SHRINKAGE: IF YOU CAN PREDICT IT THEN YOU CAN CONTROL IT

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INTRODUCTION

We start from the following assumptions:

a. In the developed consumer markets of Japan, Western Europe, and the USA, there is a large demand for cotton circular knitted goods together with a strong desire for wider choice and higher quality.

b. The demand for wider choice means that frequent changes in basic fabric types, styles and colours have to be made. It is no longer the case that a single range will suffice for a whole season.

c. This means that new products have to be continually evolved at a much faster rate than before, and consumer response to poor quality will be felt more rapidly. It also means that the size of individual orders will be smaller.

d. The consequence is that reputable, high volume multiple retailers in advanced consumer markets are becoming more interested in those suppliers who can guarantee to have the quality right first time at reasonable cost and can respond rapidly to requests for new and improved products. Such customers are prepared to develop long-term relationships based on mutual profitability.

e. There will always be competition from low cost, low quality suppliers but they will suffer from low profit margins, stiff competition from producers in less well developed economies, slow response times, poor customer service, and customers who are not very interested in long-term relationships.

Thus, one of the keys to a long-term future in supplying the advanced consumer markets is to be able to develop the appropriate technical performance in the appropriate range of fabrics and to do this very rapidly and at a reasonable price.

PROBLEMS IN UPGRADING THE PERFORMANCE OF COTTON KNITS

The most important performance attribute, which has to be improved, is the shrinkage. This is the message, which always comes back from consumers and from retailers when they are asked what are the disadvantages of cotton knits.

Many finishers of cotton knitgoods will tell you that it is often not too difficult to improve the shrinkage of a given existing fabric quality but, in order to achieve such an improvement, the fabric has to be delivered with a heavier weight and a narrower width. However, the garment cutters are not always prepared to accept a narrower fabric, and the customers are not always prepared to pay the extra cost of the heavier material.

It therefore follows that the first requirement in developing a low shrink cotton product is that the basic knitting quality has to be changed. This is not so simple as it sounds if the development has to be based on the trial and error methods, which are typical of the knitgoods industry today.

For example :

- In order to maintain the weight at a lower shrinkage, a finer yarn is required.
- In order to maintain the width, a larger knitting machine diameter or a longer stitch length is necessary.

- In order to maintain the same knitted tightness factor, or cover factor (square root of tex divided by stitch length) with a finer yarn, a shorter average stitch length must be knitted.
- Changes in yarn count and stitch length also change the stitch density which again changes the weight and the width for a given level of shrinkage. Changes in the tightness factor will change the extensibility of the fabric and will also affect the amount of spirality (fabric twisting) which may be developed.

It should also be noted that a change in the knitted tightness factor will affect the amount of difficulty that the finisher may have in meeting his weight and shrinkage targets and the garment maker may have in the cutting and sewing operation - a tightly knitted fabric is generally easier to finish and to make into garments than a slack one.

Every change that we make to the manufacturing process has more than one consequence, so it is not always easy to predict what will be the result of a given change in the basic design parameters upon the final performance of the fabric. For this reason, it is very common for knitters and finishers to carry out a number of sample trials when they have to develop a new product. These sample trials can consume significant amounts of time and raw materials, and cause considerable disruption to production schedules, before a satisfactory solution is found but they are essential to ensure that a customer's wishes can actually be met.

Finally, it is as well to recognise that the demands of customers are often based largely upon wishful thinking rather than solid experience of the product that they have in mind. In the case of a new product, this is almost inevitably the case and is to be accepted as a fact of life - part of the process of product evolution and improvement in response to market opportunities.

We are left with a few simple conclusions about the problems of upgrading the performance of cotton circular knits.

1. Developing a new fabric quality which is supposed to have a specified level of performance is a very tricky business because there is no way to predict exactly what will happen as a result of changing the different manufacturing parameters.
2. Therefore, the only methods that most companies can use to develop new qualities, or to upgrade existing qualities are "past experience", "guess-work", and "trial and error".
3. Trial and error development is not only expensive in itself - because it consumes valuable time and production resources - it is also very risky because there simply may not be enough time or resources to get it right.
4. There is very little time or opportunity to check whether the product performance that a particular customer is asking for can actually be achieved. It is not at all unusual for customers to ask for a combination of, for example weight, width, and shrinkages, which are quite impossible to obtain from the existing selection of yarns and manufacturing equipment.

COST IMPLICATIONS

Some of the cost implications of the problems inherent in developing new products with good performance are immediately obvious. For example, the cost of trial and error development is not too difficult to establish. In the UK it has been calculated that every sample piece costs in the region of GB Pounds 400 to produce. If it were possible to predict in advance exactly how a new quality should be made, then only one development trial would have to be made before the new fabric was ready for bulk production. With a trial and error system we may be lucky the first or second time but more likely we would have to spend money on buying in different yarns, knitting them up with several different stitch lengths and processing and testing all of the trial qualities with different settings at the dryer and calender before we would have a good idea of what the best compromise might be.

