineered for the required performance. If it has not, then the control problem becomes impossible to resolve, because the required weight and width will be incompatible with the required shrinkage.

Performance Targets

The major Performance Targets are usually Weight, Width, and Shrinkage.

In principle, fabric Weight can be measured and controlled on-line. However, the measurements are generally not reliable enough for control purposes. This is because they are heavily influenced by such factors as Fibre Type, Moisture Content, moisture distribution, and the presence of electrolytes on the fabric. Most often, fabric Weight is monitored by cutting samples and weighing them. This method is too slow and is also rather unreliable. Fabric Weight is not a suitable property for use as a Finishing Control Target.

Shrinkage in length and width cannot be evaluated directly on fabric in process through the finishing line. Moreover, the shrinkage test is unreliable. Measurement of shrinkage has no practical value for product and process control.

On the other hand, fabric Width can be measured and controlled reliably on-line. If the fabric Width is held constant, then the Width Shrinkage will also be constant. Most dyers and finishers correctly choose fabric Width as one of their Control Targets.

This leaves a requirement for a length control parameter, and the only suitable fabric property is the Course Density. If the number of courses per unit length is held constant, then the length of the fabric is also constant. Until comparatively recently, there were no reliable on-line sensors for measuring course density and controlling overfeed at Stenters and Compactors. It was necessary to physically

count the number of courses in the delivered fabric and make manual adjustments accordingly. This was not on-line control, and the reliability was not very good, but it was the best that could be achieved. Nowadays reliable on-line course measurement and control systems are available from a limited number of suppliers.

Important Notes:

- *It should be remembered that the Control Targets refer to the Properties of the finished fabric as it is delivered at the end of the finishing line. In other words, no account is taken of any relaxation (or growth) that may take place in the fabric from the end of the finishing line, through packaging and transit. The finisher must therefore make allowance, if necessary, in the Control Targets that he chooses to be sure that the properties of the fabric "as delivered" are as intended.*
- *If the Control Targets are chosen carefully, if the knitting quality is correctly engineered and reliably produced, if the wet processing is constant, and if the Control Targets are hit, then there is no need to measure weight and shrinkage - they will be correct.*

Achieving the Targets

The ease with which the Finishing Control Targets can be achieved depends a great deal on the processing methods that are employed. For example, one industrial-scale trial carried out on the finishing of single jersey included both tubular and open-width processing on a wide range of plain jersey constructions.

Finishing Control Targets for Width and Courses were calculated aiming for a particular length shrinkage to the five-cycle tumble-dry test.

The same fabrics, ninety different structures in all, were processed through both routes, and the final finished dimensions were controlled as well as possible by means of width setting and length overfeed.

Of forty-five fabrics knitted from singles yarns, thirty-six (80%) finished closer to target in the tubular than in the open-width state. Of a similar number of twofold structures, thirty-two (71%) finished closer to target in the tubular state.

The measured Length Shrinkage was lower in the case of seventy-two (80%) of the fabric samples that were finished in the tubular state.

There may be overriding reasons for finishing a circular-knitted cotton fabric at open-width. Printing or a chemical finishing treatment (for example crosslinking) may be more easily or more uniformly applied in open-width. The customer may demand it to suit his garment-cutting equipment, or because edge-creases would produce too much waste in his laying-up.

However, in the absence of any positive reason for slitting into open-width, the finisher will probably find that shrinkage targets will be more easily achieved on tubular fabric.

Whether tubular or open width, it is during the drying and finishing stage that the final dimensions of a fabric are set and it is here that the machinery available and techniques employed can have a decisive influence on whether the Finishing Control Targets can be met.

Development in machine design especially in the field of knitgoods finishing is proceeding at a rapid pace therefore specific recommendations would soon become obsolete. This notwithstanding, some general guidelines for selecting machinery and processes for optimising cotton knitgoods finishing can be suggested. These are discussed in the following topics:-

- Wet Spreading
- Relax Drying
- Calendering and Compacting
- Resin Finishing
- Related Topics
- Finishing

Wet Spreading

In general, it can be said that, after any preparation or dyeing process, the fabric will be too long and too narrow because no process, which involves pulling fabric through or around a machine, will be entirely tension free.

The amount of stretching can be quantified by relating the length and width of the prepared and dyed fabric to the length and width that it would have in the Reference State, when all distortions are removed. It can be calculated from the Reference Courses and Wales and the courses and wales, which are found immediately after the preparation and dyeing processes.

