proKNIT System
A Study on the Theoretical and Practical Application
of Predicting the Fabric Mass per Unit Area
for Weft Single and Double Knitted Structures

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Dedicated to my wife

and to my son Leo

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SUMMARY AND CONCLUSION

This Ph.D. project deals with the prediction of knitted fabric mass per unit area using a developed software called "proKNIT". The software has been designed according to the existing bibliography and has the ability of determining the mass of knitted fabrics in different relaxing conditions by entering process and material variables i.e. type of fabric and fiber, knitting machine gauge, yarn count, fabric loop length and tightness factor. The prediction of the fabric mass in different relaxing states is dependent upon the non-dimensional parameters of K_c, K_w, K_s and R, which have been fed into the system. Thus, "proKNIT" system has the ability of calculating the fabric mass of single and double knit structures, i.e. plain-knit, purl, 1X1 rib, 2X2 rib and interlock, for wool blends.

The whole work is divided into three main parts. The first one is concerned with the existing bibliography and the methodology used through appropriate variables and equations so as to predict the theoretical fabric mass per unit area of a knitted fabric. The second part of the project provides a step-by-step description of the development of the software for "proKNIT" where Visual Basic programming language has been used as a medium of designing it. Finally, part three deals with the development of the non-dimensional variables for wool-blended fabrics, which were then fed into "proKNIT" system and provided the basis for the experiments. Following this, predictions were made by the system and its accuracy was evaluated.

In part one, the mathematical models used in the development of the software were based on the conclusions drawn by previous workers, while the input parameters were restricted to those equations that are known before knitting commences and can be measured easily in a knitting factory. To be more specific, experimental studies have indicated that in different

relaxing states, dry-, wet- and finished-state, the following equations are applicable giving a number of different constant values (K_c, K_w, K_s and R) for single and double jersey fabrics.

$$K_c = c \times \ell$$

$$K_w = w \times \ell$$

$$K_s = S \times \ell^2$$

$$K_r = R = \frac{c}{w} = \frac{K_c}{K_w}$$

where c is courses per unit fabric length and w is wales per unit fabric width, S is loop density, ℓ is loop length in mm or cm and K_r or R is loop shape. Therefore, the fabric mass can be predicted in the different relaxing conditions using the above constant values. The mass per unit area of a fabric is again related to a host of other properties and is determined by two factors that interact on the above-mentioned equations, i.e. the loop size and the yarn size. Thus, the calculation for fabric mass in grams per square meter can be easily justified by combining the equation for loop density and the equation for tightness factor (K_f), which is:

$$K_f = \frac{\sqrt{Tex}}{\ell}$$

The second part of this thesis is concerned with the development of the software called "proKNIT". Visual Basic programming language has been chosen for the creation of "proKNIT" system as it is easy to apply but also very powerful when versatility is required. The design of each page was focused on (a) defining the project task, (b) creating the appropriate interface, (c) developing the logic behind the code and finally (d) verifying the whole procedure.

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However, due to the enormous amounts of data required in order to make the system work but also to remain as realistic as possible, it was decided in the third part of this work to carry out tests and make predictions only on wool mixture fabrics for dry, wet and finished relaxed states. For the experimental procedure of this project an electronic flat V-bed knitting machine was used to produce single jersey fabrics, plain-knit and purl, as well as double jersey fabrics, 1X1 rib, 2X2 rib and interlock. The estimation of non-dimensional parameters derived from the geometrical analysis of the fabrics using the equations, analysed in the first part.

After entering the non-dimensional variables to "proKNIT" system, it was necessary to evaluate its accuracy on predictions of fabric mass. Therefore, a new set of fabrics was produced following the same knitting procedure on the same knitting machine, using also the same types of yarns. These new fabrics produced, called "reference fabrics", were tested only for loop length and fabric mass. All actual fabric masses were compared with the ones predicted by "proKNIT" system.

The conclusions drawn out of all this work is that the attempt to predict fabric mass for wool-blended yarns was successful and the predictions did not show significant variations from actual fabric mass. The small deviation present in the different samples is a consequence of the time required by each fabric to relax (i.e. open structures need more time to relax in dry state) and on tightness factor.

Finally, the extensive experimentation with "proKNIT" has shown that although the system is, indeed, in a position to produce reliable results, at the same time there is potential for further development in the future. Before

the system can be fully operational further research should take the following considerations into account:

1. The non-dimensional parameters must be classified into small categories according to tightness factor so as to cover all existing values, i.e. from 0.9 to 2.0, when loop length is in mm.

2. The relaxation procedures must be justified with accuracy and be maintained throughout the experimental procedure of determining the non-dimensional variables.

3. The calculations for determining courses and wales per unit length can also be done through the non-dimensional values of K_s and R (the courses/wales ratio).

4. The non-dimensional variables must be determined for each category of yarn separately i.e. cotton yarn, wool yarn, man-made yarns etc.

SAMENVATTING EN BESLUIT

Het doctoraatswerk behandelt het voorspellen van de massa van breisels gebruik makend van de software "proKNIT". De software werd ontwikkeld uitgaande van informatie uit de literatuur en biedt de mogelijkheid om de massa te voorspellen van breisels in verschillende omstandigheden van relaxatie door middel van het ingeven van proces- en materiaalvariabelen, met name breisel- en vezeltype, deling, garennummer, luslengte van het breisel en dichtheidsfactor. De voorspelling van de massa van het breisel in verschillende omstandigheden van relaxatie hangt af van de niet-dimensionele parameters K_c, K_w, K_s and R, die ingebracht werden in het systeem. Als dusdanig, beschikt het proKNIT-systeem over de mogelijkheid om de massa van een breisel met enkelvoudige of dubbele breistructuren te berekenen, met name "plain-knit", "purl", 1X1-rib, 2X2-rib en interlock, voor wolmengingen.

Het werk is verdeeld in drie delen. Het eerste deel behandelt de bestaande literatuur en de gebruikte methodologie door middel van geschikte variabelen en vergelijkingen om de theoretische massa van het breisel per oppervlakte-eenheid te voorspellen. Het tweede deel van het onderzoekswerk beschrijft de ontwikkeling van de software voor "proKNIT" waarbij gebruik gemaakt werd van de programmeertaal Visual Basic. Deel drie tenslotte behandelt de ontwikkeling van de niet-dimensionele variabelen voor wolmengingen, die dan in het systeem "proKNIT" ingebracht werden en de basis vormden voor de proeven. Aansluitend werden voorspellingen gemaakt door het systeem en de nauwkeurigheid werd beoordeeld.

De mathematische modellen die gebruikt worden in de ontwikkeling van de software (deel 1) zijn gebaseerd op de besluiten van eerdere onderzoekers, terwijl de input-parameters beperkt zijn tot die vergelijkingen die gekend zijn vooraleer het breien begint, en die gemakkelijk te meten zijn in een breierij. Meer specifiek kan gesteld worden dat experimentele studies aangetoond

hebben dat in verschillende toestanden van relaxatie - droge, natte en afgewerkte toestand - de volgende vergelijkingen toegepast kunnen worden uitgaande van een aantal constante waarden (K_c, K_w, K_s en R) voor enkelvoudige en dubbele jersey-breisels :

$$K_c = c \times \ell$$

$$K_w = w \times \ell$$

$$K_s = S \times \ell^2$$

$$K_r = R = \frac{c}{w} = \frac{K_c}{K_w}$$

waarbij c rijen per eenheid van lengte van het breisel en w kolommen per eenheid van breedte van het breisel betekent, S betekent dichtheid van de lus, ℓ is luslengte in mm of cm en K_r of R de lusvorm is. Daaruit volgt dat de massa van het weefsel voorspeld kan worden in de verschillende omstandigheden van relaxatie gebruik makend van de eerder vermelde constante waarden. De massa per eenheid van oppervlakte is opnieuw gerelateerd aan een veelvoud van andere eigenschappen en wordt bepaald door twee factoren die interageren met de bovenvermelde vergelijkingen, meer bepaald de grootte van de lus en van het garen. De massa van het breisel in g/m^2 kan gemakkelijk bekomen worden door de vergelijking voor de lusdichtheid en de vergelijking voor de dichtheidsfactor (K_f) te combineren. Dit geeft :

$$K_f = \frac{\sqrt{Tex}}{\ell}$$

Het tweede deel van het doctoraatswerk behandelt de ontwikkeling van de software "proKNIT". Er werd geopteerd voor de programmeertaal Visual Basic omwille van de gebruiksvriendelijkheid en de ruime toepasbaarheid. Het ontwerp van elke pagina was gericht op (a) de omschrijving van de

opdracht, (b) het creëren van de geschikte interface, (c) het ontwikkelen van de logica achter de code en tenslotte (d) het controleren van de volledige procedure.

Echter, omwille van het enorm aantal gegevens dat vereist is om het systeem te laten werken en om zo realistisch mogelijk te blijven, werd beslist om in het derde gedeelte enkel proeven uit te voeren en voorspellingen te doen voor wolmengingen in droge, natte en afgewerkte toestanden van relaxatie. Voor het experimenteel gedeelte van het onderzoek wordt een elektronische "flat V-bed"-breimachine gebruikt om enkelvoudige jersey-breisels te vervaardigen, "plain-knit" en "purl" zowel als dubbele jersey-breisels, 1X1-rib, 2X2-rib en interlock. De raming van de niet-dimensionele parameters is afgeleid van de geometrische analyse van de breisels waarbij gebruik gemaakt wordt van de vergelijkingen die geanalyseerd werden in het eerste deel.

Nadat de niet-dimensionele variabelen ingebracht werden in het "proKNIT"-systeem, was het noodzakelijk om de nauwkeurigheid met betrekking tot voorspellingen van de massa van het breisel te evalueren. Daartoe werd een nieuwe reeks breisels vervaardigd volgens dezelfde breiprocedure en op dezelfde breimachine en gebruik makend van hetzelfde garentype. Voor deze nieuwe breisels, de "referentiebreisels", werd de lengte van de lus en de massa van het breisel onderzocht. De massa van de breisels werd vergeleken met de voorspellingen van het "proKNIT"-systeem.

Concluderend kan gesteld worden dat het voorspellen van de massa van het breisel voor wolmengingen succesvol is en dat de voorspellingen geen noemenswaardige afwijkingen vertonen van de reële massa van het breisel. De kleine afwijking in de verschillende stalen is een gevolg van de tijd die vereist is voor een weefsel om te relaxeren (b.v. open structuren hebben

meer tijd nodig om te relaxeren in droge toestand) en van de dichtheidsfactor.

Het uitgebreid experimenteel onderzoek met "proKNIT" heeft aangetoond dat het systeem in staat is betrouwbare resultaten naar voren te brengen; terzelfdertijd bestaat de mogelijkheid voor verder onderzoek. Vooraleer het systeem volledig operationeel kan worden, kunnen volgende overwegingen in beschouwing genomen worden :

1. De niet-dimensionele parameters moeten ingedeeld worden in kleine categorieën volgens dichtheidsfactor zodanig dat alle bestaande waarden opgenomen worden, meer bepaald van 0.9 tot 2.0, met een lengte van de lus in mm.

2. De procedures van relaxatie moeten nauwkeurig geverifieerd worden en behouden blijven gedurende de ganse experimentele procedure bij het bepalen van de niet-dimensionele variabelen.

3. De berekeningen voor het bepalen van rijen en kolommen kan eveneens gebeuren door middel van de niet-dimensionele waarden K_s en R (verhouding rijen tot kolommen).

4. De niet-dimensionele variabelen moeten bepaald worden voor elke garencategorie afzonderlijk, met name katoengaren, wolgaren, synthetische garens enz.

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Part One: Literature and background

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CHAPTER 1

GEOMETRY AND DIMENSIONAL PROPERTIES OF SINGLE NEEDLE BED WEFT KNITTED STRUCTURES

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1.1. Introduction

Dimensional stability of knitted fabrics has been one of the most discussed subjects in the textile industry as well as in research fields. The ideal of "maximum yield with minimum shrinkage" has been the subject of a great deal of investigation and effort for many years. Today an important trend in textiles is towards the manufacture of fabrics with inherent "easy-care" properties. This creates difficulties for wool garments since they have been traditionally recognised as "tender" articles, garments which should be dry-cleaned or carefully washed and dried. For knitwear this problem is compounded by the inherent tendency of knitted structures to change shape on the knitting machine. Felting, of course, may partly account for these changes, but even when adequately shrink-resist treated wools are used in knitwear, relatively large changes in linear and area dimensions are evident in finishing. Furthermore, the amounts of dimensional change vary considerably between structures and finishing techniques, and these changes are seemingly dependent on most fibre, yarn and machine variables.

Unlike those of synthetic and certain other natural fibres, wool knitted fabric dimensions cannot be artificially or permanently set in finishing. Basically the problem of dimensional stability is the containment or elimination of relaxation shrinkage. This shrinkage is caused by changes in the knitting loop shape from some strained, elongated shape on the machine to a minimum-energy shape in a relaxed fabric. Once relaxation shrinkage is complete, it can safety be assured that if the yarns have been previously adequately treated against felting, no further dimensional changes can occur. The answer to this problem then will be realised when we can precisely differentiate between dimensional changes due to the mechanisms of relaxation and felting, and at the same time ensure complete restriction of felting in subsequent washing.

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This problem has, of course, been realised for a long time. Numerous experimental relaxation methods have been advocated in the past, of which the majority have relied on fabric immersion in an aqueous solution followed by line or screen drying. These are usually commercially unacceptable and so industrially a continuous steaming process is customary. Unfortunately, it has been realised that none of these techniques adequately brings about a truly relaxed state.

Today a wide variety of knitted articles is available, but unhappily each individual structure tends to relax differently. For example, certain structures exhibit length and width shrinkage in relaxation resulting in measurable area shrinkage, while for others, area shrinkage may be negligible but the fabrics may nevertheless be dimensionally quite different, owing to a growth in width equal to length shrinkage. The rate of change in length, width and area may also depend on the density of the structure. A double-jersey structure, for example, takes a longer time to relax than that necessary to ensure a relaxed plain-knit fabric. Thus we must study the geometry and dimensional properties of each individual structure separately before further research can take place on any level.

At first sight this seems a difficult research field but if weft-knitting structure is analysed more carefully, immediately a pattern arises which simplifies the whole picture. Basically, the majority of weft knitted structures are similar in four major structural units of construction, i.e. plain loop, rib loop, tuck stitch and float or miss stitch.

The most studied structure, for a number of reasons, has been the basic plain-knit structure. In contrast to many other structures, it is one used in

a wide variety of fabrics, from fine gauge seamless hose to heavy, coarse gauge men's outwear. It has proved, however, to be a difficult structure to analyse, mainly because of the experimental difficulty of measuring this highly extensible and easily deformable structure and also, it now appears, because its relaxed shape is not as simple to define as first thought.

Many attempts have been made to rationalise the knitting operation [1.3, 1.4, 1.5, 1.6]. In 1914 Tompkins [1.3] was praising the virtues of scientific production methods and was describing in detail a practical method whereby fabric parameters such as fabric mass, quality and dimensions could be determined at the knitting stage. Unfortunately, neither his method nor the more recent models of Chamberlain [1.5] and Peirce [1.4] have given results sufficiently in accord with practical experience to justify their general acceptance. That time knitting was an art, therefore, because the basic laws of knitted fabric, the relationships which will predict the fabric characteristics in terms of the constituent yarn properties and knitted variables, had not been elaborated.

1.2. Plain-knit structure

In a simplest fabric construction all units are of the same sort, i.e. each loop is the same shape and is pulled through the previously knitted loop in the same manner or direction. This simplest fabric construction is called plain knitted fabric, usually abbreviated to plain fabric or structure. It is the basic structure for ladies' hosiery that is tights, socks and stockings for covering the feed and legs. The most important mechanical requirements of such garments are that they should be highly extensible in all directions, particularly in width, and that the material should be elastic to give good fit and a high recovery from strain.

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The fabric has a different appearance on each side. The technical face is characterised by smoothness with the side limbs of the loops having the appearance of columns of "V" shape in wales direction. On the technical back, the heads of the needle loops and the bases of the sinker loops form columns of interlocking semi-circles (Fig. 1.1). This structure when taken off the knitting machine it is very difficult, if not impossible, to identify the loop parts, since it is difficult to define the fabric's upright position. This structure can be unroved from the course knitted last as well as from the course knitted first. If the yarn of the fabric breaks, needle loops successively unmesh down a wale appearing a defect termed "laddering".

Technical Face   Technical Back
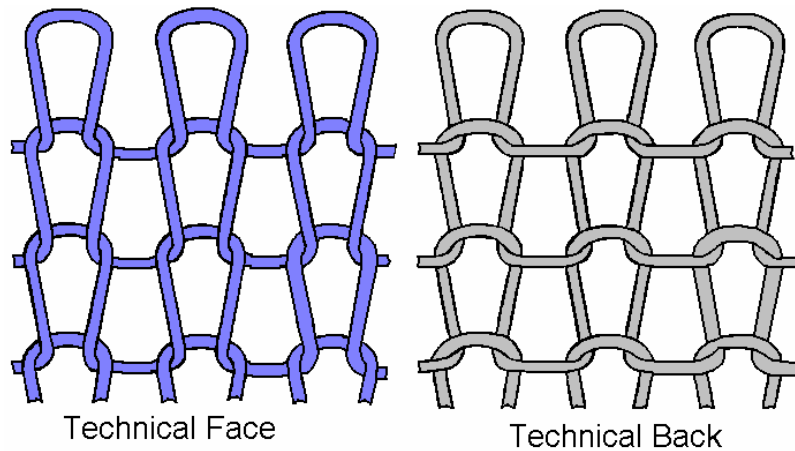
Fig.1.1 Plain fabric

Where the fabric is to be used as material for wearing apparel, there are, of course, other properties which are of practical importance. These include the requirements of stability of size and shape under various conditions of wear and use, e.g. washing, resistance to various forms of wear and abrasion, thermal insulation, air and vapour transmission, together with the physical-physiological aspects encompassed by the terms handle, comfort and appearance.

The plain fabric is extensible in a course wise direction and in a wales wise direction. However, the degree of extensibility is different when pulled top to bottom from when pulled side to side. The course wise extension is approximately twice that of the wales wise extension due to the degree of constrain imposed on each loop by its intermeshing [1.1].

In a piece of unprocessed fabric, the outer edges curl vigorously. The top and bottom curl in towards the face of the fabric and the sides towards the back of the fabric. Curling towards the face tends to diminish the forces causing the curling at the sides; likewise curling towards the back diminishes the tendency to curl towards the face. In face in the literal sense the fabric can be said to be most in a state of equilibrium when it is in a roll form. In order to minimise or eliminate such curling which is caused by directionality of the loop formation, a pressing or heat/water process is used.

1.2.1. Loop formation (plain-knit)

Most plain knit structures are produced on circular knitting machines having latch needles on the cylinder and sinkers on a ring. Cylinder and ring revolve through stationary knitting cam systems, which together with their yarn feeders are situated at regular intervals around the circumference of the cylinder. The fabrics produced on this type of machine are suitable underwear and outwear according to fashion. The raw material used for the production of these fabrics is mainly cotton or cotton mixtures i.e. cotton/polyester, cotton/viscose rayon, etc.

Plain knit structures produced from wool and wool mixture yarns and intended to be used as pullovers and cardigans used to be produced on straight bar fully fashion knitting machines (William Cotton). Nowadays this type of knitting machine has suffered a considerable decline as the result of the improvement of other types of weft knitting machines. Straight bar "V" bed knitting machine has been used a lot in the second half of the twentieth century since electronics and computers took the world by storm and were responsible for the third generation of "V" bed knitting machines. The forth and latest generation of such knitting machines came in production in 1987; one of these types of knitting machines was used in our experimental work.

The production of plain knit fabric requires a single set of needles where all active needles receive the yarn and knit constantly in every course. Since all needles are active during each traverse of the carriage and as they are all set on the same bed, the loops produced are all identical. If the structure is knitted on the frond needle bed, the face loops will be seen when someone is standing in front of the machine. However, the reverse loops will be seen if the fabric is knitted on the real needle bed. When the fabric is taken off the knitting machine it is not possible to tell on which needle bed it has been produced.

The simplest knitting cycle to produce the basic structure of plain knit is illustrated in Fig. 1.2 where a single needle shows in steps the formation of the loop using latch needle.

a. The needle has just completed the formation of the last loop. The loop formed at the previous feeder is in the closed hook. The latch is preventing the new loop from falling out of the closed hook. In order for the needle to operate it is necessary to

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have a loop in the hook. The needle starts to move to clearing position.
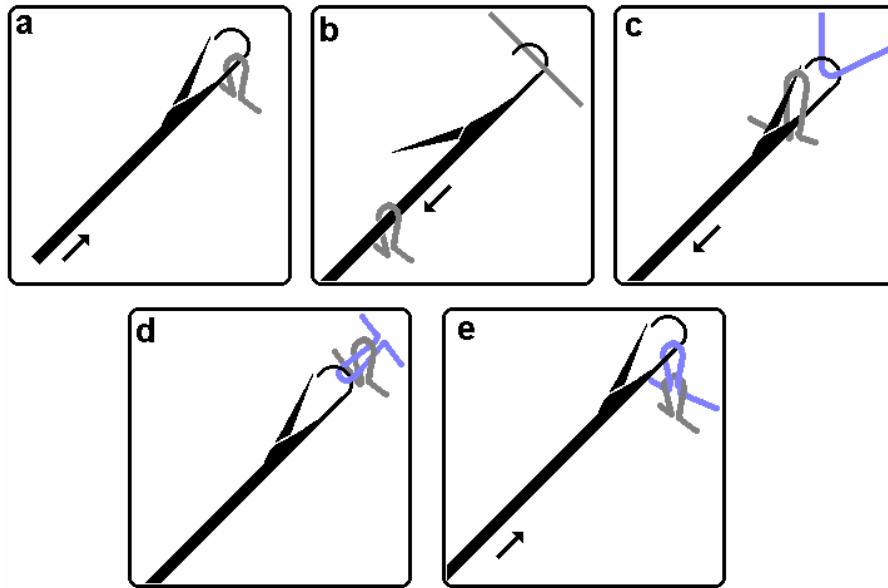
Fig. 1.2 Loop formation

b. As needle moves, the loop opens the latch and slides onto the needle's stem. The needle has approached the highest position and starts to descent. This moment the feeder passes and feeds the new yarn.

c. While the needle descents the old loop resting on the stem, slides under the open latch and forces it to close. The new yarn is now trapped inside the closed hook.

d. The needle pulls the new yarn though the old loop and by doing this it forms a new loop. The continued descent of the needle draws the loop length, which can be adjusted by the stitch cam.

e. The needle slightly ascents to complete the loop formation and remains in this position ready to start a new knitting cycle.

1.3. Elements of knitted structure

It is not possible to discuss the dimensional properties of knitted fabrics without describing the elements of a knitted structure. The smallest element of a knitted fabric is the *loop*. The constituent loop of a weft knitted fabric has the general shape shown in Fig.1.3. During knitting the loop is extended due to take down force applied to the fabric. When the fabric is removed from the knitting machine and left free from strain, then the loop takes its original form similar to that shown in Fig. 1.3. The top part of the loop (c), which is held by the needle, is called "needle loop", while the lower part of the loop (d), which joins the neighbouring loops and is held by the machine sinker, is called "sinker loop".

Single wale

Single course

Loop length
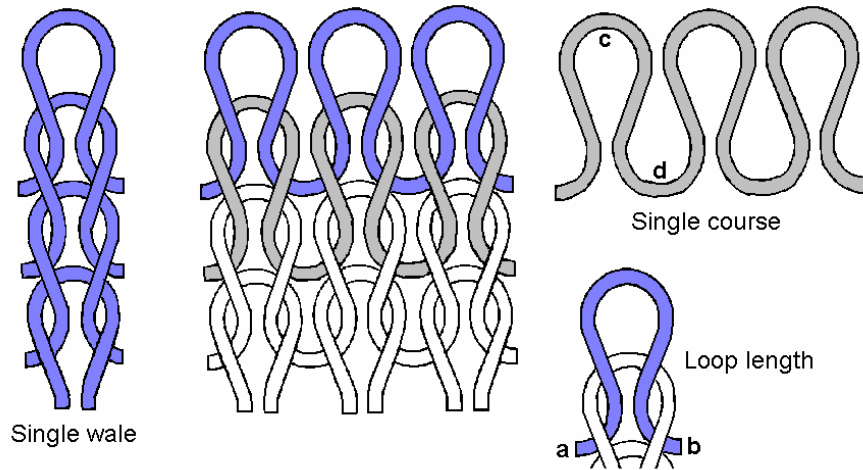
Fig. 1.3 Knitted structure elements

As it was first suggested by Doyle [1.1] the knitted loop and the length of yarn knitted into the stitch in particular, is an important parameter for the measurement of knitted quality. The loop formed is a three-dimensional unit, since, in order to produce a flat knitted structure, the yarn is bent both in the plane of the fabric and in the plane at right angles to the fabric [1.7]. The loop has a constant length (ℓ) which is equal to yarn length

needed to form a loop from "a" to "b" (Fig.1.3). This is the most important dimension within a construction and in fact decides the area covered by the loop together with loop height and width. The loop can vary in size, that is, its length (ℓ) can be altered. It is rather obvious that as the loop length increases the area occupied by the loop gets larger. Such a relationship is independent of the yarn diameter although usually within a knitted structure the yarn size increases commensurate with the loop size.