Even after all that effort, the final quality may still not be quite right but time and money would not allow any further trials to be made before a commitment was made to bulk production. In earlier days, when long runs of standard qualities were the norm, it was expected that further development to refine the performance would continue on the bulk production but such a luxury is less and less common in the modern market environment.

Several companies have reported to us that the cost of such development trials can run into tens of thousands of dollars each year.

A second cost, which is relatively easy to quantify, is the cost of wasted fabric, reprocessing, customer complaints, rejects, and even compensation on account of the performance not being as specified. Every manufacturer who is dealing with quality-sensitive customers can show examples of lost orders, returned goods, goods which had to be sold off at second grade prices, or actual claims for compensation because the performance did not conform to the original specification. Often these rejections will have arisen because an order was accepted by the salesman when neither he nor the production department had appreciated that the customer's wishes could not actually be met by the installed equipment. These amounts can also run into tens of thousands of dollars.

There are other cost penalties, which are not quite so easy to quantify. There is the cost of lost opportunity and lost reputation. If a sample is submitted which does not attain the customer's requirements then, not only does he not place the order for that product but he is less likely to request samples again for other products. If a delivery is accepted which arrives late, or does not perform up to standard, the customer may not necessarily complain or claim compensation but he is less likely to come back for more. Good suppliers can gain a reputation, which extends beyond their immediate customers and will generate business from unexpected sources.

DEVELOPMENT OF A PREDICTIVE SYSTEM

Many of these problems in upgrading the performance of cotton circular knits could be solved if we had a method of predicting what would be the performance of a particular proposed fabric quality before we ever started to make it. If we could make such predictions then:

1. We would know immediately whether our particular production equipment would allow the proposed quality actually to be produced. If the customer's request did not coincide exactly with what was physically possible, then we could offer a close compromise, which we could guarantee to produce.
2. We could dispense with guesswork and trial-and-error methods. When a new or improved quality was required, we could simply calculate how to make it and proceed directly to pre-production trials with a single target quality, or a couple of options.

The consequent savings in time and cost of development and the corresponding improvement in customer service would be enormously beneficial to the profitability of our business.

The first problem, which has to be faced in the creation of a predictive system for product development, is the question of exactly what to predict.

In order for a manufacturer to be able to deliver a fabric with guaranteed low levels of shrinkage, he first has to know what will be the dimensions of that fabric after it has been shrunk. When the dimensions after shrinking are known, then it is relatively easy to calculate the dimensions which must be delivered to the garment maker.

As a simple example:

- If the garment maker must have a width of 100 cm and the width shrinkage must be 5%, then the width after shrinking must be 95cm.
- If the same fabric has to have a finished weight of 150 grammes per square metre (gsm) and the length shrinkage must also be 5%, then it can be calculated that the weight after shrinking has to be about 165 gsm.

- Therefore, the manufacturer has to be able to predict what combination of manufacturing conditions will result in a width of 95cm and a weight of 165 gsm after shrinking.

Thus, the problem of predicting performance can be solved if only we are able to calculate the dimensions that the fabric will have after shrinking.

It turns out that there are just four major variables, which affect the dimensions after shrinking of cotton circular knitted fabrics. The effects of these four variables are most easily understood by thinking about the shape and size of each knitted loop in the fabric. Any circular knitted fabric is composed of row after row of interlaced loops. Different types of fabrics are made by different methods of interlacing the loops. Therefore, the dimensions of any knitted fabric are simply a reflection of the average shape and size of the individual loops, summed over the total number of loops in a given area.

The four major variables are:-

1. **The Yarn**

   The type and size of the yarn (yarn count, twist, spinning system) governs the weight of each loop and also determines its shape (length/width ratio).

2. **The Stitch Length**

   The average length of yarn in each loop (stitch length) determines its weight and also the overall size of the loop (number of loops per unit area).

3. **The Knitting Machine**

   The size of the knitting machine (number of needles) determines the number of loops across the width of the fabric, and hence the fabric width.

4. **The Wet Process**

   The effect of wet processing is to change the shape of each loop, mainly by changing the stiffness, the specific volume, and the twist liveliness of the yarn. In addition, wet processing will change the weight of the yarn, by removing impurities and adding chemicals (such as dyestuffs), and will change the average length of yarn in each loop, through yarn shrinkage.

   Different types of wet processing procedure will change the shape, the weight, and the length of the loops by different amounts and, therefore, they affect the length, width, and weight of the fabric by different degrees.