Typical results show that the level of distortion is strongly related to the Knitted Tightness Factor. Loosely knitted fabrics are much more extensible than tight ones, and show correspondingly higher levels of distortion after preparation and dyeing.

The removal of water after the final wet processing stage should therefore be carried out in such a way as to reverse this effect; that is to shorten the fabric length and increase the width.

This operation can be assisted by Wet Spreading in which the tubular fabric is over-stretched to significantly more than its final target width, whilst at the same time overfeed is applied in the length direction. This is best carried out after centrifuging or squeezing, but there are good machine designs that allow simultaneous water removal and wet spreading.

The amount of over-stretching to apply depends on the fabric type and construction. For Plain Jersey 15 to 25% over final target width will usually be enough. For Rib fabrics 40% or more may be required. Other fabric types generally fall between these extremes. Tightly knitted fabrics will require less width stretching than loose ones. They also react more positively, in the sense that a given degree of width stretching produces a larger amount of length contraction. Dyers and finishers should always be encouraging the knitted fabric designers to develop the tightest structures that are compatible with the customer's Performance Targets. Unfortunately, for a given weight per unit area, the tighter fabrics are often the more expensive to produce.

For open-width fabrics, wet spreading is best done after tubular preparation and dyeing, but before slitting. Even so, there is often less scope for over-stretching of such fabrics because the final (much narrower) target width may not be achievable on the stenter. In such circumstances, it is most helpful if the basic knitting quality is as tight as can be achieved, consistent with correct fabric engineering.

Open width fabric can also be stretched on the Stenter Frame whilst providing overfeed in the length. However, there are limits to the amount of width spreading that can be achieved on a stenter, because there is usually little or no opportunity to bring the fabric back to its Target Width after stenter drying. It is for this reason that, in some factories where resin finishing is applied to open-width fabric, the first drying is carried out on a relax dryer to make sure the fabric length is properly adjusted, before going to the padder and stenter to apply and cure the resin finish.

Important Notes:

- *Wet spreading can only be used effectively when there is a subsequent opportunity for the fabric width to be reduced back to below the final target width without excessive length tension, for example in a Relax Dryer.*
- *Large amounts of over-stretching of tubular fabrics should not be attempted immediately in front of a squeeze mangle, unless there is a very efficient feeding and overfeeding mechanism that can eliminate back-tensions in the cloth. Otherwise, severe creasing (crow's feet) may be generated at the fabric edges, which is very difficult to correct.*

Relax Drying

The most effective relaxation treatment for knitted cotton fabric is tumble-drying. This is why the Reference Relaxation Procedure is based on tumble-drying and why a fabric that has been subjected to this procedure is described as "fully relaxed".

This has led machinery manufacturers to explore the possibility of vibrating carriers and specially arranged hot air jets to impart more or less vigorous agitation to knitted piece-goods during drying, thereby promoting shrinkage in the fabric. Such machines are called Relax Dryers and they have been one of the most significant developments in cotton knitgoods finishing.

Importance of Moisture Content

For the effective use of Relax Dryers consideration should be given to how shrinkage develops in a knitted cotton fabric during the drying process. Shrinkage does not begin until the Moisture Content is below approximately 35% but continues all the way down to about 2% moisture content. Drying cotton to below its natural moisture content (about 7%) is expensive so the finisher sometimes has to choose between maximum relaxation and minimum cost.

Relax Drying machines can be very effective, especially if the mechanical energy is applied when the fabric is partly dry, at about 15 to 30% moisture. However, they are often said to be less efficient than Drum Dryers. For this reason, it is sometimes claimed that the ideal drying arrangement would be a fast, efficient drum unit to take the moisture down to about 40%, followed by a relax dryer to complete the process whilst relaxing (i.e. shrinking) the fabric.

It is an advantage if the intensity of agitation can be adjusted. Some fabrics are more delicate, so that the surface appearance can be degraded by excessive agitation. Here again the finisher will have to compromise between maximum shrinkage and the preservation of surface quality.

Some garment makers have installed a relax-drying machine that incorporates a spray device at the entry zone to apply about 40% of water to the dry fabric. The relax dryer is followed, after cooling the fabric, by a Compacting Finisher Calender and this set-up means that the garment maker is virtually independent of the finishing plant, so far as controlling the final dimensions of the fabrics is concerned.

