AN APPROACH TO THE 'proKNIT' SYSTEM AND ITS VALUE IN THE PRODUCTION OF WEFT-KNITTED FABRICS

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Abstract

'ProKNIT' is the result of a project based on the consideration that knitted fabrics shrink in both directions, or that some of them shrink in one direction but expand in another. This shrinkage and extension is not proportional; it varies greatly depending on the type of knitted fabric. However, one value that always changes by increasing upon fabric shrinkage is the fabric's weight. Increases in weight from shrinkage will not only increase the cost of production but may also affect the final product in a number of ways. Therefore, a program that would help to avoid problems of this nature could be created which would predict the weight of the knitted fabrics in different relaxed conditions, by using appropriate variables such as knitting machine gauge, yarn count, type of fabric, fabric loop length, tightness factor and courses & wales per unit length, but would not be too difficult to operate. This is how 'proKNIT' came about. The first part of the word 'pro' derives from the Greek meaning 'before'; therefore, the name of the system appropriately refers to the estimations made before a knitting fabric is produced.

1. Introduction

Most of the problems encountered in the knitting industry are concerned with variations in dimensions, which directly affect the fabric's weight.

So far much work has been done to determine the dimensional shrinkage of knitted fabrics, albeit without bringing results on a reasonable level so they can be applied on an industrial scale. Shrinkage has been calculated for existing dimensions, width and length.

'ProKNIT' was designed as a means of predicting and determining the weight of a knitted fabric in different relaxed conditions, based on the knowledge of knitting parameters such as machine gauge, yarn count, type of fibre, knitted fabric structure, loop length etc. Such a prediction system would have to be simple and reliable, but would be an invaluable tool in knitting production, in designing and developing new products without delay and setting new targets for finishing quality. The 'proKNIT' system is reliable as it was designed while considering the existing bibliography for determining fabric weight. It is also user-friendly, as it does not require expert computer knowledge to operate it. The VisualBasic programming language was used as the medium for designing it. More specifically, the thinking behind the creation of the system was based on the following logical premises:

1. using all the mathematical models from the existing bibliography to set up the sequence of the estimations,
2. developing three different conditions for predicting the weight of a fabric,
3. developing appropriate software which is compatible with and convenient for the industry,
4. building a comprehensive database of measurements made in several factories using different raw materials and knitted fabrics of various structural designs, and
5. producing a system that would provide logical and acceptable predictions.

2. Mathematical models

The development of the mathematical models used in the development of the software was based on the conclusions drawn by previous researchers, while the input parameters were restricted to those equations which are known before knitting commences and can easily be measured in a knitting factory.

To be more specific, on plain knitted fabrics, Doyle(1) has found that the stitch density depends only on the loop length, and is independent of the yarn and knitting variables. Munden(2) suggested that the knitted loop would take a natural shape when released from mechanical strains, and is independent of the yarn properties. A further study by Munden[3] has shown that the dimensions of plain knitted wool fabrics, in a state of minimum energy, are dependent only upon the length of yarn knitted into each loop. His experimental studies have indicated that in different relaxed states the following equations are applicable, giving a number of different constant values:

$$K_c = c \times \ell,\ K_w = w \times \ell,\ K_s = K_c \times K_w \text{ or } K_s = S \times \ell^2,\ K_r = R = K_c/K_w,$$

where c is the number of courses per unit fabric length and w is the number of wales per unit fabric width; S is the loop density; ℓ is the loop length in mm or cm, and K_r or R is the loop shape. The significance of the above equations is that plain knit fabric dimensions are uniquely defined by the length of yarn in the knitting loop. All other variables influence the dimensions only by changing this variable, that is, if the fabrics are always measured in the same relaxed state. Nutting & Leaf[4] introduced a term involving the yarn diameter, and proposed a small modification to the well-known basic equations. Knapton et al.[5] have shown that dimensional stability in plain jersey fabrics can be attained either by mechanical relaxation techniques or chemical treatments Also, they show that the stable loop geometry is almost identical for wool and cotton plain knitted fabrics.