Munden [1.7] suggested that the dimensions in the relaxed state of a knitted fabric are determined by the knitting loop taking up its configuration corresponding to minimum energy. He suggested that this configuration is a geometrical property of the loop structure and is independent of the physical properties of the yarn, or the amount of yarn knitted into loop. This assumption is a reasonable one, if compared with the case discussed by Leaf [1.8] who has shown that, when a homogeneous strip is bent into a loop in one plane by bringing its two ends together and parallel, providing the strip is not plastically deformed by the bending, it will take up a particular configuration which is independent of the physical properties, thickness or length of the material forming the loop.

The loops can be related to one another and can be intermeshed with one another to form fabrics. In a vertical direction loops can be joined together by intermeshing, forming a vertical row of loops known as "*wale*" (Fig. 1.3). The density of the wales can be measured as the number of wales per unit width/length. In imperial units, the inch is used while in metric system the centimetre is used. The fabric properties, such as appearance and behaviour, depend on the density of wales. The density is dependent on the size and density of the needles as well as on

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knitting conditions such as knitted structure, yarn parameters and yarn tension. The density and the size of the needles of the knitting machine are already set (machine gauge), in most of the cases, by machine manufacturers, therefore, little can be done.

In a horizontal direction the relationship of the loops is a simple one where a series of loops is formed by the same thread called *"course"*. In simple structures the course can have the appearance of that in Fig. 1.3, whereas in more complicated structures a course can consist of more than one thread and can be completed after several knitted cycles. The course density can be adjusted during knitting process simply by altering the needle movement to knock-over position. Measurement of the density of courses can be done in the same way as the density of wales was measured.

In a knitted structure the ***area density of loops*** can be defined as the number of stitches per square unit. In most cases the standard measurement for imperial units is the square inch, and the square centimetre for metric system (Fig. 1.4). It has been found that the surface density of unit cells, i.e. the total number of stitches per square inch of fabric, is dependent primarily on the length of yarn per unit cell and is independent of yarn material, yarn structure and the system used to form the stitches [1.1, 1.2].

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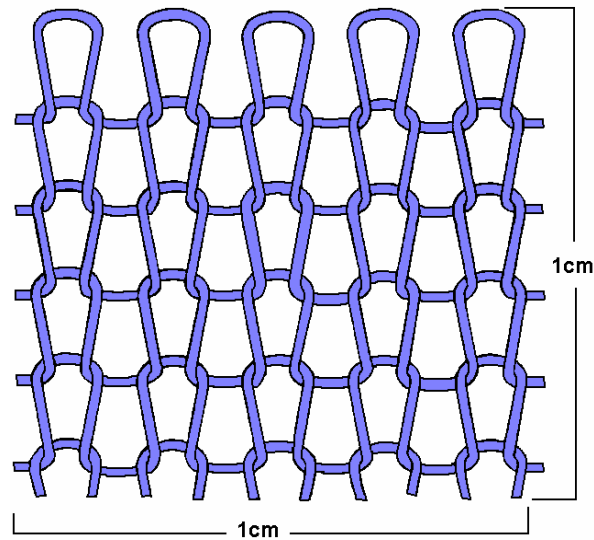
Fig. 1.4 Area density of stiches

It is always preferable to measure the density of a large area using a large magnifying glass in order to decrease the inaccuracies associated with the measuring process. The use of stitch density, or number of loops per unit area of the fabric is to be preferred to linear measurements since it is less affected by distortions. This is because an increase in length produced by longitudinal stress is always compensated to certain extent by a decrease in width [1.7].

1.3.1. Loop structures

In a knitted structure apart from the basic loop other types of stitch may be produced by varying the timing of the intermeshing sequence of the old and new loops. These stitches may be deliberately selected as part of the design of a knitted structure. The most commonly produced stitches are the tuck stitch and the float or miss stitch. Each is produced with a held loop and shows its own particular loop most clearly on the reverse

side of the stitch as the limbs of the held loop cover it from view on the face (Fig. 1.5).
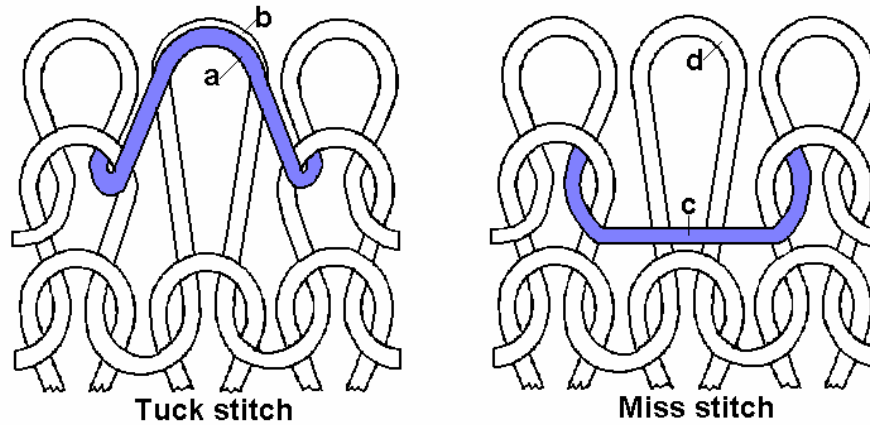
Fig. 1.5 Variaty of loop structures

A tuck stitch is composed of a held loop, one or more tuck loops, and knitted loops. It is produced when a needle holding its loop (b) also receives yarn to form a new loop which becomes a tuck loop (a) because it is not intermeshed through the old loop, but is tucked in behind it on the reverse side of the stitch. Thus the tuck loop forms an inverted U-shaped configuration as the yarn passes from the sinker loops to the head, which is intermeshed with the new loop of a course above it in the normal manner so that the head of the tuck is on the reverse of the stitch.

A float or miss stitch is also composed of a held loop, one or more miss loops and knitted loops. It is produced when a needle holding its old loop (d) fails to receive the new yarn which passes, as a float loop (c), to the back of the needle and to reverse side. The float stitch shows the missed yarn floating freely on the reverse side of the held loop which is the technical back of single jersey structures, but is the inside of rib and interlock structures.

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1.4. Yarn characteristics for knitting

An experienced knitter will describe many yarn properties which, from his experience, affect the characteristics of the knitted fabric. Yarns must be spun or produced according to specifications. Several specifications are common to all types of yarns, mainly for the purpose of identification or designation. Among the most important specifications of yarn are linear density, structural features, fibre content and an identification of any mechanical or chemical treatments. Nowadays for the production of knitted fabrics different kinds of single and plied yarns and even slivers are used. In order to obtain a finished fabric of the required physical properties it is necessary to adjust or control the following main factors:

- Yarn count

- Yarn twist

- Yarn evenness

- Yarn strength

- Yarn lubricant

- Yarn moisture content

The first factor determines the yarn linear density, which is defined as mass per unit length of a material. There are two basic categories for the expression of linear density of textile yarns; one is called direct system and the other indirect system. Since natural yarns have been used for this experimental work, it is necessary to deal with these expressions of yarn count in SI units. The most popular yarn count used in direct system is tex. The tex number is defined as the mass in grams of 1000 meters of yarn. This means that the larger the designated number, the heavier the yarn. On the opposite side, the indirect system expresses the linear

density of a yarn as the number of standard lengths of yarn per unit mass. The metric count (Nm) has gained popularity in wool and wool/mixture yarns. This system is based on the number of 1000-meter lengths per kilogram of yarn. By definition it means that the larger the designated number, the lighter the yarn. Staple yarn structures indicated to an extent by notation in the expression of yarn count, for example on metric count the single yarn number is expressed as 1/30 Nm, which is mean single yarn of 30 count. On a ply yarn the characterization of count is given as 2/30 Nm, where 2 stands for number of single yarns.

1.5. Correlation of yarn count and knitting machine gauge

The yarn count used on knitting machines depends to a large extent on the pitch and therefore on the machine gauge. Gauge (G) is determined by the number of needles present in one inch of the needle bed (Fig. 1.6). Therefore, the needle thickness, the depth of the tricks and the space between tricks are the three parameters, which all together define the machine gauge. The density of the needle bed and the size of the needle are the main factors affecting to a large extend the wales per unit width present to a fabric, thus the gauge is responsible for fabric thickness.

The question which every knitter can apply is: "What range of counts can be efficiently knitted on a given knitting machine gauge?" It should be realised that there aren't hard and fast rules as far as the relation between yarn count and machine gauge is concerned. Research work done by Rab [1.9] has indicated that the possible range of spun yarn counts for a given gauge is much wider than had previously been thought. Also the range for yarn counts used is wider for single knit than for double knit machine.

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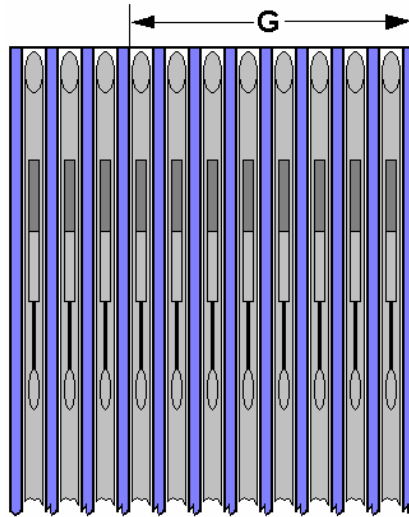
Fig. 1.6 Knitting machine gauge

The simple "rule of thumb" relationships between machine gauge, needles per inch, and yarn count are generally recognised as:

$$N_c = \frac{G^2}{18} \text{ (for single knits)} \qquad (1)$$

and

$$N_c = \frac{G^2}{15} \text{ (for double knits)} \qquad (2)$$

Where N_c is cotton count and for worsted yarn count (N_w) the following equivalent equations are apply:

$$N_w = \frac{G^2}{12} \text{ (for single knits)} \qquad (3)$$

and

$$N_w = \frac{G^2}{10} \text{ (for double knits)} \qquad (4)$$

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In order for the above equations to be converted to SI unit, using tex as yarn count, it is necessary to substitute the relation between direct and indirect yarn count systems. The relation between cotton count and tex is given by the following equation:

$$N_c = \frac{590}{Tex} \qquad (5)$$

By substituting N_c in equations (1) and (2) above they become:

$$G = \left(\frac{10,630}{Tex}\right)^{\frac{1}{2}} \text{(for single knits)} \qquad (6)$$

$$G = \left(\frac{8,860}{Tex}\right)^{\frac{1}{2}} \text{(for double knits)} \qquad (7)$$

Equations (6) and (7) only suggest a suitable relationship between yarn count and machine gauge. These equations will be used later in the development of "proKNIT" system. Also, Benerjee and Alaiban [1.24] used another empirical formula, which is very close to the one used for single knit fabrics (6) in order to determine suitable counts for the machine gauge. The equation is:

$$CottonCount = \frac{(Gauge)^2}{20} \qquad (8)$$

They are definitely not hard and fast rules. A more important question is: "What range of counts can be efficiently knitted on a given machine gauge?"

1.6. Tightness or cover factor

The most convenient means of assessing the knitting performance of a spun yarn is by the use of the "tightness factor" concept. Munden [1.10]

first suggested the use of a constant factor to indicate the relative tightness or looseness of a plain knit structure. Originally he termed as cover factor but now it is referred to as tightness factor. He suggested that in practice the numerical value for the cover factor for plain knit structures is given by:

$$CoverFactor = \frac{1}{\ell(N)^{\frac{1}{2}}}$$

where ℓ is the loop length in inches and N is the indirect count number. In this expression there are a number of omissions and assumptions [1.11] which had to be ignored in order to obtain the simple equation above. However this expression has been extremely practical and easily calculated and had a potential use in the factory. In an experimental work Knapton [1.14] saw that worsted yarns of a range of counts, from 1/12's (76 tex) to 1/44's (21 tex), have been successfully knitted and without problems at a cover factor of 1.25, which is equivalent to 1.46 tightness factor when ℓ is measured in millimetres.

Postle [1.12] has presented the term "tightness factor" to describe such a formula and this recommendation will be followed in this project. The general definition was that a ratio exists between the area covered by the yarn in one loop to the area occupied by that loop. Let as assume that a yarn has a circular cross-section with a diameter of "d". If the loop length ℓ is in mm and diameter is in mm too Knapton [1.14] then the area covered by a stitch or loop is ℓ X d (mm^2). Now if the number of loops in a square centimetre is S then the total area covered by the yarn is given by:

$$S \text{ X } \ell \text{ X } d$$

Introducing the expression $S = K_s/\ell^2$, (see chapter 1.9) the area covering 1 cm^2 of fabric is:

$$\frac{K_s \times d}{100\ell}$$

This expression is termed as "fractional cover" of the fabric, since it is the yarn area covering 1 cm^2 of fabric. A correlation for the four areas of each stitch covered by two thickness of yarn is then necessary together with an expression of yarn diameter in terms of linear density. Thus, by deleting the various constants and using only the fact that the yarn diameter is proportional to the square root of the linear density, then an expression termed "Tightness Factor" (K_f) is obtained.

$$K_f = \frac{\sqrt{Tex}}{\ell}$$

Knapton [1.13] suggested that most spun yarn single knit fabric is commercially knitted between the range of 9<K_f<19. It is essentially impossible on any machine gauge and with any yarn count to knit fabric over a wider K_f range. In practice, it is rare that fabric is knitted at the limits. A more usual knitting range, from loose to tight fabric is 11<K_f<17 with a mean value of 14. These values are valid when the loop length is measured in centimetres. In case that the loop length is measured in millimetres the above mentioned values are divided by ten to give 0.9<K_f<1.9. He also found that at approximately K_f=14, the dynamic forces required to pull a wide range of yarn counts into a knitting loop are at a low and equivalent value [1.14]. Baird and Foulds [1.18] used the above equation on a factorial analysis of two shrink-resist treatments and measured the loop length in centimetres with cover factors 13.2 to 17.5. It has been recommended [1.15] that loop length should be measured in millimetres with an optimum value of 1.47. Using Smirfitt's definition of the geometry of the 1X1 rib structure, the tightness factor formula is identical to that of the plain knit structure [1.16]. Criteria for suitable combinations of machine gauge and yarn tex could be the extent and evenness of the dispersion of possible tightness factor values around

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14.5 when using loop length in centimetres [1.24]. Through "proKNIT" system it is possible to have values of K_f using the loop length either in centimetres or millimetres.

Nutting and Leaf [1.30] found that the effect of tightness factor on linear dimensions could not be ignored. However, over a normal range of K_f (10-16 for interlock) this effect has small and perhaps even practically negligible. They reasoned that finished fabric dimensions were nevertheless dependent on the nominal yarn diameter, as similar to Natkanski's [1.31] work on 1X1 rib structure.

1.7. Determination of fabric mass per unit area

For plain knit fabric, the mass in grams per square metre can be easily determined when the amount of loops per square meter, the loop length and the linear density of the yarn are known. If the loop length is measured in millimetres the area density of the plain knit fabric can be calculated as follows:

$$\text{Loops/m}^2 \text{ X loop length (mm) X linear density (tex) X } 10^{-6},$$

the factor of 10^{-6} being introduced as there are 10^6 millimetres in one square meter.

By determining the stitch density of loops per square centimetre as "S", then the amount of loops per square meter will be:

$$S \text{ X } 10^4$$

Thus, by substituting the stitch density to area density, the relation becomes:

$$\frac{S \times \ell \times tex \times 10^4}{10^6}$$

Therefore:

$$FabricMass(g/m^2) = \frac{S \times \ell \times tex}{100} \qquad (1)$$

In case that the loop length (ℓ) is given in centimetres then on the above equation (1) 10 will substitute 100.

It is also possible to calculate the mass of a fabric per square meter using the relation $S = K_s/\ell^2$. By substituting this relation to equation (1) then the mass (g/m^2) of the knitted fabric is given by the relation:

$$\frac{K_s \times tex}{100\ell} \qquad (2)$$

1.7.1. Effect of stitch length on fabric mass

It has already been explained that a plain knit structure consists of courses and wales. If a knitting machine is producing a fabric with 10 wales by 10 courses per unit length, thus the product is 100. If the yarns' linear density changes to a lighter one and the wales per length are increased to 11, the courses will automatically become 9.09, and the product will remain unchanged at 100. The mass per unit area is then proportional to the mass per unit length of the yarn used or inversely proportional to imperial yarn count [1.6]. This relation may be stated as follows:

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$$\frac{wt1}{wt2} = \frac{yr2}{yr1}$$

This formula may be used to predict the change in fabric mass which will be caused by changing from one yarn size to another, or to determine the yarn count required to yield a desired fabric mass on the same machine with the same setting of the cams [1.6]. Keeping yarn count constant and reducing the stitch length, the mass per unit area of the fabric increases. This gain in mass is due to an increase in the number of courses per unit length. By increasing the number of courses per unit length, it is necessary the reduce the loop length so that the length of yarn in a course is reduced too. The gain from adding courses, however, is greater than the loss incurred through shortening the courses, so that the net effect is an increase in fabric mass per unit area. Lengthening the stitch length will have the opposite effect.

By plotting the area density (g/m^2) of a knitted fabric against $1/\ell^2$, while maintaining the same yarn linear density a straight line is produced. This can be easily seen from the results that have been gained during the experimental work.

1.8. Particular characteristics of single jersey structures

The load-extension behaviour of plain knit structures for length and width direction contains two distinct regions. The first one represents the initial behaviour of the loop structure changing shape to accommodate the load applied. Within this range of extension the load is taken principally by bending and twisting couples in the yarn and frictional constrains at the points of intersection of the loops. When the maximum simple readjustment of shape has been made, sideways compression of the

yarns in adjacent loops and bending into high curvatures cause the load to rise rapidly (second region). The extension along the wales is about double that for extension along the courses. This is due to the geometry of the unit cell because there are effectively two lengths of yarn in parallel supporting the load for extension along the wales, whereas these are spread out into one single length for extension along the courses [1.1].

1.9. Geometry of plain knit structure

The most studied structure, for quite obvious reasons, has been the elemental plain-knit structure. On single jersey fabrics Munden [1.7] suggested that the knitted loop length would take a natural shape when released from mechanical strains and is independent of the yarn properties. A further study by Munden [1.17] 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 courses per unit length, wales per unit length and loop length must be related to each other by constants and have the following relations:

$$K_c = c \times \ell \qquad\qquad (1)$$

$$K_w = w \times \ell \qquad\qquad (2)$$

$$K_s = S \times \ell^2 \qquad\qquad (3)$$

$$K_r = R = \frac{c}{w} = \frac{K_c}{K_w} \qquad\qquad (4)$$

In the original publication there is $K_2=K_c$, $K_3=K_w$, $K_1=K_s$ and $K_4=K_r=R$. In the above equations c and w define the courses per inch and the wales per inch respectively. S is the loop density and arises by multiplying courses and wales per inch. Finally ℓ is the loop length and can be

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measured in inches and K_r or R is the loop shape. What is significant about the above equations (1-4) is that the length of yarn in the knitting loop is the major factor determining fabric dimensions. Also fibre content and state of relaxation can be identified as variables, which produce different constant values. Munden initially defined two distinct, differently relaxed states; the dry-relaxed state, where the fabric has been left to relax for a specific time off the machine in a dry condition, and the wet-relaxed state where the fabric is left static to soak in water. He empirically determined the values of Kc, Kw and Ks for a wide range of plain-knit all-wool constructions. These were found to be different in these two relaxed states, posing the problem of why two independent relaxed states should exist.

Munden [1.17] noted that the wet-relaxed K values of non-hygroscopic yarns were essentially the same as the dry-relaxed values, though a 13-15% difference in K_s value between the same relaxed states for fabrics knitted from hygroscopic yarns (wool, cotton) was apparent. The cause of this intrinsic shrinkage in hygroscopic yarns he attributed to the chemical action of water on hydrogen bonding within the fibre. On immersion in water, breakage of the hydrogen bonds between adjacent long-chain fibre molecules occurs as the water molecules penetrate between them. These bonds, formed when the yarn was straight, are strained when the fibres are bent into the configuration of the knitted loop. It is this internal cross-linking strain which causes the yarn to straighten again when unravelled from the dry fabric. On drying from the wet state, these bonds are reformed but now the yarn can no longer return to its original straight configuration. It remains temporarily set into the "crimped" configuration of the knitted loop. Wet-relaxation fabric shrinkage, Munden theorised, is therefore caused by the release of fibre constrains and is irreversible. Experimental studies by Munden [1.7] on wool plain knit fabric indicated the values presented on Table 1.1 below for the two relaxed states.

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TABLE 1.1: Constants values (K) for fabric geometry on plain knit (Munden)

Fabric state	Parameters			
	K_c	K_w	K_s	R
Dry-relaxed	5.0	3.8	19.0	1.31
Wet-relaxed	5.3	4.1	21.6	1.29

Whatever the mechanism of wet-relaxation shrinkage, however, neither the dry- nor the wet-relaxed states represents a truly relaxed fabric state. This was emphasised initially by Nutting [1.19] who found K_s values significant by different from Munden's suggested values of 19.0 and 21.6, obtained from fabrics immersed in an aqueous solution at elevated temperatures. Moreover, Munden and Kerley [1.20], whilst investigating the felting properties of plain-knit fabrics, pointed out that a relaxed fabric state, with a corresponding K_s value of 23, could exist without signs of fabric felting.

Knapton et al [1.21] found that neither the dry- nor the wet-relaxed state for plain knit loop shape were predictable. The K values in these states were dependent upon certain fabric and machine variables, particularly take-down tension. They suggested some form of fabric agitation to allow the loops to find their least-strained shape within the fabric using a tumble-drying technique to allow drying without felting. This state was defined as "fully-relaxed" and is achieved when the fabrics have been thoroughly wetted out for 24 hours in water at 40^0C, briefly hydro-extracted to remove excess water and tumble-dried for a period of one

hour at 70^0C. The constant values (K) that were achieved in this state with 95% confident limits are:

$K_c = 5.5 \pm 0.2$

$K_w = 4.2 \pm 0.1$

$K_s = 23.1 \pm 1.0$

$R = 1.30 \pm 0.05$

They also presented all K values obtained at different tumble drying levels (15 min, 30 min etc) without any significant differences.

Postle [1.22] presented a set of constant values for wool fibres on all three of the above mentioned states, which appeared to be slightly different from those presented by the others. Also both Postle and Munden were in agreement concerning the values of K and R, in particular, which are influenced by cover factor. Dimensions of a fully-relaxed fabric are stable if the yarns have been adequately treated against felting. The values obtained by Postle are presented on Table I.2.

TABLE 1.2: Constants values (K) for fabric geometry on plain knit (Postle)

Fabric state	Parameters			
	K_c	K_w	K_s	R
Dry-relaxed	4.7±0.3	4.0±0.7	18.0±1.0	1.16±0.12
Wet-relaxed	5.4±0.2	4.2±0.1	22.8±0.9	1.28±0.04
Fully-relaxed	5.8±0.2	4.3±0.1	25.2±0.6	1.32±0.04

Another structural constant was suggested by Knapton et al [1.21]. On measuring fabric thickness they found a definite dependence of thickness

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on loop length in dry- and wet relaxed state, with thickness decreasing as loop length increased. In the fully-relaxed state, however, this dependence did not exist. They therefore defined the constant K_5 as equal to fabric thickness/yarn diameter, and found this equal to 6 approximately. This result has since been confirmed by Wolfaardt and Knapton [1.23], although they suggest K_5 is equal to about 4.

Baird and Foulds [1.18] have shown, using a factorial analysis of 54 combinations of factors for each of two shrink-resist treatments, that the most important variable influencing the shrinkage rate of plain-knit structure in washing is tightness factor. They found that this "dependence of shrinkage rate upon cover factor was independent of the level of shrink proofing treatment so that, even at the higher levels of treatment, the shrinkage rates were markedly dependent upon cover factor. The practical implication is that, at least for the two treatments investigated, for a given level of treatment, fairly strict control of cover factor is necessary to hold shrinkage rates below any prescribed level".

