Management of Quality in Finishing

Part 2: Practical Considerations

Process Control - Control Targets

To establish a useful Quality Control system for processing knitted cotton fabrics, 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 shrinkages.

Finishing Control Targets are those 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 set of fabric properties that, 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 Shrinkages 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 Shrinkages; he can not 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 shrinkages.

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

In principle, fabric Weight can be measured and controlled on-line. However, the measurements are often 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.

Shrinkages in length and width can not 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.

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.

Achieving the Targets. Tubular or Open Width?

The ease with which the targets can be achieved depends a great deal on the processing methods which 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 Targets for width and courses were calculated aiming for a particular length shrinkage to the five-cycle tumble-dry test.

Processing was as follows: -

	Tubular	**Open Width**
Dyeing	R-Jet 95	RotoStream
Hydro extract	Calator	Centrifuge
Wet-slit	no	yes
Drying	Pegg	Famatex stenter
Finishing	Heliot calender	Stenter

The same fabrics, ninety different structures in all, were processed through both routes, and 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.

Length shrinkages were 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.

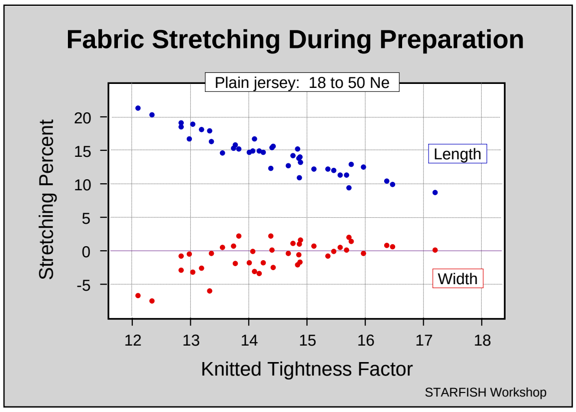
However, in the absence of any positive reason for slitting into open-width, the finisher will probably find that shrinkage targets will be more easily achieved on tubular fabric.

Whether tubular or open width, it is in the drying and finishing stage that the final dimensions of the fabrics are set and it is here that the machinery and technique has a decisive influence on whether finishing targets can be met. It is not the objective of this manual to recommend specific machines. Development in machine design, especially in the field of knitgoods finishing, is proceeding at a rapid pace, and any specific recommendations would quickly become obsolete.

Some general guidelines for selecting machinery and processes for optimising cotton knitgoods finishing can, however, be suggested.

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 that involves pulling fabric through or round 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 that are found immediately after the preparation and dyeing processes.



The graph shows some typical results on a wide range of plain single jersey fabrics. It can be seen 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 can be 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. It is clear from the above graph, that tightly knitted fabrics will require less width stretching than loose ones. They also will 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, which 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 also can be stretched on the stenter frame whilst providing overfeed in the length, but there are limits to the amount of width spreading that can be achieved on a stenter. This is 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.

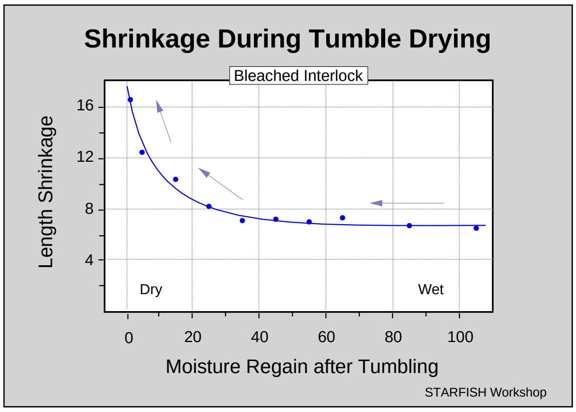
In summary, wet spreading is most effective when there is a subsequent opportunity for the fabric width to be reduced back to below the final target width without excessive length tension, for example in a relax dryer.

Large amounts of overstretching 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. That is why the Reference Relaxation Procedure is based on tumble drying, and why a fabric which has been subjected to this procedure is often described as "fully relaxed". This has led machinery manufacturers to explore the potential of vibrating carriers and specially arranged hot air jets to impart more or less vigorous agitation to knitted piece goods during drying and thereby promote shrinkage. Such machines are called relax dryers and they have been one of the most significant developments over the last two decades.

At this point, we should consider how shrinkage develops in a knitted cotton fabric during a drying process.



The diagram shows the relationship between shrinkage and moisture content as a fabric dries in a tumble dryer. Shrinkage does not start to take place until the moisture content is below 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. They are often said to be less energy-efficient than Drum Dryers, so 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.

The same technique can be used by dyers and finishers who have to cope with very difficult fabrics, such as crosstuck (piqué) or brushed fleece.