Baird & Foulds[6] have shown by using a factorial analysis of many combinations of factors that the most important variable influencing the shrinkage rate of plain knit in washing is the cover or tightness factor, which they have defined as:

$$K = C.F. = T.F. = \frac{\sqrt{T}}{\ell}$$

where T is the yarn count in tex and ℓ is loop length in cm or mm. The tightness factor is a means of assessing knitting performance, and it has been experimentally proved that its values vary from 10 to 20 when the loop length is defined in cm. It has been found that the dynamic forces required to pull a wide range of yarn counts into a knitting loop are at a minimum when K is equal to 14[18].
Numerous other expressions for cover factor are in existence, of course. Munden[7] has used the following equation:

$$T.F = \frac{1}{\ell\sqrt{N}},$$

where N is the worsted yarn count and ℓ is the loop length in inches, while Gan[8] has made use of the reciprocal of this expression. Henning[9] used the expression

$$T.F. = \frac{C+W}{\sqrt{Nm}}$$

where C is the number of courses per cm, W is the number of wales per cm and Nm is the metric yarn count. Lako[10] also suggested exactly the same expression as Baird and Foulds, but gave ℓ in mm.

On double jersey structures, Smirfitt[11] showed that the dimensional parameters of K values for worsted knitted fabrics are hardly dependent on machine gauges and types, yarn diameters or twists, and indicated that Munden's relations may also be applied to rib knitted structures. Knapton et al[12-15] have in double jersey fabrics defined the SKC (Structural Knit-Cell) term, which is the smallest repeating unit of structure. Thus, according to Knapton, Munden's equations can be modified as follows:

$$U_u = C_u \times \ell_u,\ U_w = W_u \times \ell_u,\ U_s = U_c \times U_w \text{ or } U_s = C_u \times C_w \times \ell_u^2 = S_u \times \ell_u^2,$$

where ℓ_u is the yarn length in SKC, C_u is the number of course units per unit fabric length, W_u is the number of wale units per unit fabric width and S_u is the fabric stitch density. Wolfaardt & Knapton[16] have developed a mathematical model for estimating SKC values for a 1×1 rib structure in the fully relaxed state, and shown that the experimental U-values obtained are close to those obtained mathematically. Poole & Brown[17] have shown that U-values found for a relaxed cotton 1×1 rib structure are similar to those presented by Knapton for a relaxed wool 1×1 rib fabric.

As regards the relationship between the gauge (needles per inch) of knitting machine and the yarn count, there is no basic equation to predict the appropriate yarn count. Thus, the equations given below are some which have generally been recognised by knitters[18]:

$$N_{Tex} = \frac{10630}{G^2} \text{ for single knitted fabrics}$$

$$N_{Tex} = \frac{8860}{G^2}$$ for double knitted fabrics

where N is the yarn count in Tex, and G is the knitting machine gauge (needles per inch).

The calculation for fabric weight in grams per square metre can be easily justified by combining the equation for loop density and that for cover factor.

3. Conditions for predicting fabric weight

In order to predict the weight of a fabric after knitting, three different and realistic relaxed conditions were selected in such a way that they would more or less reflect those existing in the knitting industry. The three relaxed conditions were defined according to the standard procedures used in quality control sections, and are as follows:

- dry relaxed state
- wet relaxed state
- finished and full relaxed state

In the dry relaxed state, the knitted fabrics are placed, free from constraints, on a flat surface, and allowed to condition at least for 48 hours in a standard atmosphere of 65% ± 2% RH and 20° ± 2°C in order to facilitate recovery from stresses imposed during knitting.

In the case of the wet relaxed state, all fabrics produced from wool and cotton were soaked in water at 40^{o}C for 2 hours, hydro-extracted in a domestic washing machine and left flat to dry (ISO 6330, procedure C). Then the fabrics were conditioned for 24 hours in a standard atmosphere of 65% ± 2% RH and 20° ± 2°C.