The value of K_s varies with the tightness factor for dry relaxed fabrics, however, as progressively more severe wet-relaxation treatments are applied, K_s becomes independent of the tightness of construction [1.26]. This finding conflicts with some results obtained by Knapton and Munden [1.25] who used lubricated viscose staple yarn and concluded that K_s was constant in the dry-relaxed condition, but varied with tightness for certain wet-relaxation treatments carried out at unspecified temperatures.

Knapton and Fong [1.27] observed that K_c and K_w are critically affected by yarn diameter and loop length in the dry- and wet-relaxed states, something that was not considered by Munden. In complete relaxed state of plain-knit wool fabrics, K values and tightness factor are not significant

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dependent on yarn diameter and loop length. This is a particularly satisfying conclusion because it substantiates Munden's claim that once plain-knit fabrics are relaxed, their K parameters are independent of tightness factor. Another study by Knapton et al [1.28] has shown that the stable-loop geometry in wool and that in cotton plain-jersey fabrics are almost identical.

1.10. Knitted fabric relaxation procedures

The experimental work carried out by all workers referred to above has been done under certain relaxing conditions which can be summarised in the following three main states:

- Dry-relaxed state

- Wet-relaxed state

- Full-relaxed state

Dry relaxation has been considered by Munden [1.7] and is the condition necessary to ensure that the knitted fabric is in its strain-free state. This state varies according to type of yarn used and the knitting construction. For example, a plain knit, produced from wool yarn will recover from 60-80% extension in length to its natural length after 48 hours if allowed to relax freely in the dry state. With cotton yarns the relaxing behaviour is completely different since its recovery will never be completed. The usual procedure to achieve a dry-relaxed state is to place the fabric in the standard atmosphere for testing and leave it there for the necessary time. Sometimes, however, the inter-yarn friction opposing recovery is more than the energy stored in the distorted fabric can overcome. In such circumstances, the fabric does not reach a fully dry-relaxed state unless some external assistance, such as agitation, is given [1.19].

A fabric is said to be wet-relaxed when the fabric has been allowed to relax in water until equilibrium is reached. The fabric is then carefully removed and allowed to dry under standard atmospheric conditions. According to Munden [1.7], the fabric laid flat in a tray containing water plus wetting agent at a temperature of 30^0C. The fabric remains under water for at least 12 hours, after which it is removed. The excess water is hydro-extracted and it is allowed to dry, lying flat, in an oven maintained at a temperature of 40^0- 60^0C. Finally, the fabric is conditioned in an standard atmosphere. Nutting [1.19] has shown that the wet-relaxation process is irreversible, but that the dimensions of the fabric depend upon the water temperature used for relaxation and the regain of the fabrics when they are measured.

Knapton et al [1.21] have justified the full-relaxed condition on plain knit fabrics simply by wetting-out the fabric for 24 hours, brief hydro-extraction and finally tumble-drying at 70^0C for 60 to 90 minutes. For the more complex structures, this technique may be inadequate or, conversely, more than adequate in bringing about this minimum-energy state.

1.11. Fabric shrinkage

According to Munden [1.17] the fabric shrinkage is commonly divided into three categories:

1. Relaxation shrinkage: It is associated with the release of strains imparted to the yarn in spinning and to the fabric knitted. This shrinkage is measured when the fabric is wetted out and it consists essentially in laying the fabric in water containing a softener and measuring the change in dimensions of the wet fabric after a specific time.

2. Consolidation shrinkage: A further mechanical shrinkage, normally observed in knitted fabrics other than wool during washing and after previous relaxation. It is also occurs in wool fabrics when dimensional changes occur during early washing treatments without any great area change and without any observed felting of the fabric.

3. Felting shrinkage: A property unique to wool fabrics, caused by differential fibre migration and entanglement through agitation when wet. The high extensional and recovery properties of wool molecule and the scale structure of wool fibre give it a unique differential frictional property.

Shrinkage occurs as the fabric recovers from strains imposed by the knitting machine. Up to now authors have recognised certain equilibrium situations as fabrics are subjected to a variety of "relaxation" treatments. Many observations have shown that different fibres often react in different ways to these treatments, so that the equilibrium values of the geometry "constants" vary. Although this effect has been noted, little effort has been made to explain it or explore its practical implications. In general the mechanism of shrinkage is a combination of several effects-namely loop length and shape changes, and degree of intermeshing changes. Several authors including Postle and Munden [1.29] imply that the limit of consolidation shrinkage will come when the tops and bases of the loops in alternative courses come into contact and prevent further loop sliding. Thus the totally relaxed dimensions are not necessarily subject to the same assumptions which apply to other states of relaxation. For example, yarn diameter is clearly a limiting factor in consolidation, and therefore the dimensions ultimately must be dependent upon this parameter. Clearly there is an unlimited number of possible combinations, and the utility and practical significance of any one of these, must eventually be considered. Treatments similar to those encountered in home laundering

must be used, and the results are considered in a comparative rather than an absolute way to establish a basis for further study.

1.12. Discussion

At the beginning of this chapter there is a presentation of the two basic, plain-knit and purl, knitted fabrics produced on single needle bed. The production process as well as the characteristics of both fabrics has been presented. Structural analyses of the plain-knit fabric provided a justification for its dimensional behaviour as far as the plain loop structural unit is concerned. The term "fully-relaxed", as presented by Knapton et al is a misnomer, since it is not applicable to woollen knitted fabrics, while dry and wet relaxing conditions are more appropriate as they do not create felting shrinkage to knitted fabric. Munden has shown that courses per unit length, wales per unit length and loop length are related to each other by constant values, which can be determined and have practical application. Using the appropriate constant values it is possible to predict the fabric mass in grams per square meter. The calculation for fabric mass in grams per square meter that can be easily justified by combining the equation for loop density and for cover factor.

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CHAPTER 2

GEOMETRY AND DIMENSIONAL PROPERTIES OF TWO NEEDLE BED WEFT KNITTED STRUCTURES

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$2.1.$ Introduction

The geometry and dimensional properties of plain-knit structure have been discussed in Chapter 1. The three other basic structures – 1X1 rib, 2X2 rib and interlock – must now also be considered.

For the last twenty years by far the most important development in knitting has been the extraordinary rise in popularity of double jersey cloth, particularly for ladies' outwear and even more recently in outerwear garments for men. For instance, the amount of double jersey fabric produced today is at least three times that of ten years ago, with the rate of growing showing little slackening. Unhappily, wool consumed by knitwear section has not grown as quickly because man-made yarns have covered a part of wool market. Also, most of knitwear factories do not produce one hundred percent wool products but wool mixtures, wool/acrylic, wool/nylon etc. This has to do with the market prices, the products are cheaper when produced from wool mixtures, and also with the quality characteristics where a knitted fabric from wool mixture yarns can be steamed in order to improve the dimensional characteristics of the knitwear.

Because wool knitwear can felt as well as relax, properties of "easy-care" are difficult to attain in all-wool double jersey cloth. To a great extent felting has been eliminated using different anti-felting agents, but dimensional changes due to relaxation remain a problem.

2.2. Purl structure

The simplest structure of purl fabric consists of courses of face loops alternating with courses of the back loops. This is known as 1X1 purl knitted structure. Therefore, this structure exhibits on both sides needle and sinker loops typical of the reverse side. The German name is links/links, which is translated as left/left or reverse/reverse (Fig. 2.1).
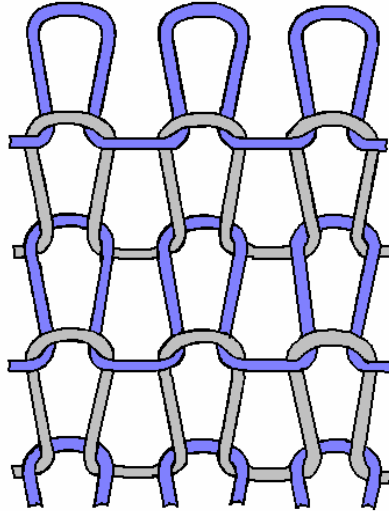
Fig. 2.1 Purl fabric

The fabric is well balanced and does not tend to curl as is the case with plain knit structure. The 1X1 purl fabric contracts in length direction and only exhibits the reverse sides of the loops because the face loops are hidden within the contracted structure. Due to contracting tendency in length, the fabric is highly elastic in this direction which is unusual for other types of knitting structures. This extensibility in length and width makes the purl fabric ideal for baby use, where elongation and expansion are required due to the fast growing rate of infants and also to simplify the dressing process. Generally speaking purl fabric is bulky and soft to touch. If the fabric has the loops formed in the way illustrated in Fig. 2.1, then the unravelling and laddering properties are similar to those of a

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plain knit structure. As with rib structures there are other combinations of simple purls, such as 2X2, 3X3 etc. These are uncommon and not particular useful.

2.2.1. Loop formation (purl fabric)

Traditionally purl structure was produced on flat purl knitting machines using one set of double-ended latch needles. The knitting machine consists of two parallel needle beds having their tricks exactly opposite to each other and in the same plane so that the single set of purl needles can be transferred across to knit outwards from either bed (Fig. 2.2).
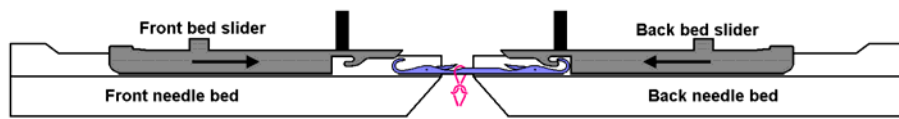
Fig. 2.2 Cross section of needle beds, purl knitting machine

Knitting outwards from one bed, the needle will produce a face needle loop with the newly fed yarn, whilst the same needle knitting outwards with its other hook from the opposite bed will produce a reverse needle loop. As the needle moves across between the two needle beds, the old loop slides off the latch of the hook. The needle hook, which protrudes from the bed, knits with the yarn, whilst the hook in the needle trick acts as a butt and is controlled by the slider. On the machine there is a complete set of sliders whose butts are controlled by the knitting-transfer cam system and they in turn control the needles. Each slider, therefore, is provided with two butts of which one for knitting and one for transfer.
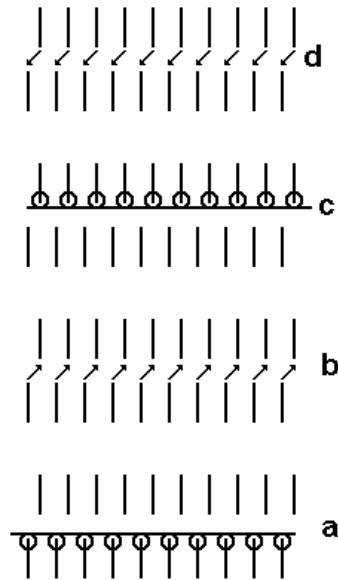
Fig. 2.3 Knitting sequence of purl structure on V-bed machine

Purl structure can also be knitted on V-bed rib knitting machines if loops are transferred across to empty needles in the opposing bed which then commence to knit in the same wale. A full sequence of loop production is illustrated in the four notation lines in Fig. 2.3. In (a) line face loops are formed on the front needle bed only. In (b) sequence, these loops are transferred to the rear needle bed, while in (c) line reverse loops are formed through face loops previously formed. Finally the reverse loops formed on back needle bed are transferred to front needle bed so that face loops can be produced through the reverse loops. The purl structure used in the experiments, in part three of this work, was produced according to the sequences presented in Fig. 2.3 on a fully computerised V-bed knitting machine.

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2.3. Fundamental aspects of rib structure

Rib fabrics, as different from plain-knit structure, can only be produced on machines equipped with either two opposed needle beds usually set to intermesh at right angles to each other, as in the case of flat-bed and cylinder/dial machines. The fabric is produced by intermeshing the loops in opposite directions on a wale-wise basis, and 1X1 rib structure, containing only rib structural units, is manufactured when the opposite intermeshing occurs in every other needle. The fabric so produced is illustrated in Fig.2.4A, where the fabric extends in a width wise direction, and diagrammatically in Fig. 2.4B. Normally, in a relaxed 1X1 rib structure, the loops would be touching each other whereas rib loops at the back of the fabric would be hidden from view. Consequently, this structure is more "bulky" than the plain-knit structure, because of its obvious three dimensional character, and high extensibility width wise.
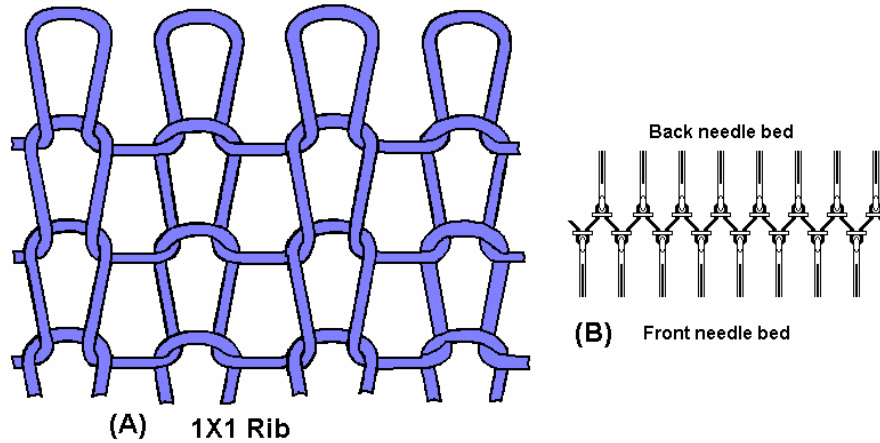
Fig. 2.4 1X1 Rib structure

In the relaxed state, the 1X1 rib structure is deceptively similar in appearance to the plain-knit structure. In some ways it may be likened to a blend of the two sides of the plain-knit structure connected together by

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a short "link" piece of yarn. The dimensional behaviour in relaxation of these two structures is dissimilar, however, and cannot be easily compared. It is a more expensive fabric to produce than plain-knit and is a heavier structure and the rib machine requires a finer yarn than a similar gauge plain machine. Like all weft-knitted fabrics it can be unroved from the end knitted last by drawing the free loop heads through to the back of each stitch. It cannot be unroved from the end knitted first because the sinker loops are securely anchored by the cross-meshing between face and reverse loop wales. This characteristic, together with its elasticity, makes rib structure particularly suitable for articles such as tops of socks, the cuffs of sleeves, rib borders for garments and strolling and strapping for cardigans. Rib structures are elastic, form fitting, and retain warmth better than plain structures.

It is apparent that such a structure offers an additional degree of freedom as far as extension along the course is concerned. The connecting loops between the two surfaces of the fabric can be made to rotate about an axis parallel to the wale lines until they are brought into the plane of the fabric. Theoretically for 1x1 structure, an extension of about 250 per cent is possible in addition to the normal width wise extension of the individual loops [2.1].

2.3.1. Loop formation of 1 x 1 rib structure

The simplest double knit fabric, which is 1X1 rib, is produced when all cylinder or front bed and all dial or back bed needles are brought forward successively at each feed to receive yarn into their hooks. The sequence of loop formation requires the feeding of yarn into one front bed needle followed by adjacent back bed needle. The method of notating this structure is shown on Fig 2.4B, which is a schematic view of the path of the yarn between the two sets of needles.

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Normally, 1X1 rib is produced in circular knitting machines, which have cylinder and dial. Thus, in this knitting machine there is one set of needles on the circumference of the vertical cylinder and a second set of needles, arranged perpendicular to the first set and mounted on the horizontal dial. However, for our experimental work a V bed flat knitting machine was used to produce the required rib structures. The V-bed machine used has two rib gated, diagonally approaching needle beds, set at between 90 degrees to each other giving an inverted V-shape appearance.

Figure 2.5 illustrates the knitting action of this electronically controlled knitting machine. The letters A – F correspond to the number of the knitting action illustrations assuming that a carriage traverses from one side of the machine to the other. The same applies when the carriage moves to the opposite side.

A. *Rest Position:* The tops of the heads of the needles are level with the edge of the knock-over bits. The butts of the needles are on a straight line until contact is achieved with the raising cam. The lifting of the needles is an alternative action, which always take place as the traverse commences and each needle butt comes in contact with the raising cam.

B. *Clearing:* The needles from both beds start to lift as soon as their butts come in contact with the front and back raising cam. The old loops clear the hooks and leave the latches open ready for the next yarn feed. The needles are lifted to full clearing height position.

C. *Yarn feeding:* The yarn is fed as the needles descend under the control of the guard cam and each needle draws the required loop length as it descends under the control of the stitch cam.

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D. *Latch closing:* At this time the new yarn is fed through a hole in the feeder guide to the descending needle hook as there is no danger of the yarn being fed below the latch. The old loop contacts the underside of the latch causing it to close on to the hook.
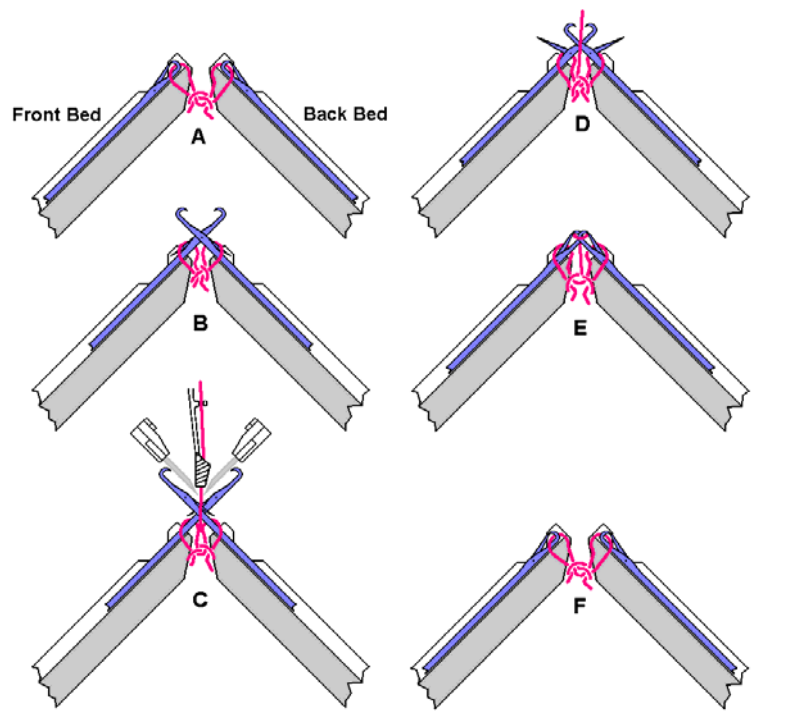
Fig. 2.5 Loop formation of 1X1 rib structure

E. *Knocking –over:* To produce simultaneous knocking-over of both needle beds, the stitch cam of the front and back bed are adjusted to knock-over both sets of needles at the same time. The needles are withdrawn into their tricks so that the old loops are cast off and the new loops are drawn through them.

F. *Loop length formation:* The continued descent of the needle draws the loop length below the surface of the trick-plate supporting the

sinker loop. The distance is determined by the depth setting of the stitch cam which can be adjusted.

2.3.2. 2x2 rib structure and production

Other constructions of rib are possible and are widely used. A fabric in which all the loops of alternative pairs of wales are intermeshed in one direction and all the loops of the other pairs of wales knitted at the same course are intermeshed in the other direction is called 2 x 2 rib (Fig. 2.6).
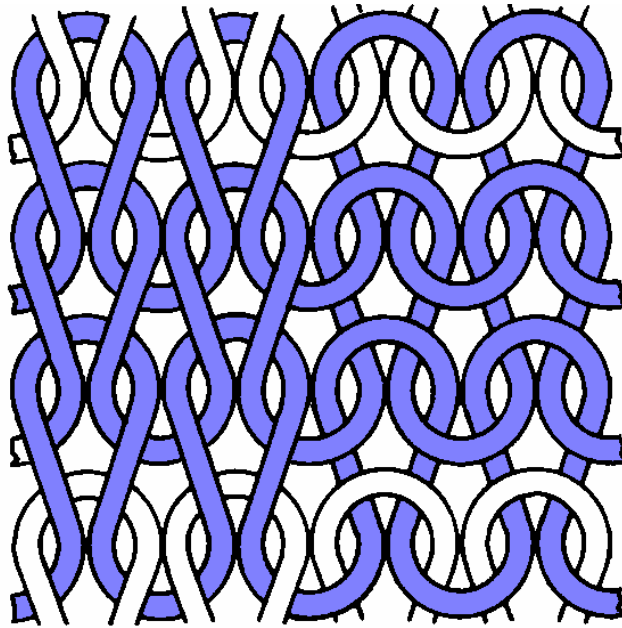
Fig.2.3 2X2rib structure

The 2 X 2 structure is not one which is often used in apparel fabrics, because of its inherently high contraction properties which result in large differential fabric distortion in the width-wise direction. Its general use is for cuffs and sweater waists where its contraction properties are utilized to ensure a snug fit. However, nowadays it is being used a lot more in

apparel due to trends in fashion. The 2 X 2 rib is probably the most commonly used structure for garment borders i.e. the elastic bands of knitted outwear products. It will only unravel from the end last knitted like 1X1 rib. Such a property reinforces the argument for using ribs on the extremities of garments.

In industry the expression "rib fabrics" denotes fabrics in rib, executed in two needle beds, by means of needle beds with needles out of action. The most common of these are 2/3 rib and 2/4 rib. As its name indicates, the 2/3 rib is knitted with a needle bed comprising 2 needles in action out of three. In other words, one needle is out of action (Fig 2.7). This 2X2 rib structure has been produced during the experimental work.
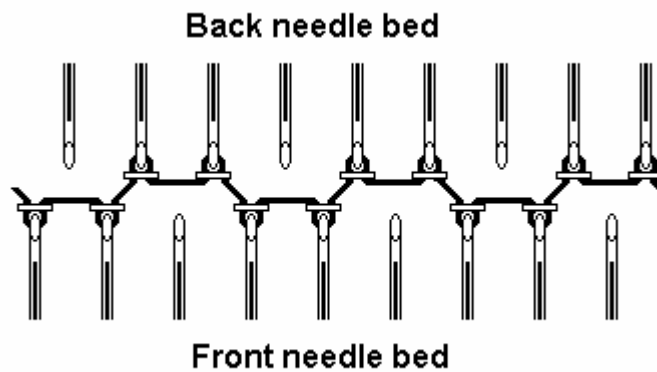
Fig. 2.7 2X2 rib with 2 needles in action out of 3

The 2/4 rib is composed of 2 needles in action alternating with 2 needles out of action. This needle arrangement for the production of 2 x 2 rib is more popular in knitting factories because it presents better elastic properties compared to 2/3 rib or needle arrangement. The uniformity of the inter-stitches of this type of rib involves the needle beds being placed in a half rack, i.e. when the tricks of one needle bed are situated opposite the tricks of the opposing needle bed (Fig 2.8).