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 easily be 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.

Compacting and Calendering

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 being among 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 blanket or 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 shrinkage 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. There are some interesting calenders on the market which include two felt blanket compactor zones, one for each side of the fabric, which are specifically recommended for following relax dryers.

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:

$$100 * 0.3 * 80 / 540 = 4.4 \text{ g steam}$$

If the cotton contains 7% moisture, then a further 1 g 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.

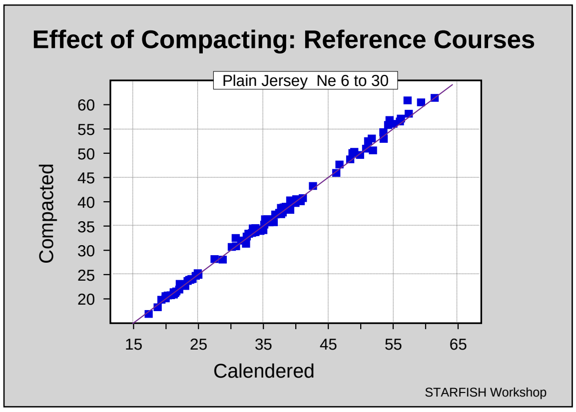
The easiest way to achieve both of these objectives is to ensure that the fabric emerges from the dryer with about 10 - 12% moisture content and passes between cooling fans. In this way, the last two to three percentage points of moisture removal occur by natural evaporation. Natural evaporation has 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 can not be achieved in the relax dryer.

The efficiency of compacting also 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.

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 making-up 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, as we have already seen, the finisher must maintain the consolidation, or thickness, of the fabric in order to obtain good stability.

So far as the Finishing Control Targets are concerned, whether 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 cm or per inch 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 which have been highly stretched during preparation and then given a very large amount of compressive shrinkage (say ten percent 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 at the garment-making factory.

Before leaving the subject of compactors one important observation should be made.

The compactor is the only machine in the production line that offers (more or less) precise control over the course density of the delivered fabric. Machinery builders tend to advertise that their compactors are capable of providing large amounts of compressive shrinkage – up to about 20%. However, in a modern finishing plant, equipped with good relax dryers, a large degree of compaction is neither necessary nor desirable.

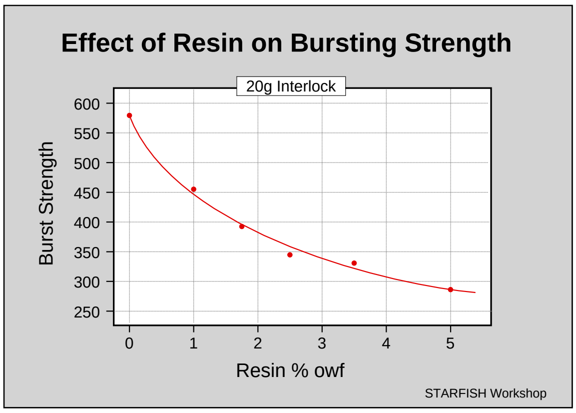
What is important is that a moderate to low degree of compaction must be obtained accurately and consistently. Therefore, when evaluating or setting up compactors, attention should be focused primarily on the efficiency of its control systems.

Ideally, the compactor should be capable of accepting an automatic control system based on electronic counting of course density in the delivered fabric coupled with a feed-back signal that alters the degree of compaction according to the deviations in the delivered fabric from a pre-determined set point.

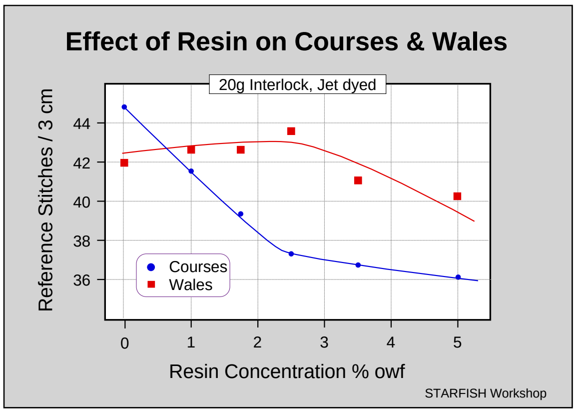
Resin Finishing

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 which may not be desirable.

- The Reference State will be altered to a more open construction. This will improve stability, but may 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 even by some National legislations 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 the length shrinkage) 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 an industrial 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 averages were calculated for the Reference Dimensions.

	Reference State Dimensions		
	No Resin	**Resin**	**Difference %**
Courses / 3 cm	60.4	57.4	5.0
Wales / 3 cm	46.4	45.1	2.8
Weight gsm	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 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 sometimes 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.

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