In the case of the finished and full-relaxed state, the procedures were as follows:

1. Knitted fabrics produced from wool yarns and their mixtures were steamed flat in an industrial steamer, and were afterwards hand-washed at 30ºC with a household mild detergent for 15 minutes at 30°C. The excess water was hydroextracted in a domestic washer of front-load, horizontal-drum type and left flat to dry (ISO 6330, procedure C). Then the fabrics were conditioned for 24 hours in a standard atmosphere of 65% ± 2% RH and 20° ± 2°C.
2. Knitted fabrics produced with cotton yarns and their mixtures were washed and tumbled-dried according to standard ISO 6330. A horizontal rotating drum washing machine was used at 60°C washing temperature (procedure No 3A^h), using a non-phosphate ECE reference detergent A (without optical brightener). Tumble-drying was carried out at 60°C until the fabrics were dried. Finally, conditioning took place in a standard laboratory atmosphere for 24 hours.

4. Method of measurement

At each relaxation state, the values of courses per cm, wales per cm, loop length and fabric weight (g/cm^2) were measured. The yarn count was estimated before knitting. Using the above measurements of courses and wales per cm, loop length and yarn count, the following calculations were made:

1. Fabric tightness factor (K), using the equation $K = C.F. = T.F. = \frac{\sqrt{T}}{\ell}$ where T is tex and ℓ is the loop length in mm or cm.
2. The constant values of Kc, Kw, Ks and Kr using the appropriate equations.

All this data was fed into the 'proKNIT' software system to make the whole system operational.

5. Analyzing the 'proKNIT' system

Using the 'proKNIT' system it is possible to estimate/predict with substantial accuracy what the weight (gr/cm²) of different basic knitted structures, such as single jerseys (plain and purl) and double jerseys (ribs and interlock), will be when these fabrics come out of the knitting machine, when applying a certain relaxation procedure, and when they are completely finished.

The first two pages of the program contain the title and general information concerning the use of the system (Figure 1). By moving the cursor onto the 'ProKNIT' system logo and left-clicking the mouse button, the second page appears.

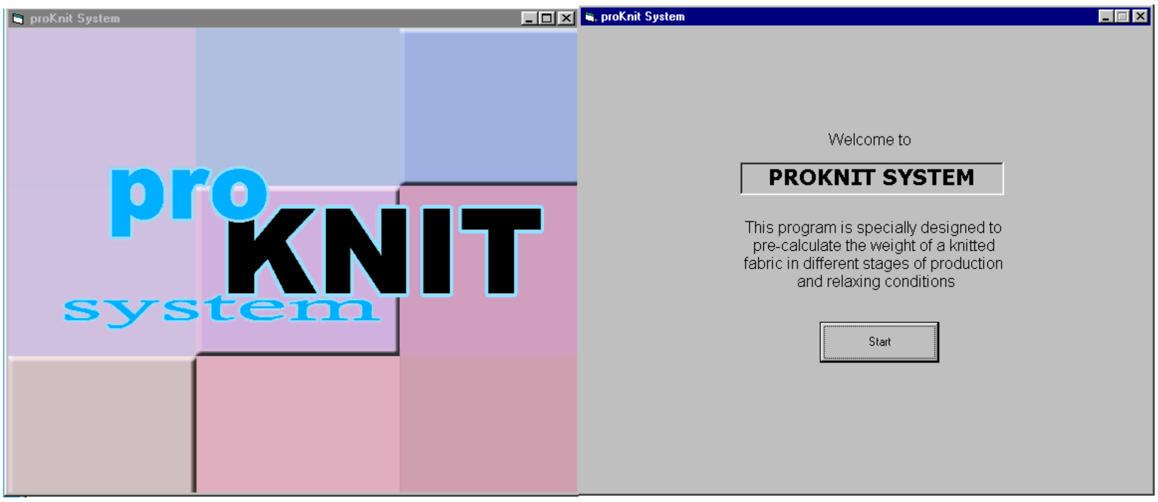

Figure 1. Page 1 and Page 2

The program will function as soon as the button ‘Start’ is pressed. On the third page, a table of different yarn characteristics appears (Figure 2). The yarns are classified into eight categories for the two most widely used natural fibres, namely cotton and wool. The user can choose between dyed and undyed yarns and their mixtures. If ‘wool’ yarn is chosen, then it means that it is an undyed natural coloured worsted yarn. In the case of ‘cotton’, it is a natural colour combed yarn. The mixtures cover the following combinations:

- Cotton/polyester
- Cotton/viscose
- Cotton/nylon
- Wool/acrylic
- Wool/nylon

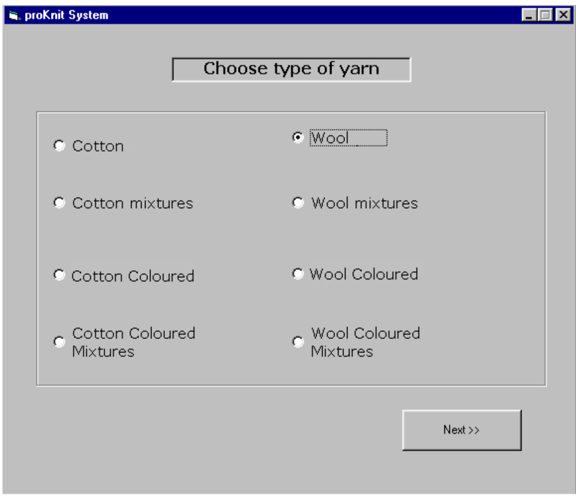

Figure 2. Page 3

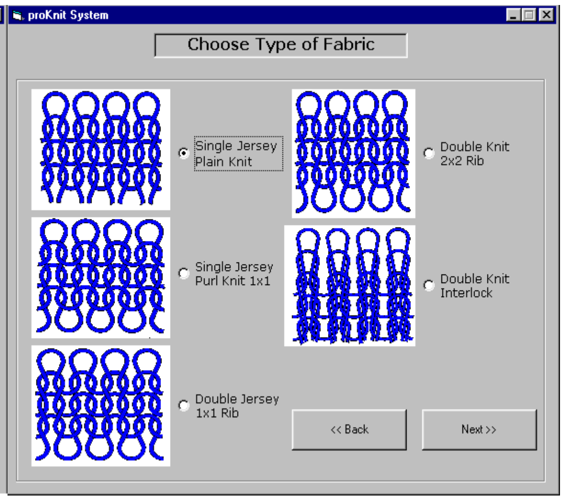

Figure 3. Page 4

Let us assume that ‘Wool’ yarn has beenselected. By pressing ‘Next>>‘ the fourth page appears, where the type of knitted fabric must be chosen. These fabrics have been selected because they have a substantial existing bibliography and because of their structure, which is less complicated compared to others (Figure 3).

We choose ‘Plain Knit’ fabric on page 4. From this page and up to the last one, it is possible for the user to go back to the previous page using ‘<<Back’ button, for alterations, or to move forward by pressing ‘Next>>’. When pressing ‘Next>>’ page 5 will appear on the screen. Here, the user is able to select the type of knitting machine gauge according to the variety of the knitting machines available for production. As soon as a knitting machine gauge has been chosen, the ‘proKNIT’ system will present the range of yarn counts suitable for the chosen gauge as well as the estimated one (Figure

4). Let us assume that a gauge of 14 has been chosen; in order to continue the procedure, the estimated yarn count for gauge 14 is 54 tex, while the range of yarns suitable for this gauge is 42 to 70 tex. Now the user has two options: the first is to keep the reference yarn count, or alternatively to alter it according to the schedule of production. By pressing ‘Next>>’ Figure 4.1 appears, and alterations can take place. If the user answers ‘No’ to the question ‘Do you wish to keep the estimated yarn count?’, then a new window opens with the title ‘Enter new yarn count’. By entering the required new yarn count and pressing ‘OK’, the system moves to page 6.