Dyers and finishers who have to cope with very difficult fabrics, such as Crosstuck (piqué) or brushed Fleece can use the same technique.

Importance of Consolidation

In order to reproduce the effect of tumble-drying in the relaxation process the third dimension must not be disregarded. Tumble-drying can increase the thickness of a knitted cotton fabric by as much as 40%. This effect is called Consolidation. It is important not only in reducing the amount of potential shrinkage in the fabric but also to ensure that any further reduction in fabric length achieved by Compacting does not immediately "fall out" again on the cutting table.

The importance of consolidation, i.e. developing the fabric thickness, can be easily recognised if the last operations in the finishing line - compressive shrinking and calendering, are considered. These operations act by squeezing the fabric between a cylinder and a blanket (or a polished steel shoe). Thus they have a potential for reducing the fabric thickness and, therefore, pushing out the fabric length. This is probably inevitable but can be minimised if the degree of compaction required is relatively low.

If relaxation is carried out as efficiently as possible at the drying stage there should be little or nothing for the compressive shrinking unit to do. Its function then becomes simply to hold the length that has already been developed by Relax Drying. With some fabrics, it may even be possible to eliminate this operation and finish with a light calendering to set the fabric width and produce an acceptable appearance.

In any event, the operations prior to final compacting should be so organised that the compactor is never required to reduce the fabric length by more than about 5%. If this can be achieved, then Calenders and compactors can be chosen with regard to minimising the flattening and spreading effect.

Calendering and Compacting

Compacting or compressive shrinking is a mechanical means of reducing the residual length shrinkage in a fabric by forcibly reducing its length. The earliest devices for this were designed for woven fabrics, the Sanforizing® process probably being the first, and certainly the best known. These were, and still are, based on the compressive force applied to the fabric by changing the degree of curvature of a thick rubber belt against which the fabric is pressed.

For many years, knitted fabrics were considered to be too difficult or too delicate to be handled in this type of process, and an alternative technique, "confining passage", was developed specifically for the control of tubular knits. Nowadays, many compacting machines for knits tend to be of the felt blanket type, which is said to give minimum change in surface appearance of the fabric, and to maintain the fabric thickness and softness better. There are some interesting calenders on the market that include

two felt blanket compacting zones, one for each side of the fabric, that are specifically recommended for following Relax Dryers.

Importance of Moisture Content

Moisture content is the key both for effective compacting and for good calendering. For the best, most uniform results, the fabric should contain about 10-15% of moisture. For this reason, most machines incorporate a steaming unit to condense moisture into the fabric before compacting or calendering. However, remember that steam will not condense easily on a hot, dry fabric.

In a short, atmospheric steaming box, such as those in front of calenders and compactors, the amount of water that condenses onto the fabric depends mainly on the temperature and moisture content of the fabric. The specific heat of dry cellulose is about 0.3 and the latent heat of condensation of steam is about 540 Calories per gram. Therefore, in theory heating 100 grams of cotton from 20 to 100 °C requires:

100 * 0.3 * 80 / 540 = 4.4 g steam

If the cotton contains 7% moisture, then a further 1g of steam is condensed.

In the following table are two theoretical examples

Fabric Before Steaming		Fabric After Steaming
Temp. °C	Moisture %	Moisture %
20	7	12.4
50	2	4.5

Of course, the theoretical calculations will not be replicated exactly under production circumstances, but they indicate an important point. Hot, bone-dry cotton will not respond very well either to calendering or to compressive shrinking. The fabric must be cooled after drying, and before steaming in order to allow moisture to be absorbed back into the cotton. Moreover, the moisture content must be uniform along the length and across the width of the fabric, otherwise compacting efficiency will be different from place to place.

The easiest way to achieve both of these objectives is to ensure that the fabric emerges from the dryer with about 10 - 12% moisture content and passes between cooling fans. In this way, the last two to three percentage points of moisture removal occur by natural evaporation. Natural evaporation has the effect of cooling the fabric and is a self-regulating process, so that moisture distribution is more or less even. The drawback is that the maximum possible fabric shrinkage and Consolidation cannot be achieved in the relax dryer.

Importance of adequate and uniform lubrication

The efficiency of compacting depends on the frictional characteristics of the fabric. Moisture content plays a part in altering the frictional properties, which is one reason why a uniform moisture content is important.