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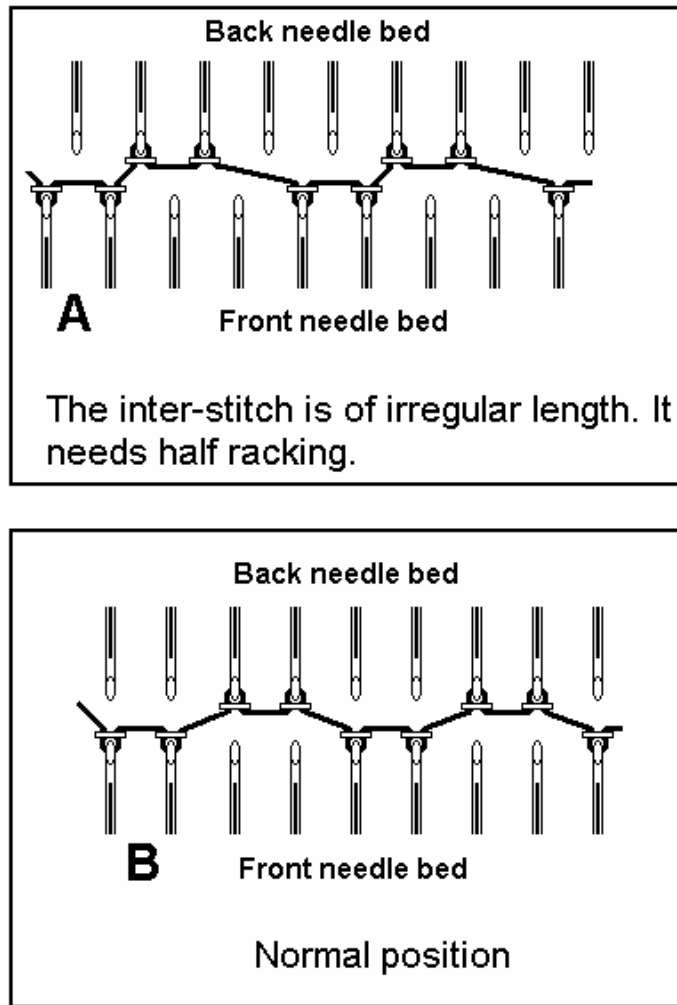
Fig. 2.8 2X2 rib with 2 needles in action out of 4

2.4. Characteristics of interlock structure

Interlock was originally derived from rib but requires a special arrangement of the needles knitting back-to-back in an alternative sequence of two sets so that the two courses of loops show wales of face loops on each side of the fabric exactly in line with each other thus hiding the appearance of the reverse loops. Interlock consists of two 1 X 1 rib

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fabrics knitted in such way that they are locked together. Fabric knitted in such a way is extremely stable and if produced from cotton yarn it is widely used in men's underwear and leisurewear. Interlock has the technical face of plain fabric on both sides but its smooth surface cannot be stretched out to reveal the reverse meshed loop wales because the wales on each side are exactly opposite to each other and are locked together (Fig. 2.9).
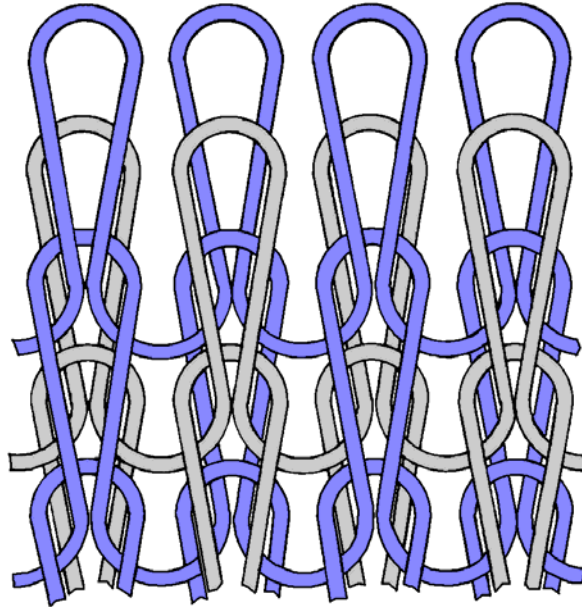
Fig. 2.9 Interlock structure

Interlock is a balanced structure, which lies flat without curl. Like 1 X 1 rib, it will not unravel from the end knitted first but it is thicker and heavier and narrower than rib of equivalent gauge and requires a finer, better and more expensive yarn. The productivity of interlock structure is half of that of rib structure. When two different colours of yarns are used, vertical strips are apparent if odd needles or feeders knit one colour and even needles or feeders knit the other colour (Fig. 2.9), whereas horizontal

stripes are produced when the same colour is knitted at two consequent feeders.

On a circular interlock machine the needles in the cylinder and the dial are directly aligned. For this reason this knitting machine cannot be used for individual needle selection. However, selection has in the past been achieved by using four feeder courses for each pattern row of interlock.

2.5. Production of interlock structure

Interlock knit is produced mainly on special cylinder and dial circular knitting machines, on circular electronic control machines and on electronic V–bed flat machines. The basic interlock machine has the needles in the cylinder and dial directly aligned. This arrangement permits finer gauges to be knitted than on rib machines although not all needles in both dial and cylinder can knit at any one feed. Two separate cam systems, one at each bed, are controlling half of the needles in alternative sequence. The needles on the machine are set out alternatively; one is controlled from one cam system the next from the other, while diagonal and not opposite needles in each bed knit together.

The conventional interlock-knitting machine has needles of two different lengths, long needles (L) knit in one cam track and short (M) needles knit in a different cam track (Fig 2.10). Always the long needles knit first followed by short needles on the second feeder since needles are set out alternately in each bed with long needles opposite to short needles.

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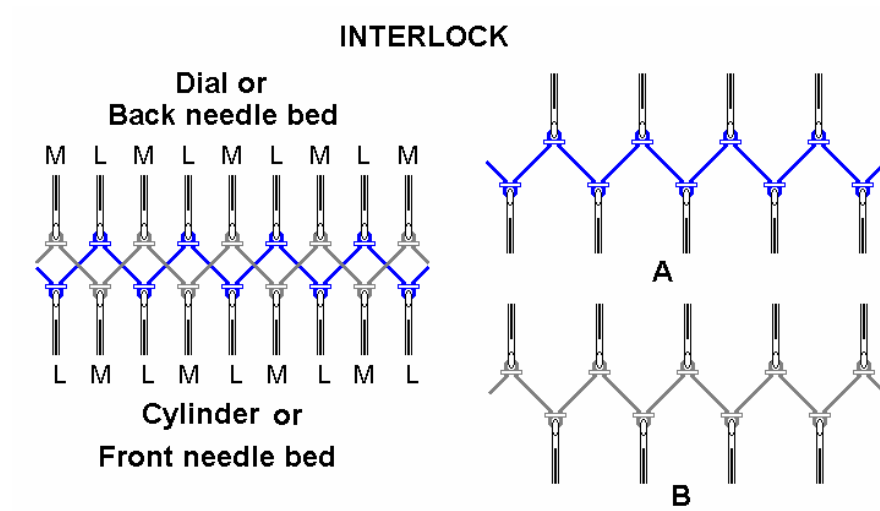
Fig. 2.10 Interlock needle arrangement

2.6. The geometry of relaxed double jersey structures

The majority of the researchers who have studied the dimensional properties of the relaxed 1X1 rib opted to consider it as an extension of plain-knit structure and not as a unique structure. Perhaps for this reason, agreement between theoretical models and experimental evidence was found. Although Tompkins [2.2] first dealt with 1X1 rib fabric, relatively little work on structures other than single jersey was carried out.

A theoretical approach on double knit structures has presented by Nutting and Leaf [2.3] who introduced a constant value and a term

concerning the yarn diameter on the base equations of the constant values K, which can be written in the form:

$$\frac{1}{C} = A\ell + DT^{\frac{1}{2}} \qquad (1)$$

$$\frac{1}{W} = A\ell + DT^{\frac{1}{2}} \qquad (2)$$

 where A and D are constants whose numerical values will depend on the fabric construction, T is the yarn tex value and C or W refers to courses and wales per unit length respectively. Empirical results showed that values of D were significantly different from zero for several structures, including 1x1 rib at different relaxed states. The above equations indicate that yarn diameter is a significant factor in determining fabric dimensions, contrary to Munden's [2.5] basic approach. However, although the D values were statistically significant, Nutting and Leaf suggested that they were too small to be commercially significant and could be omitted.

Experimentally, however, certain similarities with the plain-knit loop cannot be disregarded. For example, Smirfitt [2.4] was the first to show that for most practical purposes the dimensional properties of the all-wool 1X1 rib structure could also be described by K parameters. Values given to these parameters were similar but not identical to those found for plain-knit structure. He defined the repeating unit as the length of the yarn in the knitted loop showing on the face, or the back, of the fabric; that is, the length of yarn (ℓ) associated with any one needle, and calculated the K values from measurements of courses per inch (c) and ribs per inch (r) as seen on the fabric face. Fabric dimensions for a series of worsted count yarns, knitted into 1X1 rib structure, were measured by Smirfitt in the dry-relaxed state, under water, the wet-relaxed state and after a further wet-relaxation followed by tumble-drying for 30 minutes.

On plotting c and r against 1/ℓ, Smirfitt reported that intercepts other than zero appeared on the ordinate, suggesting that the geometry of the relaxed 1X1 rib structure was more complex than that of the plain-knit structure relaxed under identical conditions. He also noted a tendency for the significance of these intercepts to increase as the relaxation treatment progressed. To account for these intercepts, Smirfitt suggested similar equations to those proposed by Nutting and Leaf [2.3]. They have the form:

$$\frac{1}{c} = a_c \ell + b_c \qquad (3)$$

$$\frac{1}{w} = a_r \ell + b_r \qquad (4)$$

where α_c, α_r, b_c and b_r are constants. He also proposed that b_c and b_r were functions of the effective diameter of the yarn similar to that of Nutting and Leaf.

Smirfitt then proposed that for most practical purposes, these intercepts could be ignored and a sufficiently accurate prediction of dimensions could be obtained using the simple K values similar to those used for plain-knit structure. The constants he obtained are presented on the Table 2.1.

TABLE 2.1: Constant values (K) for fabric geometry of 1X1 rib (Smirfitt)

Fabric state	Parameters			
	K_c	K_w	K_s	R
Dry-relaxed	4.51	3.34	15.0	1.35
Wet-relaxed	5.00	3.27	16.3	1.53

There are two important facts to be gained from Smirfitt's work. First on initial immersion in water little subsequent change in K_s occurs in further relaxation. Secondly, R values increase with progressive relaxation, particularly after wetting-out and tumble-drying.

Another investigation concerning 1X1 rib fabrics took place by Natkanski [2.7] who attempted a theoretical analysis of the geometric shape of 1X1 rib knitted loop. He considered a two dimensional "elastica model" of a single rib loop, based on the theory of Postle and Munden [2.6] and his calculations showed completely different values from those obtained by Smirfitt and his experimental work. Natkanski, and Knapton et al. [2.8], have independently shown that the intercepts ascribed by Smirfitt to an effect of yarn diameter were probably due to incomplete relaxation. This opinion is also held by Centre de Recherches de la Bonneterie [2.9]. Knapton et al. suggested that equations of the form:

$$\frac{1}{c} = a_c{}^p \ell \qquad (5)$$

$$\frac{1}{r} = a_r{}^q \ell \qquad (6)$$

more precisely define the relationship between c, r and ℓ in the dry-relaxed state. The values of p and q were not equal to unity in dry-relaxed state, whereas in fully-relaxed state the values of p and q were equal to unity.

The paper presented by Knapton et al. [2.8] introduced a new term called "structural knitted cell" (SKC), that is, the smallest repeating unit of structure, and suggested that for the 1X1 rib structure the smallest repeating knit unit is not one loop, but two adjacent loops, for 2X2 rib structure four adjacent loops and for interlock four adjacent loops [2.10]. A more resent work by Woolfardt and Knapton [2.11] introduced this three dimensional loop model based on the same principle of similarity introduced by Munden [2.15] but modified by introducing a certain assumptions related to geometrical configuration of the knitted stitch. The effective loop length should be the length of yarn in one SKC, defined as the structural-cell stitch length (ℓ_u), and the depth and width, respectively, of the SKC were defined as $1/C_u$ and $1/W_u$ where c_u is equal to courses units/unit fabric length and w_u equal to wale units/unit width. Thus for any weft-knit structure, Munden's classical equations (1-4) (Chapter 1.9) of knitted loop geometry would be altered such as:

$$U_c = c_u \times \ell_u \qquad (7)$$

$$U_w = w_u \times \ell_u \qquad (8)$$

$$U_s = c_u \times w_u \times \ell_u^{\,2} \qquad (9)$$

$$R = \frac{U_c}{U_w} = \frac{c_u}{w_u} \qquad (10)$$

Woolfardt and Knapton [2.11] showed that their "fully-relaxed" wool rib fabrics behaved essentially like Munden's [2.15] jersey fabrics. Thus linear relationships were shown to exist when c_u and w_u were plotted against $1/\ell_u$, with best-fit lines exhibiting highly significant correlations but non-significant intercepts. No felting had occurred and the conclusion was reached that there was no significant effect of yarn diameter over the normal commercial range of fabric tightness.

Table 2.2 presents the results obtained by several workers for 1X1 structure in fully-relaxed state, which has been recalculated so as to be presented on both parameters of "u" and "K". The differences in values that exist between them can be explained partly by experimental error and partly by experimental differences between the workers.

TABLE 2.2: Values of "u" obtained by several workers for 1X1 rib structure (fully-relaxed state)

	Parameters						
	u_c	K_c	u_w	K_w	u_s	K_s	R
Knapton [2.8]	10.6	5.30	6.03	3.01	63.7	15.93	1.76
Woolfardt [2.11]	10.7	5.35	5.85	2.92	62.7	15.68	1.84
Natkanski [2.12]	10.7	5.35	6.32	3.16	67.6	16.90	1.69
Smirfitt [2.4]	10.6	5.30	6.28	3.14	66.6	16.65	1.69
Fong [2.13]	11.1	5.55	5.76	2.88	63.8	15.95	1.92

Statistical analysis of the results obtained by Woolfardt and Knapton shown that the dimensional behaviour of tumble-relaxed wool 1X1 rib structure is indeed similar to that of the plain-knit structure, i.e. courses and wales per unit length and width are related to loop length by simple relations such as those given by the equations (7)-(10).

TABLE 2.3: Values of "u" obtained by Pool and Brown for 1X1 rib cotton structure

	Parameters						
	u_c	K_c	u_w	K_w	u_s	K_s	R
Dry-relaxed (Cotton)	8.20	4.10	5.69	2.85	46.70	11.67	1.44
Wet-relaxed (Cotton)	9.64	4.82	5.90	2.95	56.88	14.22	1.63
Fully-relaxed (Cotton)	10.19	5.09	5.99	2.99	61.04	15.26	1.70
Dry-relaxed (Cot/Blend)	8.17	4.08	6.16	3.08	50.33	12.58	1.33
Wet-relaxed (Cot/blend)	8.86	4.43	6.18	3.09	54.75	13.69	1.43
Fully-relaxed (Cot/blend)	9.75	4.87	6.02	3.01	58.69	14.67	1.62

A more recent work done by Poole and Brown [2.14], on 1X1 rib structures used all cotton and cotton blends yarns, produced the "u" and "K" parameters shown on Table 2.3. According to the obtained values, it is clearly seen that there is distinctive difference between the two categories i.e. cotton and cotton blends. Fabrics produce by 100% cotton yarns present a greater level of shrinkage compared to cotton blend fabrics. Thus, if these values are going to be used for the theoretical determination of the fabric mass per unit area it is important that the

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calculations between the two categories of fabrics are distinguished for cotton and cotton/blends. The general conclusion is that 1X1 rib structures behave very similarly to single jersey fabrics when subjected to relaxation treatments. Woolfardt and Knapton have also reached this conclusion.

TABLE 2.4: Constant values of "u" obtained by Knapton et al. for 2X2 rib wool structure

	Parameters							
	u_c	K_c	u_w	K_w	u_s	K_s	R_u	R
Dry-relaxed	19.35	4.84	7.31	3.66	141.5	17.69	2.65	1.32
Wet-relaxed	20.47	5.12	7.02	3.51	143.7	17.97	2.92	1.46
Fully-relaxed	22.30	5.58	6.33	3.16	141.2	17.63	3.5	1.76

Knapton et al. [2.8] also made a preliminary study of the dimensional behaviour of 2X2 rib wool structure without, however, giving any details on the knitting process, which is an important omission, since a 2x2 rib fabric can be knit in either 2 by 1 or 2 by 2 needle arrangement i.e. in a 2 by 1 needle arrangement there are two active needles for loop formation and one inactive (Fig. 2.7). Therefore, the inactive needle arrangement must be specified because the fabric displays different properties and its behaviour during subsequent treatments is completely different. Their general conclusion was that the tighter fabric structures, i.e., those with a small loop length, exhibit the larger area shrinkage in fully-relaxed state. For practical purposes, it was suggested that, for increased contraction properties, small loop length or an increase in cover factor is advisable. A

series of constant values "u", was obtained by Knapton et al. which have been recalculated in order to be comparable with the results obtained by the author and are presented on Table 2.4.

A study by Knapton and Fong [2.16] on interlock fabric, using wool yarns with three different ranges of loop length or structural cell-stitch length (SCSL), as they call it, has shown that the "u" values are not constant in dry and wet relaxed states but are significantly dependent on loop length. However, in the fully relaxed state, no significant dependency of "u" values on SCSL was observed. They also observed that the standard deviations of u_s and u_c/u_w values in fully relaxed state were surprisingly large, suggesting that some felting occurs in tumble-drying. The different "u" values, which they obtained have also been recalculated and presented on the Table 2.5.

TABLE 2.5: Constant values of "u" obtained by Knapton and Fong for wool interlock structure

	Parameters						
	u_c	K_c	u_w	K_w	u_s	K_s	R
Dry-relaxed	16.91	4.23	10.26	2.57	173.4	10.87	1.65
Wet-relaxed	17.74	4.44	10.3	2.58	182.7	11.45	1.73
Fully-relaxed	20.48	5.12	9.78	2.45	200.4	12.54	2.10

The only way to be sure that a knitted fabric really is in a "fully-relaxed" condition is to confirm that subsequent laundering causes no appreciable dimensional changes. So far, little data is available on laundering of wool double jersey although Knapton and Fong [2.16] have tested interlock and Swiss Double Pique choosing 10 machine-wash and tumble-dry cycles from defined full-relaxed state. Even by these standards their "fully relaxed" technique did not sufficiently relax the interlock structure; for subsequent linear changes numerically greater than ± 5% were occasionally observed even after 15% area relaxation shrinkage. However, because the majority of residual relaxation in laundering occurred in the initial wash, Knapton and Fong recommended an additional tumble-drying relaxation process to bring subsequent dimensional changes within their chosen limits. But clearly the anti-felting treatment must be strong enough to inhibit all possible signs of felting.

2.7. Felting behaviour of double jersey structures

Knapton and Schwartzkopff's [2.10] work with tumble-drying relaxation technique suggests that an absolute discrimination between fabric dimensions changes due to relaxation and changes due to felting is unlikely in untreated wool double jersey fabric. Nevertheless, they almost separate, which essentially agrees with Brown and Mehta [2.17], who hold the opinion that relaxation precedes felting during washing. Perhaps it is more correct to say that both mechanisms occur simultaneously but that the greater majority of relaxation changes occur well before felting gets under way.

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Knapton and Fong [2.16] have shown that some felting of untreated fabrics begins in relaxation. For these fabrics the amount of felting in tumble-drying depends to some extend on both loop length and yarn twist. Once machine –washing begins, the area shrinkage of untreated fabrics increases rapidly in a way exactly similar to that found for the plain-knit structures [2.18]. Felting rates of these untreated fabrics depend on tightness factor and also yarn twist. However, neither fabric tightness nor the level of yarn twist is enough to give dimensional stability adequate for reasonable machine-washable standards. By plotting percentage area shrinkage against the number of machine wash and tumble-drying cycles for double jersey structures, the sample felt in much the same way as the plain-knit or rib structure. Thus, exactly the same mathematical analysis can be used to describe this behaviour, indicating that felting is indeed a phenomenon of yarn length shrinkage within the fabric. Therefore, using the argument that felting of knitted fabrics is dependent only on the yarn length changes in the relaxed, essentially forms a stable knit cell, they were able to prove that felting rates were given by:

$$\ell_n(a\beta) = A - B(TF) \qquad\qquad (11)$$

where A and B are constants which assume values varying with construction details and TF represents tightness factor. Values of α and β, and therefore felting rates, $\ell_n(\alpha\beta)$, can be calculated from the area shrinkage (A_s) versus washing time (t), curves expressed by the general equation:

$$A_s = a^{\left(1 - e^{-\beta t}\right)} \qquad\qquad (12)$$

Furthermore, the majority of the shrinkage occurs in the first wash, which suggests that the residual relaxation within the fabric will be eliminated in the initial wash.

$2.8.$ Theoretical models of complex structures

Experimental evidence essentially justifies Munden's [2.5] original claim that knitted fabric dimensions are uniquely determined by loop length. His predictions were based on a simple geometrical model of the knitted loop configuration, two important assumptions being that the loop length/yarn diameter ratio was a constant and that the fabric was relaxed.

In an incompletely relaxed fabric state Munden's claim is invalid. Because in manufacture the loop configuration is constrained to some distorted shape, work must be applied to the fabric to release the high internal strain energy. Fabric dimensions off the knitting machine are therefore highly irregular, making comparisons with any loop model difficult. But in relaxation of knitted wool fabric the loop shape tends to a fixed and stable configuration, which is perhaps easier to analyse.

Unfortunately, all theoretical models of any simple or complex knitted structure predict that dimensions must depend pertly on yarn diameter. This applies whether the model is geometrical or is derived from a study of the forces supposedly keeping the yarn in its relaxed looped configuration. Clearly with wool these models do not apply, at least over the normal range of tightness of construction. One is therefore led to the conclusion that the diameter of wool yarn in the relaxed fabric is quite different from the "nominal" yarn diameter.

Although these changes in diameter were observed experimentally by Postle [2.19], no theoretical model satisfactorily takes them into account. Equally important, the problem of hydroscopic yarn setting has not been carefully considered in the formulation of any theoretical model, since

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there are also additional complexities due to the yarn interlocking arrangements of double jersey structures.

2.8.1. Geometry of tuck stitch

Tucking is a simple and useful means of creating a new effect in any weft-knitted structure, but as a stitch it can only be used in conjunction with the other basic structural knit units. There is no such thing as an all-tuck fabric. Consequently, this basic unit is more difficult to analyse because its shape can only be indirectly measured by studying its effect on the shape of other structural units. The production of the single tuck stitch has been presented on Chapter 1.

Many tuck fabric structures rely for their effect upon unequal distribution of yarn among the loops. This is exemplified in the half-cardigan structure the face side of which is shown in Fig. 2.11A in a width wise extended position. The structure is produced on a rib machine knitting 1X1 in one cam traverse, and then on each alternative traverse the needles on the back bed tuck instead of knit (Fig. 2.11B). Therefore the structural repeat unit for half-cardigan consists of three knitted loops and one tuck loop.
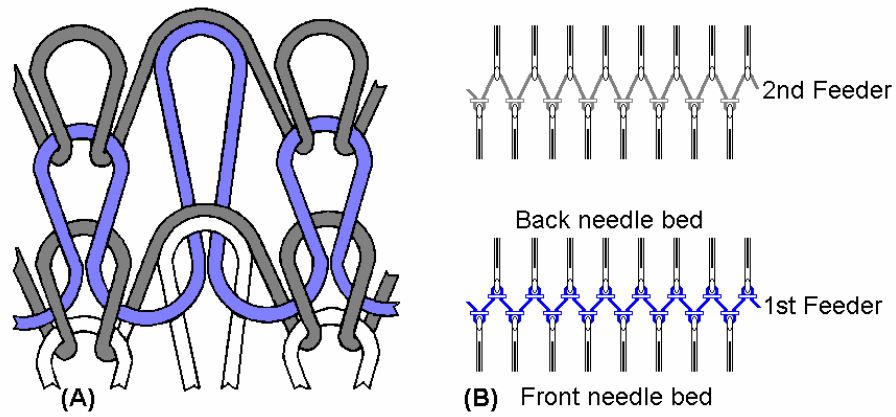
Fig. 2.11 Half-cardigan

It is well known that the introduction of tuck loops into rib structures tends to reduce the number of wales per unit width. This applies more to the balanced structure of full-cardigan structure, however, than it does to the unbalanced half-cardigan. In the later case, the wale spacing is determined by those wales, which consist of knitted loops only, and this gives a high reading of stitch density.

Song and Turner [2.20] show that the established, simple, weft-knitted fabric geometry ($S=K_s/\ell^2$) could be extended to accommodate the tuck variations of 1X1 rib. This is also agreed upon by Nutting [2.21] who found that in dry- and wet-relaxed states, K parameters were evident, having values roughly equivalent to those of the other simple knitted structures.

Knapton, Fong and Slinger [2.18] showed that the intercepts that were appeared in dry- and wet-relaxed states disappeared in fully-relaxed state. Again relaxing procedures consisted of wetting-out and tumble-

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drying. Using standard definitions and the Structural Knit-Cell definition used by them, the values presented on Table 2.6 were obtained.

TABLE 2.6: Constant values of "u" obtained by Knapton and Fong for wool half-cardigan structure

	Parameters							
	u_c	K_c	u_w	K_w	u_s	K_s	R_u	R
Fully-relaxed	18.10	4.52	8.40	4.2	152.0	19.0	2.16	1.08

Therefore, the half-cardigan structure behaves in washing in much the same way as the 1X1 rib structure. Once again, it can be concluded that Munden's original plain-knit loop theory can be applied to the tuck stitch if the structure is in fully-relaxed state.

2.9. Discussion

According to the above references it can be seen that the dimensional properties of wool double jersey structures have shown the existence of stable loop geometry. The geometrical equations developed by Knapton et al are based on Munden's simple equations of fabric geometry giving out the same conclusions.

There are many problems regarding the fully relaxing procedures of wool knitted fabrics, because it is commercially difficult to fully-relax knitted fabrics by tumble-drying techniques. Also, drying techniques are not standardised and dimensions of wool knitted fabrics often vary depending

on the form of drying. All these are some points, which must be considered in case that further research is going to take place.