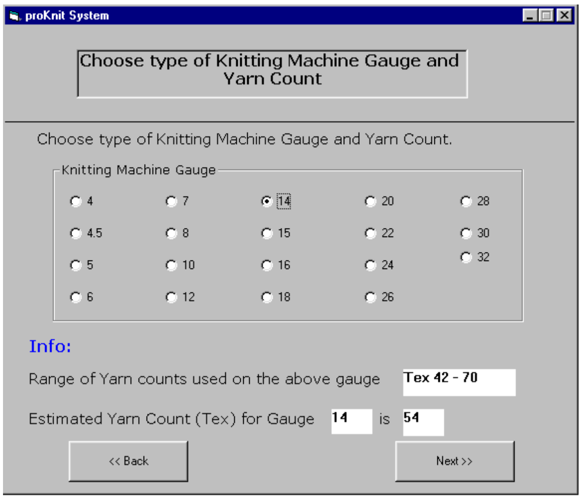

Figure 4. Page 5

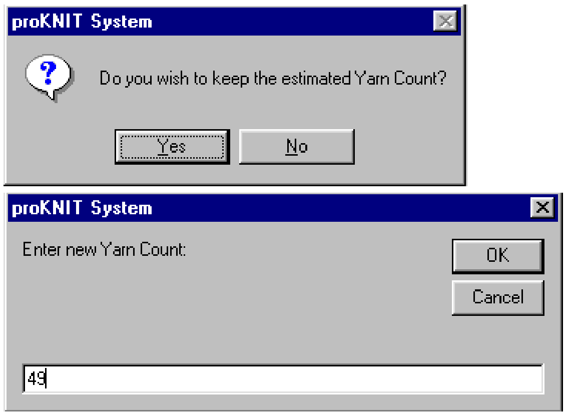

Figure 3. Page 5

Let us now assume that a yarn count of 49 tex will be used in the calculations, instead of 54 tex, which is the estimated value. By pressing ‘OK’ the new page appears, as already mentioned, and new values are required in order for the system to cover the information (Figure 5). In this new window the unit of loop length must be selected first. As soon as the unit of loop length has been chosen (mm), the information below the line appears where the tightness factor must be provided within the available range. The choice of loop length in mm presents a range of tightness factors starting from 0.8 and rising to 2.0, with an average value of 1.46. From the given range of tightness factors, 1.2 is chosen; by pressing ‘OK’, the last line appears indicating that, according to the data provided, the loop length value is 5.83 mm, giving also an analysis of the exact value estimated (i.e. 5.833333). Naturally, the same procedure would be followed if the loop length were chosen in cm.

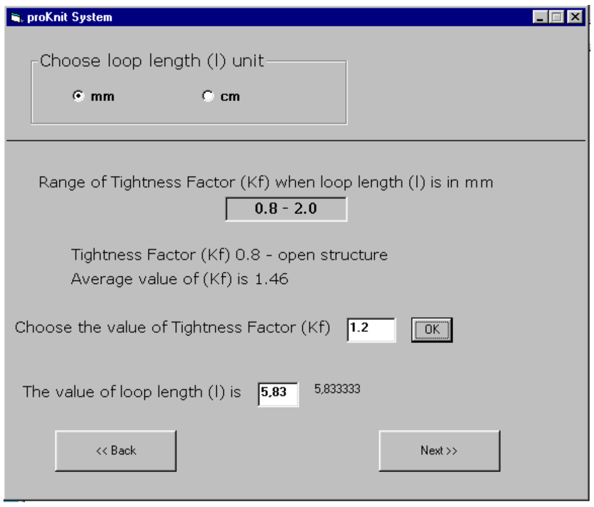

Figure 5. Page 6

The next page is concerned with justifying the relaxed state of the knitted fabric, where the estimations will be made. Therefore, the user can choose between the dry relaxed, wet relaxed and fully relaxed state. For our example, ‘dry’ and ‘finished-full’ relaxed state has been chosen. By

pressing 'Next>>' the eighth page appears, where after pressing the button 'Calculate' the estimations of courses per cm, wales per cm, loop density and loop shape, in a dry relaxed state, appear on the screen (Figure 6). Exactly the same procedure is used on page 9, where the estimations are presented for the fabric in a finished-full relaxed state (Figure 7).
By pressing 'Next>>', page 10 appears (Figure 8) where the estimations of weight of the chosen knitted fabric, in the given relaxed state, are provided in grams per square metre, while their percentage difference is also estimated. On the last page a full list of the values is finally given, so that the knitter has an overall view of the data he has chosen (Figure 9). This page can be printed and/or kept on file for reference. The user can also go back to page 7 and to alter the chosen relaxing states, by pressing '<<Back', or to go even further back in order to add new values.