From this simple analysis, it now becomes clear that, in order to set up a system for predicting the dimensions and shrinkage of cotton knit fabrics, the first requirement is that we must be able to calculate the average dimensions of the loops from a knowledge of the knitting parameters and the type of wet processing. In other words, it is necessary to have a set of equations which link the dimensions of a given fabric after shrinking to the yarn type and size, the knitting machine used, the average stitch length, and the wet process route. Comparison of these dimensions with the specification demanded by the customer will then yield the values for weight, width and shrinkages in the "as delivered" cloth.

It is also necessary to define more closely what we mean by "after shrinking".

In the case of a particular customer, obviously "shrinkage" means "according to the method that the customer uses himself". But most manufacturers have more than one customer and they will not all use the same test methods. In addition, if the final shrinkage performance is to be guaranteed, then it is necessary to consider what will be the largest possible shrinkage that the fabric will ever experience in the hands of the ultimate consumer. How can we know what this will be and how can we relate it to the customer's definition of "shrinkage"?

For the purposes of making predictions about shrinkage, the test method that we use for this definition is one which involves five cycles of washing and tumble drying. We call the

Reference Relaxation Procedure and after a fabric has been subjected to this procedure, it is said to be in its **Reference State**.

The reason that we use this very intensive relaxation procedure is that it removes essentially all of the shrinkage in nearly all knitted cotton fabrics. In this way, we achieve two important objectives.

The first is that we gain a knowledge of the ultimate shrinkage of any given product. This is a value, which is very seldom seen by manufacturers or retailers, but it is what the ultimate consumer may actually experience in practice under the worst conditions. If we can accommodate the worst conditions, then we know that our product can give satisfaction in the market.

The second is that it reduces all different fabric types and qualities to a common, comparable state. It is only when we have such a common state - a Reference State -that we can make reliable comparisons and develop reliable prediction equations for the final fabric dimensions.

In fact, the only two dimensional properties for which prediction equations are needed are the number of *courses per unit length* and the number of *wales per unit width* in the fabric after shrinking to its Reference State. This is because all of the other properties that are of interest can be derived from these and from the target "as delivered" specification.

Thus :-

- Width is given by the number of needles and the number of wales per unit width,
- Weight per unit area is given by the product of yarn count, stitch length, courses per unit length, and wales per unit width.
- Shrinkage is given by the differences in courses and wales between the target "as delivered" state and the Reference State.

DEVELOPMENT OF THE PREDICTION EQUATIONS

The prediction equations which allow us to calculate the course and wale densities in the Reference State for any given quality of fabric have taken a great deal of time and an enormous quantity of money to discover. In order to do this, we have had to produce more than two and a half thousand different qualities of fabrics, subject them all to commercial wet processing procedures of many different types, and carry out extensive laboratory testing on the fabrics both "as delivered" and after relaxation to the Reference State. This yielded a very large data base which was then subjected to comprehensive mathematical analysis in order to discover the underlying relationships.

Once these underlying relationships were known, then it was possible to build a special computer program, which would allow the dimensions after shrinking for any fabric within the original database to be calculated very rapidly. The computer program, and the technology for upgrading the performance of cotton circular knitted fabrics which has been built up around it, have been called "**STARFISH**".

In the first phase of the project, we collected and analysed a wide range of data on plain single jersey, 1x1 rib, and interlock fabrics made with combed ring yarns. These fabrics were all incorporated in the first commercially released computer program, which was called **STARFISH VERSION 4**. About 50 copies of this first program are in use all around the world on IBM - compatible personal computers.

In a second phase, additional data was collected including, for example, data on plain jersey fabrics made from open-end rotor spun yarns and from carded yarns, and also on single jersey crosstuck (pique) fabrics. In addition, a brand new analysis of the larger database was carried out. This has resulted in a new set of equations with a significant improvement in reliability and also has allowed us to increase the range of wet processing treatments which can be modelled by the program.

Therefore, we have been able to develop a new, upgraded computer program - called **STARFISH VERSION 5.0** - which was announced officially for the first time in Japan, in July 1992, and is now being made available world-wide.

The collection of data and the analysis and interpretation of the database is still continuing. We are currently examining plain jersey and interlock fabrics made from open-end rotor yarns and we are looking at the effect of twist and twist liveliness on fabric dimensions and spirality. We also have extensive data on the effect of crosslinking (resin finishing) on several fabric types and we are beginning to collect data on single jersey loopback (fleecy) fabrics. These new data will be analysed and the results will be incorporated into future upgrades of the system.

Three further points should perhaps be mentioned in connection with the collection of the **STARFISH** database. The first is that almost all of the fabric samples have been manufactured and processed under fully commercial conditions, so that the results are a realistic representation of practical large scale operations in the industry.

The second is that, we have been fortunate in securing a very broad measure of support from the industry in preparing these samples. In order to carry out the necessary trials, co-operating mills were required to disrupt their normal production by setting up knitting machinery and wet processing equipment to produce and finish large quantities of non - standard as well as standard qualities, and at the same time to allow our technical staff to closely monitor all aspects of the production and processing.