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Part Two: Developing "proKNIT" system

CHAPTER 3

"proKNIT" PROJECT – DEVELOPING THE SOFTWARE

3.1. Introduction

The system for predicting and determining the knitted fabric mass per unit area is called "proKNIT» and it has been developed using Visual Basic programming language as a medium of designing it. The question, which can be put forward is "Why Visual Basic?". The answer to this question lies in the following points:

❑ The microcomputer industry has revolutionized the "graphical user interfaces". This means that users can spend more time mastering the applications and less time worrying about which keystrokes do what within menus and dialog boxes.

❑ Developing a Windows application required expert C programmers and hundreds of lines of code for the simple task. Even the experts had trouble. Thus the first release of Visual Basic by Microsoft had shown that this new miracle will dramatically change the way people feel about the use of windows. First because Visual Basic applications can now be developed using even Windows NT in a fraction of time previously needed, but basically because it is a simple programming language, which combines designs and programming code.

❑ Visual Basic lets us add menus, text boxes, command buttons, option buttons for exclusive choices, list boxes, scroll bars and file and directory boxes to blank windows. We can use grids to handle data and also can communicate with other Windows applications. Thus Visual Basic is an easy method to let users control and access databases. Also it offers more Internet features, better support for database development and more language features to make our programming jobs easier.

Taking all these parameters into consideration Visual Basic was an ideal for producing a system that would not be too difficult to design but which, nevertheless, would prove an invaluable "tool" in making the process of

calculating fabric mass one that would otherwise be rather tedious and time consuming (if it was done manually), simple effective for both the designer of the programme, but also the potential user of it in the long run.

Therefore, "proKNIT" was designed as a means of predicting and determining the mass per unit area 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 as reliable as possible taking into consideration the existing bibliography for determining the knitted fabric mass pre square meter, while it would be user-friendly, not requiring expert knowledge in computers to operate it. The first part of the word 'pro' deriving from Greek means "before", therefore, the name of the system appropriately referring to estimations made before the production of a knitted fabric. More specifically, the thinking behind the creation of the system was based on the following logical premises:

❑ Using all mathematical models from the existing bibliography to set up the sequence of the estimations. The development of the mathematical models was based on the conclusions drawn by previous workers (see Chapter 1 and Chapter 2), while the input parameters were restricted to those equations that are known before knitting commences and can be measured easily in a knitting factory.

❑ Developing three different conditions for predicting the mass of a fabric. The three different and realistic relaxed conditions were selected in such a way that they would reflect, more or less, those existing in the knitting industry.

❑ Developing appropriate software compatible and friendly to user.

❑ Building a comprehensive database of measurements made in different raw materials and knitted fabrics of various structural designs.

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❑ Producing a system that would make logical and acceptable predictions.

Visual basic was selected as the programming language for reasons explained above. The forms of "proKNIT" project have been developed based on the following steps (see also Appendix):

      A. Defining the project task

      B. Creating the visual layout or interface

      C. Developing the logic behind the code

      D. Project verification

3.2. Developing Form1

The project task is to create an opening window with the logo **"proKNIT system"**. In order to develop the required form it is necessary to open Visual Basic Integrated Development Environment (IDE). The background was created using pale colours on a square motive on the Adobe Photoshop design system. By choosing the image object from the toolbox an image frame was created and from the image properties window the image to be displayed was chosen.

By double-clicking the image, the Code window opens. The code itself is presented analytically on the Appendix under the title "**frmMain (Form1.frm)**". The code has been developed between Private Sub and End Sub lines. The command "Image1_Click()" is executed when a single Click occurs on the picture of the main form (Fig. 3.1), which on appearing causes the rest forms of the program to disappear from sight (Form2.Hide etc).

The letters q and w in the code refer to coordinates, which justify the position of the form on the monitor. By single-clicking on the main form, it automatically unloads giving its place to the second form (Form2.Show), which indeed replaces it on the screen.
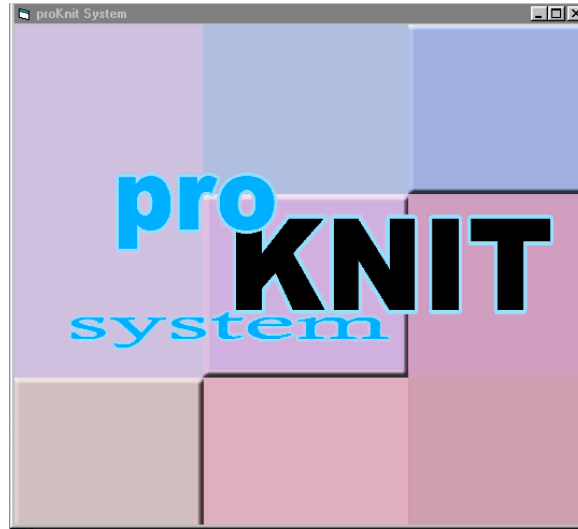
Fig. 3.1 Form1

3.3. Developing Form2

The main purpose of Form 2 is to provide the user with a welcome message and a brief introductory note about the general use of the "proKNIT' system. The texts were placed in label boxes so as to be justified and therefore easily handled on the form. The "Start" button was individually designed as a Command Button taken from the Tool Box. By clicking on the "Start" button the system operates in a similar way as when clicking on the main Form image, that is, Form 2 is automatically replaced by Form 3. Fig. 3.2 shows the form of the Layout window, where the design takes place and also the final appearance of the page while the system is running.

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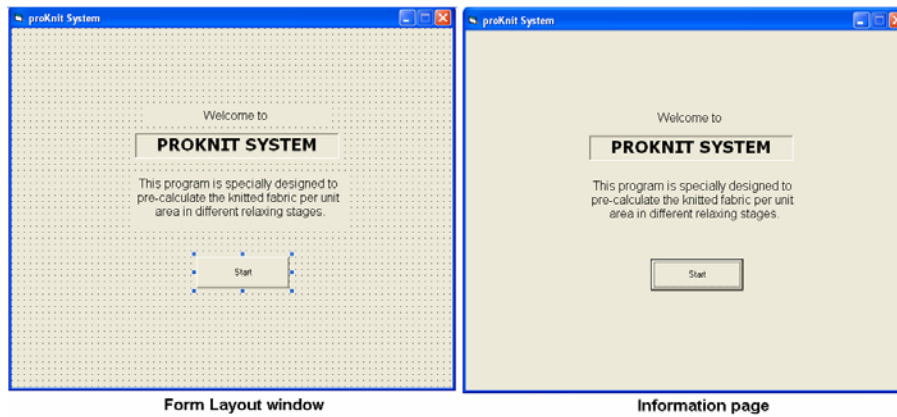
Fig. 3.2 Form2

3.4. Developing Form3

As it has already mentioned the program will function as soon as the button "Start" is pressed on Information page. On the third page a table of different yarn characteristics appears. The yarns have been classified into eight categories for the two most widely used natural fibres, which are cotton and wool. The user has the ability of choosing between dyed and undyed yarns and their blends. If "wool" yarn is chosen, then it means that it is an undyed, natural colour, worsted yarn (Fig 3.3). In the case of "cotton", it is a natural colour, combed yarn. The yarn blends for natural fibres, wool and cotton, cover the most popular combinations existing in the market such as Cotton/polyester, Cotton/viscose, Cotton/nylon, Wool/acrylic and Wool/nylon.

At an experimental level the attempt of predicting the fabric mass per square meter has been carried out on wool mixture yarns. By choosing the right category of yarn and pressing "Next>>" the forth page comes on,

Fig. 3.3 Form3 - Yarn characteristics

Once again, an analysis of the code of this Form is presented on the Appendix. On Form3 (Fig.3.3) eight option buttons are contained in a frame box. Each one of them refers to a different type of yarn. Each option button has its own Boolean variable. Thus by selecting one, it is set to True and all the others to False.

If Option1.Value = True Then
cotton = True
Form3.Hide
Form4.Show

When clicking on the "Next" button, it automatically stores the selected option, an operation that will enable the program to retrieve all information concerning the chosen type of yarn and facilitate calculations at the later stage.

If for any reason no selection of a yarn is made, a message box appears with a warning "Please make a selection", concerning the omission.

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```
Dim Msg1 As String
Msg1 = MsgBox("Please make a selection.", 32, "proKNIT System")
```

Taking a closer look at the code it is obvious that there are no data available for yarn categories:

- ❑ Cotton coloured yarns

- ❑ Cotton coloured mixtures and

- ❑ Wool coloured yarns.

Therefore, the code line giving the above information for cotton coloured yarn only is:

```
If Option5.Value = True Then
Msg2 = MsgBox("No data available.", 0, "proKNIT System")
```

Similarly here are equivalent programming lines for the other two yarn categories mentioned above where a Message box giving the information of "No data available" appears on the screen.

On pressing "Next" the forth form will appear replacing form3 at the same position on the monitor.

3.5. Developing Form4

By choosing the right category of yarn and pressing "Next>>" the forth page comes on, where the type of knitted fabric has to be selected. Plain knit, 1X1 rib and interlock fabrics have been chosen due to abundance of provided information, so that the estimation of our K values can be compared with the values predicted by other researchers. The purl structure has been chosen because it is a single needle fabric with wales containing both face and

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reverse meshed loops. Finally, the 2X2 rib structure was selected although very little work has been done for predicting K values for it, it is a simple structure that does not involve complicated calculations and can therefore produce "safe" results. From the forth page until the last one, it is possible for the user to go back to the previous page using the "<<Back" button, for alterations, or to move forward by pressing "Next>>" (Fig.3.4).
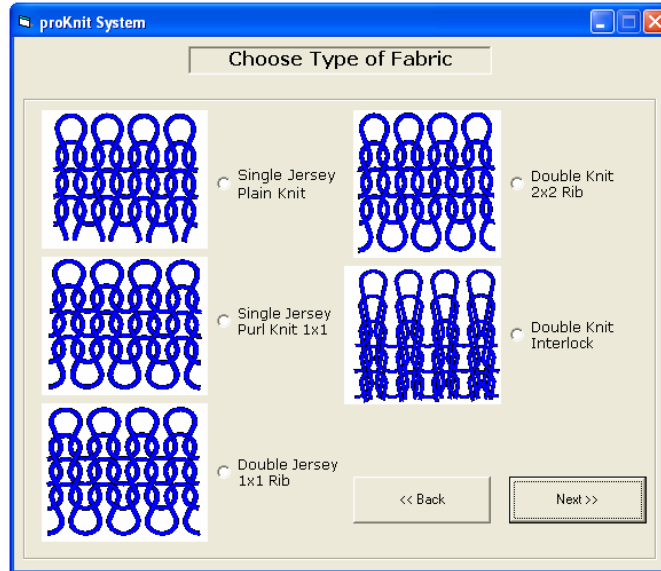
Fig. 3.4 Form4 - Types of fabrics

From Fig. 3.4 it is clear that there are two main fabric categories, that is, one of which belongs to single jersey fabrics and the other to double jersey fabrics. If a single jersey fabric was selected then it corresponds to a number taken from the equations (6), Chapter 1.5, which will be used later on in the calculation. A corresponding number is also the case for double jersey structures and comes from equation (7) in the same chapter. All this information is presented on the following programming lines:

A. Single jersey

If Option1.Value = True Then

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```
fab = 10630
doub = 1
sjplain = True
fabtype = "Single Jersey Plain Knit"
```

B. Double jersey

```
ElseIf Option3.Value = True Then
fab = 8860
doub = 2
djrib = True
fabtype = "Double Jersey 1x1 Rib"
```

The programming lines for "<<Back" button, and "Next>>" button respectively relate to the following programming lines.

```
Private Sub Command2_Click()
Private Sub Command1_Click()
```

The ability to increase the size of each picture by clicking on it is attributed to the following programming lines.

```
Private Sub Image1_Click()
Img1.Show
```

3.6. Developing Form5

The fifth page will appear on the screen as soon as "Next>>" is pressed. Here, the user is able to select the type of knitting machine gauge according to the variety of the knitting machines available for production and "proKNIT" system will present the range of yarn counts suitable for the chosen gauge as well as the estimated one (Fig. 3.5). All available data have been based on information presented by different knitting machine producers. Inside the software the data was tabulated as shown on Table 3.1, where the yarn count suitable for each machine gauge is written as a total value of tex, and not in the commercial form i.e. Tex 50/2. Since there is not a basic equation

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to predict the appropriate yarn count for each knitting machine gauge, the estimated value for each machine gauge as presented on Table 3.1 is based on the equations (6) and (7), Chapter 1.5 and it also appears on the fifth page of the "proKNIT" software. The constant values used in these equations have also been used on the code lines for Form4.

Fig. 3.5 Form5 - Machine gauge and yarn count

Let us assume that a gauge of 14 has been chosen, the estimated yarn count for gauge 14 is 54 tex, while the range of yarns suitable for this gauge is 42 to 72 tex (Table 3.1). When "Next>>" is pressed the user is presented with two options: the first one is to keep the reference yarn count or alternatively to alter it according to the schedule of production (Fig. 3.6). If on the other hand the user presses "No" to the question "Do you wish to keep the estimated yarn count?" then a new window opens having the title "Enter new yarn count". By entering the required new yarn count and pressing "OK", the system moves to the sixth page. If "yes" is pressed the programme proceeds with the following page.

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TABLE 3.1: Machine gauge (needles per inch) and yarn count (tex)

Machine gauge (npi)	Single Jersey		Double Jersey	
	Range of yarn count	**Estimated yarn count**	**Range of yarn count**	**Estimated yarn count**
4	680 – 248	664	590 – 413	554
4½	547 – 205	525	472 – 354	437
5	500 – 169	425	413 – 295	354
6	338 – 124	295	270 – 180	246
7	260 – 100	217	260 – 150	180
8	169 – 84	166	180 – 120	138
10	113 – 56	106	120 – 60	88.5
12	84 – 49	73	75 – 45	61.5
14	72 – 42	54	49 – 36	45
15	56 – 36	47	42 – 31	39.5
16	50 – 31	41.5	37 – 27	34.5
18	42 – 25	33	28 – 25	27
20	33 – 23	27	25 – 20	22
22	28 – 20	22	21 – 17	18.5
24	25 – 17	18.5	18 –14	15.5
26	23 – 14	16	17 – 12	13
28	20 – 12	14	14 – 11	11.5
30	17 – 8	12	12 – 10	10
32	14 – 7	10.5	11 – 8	9

Here the system works with the information gained from Form4. By choosing single or double knit the appropriate calculations take place according to previously mentioned equations which are presented on the following code lines.

```
Private Sub Option5_Click()
Text1.Text = Option5.Caption
Text2.Text = Format(fab / 7 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 100 - 260"
x = 100
y = 260
```

The above programming code shows that for "option5_Click", which refers to gauge 7 for single jersey fabric, "if fab = 10630 Then" indicates that the yarn

count ranges between the values of 100-260 tex. Therefore, the calculation of the estimated yarn count is taking place from the code line "Text2.Text=Format(Fab/ 7^2," and the value is presented as an integer number "###" of three digits.

If double jersey is previously chosen and also gauge 7 then the appropriate code lines are as follows using the previously mentioned code lines.

```
Else
Text3.Text = "Tex 150 - 260"
x = 150
y = 260
End If
End Sub
```
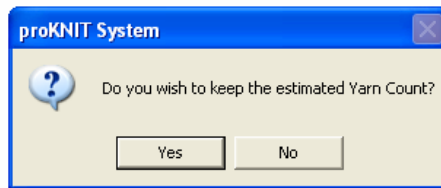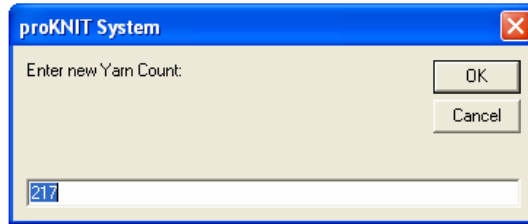

Fig. 3.6 Message and Input boxes

The appearance of the message box and input box (Fig.3.6) is possible through the following code lines:

```
Msg2 = MsgBox("Do you wish to keep the estimated Yarn Count?", 36, "proKNIT
System")
   If Msg2 = 7 Then
      msg3 = InputBox("Enter new Yarn Count:", "proKNIT System", est)
      If msg3 > y Then
```
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```
        msg4 = MsgBox("The value you have entered is not valid.", vbOKOnly,
"proKNIT System")
        ElseIf msg3 < x Then
        msg4 = MsgBox("The value you have entered is not valid.", vbOKOnly,
"proKNIT System")
        ElseIf StrPtr(msg3) = 0 Then
        MsgBox "!"
```

where the Message box with the indication " Do you wish to keep the estimated Yarn Count?" comes on as soon as the button "Next>>" has been pressed. If "No" is chosen (If msg2=7then) then the input box appears indicating "Enter new Yarn Count". If the value chosen is outside the lower and upper limits then a message box appears indicating, "The value you have entered is not valid".

3.7. Developing Form6

Having entered the new values of yarn count in the Input box and on pressing "OK", page six appears. Here new values are required for the system to cover the puzzle of information (Fig. 3.7). In this new window the unit of loop length in mm or cm must be selected first. As soon as this has been done, the information below the line appears where the tightness factor has to be provided according to the available range. The choice of loop length in mm presents a range of tightness factor ranging from 0.8 to 2.0 with an average value of 1.46 [3.1], while in the case of the loop length being chosen in cm this range increases by 10 with a normal value of 14-14.70 [3.2], [3.3], [3.4]. Loop length has been estimated according to yarn count and the chosen tightness factor using the following equation:

$$K_f = \frac{\sqrt{tex}}{\ell}$$

By choosing the value of tightness factors and by pressing "OK", the last line appears indicating the size of the loop length value in millimetres or centimetres according to the selected unit above.

Fig.3.7 Form6 - Loop length estimation using Tightness Factor

In order for the system to work on the estimations of loop length it requires the previous information concerning the value of tex from Form5. The code lines for this form are also analytically presented on Appendix. The selection of the loop length in mm comes from the code shown below:

```
Private Sub Option2_Click()
test1 = 0.8
test2 = 2
Label1.Caption = "Range of Tightness Factor (Kf) when loop length (l) is in mm"
Label2.Caption = "Tightness Factor (Kf) 0.8 - open structure"
Label3.Caption = "Average value of (Kf) is 1.46"
Label4.Visible = True
Label4.Caption = "0.8 - 2.0"
Label5.Caption = "Choose the value of Tightness Factor (Kf)"
Command2.Visible = True
Text1.Visible = True
End Sub
```

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By selecting in mm option for units of loop length the information below the line appears and is written on the code lines as "Label.Caption". A proportional Code exists also when cm is chosen as unit of loop length. The differences between the two codes are the values of tightness factor (i.e. 0.8-2.0 when ℓ in mm and 8-20 when ℓ in cm). The estimation of loop length based on the code lines shown below using the information of tex gained from Form5 and the equation of tightness factor.

```
kf = Val(Text1.Text)
Label6.Visible = True
Text2.Visible = True
Label6.Caption = "The value of loop length (l) is"
el = (Sqr(Tex) / kf)
Text2.Text = Format(el, "#0.00")
Label8.Caption = el
Command1.Visible = True
End If
End Sub
```

Also inside the code shown in the Appendix there are the appropriate code lines for the different message boxes when the values entered for tightness factor are above or below the limit (i.e. "The value you have entered is not valid").

3.8. Developing Form7

The next page is concerned with the justification of the relaxed state of the knitted fabric, where the estimations of the fabric mass/m^2 are going to be made (Fig. 3.8). In order to predict the mass of a fabric after knitting, three different and realistic relaxed conditions were selected in such a way that

they would reflect, more or less, those existing in the knitting industry. The three different relaxed states have been defined according to standard procedures used in quality control sections and are as follows:

- ❑ Dry-relaxed state

- ❑ Wet-relaxed state

- ❑ Finished and fully-relaxed state

More information for the above mentioned states of fabric relaxation are given on Chapter 5 "Test Methods" (5.3).
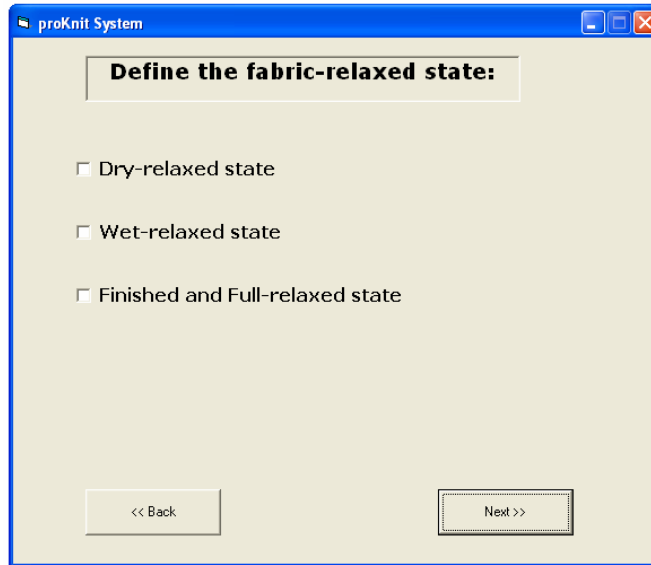
Fig. 3.8 Form7 – Fabric relaxed states

In this form the code lines are simple and have to do with the so-called "Global Variables" which will be transferred to the next form in order for the system to proceed with the appropriate calculations. The "Global Variables" are concerned with the selection of the relaxed state. It is possible to select one or two relaxing stages but it is not possible to select all three stages. In the case that a miss selection occurs then message boxes appear indicating

the correction of the selected relaxed state. The code lines concerning the Global Variables are as follows:

```
If Check1.Value = 1 Then
dry = True
dry2 = True
End If
If Check2.Value = 1 Then
wet = True
wet2 = True
End If
If Check3.Value = 1 Then
fin = True
fin2 = True
End If
```

3.9. Developing Form8

Clicking "Next>>" the eighth form appears, where the estimations of courses per cm, wales per cm, loop density and loop shape in the chosen relaxed state appear after pressing "Calculate" (Fig. 3.9). This form remains in position until all the calculations of the above parameters and of the chosen states of relaxation have been completed. For example, if both dry and wet-relaxed state have been selected on Form7 then Form8 will appear twice with the estimated values. That is to say by pressing the "Calculate" button ones the estimated values of dry-state will appear in the empty boxes while by clicking "Calculate" a second time the estimated values for wet-state will appear in the same empty boxes.

Fig. 3.9 Form8 – Estimations of fabric geometrical parameters

Before the main points of the programming code used for this form are presented it is necessary at this point to provide some explanation concerning the way of the different values are presented. It has already been mentioned that single jersey fabrics are produced using one set of needles; therefore, courses and wales per centimetre are all observed on the face of the fabric and can be easily counted. However, the production of double knit structures is based on two sets of needles one on the front needle bed and one on the back needle bed. Thus, while all courses per cm can be seen on the face of the fabric, half of the wales are shown on the face of the fabric with the remaining half hidden at the back of the fabric, which is due to the two sets of needles. Therefore, if a double knit structure (i.e.1x1rib, 2X2 rib, and interlock) has been chosen the values for wales per cm presented on Form8 are those existing on the face of the fabric. More details on this logic of wales per cm are given in Chapter 6.

Form8 contains the longest and most complicated code since the equations for the non-dimensional parameters and the constant values obtained from the experimental work, for all fabric-relaxed conditions, have been integrated into the code. The equations for determining the non-dimensional parameters used are the following (see also Chapter 1.9 for more details):

$$K_c = c \times \ell$$

$$K_w = w \times \ell$$

$$K_s = S \times \ell^2$$

$$K_r = R = \frac{c}{w} = \frac{K_c}{K_w}$$

Some of the constant values obtained and integrated inside the code are given on Table 3.2 below. All constant values used in "proKNIT" system are presented on Table 6.4.

TABLE 3.2: Non-dimensional parameters used on "proKNIT" system for wool blended undyed yarns

Type of fabric	Process	K_c	K_w	K_s	R
Plain-knit undyed yarn	Dry	50.0	38.8	1940	1.29
Plain-knit dyed yarn	Dry	50.0	39.5	1975	1.27
Plain-knit undyed yarn	Wet	54.0	41.0	2214	1.32
Plain-knit dyed yarn	Wet	53.0	40.0	2120	1.32
Plain-knit undyed yarn	Steamed	52.0	40.0	2080	1.30
Plain-knit dyed yarn	Steamed	53.2	40.0	2128	1.33

The values shown on Table 3.2 are those obtained from the produced fabrics, which were tested for geometrical variables. The above values refer to plain-knit structure, which was produced using wool blend yarns taken directly from a spinning mill.

On Form8 the four written lines for which values are required are at the beginning of the first code lines where the data of the previous Forms are collected for each relaxed state separately. The written lines on the form for dry-relaxed state are as follows:

Label1.Caption = "Courses per cm (c) in Dry-relaxed state"
Label2.Caption = "Wales per cm (w) in Dry-relaxed state"
Label3.Caption = "Loop density (S) in Dry-relaxed state"
Label4.Caption = "Loop shape (R)"

Let us assume that wool mixtures (wm) (wool blended undyed yarn) have been chosen in Form3 and the chosen fabric is single jersey plain-knit (sjplain) in dry-relaxed form. Then the data shown on Table 4.2 will be used on the calculations and have been integrated into the code in the following way:

```
If sjplain = True Then
ks = 1940
kc = 50
kw = 38.8
r = 1.29
```

The above code sequence starting from "If" and up to "r=1.29" is repeated for all relaxation states and for all categories of yarns and fabrics.

The necessary calculations for courses per cm, wales per cm, stitch density area and R are the result of the above equations of the non-dimensional variables. As soon as single jersey plain-knit (sjplain) has been verified as "True", the estimations of the geometrical variables result from the following code lines:

```
Text1.Text = Format(kc / (mm * el), "#0.00")
Text2.Text = Format(kw / (mm * el), "#0.00")
dryc = kc / (mm * el)
dryw = kw / (mm * el)
Text3.Text = Format(dryc * dryw, "#0.00")
sdry = dryc * dryw
Text4.Text = Format(dryc / dryw, "#0.00")
```

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At the end of the code there is a number of commands for checking all input parameters before the required results.

When "proKNIT" system completes the presentation of the required data for the geometrical variables, "Calculate" is replaced by "Next>>" according to code line "Command1.Caption = "Next >>".

3.10. Developing Form9

By pressing "Next>>", Form9 appears where the mass of the chosen knitted fabric or fabrics in the given relaxed state, is provided in grams per square meter, while their percentage difference is also estimated in the case of two fabrics being chosen (Fig. 3.10). The calculations concerning the fabric mass are based on the equation:

$$FabricMass(g/m^2) = \frac{S \times \ell \times tex}{100}$$

where S is stitch density, ℓ is the loop length and tex is the yarn count. This equation is applicable when ℓ is in mm. If ℓ is in cm then the numerator is divided by 10. For single jersey fabrics the fabric mass per unit area is given directly by this equation. However, in the case of double jersey, the fabric mass must be twice the estimated value produced by the equation, since the wales per cm calculated by the system are only those existing on the face of the fabric. Therefore, the mass of the fabric must be twice the estimated one since S has only been estimated with the wales shown on the face of the fabric.

Fig. 3.10 Form9 - Estimation of fabric mass per unit area

The percentage difference between two states of relaxation is calculated according to the following equation:

$$\% Dif. = \frac{Fab.massWet - Fab.massDry}{Fab.massWet} \times 100$$

If the fabric mass has to be estimated only in the dry-relaxed state then the code lines are:

```
If dry2 = True Then
Text1.Visible = True
Label1.Caption = "Fabric mass (g/m2) in dry-relaxed state"
Text1.Text = Format((sdry * el * mm * Tex) * doub / 100, "#0.00")
drywe = (sdry * el * mm * Tex) * doub / 100
```

The above code lines indicate that:

If "dry" has been selected then the Caption "Fabric mass (g/m^2) in dry-relaxed state" appears on the screen. Then the equation of the fabric mass

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presented above is analysed together with the form of the resulting values. There are similar code lines for all stages of fabric relaxation.

If the fabric mass has to be estimated in dry relaxed state and in wet-relaxed state then the code lines are:

```
If dry2 = True And wet2 = True Then
Label3.Caption = "% Difference of fabric mass between dry and wet state"
Text3.Visible = True
Text3.Text = Format((wetwe - drywe) / wetwe * 100, "#0.00")
dif = (wetwe - drywe) / wetwe * 100
```

It is clear from the above that the system offers a choice of two options "dry" and "wet". Therefore, the system has to show label captions for "dry" and "wet" states of fabric as well as the label for the percentage difference between the two relaxed states. The program has three different combinations of estimating the percentage difference between the relaxing conditions. One is between "dry and "wet" state, the second is between "dry" and "finished" state and the third is between "wet" and "finished" state.

3.11. Developing Form10

On clicking "Next>>", the last page, which is a full list of values is finally given so that the knitter can have an overall view of the data he has chosen and those estimated by the system so far (Fig 3.11). By pressing "<<Back" the user still has the ability to go back to Form7 and to alter the chosen relaxing states or to go further back in order to add new values. The data outlined on Form10 are:

- ❑ Knitting machine gauge

- ❑ Yarn count

- ❑ Type of fabric

- ❑ Tightness Factor

- ❑ Loop length

- ❑ Fabric geometrical variable from the chosen states of relaxation and their percentage difference.

Fig. 3.11 Form10 – Full list of the chosen parameters

The code lines on which the data presented are based refer to the information accumulated and their presentation in the boxes shown on this page. All captions have a reference number that is connected with the required information, the code lines for which are shown below:

```
Label7.Caption = gau
Label8.Caption = Tex
Label9.Caption = fabtype
Label10.Caption = kf
Label11.Caption = Format(el, "#0.00")
```

```
If dryc = 0 Then
Label20.Caption = ""
Else
Label20.Caption = Format(dryc, "#0.00")
End If
```

Label7. Caption is responsible for presenting the gauge of the knitting machine used, Label18 for the tex and so on. The above code lines are repeated for all combinations of yarns, fabrics and relaxation procedures.

The code lines, which refer to «Global Variables», are there in order to give a continuous run of all forms until "EXIT" is pressed to terminate the application.

3.12. Discussion

In this chapter an attempt has been made to create software suitable to operate in a Windows environment but also to have the ability of predicting the fabric mass per unit area. The presented system has been developed by a textile technologist and not from a professional programmer.

The system was seen as a first attempt at predicting fabric mass per unit area for one category of yarns (wool blends) at different states of relaxation, with the potential of being enriched and made applicable for other types of yarns, once it was proven that it can work and produce results that are reliable and realistic.

Since the designer of the programme is not a professional programmer, it was considered important to keep the information load within such limits as

to make any alterations manageable. It is quite obvious that the amount of information already fed into the system for the chosen category of yarns was enormous without looking at other combinations of yarns.

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Part Three: Experimental procedure

CHAPTER 4

KNITTED FABRIC PRODUCTION

4.1. Introduction

This chapter deals with the production of different knitted fabrics used later for the quality control tests. The fabrics produced belong to weft-knit category, where the loops are formed in succession one loop at a time when the yarn travels across the fabric as it is being formed. Each new row of loops is drawn through the previous row of loops in the fabric. All the loops in one row are produced from one yarn, unless special colour effects are required.

Weft-knitting machines are either flat or circular. The flat machines have all the needles arranged in straight rows. Usually there are two beds in an "inverted V" position to hold the needles. The yarn is fed back and forth across the width of fabric, and flat lengths of fabric or garment parts are produced. Circular machines feed the yarn continuously in one direction to the needles, which are arranged in circular formation, and consequently the fabrics or garment blanks produced are usually tubular. Instead of feeding only one yarn to the circular machine, and having most of the needles inactive whilst the yarn is being knitted on its circuit, a succession of yarns is fed to the needles with the result that there are a number of knitting zones around the periphery.

Depending on the choice of flat machine and the way it is operated garments as opposed to fabric lengths, or complete seamless garments, may be formed during the knitting process. Knitwear, such as sweaters and cardigans, may have parts of the garment made on the machine. This consists of either producing body lengths with ribbing attached for the waist and cuffs, or introducing shaping in flat pieces of fabric by "fashioning", which widens and narrows the fabric automatically as required. Fifth and latest generation flat knitting machines employ four knitting beds, instead of

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two, and have the ability to produce a complete seamless garment, using the technique of loop transfer.

Single jersey and double jersey are the two main categories of fabric structures. Single jersey requires only one set of needles; double jersey can only be made on flat or circular machines with two sets of needles positioning at right angles to each other. Both single and double jersey fabrics are available self-coloured, or patterning by the introduction of dyed yarns.

For the experimental procedure of this project an electronic flat V-bed knitting machine was used to produce single jersey fabrics, plain-knit and purl, as well as double jersey fabrics, 1X1 rib, 2X2 rib and interlock.

4.2. The knitting machine

The fourth generation of flat knitting machines was presented at I.T.M.A. exhibition in 1989. After that time Stoll Company presented a new fully electronic type of V-bed flat knitting machine called CMS, which incorporated an unusual combination of features with useful old ideas alongside, brilliant new innovations. A knitting machine of this kind has been used to produce our samples.

The knitting machine is characterised as CMS 411, which means that there are two independent carriages (1+1) that can operate together or separately (Fig 4.1). In case that both systems are working together then the machine can produce two rows of loops in one traverse of the carriage. When they

are separated, then two independent pieces of fabric can be produced. All the machine specifications are presented on the Table 4.1.

TABLE 4.1: Knitting machine specifications

CMS	411
No. of carriages/knitting systems	2X1
Maximum knitting speed (m/s)	1.2
Gauge npi (needles per inch)	7
Controlled sinkers	Yes
Electronic needle sensor	Yes
Operating needle bed	244cm or 2X117cm
Yarn control units (number)	20
Feeders per rail	4
Number of rails	4
Main fabric takedown	Yes
Upper fabric takedown	Yes
Data control (microprocessor 1.5MB)	Yes
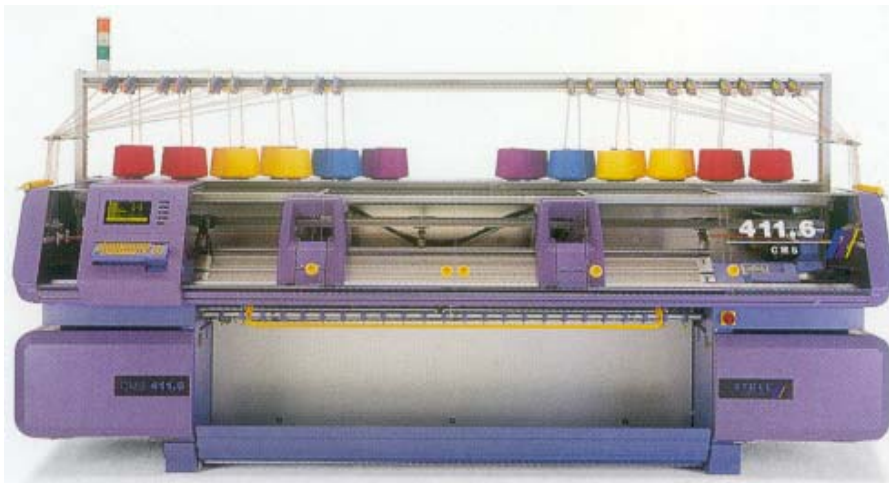
Fig. 4.1 Stoll CMS 411 knitting machine

4.3. Yarn feeding

The feeding of the yarns comes from the cones, which are placed on the table attached to the knitting frame. The machine has a special storage unit where bobbins can be placed on special "slides" in order to simplify the changing, replacing and threading operations. On its way to the needles, the yarn passes through pot eyes, knot catchers and tension devices, which are responsible for guidance and monitoring the yarn.

The cone is placed on the table and the yarn is taken over the top of the cone through the first pot eye. Then the yarn is guided to yarn control and monitoring unit, which is above the knitting bed (Fig 4.2). The yarn passes through the unit, which contains a set of spring loaded brake discs, a tension arm and sensors for small and large knots. The yarn control and monitoring unit has a visible warning lamp that is activated when an error occurs i.e. too thick yarn exists in the unit.
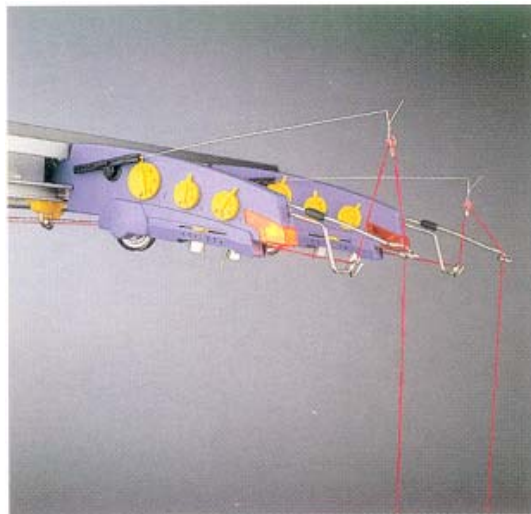
Fig. 4.2 Yarn control unit

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On the way out of the control unit the yarn passes also through another pot eye. Then the yarn is guided to the machine side and through a deflector it is fed to the lateral yarn tension unit, which is just below the deflector. This unit takes care of the minimum strain on the thread, resulting in fewer faults in the fabric and gives a greater machine capacity utilisation. A stop motion is also present in this unit (Fig 4.3).
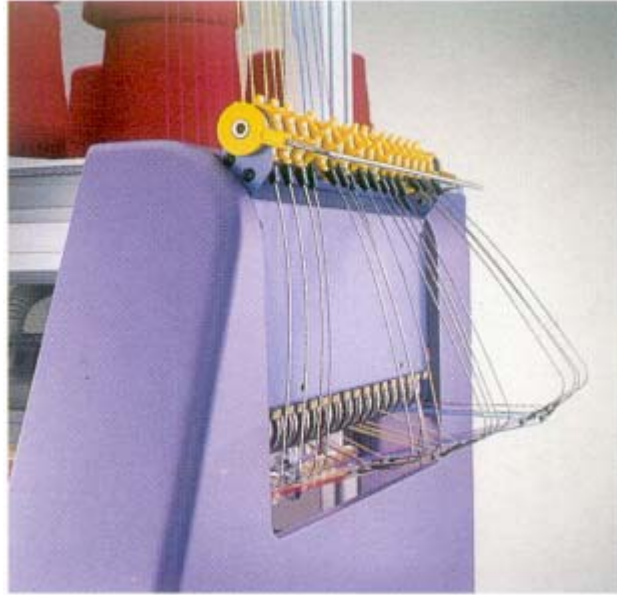
Fig. 4.3 Lateral yarn tension unit

4.4. Yarn carrier or feeder

The knitting machine is equipped with special yarn guides, which are arranged on four double prism rails. They work without the aid of stop-blocks. Every yarn guide can operate without any limitation in any knitting system. The yarn feeder plungers can be switched on and off at any position along the double prism rails. This information is contained in the knitting

program of the machine. The instruction "YD" (yarn carrier distance" controls the switching on and off of the yarn carriers. It determines at which end point in relation to the selvedge the yarn carrier should be positioned.
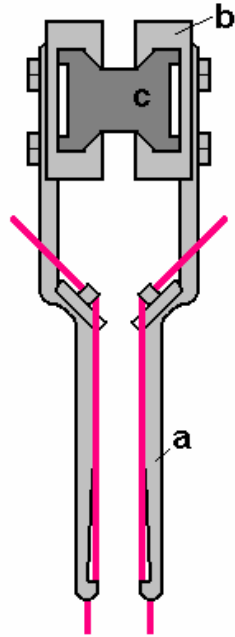
Fig. 4.4 Yarn carriers

Fig 4.4 shows in cross section the double prism rail (c) and two carriers (a). Each carrier is fastened to a plastic block (b), which holds onto the slides along the rail. At the top of each plastic slide is a slot into which a metal plunger drops from the carrying system in order to engage and then pulls the carrier along the rail so as to feed the needles that are selected by the carriage.

4.5. The needle bed

The working width for CMS 411 knitting machine is 244 cm when the two carriages are working together. In the case of separation the knitting width

for each carriage becomes 117 cm. The gauge for this knitting machine is 7 needles per inch with a total number of 627 needles per bed.
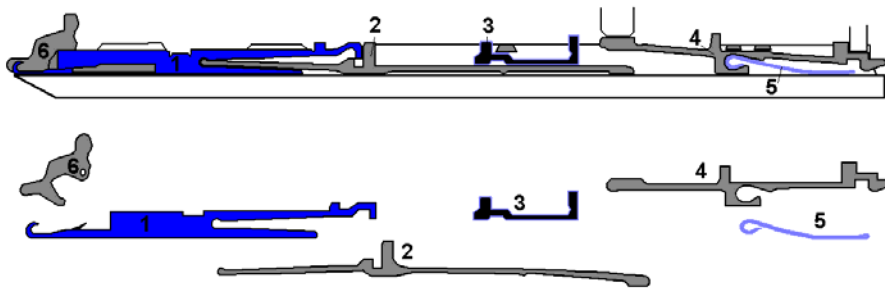
Fig. 4.5 The knitting elements of Stoll machine

Every trick accommodates the needle and the knitting elements (Fig 4.5). The function of each one is as follows:

1. The needle: Its shape is such in order to fit inside the needle slider.

2. The needle slider: It is permanently attached to the needle and it has only one butt that comes in contact with cam system in order to ascent or descent the needle. Needle slider controls all needles' actions.

3. The pressing Jack: It is responsible to act on the needle slider. It contains two butts and has the ability to slide forwards and backwards. When the pressing jack moves backward the bump closed to front butt depresses the needle slider and the last misses the raising cam and thus the needle remains inactive. When the pressing jack slides forward the needle slider is released from the pressing jack and its butt raised to activate the needle.

4. Selector: The selector comes in contact with electromagnetic selecting point. If the electromagnet is activated at the right moment then it holds the selector upwards. Thus the selector cannot come in contact with the pressing jack, which depresses the needle slider and the needle remains inactive. If the selector has not been attracted by the electromagnet (no pulse from computer), the spring (5) tilts the selector

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so that the selector butt meets the appropriate cam and slides forward pushing at the same time the pressing jack. This move releases the needle slider and its butt is raised to meet the appropriate raising cam.

5. Spring

6. Holding down singer: It is a piece of metal responsible to press the fabric downwards and to hold it there while the needles are ascending (Fig 4.6).
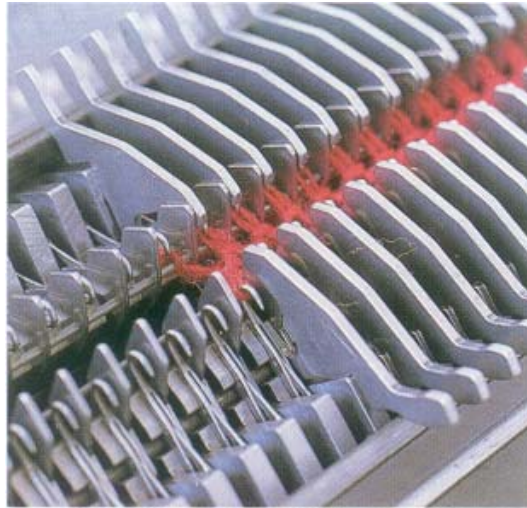
Fig. 4.6 Holding down singers

4.6. The cam system

As is the case with all flat V-bed knitting machines each carriage contains two identical cam boxes one for the front needle bed and one for the back needle bed. Each cam box contains two identical knitting systems S1 and S2 (Fig 4.7). Knitting system S1 will be activated when the carriage moves from right to left while system S2 is activated when the carriage moves from left to right.
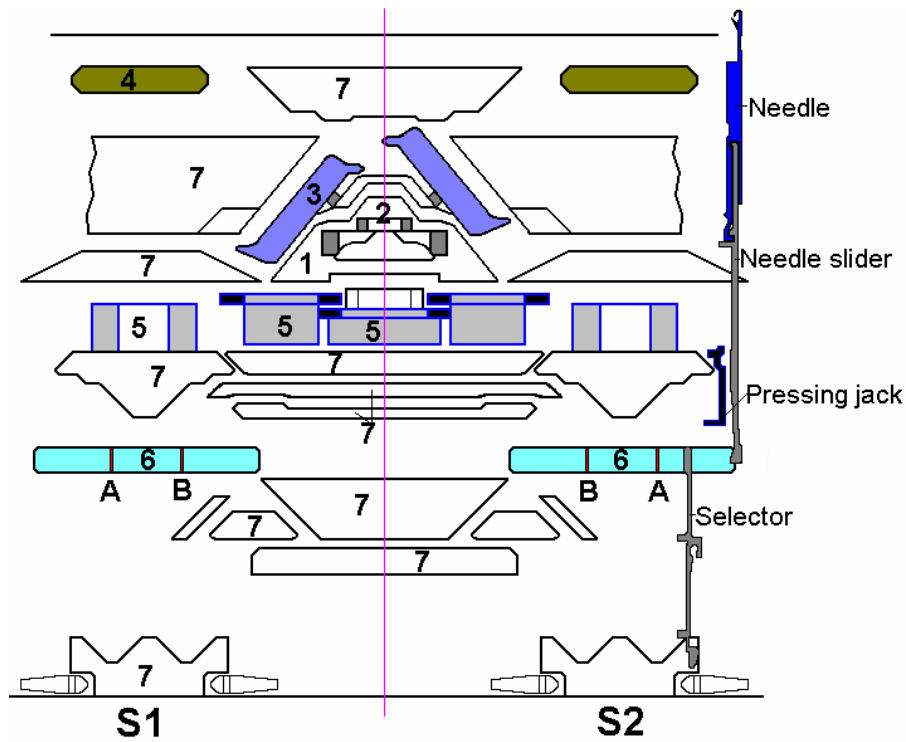
Fig. 4.7 Stoll cam systems

The selection of any needle is independent within each knitting system. Every needle can be chosen to operate in five different positions, i.e. out of action, tucking, knitting, loop transferring and loop receiving. This means that every system is capable of knitting without restriction using the "tree-way technique" i.e. knit, tuck, miss.

The cam assembly of one side of the knitting system consists of the following types of cams:

1. Raising cam: It is responsible to guide the needle slider with the needle upwards to miss or knit position.

2. Clearing cam: When it is in action the needle slider with the needle lifted to full clearing height or when it is out of action the needle slider with the needle are raised to tucking height.

3. Stitch can: It is a movable cam and is responsible for the size of the loop.

4. Alignment cam: It is equipped with a micro switch designed to stop the machine if a needle is not moving according to the cam track.

5. Pressing cam: It is responsible for pressing the butts of the pressing jack in order to deactivate the needle.

6. Selection area: It is responsible for magnetising or choosing the selector at A and B points.

7. Fixed cams: They are rigidly set in the cam box and form amongst them the tracks in which the butts of the knitting elements can slide.

4.7. Needle selection

As it has already mentioned, the needles can be selected individually in order to perform different actions according to the fabric design. The logic of selection is based on the principles that all the needles are pressed into their tricks in the needle bed and are locked in this position by the pressing jack. Thus only released needle sliders are activated to knit or transfer.

Fig. 4.8 Pressing by offering cam

Each selector is pressed by offering cam at "P" position causing the front part of the selector to lift slightly (Fig 4.8). This movement offers the front tip

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of the selector to permanent magnets in the selection area. The selection area has two permanent magnets, behind the position A and B (Fig 4.7), which are computer controlled. As the selector passes in front of these magnets it can either retain its position, since it is attracted by one of the permanent magnets, at A or B position, or be rejected by the computer, which transmits a pulse equivalent to generate an opposing magnetic field to that of permanent magnet. Therefore, the selector has the following two possibilities:

1. The magnet holds the selector to its position: In this case the butt of the selector is sunk into the trick in the needle bed and therefore remains inactive with the rest of the knitting elements including the needle too. The needle misses the yarn and a missing stitch is formed.

2. The magnet rejects the selector: Here the selector is tilted by the spring and its butt, which protrudes from the needle bed and can be selected by the raising cam.

4.7.1. Knitting needle

If the computer at A selection point transmits no pulse, the selector retains its position and travels along the selection area. While the selector passes from B selection point a pulse is transmitted by the computer, then the selector is rejected and its butt springs out of the needle bed trick. Since the selector is released at B selection point, the pressing jack (3) is pushed and guided through a different track in the cams. This movement of the pressing jack releases the butt of needle slider (2), which meets the raising cam and starts to move to clearing position in order to form a knitted loop (Fig 4.9). The butt of the needle slider follows the track shown by the red line.
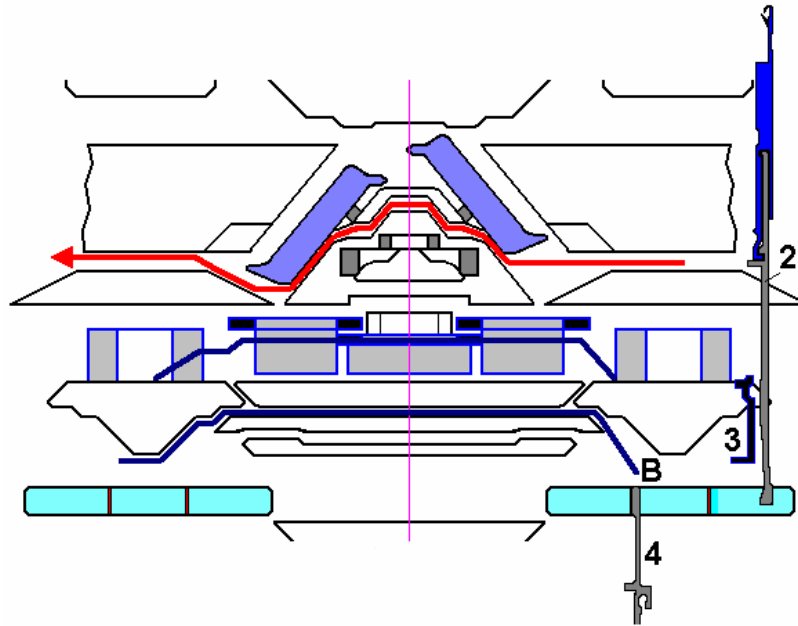
Fig. 4.9   Knitting needle selection

4.7.2. Loop transfer and receiving

Flat V-bed knitting machines have the ability to transfer loops from a needle in the front bed to a needle in rear bed and vice versa. The loop transfer operation involves the raise and the engagement of two needles, one of the front needle bed and one needle from the rear needle bed. Each needle has an additional attachment called the transfer spring. During loop transfer the delivery needle rises high enough so that the loop moves down to the end of the stem where the transfer spring is positioned. The loop is stretched over the transfer spring. The receiving needle is raised slightly, enters the transfer spring of the delivery needle and penetrates the loop to be transferred. The delivering needle retreats leaving the loop on the receiving needle.

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The above sequence of the needle's movement comes through the cam boxes and the red line in Fig 4.10 indicates the path followed by both needles, one of the front needle bed and one from rear needle bed. The loop will be transferred from front needle bed to rear needle bed.
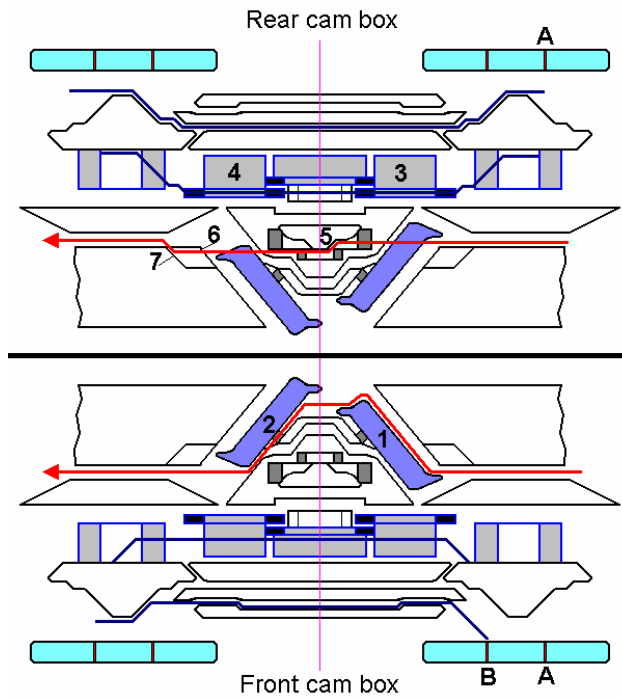
Fig. 4.10 Loop transfer and recieveing

The loop transfer can take place under the following conditions:

1. Needle selection

2. Special cam arrangement

Each cam system is equipped with two stitch cams (1) and (2), (Fig 4.10) which bring the needles to knock-over position. The carriage moves from left to right with the stitch cam (1) at its lower position in order to block the regular knitting track and to open an alternative needle path.

The selector is released at B position thus releasing the pressing jack and the needle slider. The butt of the slider follows the track formed over the stitch cam and the needle slider with the needle is driven higher than the clearing position. The loop held by this needle is now stretched over the transfer spring.

Now, while the above take place at the front cam box, at the rear cam box the pressing cams (3) and (4) are lowered into a new position. The selector released from the magnet at A position allowing the pressing jack to be released earlier than it happened in the front cam box. The pressing jack is guided to the pressing cam (3) and pressed into the trick in the needle bed. In the distance between the two pressing cams (3 and 4) the pressing jack is released allowing the needle slider butt to protrude from the trick for a short time. During this period, the butt is allowed to ascend slightly over a special rising cam (5). This movement is enough to raise the needle high enough so as to enter the transfer spring of the opposing needle.

The pressing jack is pressed again by the second pressing cam (4) so that the butt of the needle slider is not affected by the lower stitch cam (6). The needle slider with the needle is lowered later by the auxiliary lower cam (7). Delay in the descent is required to allow the retreat of the delivering needle so that the loop stays in the hook of the receiving needle.

4.8. Knitting machine electronic control

The Stoll CMS knitting machine works with latest technology as far as the electronic control is concerned. The electronic controller is accommodated in a box on the left hand side of the machine bellow the needle bed. An operating software is already stored in the machine control capable of

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reading the programmes fed from an outside source and of interpreting the knitting instructions which are included within the programmes.

The different combinations of the operating system and the knitting programme are transmitted in the form of electrical signals to various machine elements. The latter are activated and perform the required knitting functions. The electrical signals pass to D.C. motors and to electromagnets. Steps motors are connected to the stitch cam, synchronized servomotors to the carriage drive and a rotary field magnet motor to the fabric take down system. Also, electromagnets operate the yarn carriers, automatic lubrication, etc.

The input and monitoring unit is illustrated in Fig 4.11 as an integral part on the knitting machine. The whole assembly is mounted on a slider in the front of the machine. The information passed to the machine through electrical contacts in the slide, thus making possible to shift the control desk over the whole length of the machine. It is possible to stop it at any position and to issue the appropriate instructions to the system. The unit is divided into three sections:

- The keyboard (A)

- The display monitor (B)

- The signal area (C)

The keyboard (A) is composed by alphabetical and numerical buttons arranged in a typewriter or computer keyboard standard. Full programmes can be directly input into the machine computer via the keyboard. More frequently it is used to interfere with a pre-programmed knitting sequence in order to change some parameters of the knitting process.

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Fig. 4.11 Movable input and monitoring unit

The display monitor (B) shows required information such as the parameters of the knitting programme or production data of the machine at a certain time. Apart from the information required by the operator, the monitor shows the reasons for certain failures, which can occur during production.

The final part is the signal zone (C), which consists of a series of indication and warning lights. Starting from the top the lights indicate the following problems:

❑ A control-oriented problem: At the moment the controller is not able to control the machine operation.

❑ This signal directs to monitor where is the cause of the failure clearly displayed.

❑ A fabric takedown problem has occurred.

❑ A sign of yarn cone indicates a yarn breakage.

❑ Main power is on.

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The knitting programme can be displaced on the monitor and is written as an ordinary computer programme. The programming language is called "Sintral" and has been specially developed in order to cover the requirements of Stoll electronic machines. "Sintral" is written similarly to a normal "basic" computer programme in numbered command lines.

<u>**Musterbeispiel**</u>

2 Farben Jacquard mit 2x1 Anfang