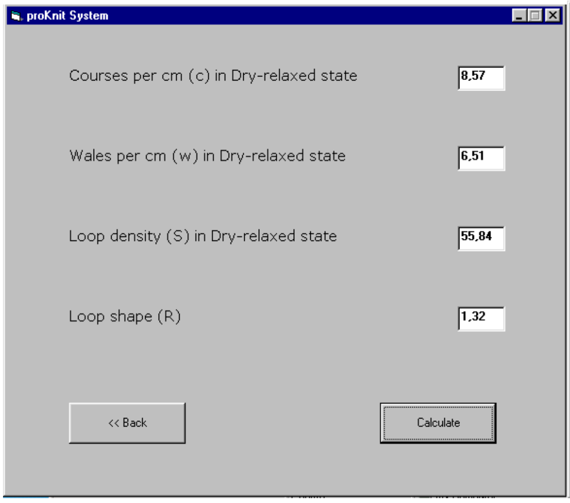

Figure 6. Page 8

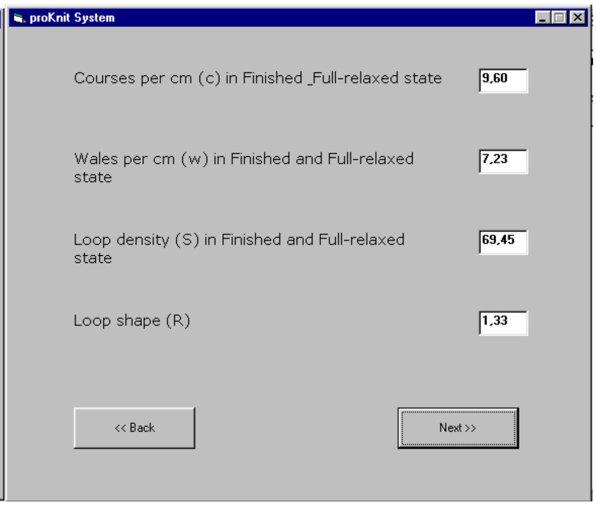

Figure 7. Page 9

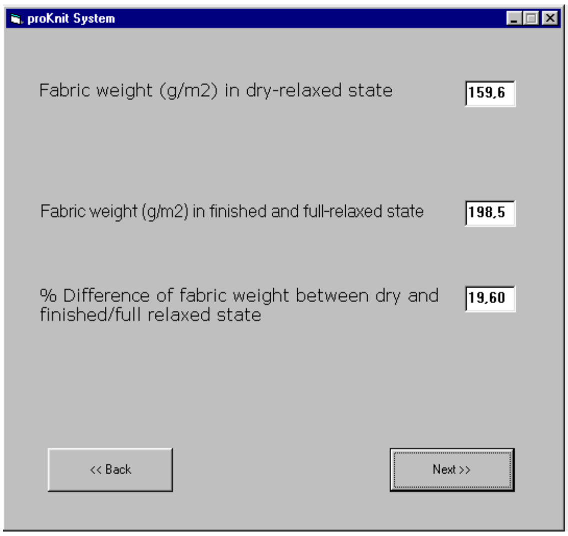

Figure 8. Page 10

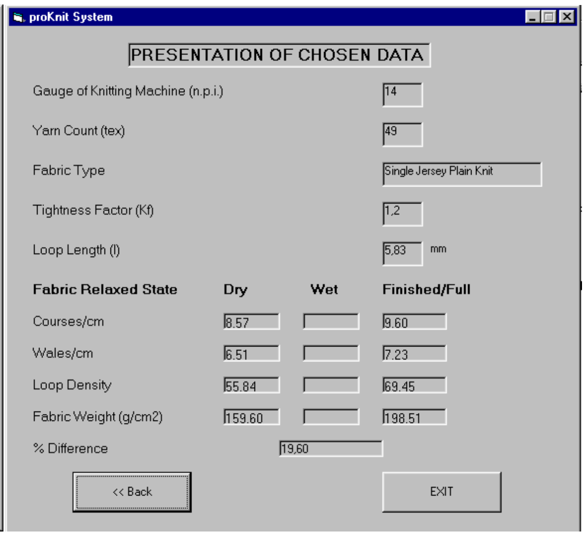

Figure 9. Page 11

6. Results and discussion

The first results produced by the tests carried out on dry relaxed fabrics produced with cotton yarns appeared to be very promising, because they proved that the system is both reliable and operational (Table I).

The fabrics, plain jersey, 1×1 rib and interlock structure, were taken from three different knitting machines of 18, 15 and 22 needles per inch respectively; they were then left in a conditioning atmosphere of 65% relative humidity and a temperature of 20^{0}C for 48 hours in order to release the strains; following that, the variables of yarn count, loop length, courses and wales per centimetre and fabric weight in grams/cm^2 were measured. In each case, ten measurements were taken and the average values were recorded in Table I. Then the values of machine gauge, yarn count and tightness factor were entered into 'proKNIT' and the system estimated the loop length, courses & wales per centimetre and fabric weight. The results received by this procedure were also presented on the same table.

By making a simple comparison of the Figures listed, it appears that 'ProKNIT' system in all cases gave 2% higher values, which is not a significant difference because it is within the acceptable limits. The existing difference between the loop lengths is a result of the difference in yarn count. The yarns were characterised as 40 tex for single jersey and 1×1 rib and 20 tex for interlock in using the 'proKNIT' system. However, during the tests these yarns showed small differences in yarn count compared to the nominal ones. These small differences in courses and wales per cm are the result of the constant values that we used in the software programming of the system.