However, it usually helps to apply a good lubricant. Fortunately, the same lubricants that are used to give good sewing characteristics also give good frictional properties for compacting. However, it is not always appreciated that these lubricants are sometimes quite difficult to apply in a uniform manner. Non-uniform lubrication means non-uniform compacting. Those lubricants that have a high affinity for the fibre (e.g. cationics) are the most difficult in this respect. Steps should be taken to check that lubricants are being applied uniformly.

Note:

Aggressive compacting will not restore over-stretched fabric to a stable condition and it may change the surface appearance of the fabric. The two sides of the tubular fabric may look different and there may be some apparent loss of colour.

Often in garment making, it is found that compacted fabric extends readily in the laying-up operation, so that the resulting garment shrinks even though the fabric was delivered with low shrinkage. Compacting without adequate consolidation is the reason for this and therefore the

finisher must maintain the consolidation, or thickness, of the fabric in order to obtain reliable stability.

So far as the Finishing Control Targets are concerned, whether the fabric is compacted, calendered, or neither has no influence. The same targets can be used. Compacting may help in achieving the targets but, in principle, it does not affect the number of courses per inch or per cm that must be in the delivered fabric in order to guarantee a certain weight and length shrinkage.

We have carried out several large trials, with many different fabric qualities, comparing compacted and uncompacted fabric, and there is no evidence that compacting has any effect on the course density in the Reference State. If the Reference Courses are not changed, then neither are the Finishing Control Targets.

An exception to this general rule can be imagined for fabrics that have been highly stretched during preparation and then given a very large amount of compressive shrinkage (say 10% or more), without the benefit of relax drying to develop the fabric thickness. With these fabrics, it may be necessary to deliver the fabric with more than the Target number of Courses because they have a tendency for greater elongation during the fabric spreading operation in the garment-making factory.

Resin Finishing

Crosslinking or Resin Finishing can be employed, if desired, to help with stabilisation of open-width fabrics. It must be remembered however, that crosslinking will introduce several changes in fabric properties that may not be desirable.

The Reference State will be altered to a more open construction. This will improve stability, but produce a thinner structure and a lighter weight.

The handle will be affected, so that it may be necessary to include other additives in the resin bath to restore the handle to a more desirable state.

There may be free formaldehyde on the fabric, which is restricted by many customers and in some countries by National legislation, although there seems to be no definite proof of risk to human health.

Fabric strength will be reduced, by between 30 and 50 %

Stitching damage and dust generation in the garment making operation may be worse.

In principle if the same Finishing Control Targets can be maintained for resin treated as for the same fabric not resin treated, then the stability of the resin treated fabric (especially in the length direction) will be superior. This is because resin finishing has the effect of reducing the course density in the Reference State. The amount of the difference depends on the fabric type and the amount of resin that is applied (and fixed). In general the wale density seems to be affected less than the courses.

A typical example of a commercial resin finishing process is illustrated by the results obtained from a commercial case study that looked at a 24g Plain Jersey fabric produced from Ne 30 at a Stitch Length of 0.280 cm. A large number of samples were taken over a period of several weeks and the averages were calculated for the Reference Dimensions.

Reference Dimensions	No Resin	Resin	Difference %
Courses / 3 cm	60.4	57.4	5.0
Wales / 3 cm	46.4	45.1	2.8
Weight g / m²	157.7	151	4.2

Spirality in single jersey fabrics, and Seam Displacement in garments is usually reduced slightly by resin finishing. In addition, resin finishing results in a fabric that maintains its appearance much better during its (shortened) lifetime. This is because resin finished fabrics do not develop the hairiness typical of cottons that have been laundered many times. For the same reason, resin finished fabrics are less comfortable to wear. Resin finished fabrics are quicker to dry after washing, because they absorb less water from the washing liquor.

The STARFISH Database contains many examples of resin-finished fabrics. It would have been possible to include resin finishing as a standard processing option (or modification) in the STARFISH Prediction Software. This was not done because the advice received from industry was that they

would rather do without resin finishing, if possible, and that retail organisations were pressing for a reduction or elimination of formaldehyde.

If enough STARFISH users insist that they want to see resin finishing as a process option then it can easily be included in a future upgrade.

Note:

Resin Finishing needs considerable expertise and should be approached with caution. For shrinkage control, it should be used only as a last resort.