```
1  C  CMS-400.JAC-2-FABRIC
2  C                        WM KORREKT EINSTELLEN
3  C                        NP KORREKT EINSTELLEN
4  C                        RS1 = 2X1 RAPPORT
5  C                        RS2 =MUSTER RAPPORT
11 NP1=10.0 NP2=11.0 NP3=12.0 NP4=13.0 NP5=13.5
30 START
50 YG:8/335566;
51 C            FADENFUEHRERGRUNDSTELLUNG
52 C--------------------------------------------------------------------------------
53 C < ! > !   !  JAC-SYMBOL          !          FADEN
54 C--------------------------------------------------------------------------------
55 C    8   !  !                       !          TRENNFADEN
56 C           ! 3/3/6/6      ! .      !                    GRUNDFARBE
57 C           ! 5/5         ! A       !                    BEIFARBE
58 C--------------------------------------------------------------------------------
100  SEN=1-#138
105  JA1=1120(1102-1120)
110  PA:JA1;
115  FA=1-10
120  PM:<FA>;

125  F:2X1
130  F:R-R
135  F:JAC-2C*RS2
140  END
1102      .  .  .  . A .  .  .  .  .
1104      .  .  . A A A .  .  .  .
1106      .  . A A . A A .  .  .
1108      . A A . . . A A .  .
1110    A A . . A . . A A .
1112      . A A . . . A A .  .
1114      .  . A A . A A .  .  .
1116      .  .  . A A A .  .  .  .
1118      .  .  .  . A .  .  .  .  .
1120      .  .  .  .  .  .  .  .  .  .
```

Fig. 4.12 "Sintral" programming language for Stoll knitting machines

The construction of the programme is shown in Fig. 4.12 and is subdivided into the following lines:

1	-	10	General comments
11	-		Instructions on the stitch cam positions
30	-		Start
50	-		Yarn carriers ground position
51	-	58	Yarn carrier instructions
100	-	999	Control programme
1000	-	4999	Jacquard programme instructions. The different symbols indicate loops knitted at different colours.

4.9. Knitted fabric production

In order to determine the dimensional parameters of K_s, K_c, K_w and R, which will be fed into the software, it is necessary to produce a range of knitted fabrics similar to those presented by "proKNIT" system. As it has been previously mentioned, the fabrics required are classified into single and double knits. In the category of single knits two structures have been considered, plain-knit and purl, whereas in double knits 1X1 rib, 2X2 rib and interlock have been chosen.

On Stoll CMS knitting machine, the production of the above knitted structures requires the appropriate software commands. However, before presenting the instructions for the fabric production it is necessary to give some basic information concerning the different symbols used on the

programming lines of the software. Programming lines can be classified into the following categories:

1. Lines starting with abbreviation "Rem" (i.e. "remark") or with letter "C". Lines containing these commands are not operational instructions for the machine, but they are clarifications for the instruction of the programme.

2. Lines starting with symbols <<, >> or <> contain operational instructions for the carriage such as cam operation, needle selection, yarn carriers etc.

3. Lines with commands to other machine elements such as counters, arrangements of yarn carriers etc.

All components contained in each programming line are not easy to analyse because it requires time, a lot of practical work and plenty of information. However, in order for someone to follow the logic behind the production of the required fabrics which entirely depends on the movements of the carriage, the programming line in Fig 4.13 has been analysed as an example.
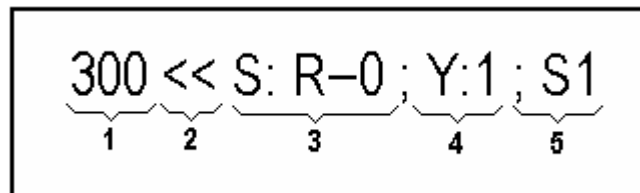
Fig. 4.13 Programming line

The different commands presented in Fig 4.13 are as follows:

1. The number of the instruction line. The lines are numerically placed in ten i.e. 10, 20, 30, etc. This numerical arrangement allows further instructions to be put in-between.

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2. The symbols "<<" indicates the carriage direction which is from right to left. These symbols in the opposite direction indicate that the carriage moves from left to right.

3. Here are all instructions for the cam box. "S" means "Strickerei" which means knitting command. The symbol ":" is a colon symbol which follows "S" indicating that all the following commands are part of knitting instructions. The "R" comes from the word "Rechts" which means "all needles knit", therefore, all needles move to clearing position and it has application to the needles on the front cam box. The line (-) separates the instructions for the front and rear cam box. The sign "O" indicates that no knit take place at the rear cam box, thus all needles of the rear bed remain inactive. A semi colon symbol, ";", separates a full set of instructions from a second set of instructions.

4. In this area the commands of yarn carriers are placed. The symbol "Y" is used as an abbreviation for "yarn carrier" and as above the colon symbol indicates that the following instruction is part of yarn carrier. The number "1" indicates which carrier will be engaged in the carriage for knitting. Also in this case the semi colon symbol separates a full set of instructions from the following one.

5. Here the symbols indicate the knitting system. S1 is the first knitting system within the carriage.

4.9.1. Plain-knit

The plain-knit structure is produced on the front needle bed having all needles active without needle selection. Thus, the butts of the needle sliders come in direct contact with the raising cam and the needles ascend to

clearing position. All needles at the rear bed are out of action. The needle notation, of plain-knit structure is shown in Fig 4.14.
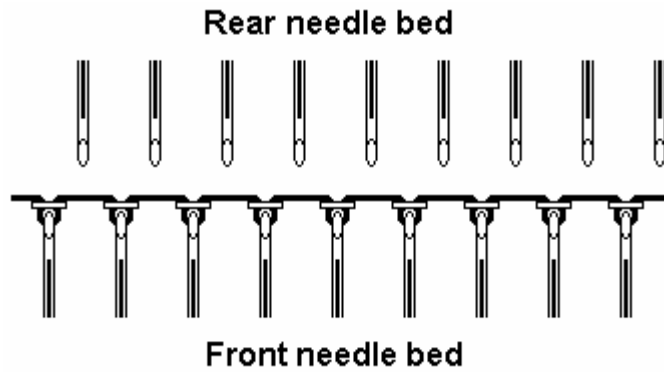
Fig. 4.14 Needle notation of plain-knit

Therefore, the face of the knitted fabric can be seen from the front part of the knitting machine while the reverse side of the fabric faces the back part of the knitting machine. The fabric produced is presented on Fig 4.15.
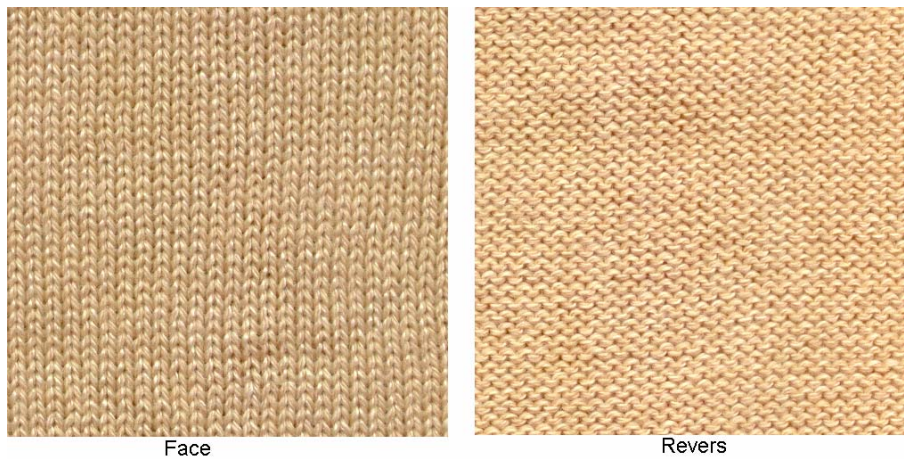
Fig. 4.15 Plain-knit, face and reverse

The line produced on "Sintral" software for the production of the above structure is presented on Fig 4.16. According to the explanations given previously the symbols contain the follow commands:

1. "400" = Line number

2. "<<" = The carriage moves from right to left

3. "S" = Knit

4. "R" = All needles in front bed

5. "O" = No active needles in the rear bed

6. "Y" = Yarn carrier

7. "1" = First

8. "S1" = Leading knitting system is active

```
400 RBEG*RS2
410 << S: R−0 ; Y:1 ; S1
420 >>                S1
430 REND
```

Fig. 4.16 Programming lines for plain-knit

The two knitting instruction lines, 400 and 430, consist of a "repeating" routine as indicated by RBEG and REND. Also, the number of routine cycles knitted is determined by "switch" "RS2" which is assigned a value in another part of the programme. The third instruction line 420 is added to cover the return journey of the carriage from left to right. Here, there aren't any further commands for the various carriage controls, which are identical to the instructions in previous line.

Two plain-knit fabrics were produced and every fabric was knitted at three different fabric tightness i.e. three different loop lengths, making a total

number of six fabrics or alternatively three fabric pairs. The fabric tightness was determined by the stitch can position. On CMS machines it is possible to apply values of 5.6 to 23.3. These values are not correlated to stitch length nor to tightness factor, however, a value of 12.5 will create a smaller loop length than a 13.5 value and so on. The value used for adjusting the position of a stitch cam also depends on the size of the yarn. For thicker yarns bigger values of stitch cam settings are used.

The commands used to set the stitch cam position for the different plain-knit structures are: NP=12.5 for one set of fabrics, NP=13.5 for the second set of fabrics and NP=14.5 for the third set of fabrics. These cam settings refer to only one type of yarn count, i.e. finer yarn. Since two different yarn counts have been used, the second arrangements of cam settings for the thicker yarn were: NP=13.5, NP= 14.5 and NP= 15.5. Figure 4.12 shows a set of these kinds of values (on command line 11).

A rotary field reluctance motor drives the fabric take-down roller, which is located under the needle beds. The take-down tension is made up of two individual tensions. A pretension is applied to the fabric during reversal of the carriage and a continual drawing downwards of the knitted fabric is also applied during knitting process. Both tensions are independently programmed.

The command "WMI" is provided for setting the pretension, which can vary from 0-15. The main take-down tension is controlled by the command "WM" and can be set to a range of 0-31.5 with an average take-dawn setting of 10. Thus for all fabrics produced, i.e. plain-knit, purl, 1X1 rib, 2X2 rib and interlock, the fabric pretension "WMI" was automatically regulated by the knitting machine at the start of the programme at the value of 3 and the main take-down tension at 10 i.e. "WM=10".

4.9.2. Purl knit

The purl structure produced on Stoll CMS flat knitting machine is presented on Fig 4.17. Its production is based on the principle that loops are transferred from one needle bed to the other in order to draw reverse loops through face loops and vice versa. This sequence has been shown in Chapter 1, Fig 1.5. This structure has also been produced without needle selection. The four different notation lines in Fig 1.5 correspond to four programming lines of "Sintral" software used by Stoll and presented on Fig 4.18.
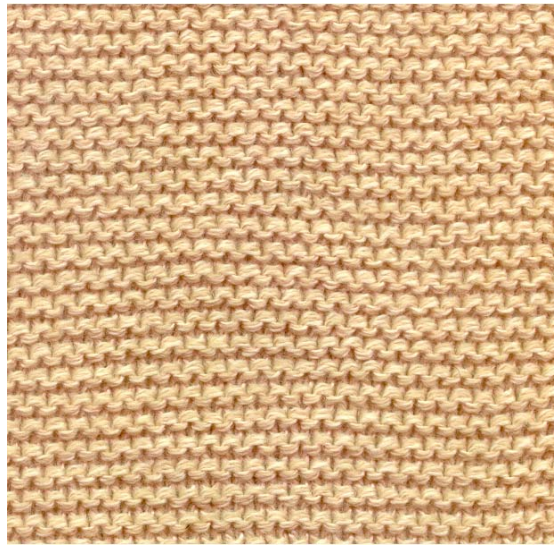
Fig. 4.17 Purl structure

The new symbols appearing in the four-notation lines software can be explained as follows:

1. The symbol "UΛR" is used to indicate that loop transfer operation (U) takes place from front needle bed to rear (Λ) needle bed and

that all needles in action participate in the transfer operation (R). "U" is the first letter of the German word "Umhängung".

2. The symbol "UVR" indicates that loop transfer operation (U) takes place from rear needle bed to front needle bed (V) and that all needles in action participate in transfer operation (R).

```
400 RBEG*RS2
410 << S: R−0 ; Y:1 ; S1
420 >> S: U∧R ; Y:0 ; S1
430 << S: 0−R ; Y:1 ; S1
440 >> S: UVR ; Y:0 ; S1
450 REND
```

Fig. 5.18 Programming lines for purl knit

Also in this structure the fabric tightness was set at three different levels for each yarn count. For thinner yarn it was set at: NP=12.5 for the first set of fabrics, NP= 13.5 for the second set of fabrics and NP=14.5 for the third set of fabrics. For fabrics produced from thicker yarn, the can setting was positioned at: NP=13.5 for the first set of fabrics, NP=14.5 for the second set of fabrics and NP=15.5 for the third set of fabrics.

4.9.3. 1X1 Rib knit

To knit a simple 1X1 rib structure requires two sets of needles operating in between each other and both cam boxes are simultaneous by activated in order to knit with all the needles of both beds without needle selection. The

fabric has vertical cord appearance on both sides, face and reverse (Fig 4.19).

As was the case with previous fabrics, here also the stitch cams were also adjusted at three different levels according to yarn count. For thin yarn the settings were: NP= 10.5, NP=11.5 and NP=12.5. On the contrary for thick yarn the cam settings were: NP= 11.5, NP=12.5 and NP=13.5.
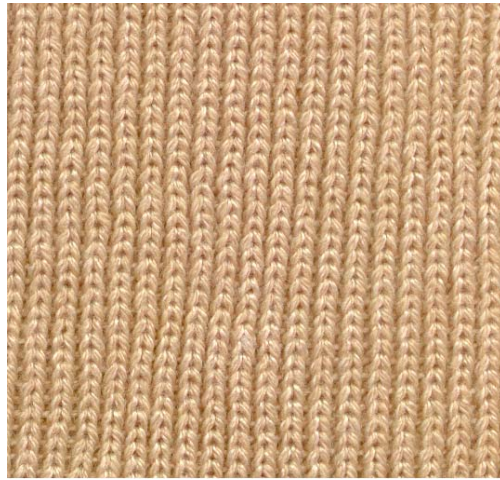
Fig. 4.19 1X1 rib knit

The programming lines of the "Sintral" system are very simple because the aim is to knit with all needles of the front and back bed "R-R" using one knitting system without needle selection and the first yarn carrier (Fig 4.20).

```
400 RBEG*RS2
410 << S: R–R ; Y:1 ; S1
420 >>              S1
430 REND
```

Fig. 4.20 Proggramming lines for 1X1 rib knit

4.9.4. 2X2 Rib knit

The 2X2 rib structure is probably the most common structure used for garment borders but nowadays this structure is used for knitted outwear products too (Fig 4.21). The way of needle arrangement during production of this structure has been previously analysed (Chapter 2.3.2). The production process involves the arrangement of two needles in action out of three (2/3 needle arrangement), thus, to produce a knitted fabric with such a needle arrangement requires the machine to operate with needle selection (Fig 4.23).

Fig. 4.21 2X2 rib structure

Therefore, the knitting machine must have the ability to distinguish between the two active needles and the single inactive one by means of an appropriate system of needle selection in the carriage. The machine controller sends coded information to posts activating the electromagnets in order to release the needles required and to produce loops. At the same time the controller retains the others pressed into the tricks of the needle bed.

The 2X2 rib structure can be produced using two different ways of programming. The first one is through the technical draft placed in the knitting programme. The second one is through "Sintral" lines, as it happens in all above cases, but the only difference now is that knit, miss or tuck commands must be used. Therefore using the second way of programming the lines in Fig 4.22 have been produced.