Generally, it can be said that the results obtained so far allow us to be rather optimistic, and provide us with an incentive for further investigation in the remaining states of relaxation, perhaps using a wider range of samples.

Table I. Comparison between 'ProKNIT' system and samples of knitted fabrics taken out of production (dry relaxed state)

Conditions	ProKNIT system plain knit	Sample plain knit	ProKNIT system 1×1 rib	Sample 1×1 Rib	ProKNIT system interlock	Sample interlock
Gauge n.p.i.	18	18	15	15	22	22
Yarn count (Tex)	40.00	40.50	40.00	40.39	20	19.64
Loop length (ℓ) mm	4.49	4.50	4.45	4.47	3.31	3.29
Tightness factor (K)	1.41	1.41	1.42	1.42	1.35	1.35
Courses per cm	9.70	9.50	9.54	9.20	15.09	13.61
Wales per cm	7.60	7.50	7.50	7.60	11.47	12.30
Fabric weight g/cm^2	132.4	129.8	254.7	249.6	229.16	224.20
% Difference	2%		2%		2.2%	

7. Conclusion

The 'ProKNIT' system was originally intended for use for research purposes only. However, it soon became apparent, through contact with a number of people directly involved in the knitting sector, that being able to apply the program to industry itself would not only be useful but rather easy to operate as it does not demand a high level of competence in computer use. The 'ProKNIT' system has been created according to the existing literature on the geometry and dimensional properties of weft knitted fabrics. The different values presented by the system are real ones, and give an estimation of the fabric weight before knitting. The whole system is constantly being replenished with more data in order to cover a much wider variety of cases, so as to make it more flexible and minimise errors. From the first tests that have been carried out on single jersey, 1×1 rib and interlock fabrics, we have come to the conclusion that the predictions made using the 'proKNIT' system are very close indeed to the reality of production, which is a hopeful sign of its full potential. At the moment, the system is being tested with a considerable degree of success by two knitting factories, one of which produces cotton knitted fabrics, and the other woollen knitted goods.

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