The third is that the validity of the **STARFISH** equations has been extensively checked by means of case studies carried out in the industry. This is done by taking random samples over a period of time from the standard production of individual fabric qualities. When enough samples are available, we can obtain a good idea of the normal random variation to be expected in commercial production. If we calculate the mean and standard deviation from the measurements for each property of interest for a given quality, then we can say that, to a first approximation, the difference between the mean value and the value predicted by **STARFISH** should be less than one standard deviation most of the time. About 95% of the measured values should be within two standard deviations of the predicted value. Several sampling exercises of this type have been undertaken and it has been found that the **STARFISH** predictions are in fact usually contained within the normal production variations.

The original research, together with the validation exercises, has required the development of a tremendous level of co-operation and trust with several manufacturing companies as well as a large degree of foresight and quite some investment in time, facilities and lost production efficiency by those companies involved. The work has been carried out over a very wide geographical area, including companies and research institutes in Brazil, Denmark, Germany, Italy, Japan, Portugal, Sweden, Switzerland, USA, and Great Britain.

THE STARFISH COMPUTER PROGRAM

The name **STARFISH** is contracted from the phrase "**START** as you mean to **FINISH**". It embodies the principle that, in order to know how to produce a knitted fabric with the desired dimensions and performance, we must first have an accurate knowledge of the final finished product. For example, we must be able to calculate in advance what will be the consequences, in terms of final fabric performance, of finishing a given quality of fabric to specified targets of weight and width using a specified wet processing regime.

Once the equations of the Reference State are available, they can be used to calculate the Reference Dimensions of any conceivable fabric quality within the range of the database. When the Reference Dimensions are known, it is easy to find out what the gross, "as delivered" dimensions must be in order to guarantee a given level of weight and width, and to calculate what will be the corresponding shrinkage. Conversely, if the target finished weight and width are specified, then it is easy to discover what fabric quality has to be knitted in order to be able to guarantee a given level of shrinkage.

In effect, the **STARFISH** computer program is a simulator; it models the key elements in the production and processing of circular knitted cotton fabrics and calculates their expected performance. This means that in the space of a few minutes, a yarn and knitting machine can be selected, the fabric tightness specified, an appropriate wet finishing process selected, the desired "as delivered" finishing targets indicated, and the weight, width, and shrinkage of the finished fabric discovered without spending a penny on materials and processing.

If the simulation does not match the desired performance, then the key production elements can be altered repeatedly until a suitable fabric quality is found. In this way, large scale product development exercises can be carried out in a very short time and at very little cost. In addition, the desires and demands of customers can very quickly be checked out against what is really possible, so that orders which are bound to give production problems can be avoided or can be amended during discussion with the customer.

With the **STARFISH** computer program available, the central problem of defining a proper production specification to achieve particular performance targets has been solved in a very effective and satisfying manner, at least for plain jersey, single jersey crosstuck, 1x1 rib, and interlock fabrics. However, this knowledge alone is not sufficient to guarantee consistent performance levels for two reasons.

The first reason is that the **STARFISH** predictions refer to *average* performance values and they assume that the specified production conditions are being strictly maintained. In practice, there is always some variation in control of production conditions and this means that there will be variation in performance. Therefore, the first essential component of the introduction of the **STARFISH** system into any manufacturing regime must be an increased awareness of quality assurance and quality control and much closer attention to the key factors in production which lead to avoidable variations in the product. This aspect of the **STARFISH** system is summarised in the Reference Manual which accompanies the software, but it is treated in greater depth in the special **STARFISH** training courses.

The second reason is that, although the computer program is able to help in the setting of proper targets for the finisher - for example in terms of the length and width which must be delivered in order to achieve specified performance targets - it does not tell the finisher how to achieve these targets in practice. Therefore, the second essential component which accompanies the introduction of the **STARFISH** system is the latest finishing technology and know how. If a really good performance (i.e. low shrinkage) is required, then it will be found that the traditional finishing technology may not be adequate - especially for some of the more difficult fabrics such as interlock and single jersey crosstuck. It goes without saying, of course, that additional attention to certain aspects of quality control is also necessary in the finishing plant. The question of finishing technology, as well as quality control in the finishing plant is also covered in the **STARFISH** Reference Manual and training courses.

Thus we see that upgrading the performance of cotton circular knitgoods in general requires three main elements, each of which is dependent upon the other.

1. A rational system of fabric engineering based on the ability to predict the dimensions of the fabric in its Reference State.
2. The introduction of specifically targeted Quality Assurance and Quality Control systems.
3. The installation of the latest finishing technology and the application of the corresponding technical know-how.

Item 1 is supplied by the **STARFISH** computer program. Items 2 and 3 are summarised in the Reference Manual and are treated in depth by the **STARFISH** training courses.