```
400 RBEG*RS2
410 << S:DI.I−DII.;Y:1;S1
420 >>                    S1
430 REND
```

Fig. 4.22 Programming lines for 2X2 rib knit

According to the programming lines in Fig 4.22 it is seen that there are certain new commands, which can be explained as follows:

1. The letter "D" which is an abbreviation of the word "Direct" indicating that the following symbols are part of the knit or no-knit instructions for the individual needles.

2. The command "DI.I" is for the front cam box while "DII." command is for the rear cam box. The symbols "I.I" and "II." are a copy of needle stitch arrangement of Fig 4.23, where in the front needle bed the first needle knits "I", the second needle misses "." and the third needle knits "I" while in the rear needle bed the first and second needle knit "II" and the third needle misses ".".
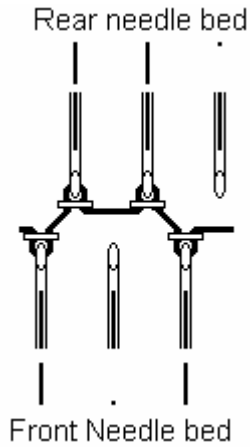
Fig. 4.23 Needle arrengement for 2X2 rib

3. The dot line "-" separates the front cam box from the rear cam box commands.

4. The symbol "D" on front and rear cam box indicates that direct needle selection on both needle beds takes place.

5. "S1" indicates that only one knitting system is used.

The cam settings for 2X2 rib structure were similar for both types of yarns (thin and thick). The values used were: NP=11.2, NP=12.2 and NP=13.2.

4.9.5. Interlock structure

This is the final structure from the five ones which have been selected for the "proKNIT" project to be analysed in order to define the non dimensional constant values of K and also to predict the fabric mass in grams per square meter. The characteristics of the fabric and the needle movement have been presented in Chapter 2, here we consider the production of this fabric on a flat V – bed knitting machine. The appearance of the fabric is identical on both sides and looks like a plain-knit structure (Fig 4.24).
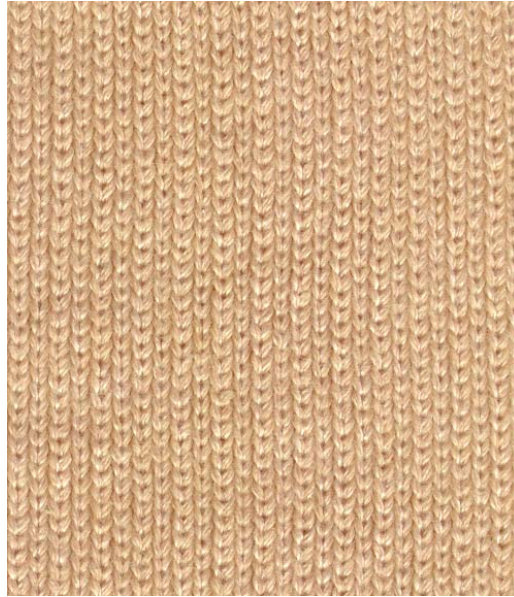
Fig. 4.24 Interlock structure

As it has already been explained the knitting procedure of an interlock structure on a V – bed machine involves half racking in order to bring the needles opposite to each other, and then needle selection. On the first traverse of the carriage all odd needles, on both needle beds, will knit so as to produce a 1X1 rib structure. On the second traverse all even needles will form loops on both beds, producing a second 1X1 rib structure in alternative needles (Fig 4.25).

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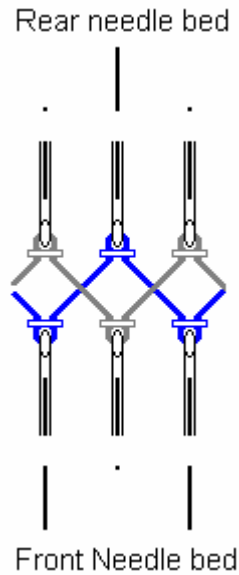
Fig. 4.25 Needle arrangement of interlock fabric

In the first traverse of the carriage and on the front needle bed the first needle knits "I", the second needle misses "." while on the back bed the first needle misses "." While the second needle knits "I" and so on (Fig. 4.25). This notation "S:DI.-D.I" is presented on line 410 while the carriage moves from right to left "<<", using feeder number one "Y:1" and half racking "V#".

Fig. 4.26 Programming lines for interlock structure

On line 420 the carriage moves from left to right ">>" and the selection of the needles is opposite "S:D.I-DI." in order to form the second inverse 1X1 rib

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structure while using the same yarn feeder and the same knitting system (Fig. 4.26).

4.10. Discussion

This chapter contains two parts; where in the first one there is a general description of the knitting machine used and its potential in the production of the samples, while the second part refers to fabric production programming.

The commands used to produce the varieties of required structures are given through appropriate programming lines and the different values of stitch cam settings for all knitted structures (plain-knit, purl knit, 1X1 rib, 2X2 rib and interlock) are presented on Table 4.3 together with the theoretical total value of yarn sizes.

TABLE 4.3: Stitch cam settings

Type of knitted fabric	Yarn count (tex)	Stitch cam setting		
Plain-knit and Purl knit	215	12.5	13.5	14.5
	235	13.5	14.5	15.5
1X1 Rib Knit	215	10.5	11.5	12.5
	235	11.5	12.5	13.5
2X2 Rib Knit	215	11.2	12.2	13.2
	235	11.2	12.2	13.2
Interlock	215	11.5	12.5	12.5
	235	11.5	12.5	12.5

According to the number of available yarns used and to the number of stitch cam settings used for each structure, i.e. plain-knit etc, a total number of 36 fabrics were produced. For example, 6 different yarns multiplied by 3 different stitch densities multiplied by 2 fabrics at each stitch density makes a total number of 36 samples for each knitted structure. The "proKNIT"

system requires five different structures, thus an overall number of 180 pieces of fabrics were produced. The size of each sample was 50X50 centimetres and their production was continuous. More details of yarn counts are given in Chapter 6 were appropriate tests were carried out to determine the exact count of each yarn.

There is also another set of fabrics produced after determining the dimensional parameters of K_s, K_c, K_w and R of the above knitted fabrics. These fabrics were used to compare the theoretical values of fabric mass presented by "proKNIT" system with the actual ones found the fabrics used as reference.

REFERENCES

[3.1] Stoll, "Manual book for CMS knitting machines".

[3.2] Raz Samuel, "Flat knitting- The New Generation", Meisenbach GmbH (1991).

[3.3] Gravas Efthymios, "Knitting Technology" (in press).

CHAPTER 5

TEST METHODS

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5.1. Introduction

In order to predict with substantial accuracy the fabric mass per unit area, using "proKNIT system" it was important to establish our own database of the dimensional parameters (K values) and to do this it was considered extremely important to produce the knitted fabrics, in the way described above. Afterwards these fabrics would be subjected to the selected treatments and by analysing them, the required results would be obtained, which would be fed into "proKNIT" system, thus making it more accurate and realistic.

However, due to the enormous amounts of data required in order to make the whole system work but also to remain as realistic as possible, it was decided to carry out tests and make predictions about wool mixture fabrics only in dry, wet and finishing-fully relaxed states.

All tests were carried out under a testing atmosphere, which is specified as one with relative humidity of 65 per cent plus or minus 2 per cent and a temperature of $20^0 \pm 2^0$ C.

One of the problems facing a textile technologist is that of units. The imperial units have been used for many years in the textile industry. Nowadays many companies have adopted the SI units (Système Internationale d' Unites), which is a version of the metric system. In this project all values obtained are classified as SI units and these are:

❑ Yarn linear density in Tex: Tex is defined as the mass in grams of one kilometre of yarn. This is called direct yarn counting system and is simple to define and use.

❑ Courses per unit length: This is defined as courses per centimetre.

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□ Wales per unit length: This is defined as wales per centimetre.

□ Stitch Length: This is defined in millimetres or centimetres.

□ Fabric mass per unit area: This is defined as the mass of a knitted fabric in grams per square metre

5.2. Estimation of yarn linear density

The yarn linear density is a numerical expression, which defines the thickness or fineness of the yarn. This numerical expression is also called "yarn count". The determination of yarn count in tex has been done according to ISO standards [5.2]. The yarns used in this experiment were taken from industry and cover the most popular mixtures and yarn sizes used in the production of knitted goods. Yarn samples wound on appropriate bobbins were placed in a standard laboratory atmosphere for 24 hours in order to bring them to moisture equilibrium for testing.

From each category of yarn, five bobbins were placed in the appropriate apparatus i.e. an electrical moving real having a perimeter of 100 yards, which is equivalent to 91.44 meters. The instrument was fed with an adjustable tension device giving out a control tension of 0.5 ± 0.1 cN/tex so as to eliminate the variations in the specified lengths (Fig. 5.1). Two separate skeins were taken from each bobbin and the mass of each was determined giving out a total number of ten measurements for each type of yarn.

Fig.5.1 Apparatus for measuring the length of the skein

The yarn count in tex was then calculated according to the existing equation. The average values of all yarn samples used in the production of knitted fabrics together with their specifications are listed on Table 5.1. When knitting fabrics using a thinner yarn count, it is common practice to combine two or three separate ends of the fine yarn, rather than to use a single multi-folded yarn. The difference in dimensional parameters (K values) for the fabrics produced by separate ends and those produced by multi-folded yarn are fairly small, provided that the total number of ends knitting singles and multi-fold yarns is the same [5.1]. Therefore it is seen from Table 5.1 that according to the yarn count, two and three parallel ends were used to produce the required fabrics (column 4).

Here it is necessary to clarify some important points, which are:

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1. In industry the yarn count for wool and wool blends is given in metric number (Nm) and the arithmetic value of 2 before the count number shows that the yarn is made up of two single yarns having a metric number of 28 each (i.e. 2/28 Nm) (column 3).

2. Metric system for yarn counting belongs to indirect systems and is defined as the number of 'units of length' per 'unit of mass', where 'unit of length' is the kilometer and 'unit of mass' is the kilogram. Therefore, the relation between metric number and tex is given by the following equation (column 5):

$$Tex = 1000 \times Nm^{-1}$$

TABLE 5.1 : Specifications of yarns used in the production of knitted fabrics

Yarn composition	Yarn count		Measured yarn count (tex)	No ends used	Total yarn count (tex)
	Nm	Tex			
	(1)	(2)	(3)	(4)	(5)
50% Acrylic / 50% Wool extra fine (undyed)	2/28	2/35.7	2/36.40	3	218.4
70% Acrylic /30% Wool (undyed)	2/28	2/35.7	2/36.35	3	218.1
50% Acrylic / 25% Viscose / 25% wool (undyed)	2/17	2/58.8	2/58.60	2	234.4
50% Wool Merinos / 50% Dralon (dyed blue)	2/28	2/35.7	2/36.60	3	219.6
Dry Relaxed 70% Wool / 30% Acrylic (dyed brown)	2/28	2/35.7	2/36.40	3	218.4
50% Acrylic 25% Viscose 25% Wool (dyed beige)	2/17	2/58.8	2/64.20	2	256.8

On the table 5.1 columns 1 and 2 present the values of yarn count given by the factory, while column three shows the values obtained after the yarn

count determination. Column five shows the total yarn count used on the knitting machine to produce the fabrics. "ProKNIT" system has been designed so that the yarn count used for the determination of fabric mass is given as a total value of size and not in the commercial form i.e. 2/28.

5.3. Relaxation procedures

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

Dry relaxed state: Knitted fabrics conditioned for 48 hours in a standard atmosphere of 65% ± 2% RH and 20° ± 2°C.

Wet relaxed state: knitted fabrics are soaked in water at 40°C for 2 hours, hydro-extracted in a domestic washing machine and left flat to dry [5.3]. Then the fabrics are conditioned for 24 hours in a standard atmosphere.

Finished and full-relaxed state: Wool knitted fabrics and their mixtures are steamed flat in an industrial conveyor belt steamer and afterwards are hand-washed at 30°C with a household mild detergent for 15 minutes at 30°C. The excess water is hydro-extracted and fabrics left flat to dry [5.3]. The fabrics are conditioned for 24 hours in a standard atmosphere.

Cotton knitted fabrics and their mixtures are washed and tumbled-dried according to ISO standards. Washing is done at 60°C washing temperature (procedure No 3A[h]), using a non-phosphate ECE reference detergent A (without optical brightener) [5.3]. Tumble-drying is done at 60°C until the fabrics are dried. Finally, conditioning takes place in a standard laboratory atmosphere for 24 hours.

5.4. Steaming process

In industry cardigans and pullovers from wool or wool blends are steamed relaxed. Therefore it was a thought that for finishing and fully relaxed state to apply first a steaming process and afterwards the appropriate washing treatments without tumble drying, which creates felting in wool knits.

The steaming process was done in an industrial steamer using steam that did not exceed the pressure of 3.5 atmospheres. The fabric was placed on a conveyor belt with the border-rib in front. Special care was given so that feeding rollers during the process will not extend the piece of fabric. One full set of knitted samples for all categories of fabrics, yarns and stitch cam settings passed through the steaming process before subsequent treatments and testing took place.

5.5. Fabric dimensional measurements

Different workers have been involved in a lot of discussion and put forward recommendations that the fabric dimensions must be measured under the water or after drying of wet relaxed state. In reality wet or dry fabric dimensions are the same and appear different only because of the difficulties involved in measuring. Therefore, it was decided that for the fabric dimensional measurements to apply the guidance of international standards and also the methods used in this field by the industry itself.

Therefore all measurements were made under standard atmospheric conditions using:

1. A magnifying glass for measuring courses and wales per unit length.

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2. A Shirley Crimp tester to determining the course length and thus the loop length. The Shirley Crimp tester has been chosen instead of the Hatra Course Length tester because it is more accurate in small course lengths.

3. The Fabric Yield Package system to determine the fabric mass per square meter. This package consists of a sample cuter and an accurate balance.

5.5.1. Measurement of courses per unit length

Chapter 1 deals in detail with defining courses per unit length of a knitted fabric. The measurement of courses per unit length can be done in the following ways [5.4]:

1. Using 1X1 inch square folding metal aperture with a magnifying lens and a counting needle with a handle.

2. Using a dual scale with travelling lens and pointer.

3. Using a Multi-Aperture Pick Counter with a rotating magnifying glass and a counting needle with handle.

The knitted fabric was placed with extra care flat on a bench and the three centimetres measuring slot of the Multi-Aperture Pick Counter was placed on the fabric with its slot of 3 cm parallel to the fabric wales (Fig. 5.2). The particular slot was chosen due to large counting area available, which would minimize the likelihood of error in the counting procedure. Through the magnifying glass all loops were easily distinguishable. Using the counting needle the number of courses present in the slot was counted. For each fabric ten measurements were made in random order and the values tabulated so as to estimate the mean value, which was then divided by three in order to determine courses per centimetre.

Fig. 5.2 Multi-Aperture Pick Counter

5.5.2. Determination of wales per unit width

Wales per unit width were estimated in exactly the same way as that for courses per unit length. The Multi-Aperture Pick Counter was placed on the knitted fabric in such way that the 3 cm slot was vertical with the ribs of the fabric. The counting of the wales took place on the slot using the magnifying glass and the appropriate counting needle (Fig. 5.2). Ten random estimations of the wales per three centimetres were taken and calculated the average value.

On single jersey fabrics wales are very clear and can be indicated directly on the surface of the fabric. However, on the double jersey knits the procedure is not so simple. For example on 1X1 rib structure both sides are identical, which means that the measurement of the wales must be carried

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out with a clear indication of how the numbers are obtained. That is in the relaxed condition of double jersey structures the wales or loops on the reverse side are not distinguishable, therefore, in counting the wales on one surface, only half of those in the fabric are actually observed. In practice, the usual way of counting wales per unit width is done on one surface only and the value obtained is multiplied by two. The different values of wales per unit width obtained on double jersey fabrics (1x1 rib, 2X2 rib and interlock) are presented with a slash and a value of 2, which refers to the double amount of wales (see Appendix).

5.5.3. Fabric loop length

It has been found that the most accurate fabric parameter is the length of the yarn per loop. This does not vary regardless of the strain conditions of the fabric and therefore geometrical parameters of a knitted fabric may be determined knowing the yarn length per loop.

In this experimental work the procedure followed for determining the yarn needed per loop was in accordance with ISO 7211, where by a certain length of yarn is unravelled from a known width of knitted fabric and after the appropriate tension is applied to it, it straightens up to its original length, which is then defined in millimetres or centimetres. Therefore, the loop length can be calculated simply by dividing this predetermined length by the number of wales corresponding to the knitted fabric width from which the unravelled yarn was taken.

The apparatus used (Fig.5.3) consists of the following parts:

  A. The main body, which has a length of 1.5 meters and on top of it there is a scale in centimetres and millimetres.

B. The balance, which has a grip (J) to fasten the yarn and a sliding mass to apply the appropriate tension to the yarn.

C. The sliding grip, which is used to straighten up the thread.

D. The scale, which indicates the amount of tension in grams applied to the yarn.

E. The sliding mass, which determines the yarn tension.

F. The tilted mirror to view the horizontal level of the balance.
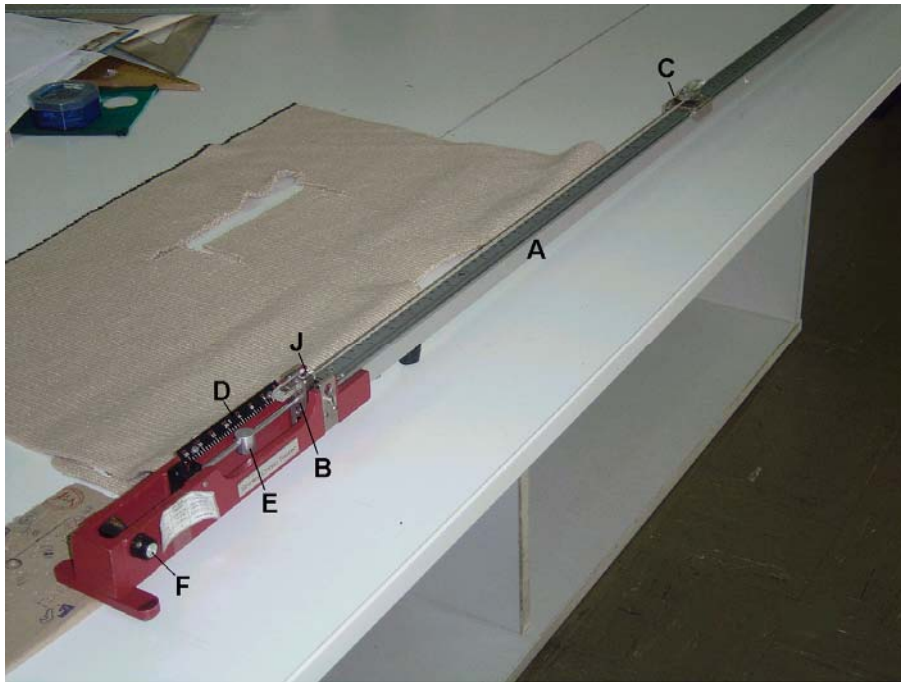
Fig. 5.3 Shirley Crimp tester

The preparation of the specimens was as follows (Fig.5.4):

1. Using a permanent marker a horizontal line along the points A'-B' was drawn.

2. Using a pair of scissors a cut along the line A'-B' was created.

3. A distance of 15 cm was marked and two vertical cuts at each end of it were made. A and B position.

4. A certain number of odd course lengths were removed until an even length was obtained, which covered the whole distance from A to B cut.

5. Ten even lengths were unravelled along the distance A-B and their straightened length was measured.
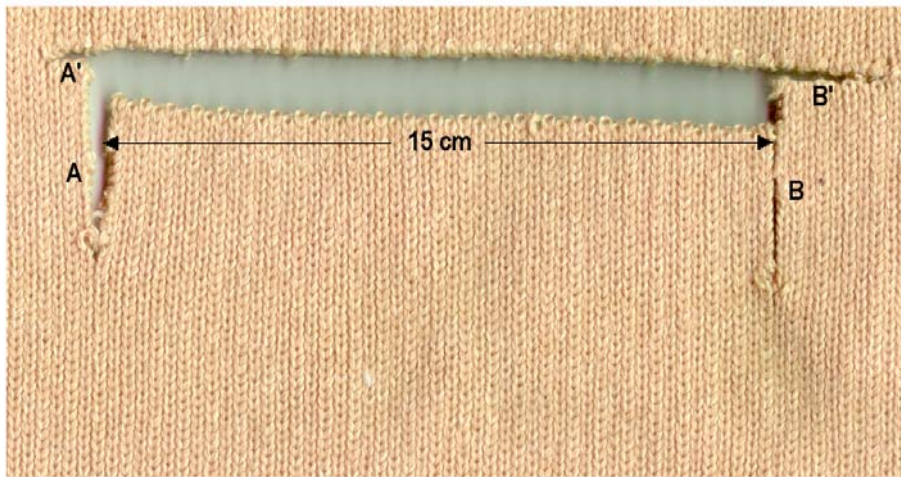
Fig. 5.4 Preparation of the speciment for loop length determination

Before the measurements of the course length commence it is necessary to adjust the tension on the balance. The required tension in grams for the yarns used in the production of the knitted fabrics is determined by two factors yarn composition and yarn count. For wool yarns having a tex of 60-300 the tension required is given by the relation 0.07tex+12. Thus, a yarn having a tex 218.4 requires a tension of 27 grams (i.e. 218.4X0.07+12).

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As soon as the tension of the balance is adjusted to the required level, one end of the removed thread is then clamed to grip "J" with its extreme tip in line with a datum line marked in the transparent upper face of the grip. The other end is then clamped in the sliding grip "C" in a similar manner. Now the sliding grip "C" is slowly moved along the body of the instrument, and through the mirror the position of the balance is observed. As soon as the line present on the balance is aligned with the stationary line existing on the body of the instrument, the sliding grip stops moving. The yarn length is read in millimetres or centimetres from the existing scale using the datum line marked in the transparent base of grip "C".

Ten measurements were taken and the mean value was estimated. The loop length was calculated simply by dividing the mean thread length by the total number of wales present in the 15-centimetre fabric width. The mean values of loop length found for each knitted fabric are presented in the appendix.

5.6. Determination of fabric mass per unit area

The mass, per unit area can be expressed in grams per square metre. The method of obtaining this value is implicit in the title, where one has merely to weigh a known area of fabric. The whole procedure followed complies with ISO 3810 where a sample of 100 cm^2 is cut and placed on the scale, which directly determines the fabric mass in grams per square meter (g/m^2). The area measured and cut should be to accuracy of 1 per cent and for small areas a cutting die is recommended.

The mass per unit area is determined while the fabric is conditioned in a standard atmosphere using a sample cutter and balance. The knitted fabric to be cut is placed flat, without stress, between the sample cutter (A) and the special cutting board (B). When the safety catch from the cutter is released,

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slight pressure on the hand-wheel brings the internal blades into contact with the fabric. The specimens are cut out simply by rotating the hand-wheel under pressure. The specimens must be removed cleanly and have smooth edges (Fig. 5.5).

Fig. 5.5 Sample cutter and balance to determine fabric mass (g/m^2)

The diameter of the sample cutter is 113 mm, which refers to a cutting sample of 100 cm^2. This specimen is weighed on the small digital electronic balance. Since 100 cm^2 is exactly one hundredth of a square metre, the mass of the sample in grams is multiplied by 100 to give the final fabric mass in grams per square meter. The readability of the electronic balance used in our case was to four decimal points (i.e. 0.0001). From each fabric five samples were taken and the mean value of fabric mass was calculated.

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The new, or reference, knitted fabrics were tested only for fabric mass in grams per square metre so as to facilitate comparison with the values predicted by "proKNIT' system.

5.7. Estimation of dimensional parameters

The estimation of the dimensional parameters was done according to the equations presented by Munden (Chapter 1) [5.6] and are as follows:

$$K_c = c \times \ell$$

$$K_w = w \times \ell$$

$$K_s = S \times \ell^2$$

$$K_r = R = \frac{c}{w} = \frac{K_c}{K_w}$$

In the above equations c and w define the courses and the wales per centimeter respectively. S is the loop density and arises by multiplying courses and wales per centimeter. Finally ℓ is the loop length and can be measured in millimeters or centimeters and K_r or R is the loop shape. All these values can be determined from the values found during fabric analysis.

The above relations have been taken into serious consideration in the development of "proKNIT' software as they play an important role in the systems ability to calculate the fabric mass per unit area. Table 5.2 shows some of the values obtained for all structures in the dry-relaxed state. However, what needs to be pointed out is that the above equations, as defined by Munden, are applicable mainly to single jersey (plain-knit and

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purl) and can have a practical value in determining the knitted fabric mass per unit area. On the other hand, when it concerns double knits (1X1 and 2X2 rib and interlock), which due to their different structure produced thicker fabrics in two needle beds, it is necessary to make some appropriate modifications to the calculations in order to achieve the required results.

TABLE 5.2: Estimation of dimensional parameters in dry-relaxed state (undyed yarn)

Type of Fabric	Geometrical Dimensions				Dimensional Parameters			
	cpc	wpc	ℓ (mm)	S	K_C	K_w	K_s	R
Plain-Knit	5.3	4.1	9.5	21.73	50.3	39.0	1961	1.29
Purl structure	7.1	3.8	9.7	26.98	68.9	36.9	2538	1.87
1X1 rib	5.3	4.0/2	8.52	21.20	45.2	34.1	1541	1.33
2X2 rib	5.4	4.2/2	9.12	22.68	49.2	38.3	1884	1.29
Interlock	4.7	4.4/2	10.23	20.68	48.1	45.0	2165	1.07

The calculations to determine the dimensional parameters of single jersey structures are straightforward according to the Munden's equations. However for double knits the calculations of dimensional parameters are based only on the wales seen on the face of the fabric according to the values presented on Table 5.2. It is clear seems that the number of wales, in all double structures, is twice the values referred in the calculations (i.e. 4.0/2 =8.0). This way of estimating the dimensional parameters for double knits gives us a better view to the way of loops rearrangements within the fabric structure compared to single jersey structures. Also on double knits, the estimation of fabric mass per unit area was done according to the above dimensional parameters as a single jersey and by increasing twice the estimated fabric mass, see also Chapter 3 development of "proKNIT" System.

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The tightness factor was also estimated using the following expression and the values of loop length and yarn count in tex.

$$. \; K_f = \frac{\sqrt{Tex}}{\ell}$$

5.8. Discussion

In this chapter the tests carried out for all types of knitted fabrics produced have been described. The tests comply with ISO standards and include details concerning the methods of determining:

- ❑ Yarn count in tex
- ❑ Courses and wales per centimetre
- ❑ Loop length in millimetres
- ❑ Fabric mass in g/m^2

Taking into account the results obtained the non-dimensional parameters and the tightness factors for all types of fabrics were estimated. The average values obtained for all fabrics are presented analytically on the Appendix. All values concerning the non-dimensional parameters were also used in the development of the software for the determination of fabric mass per unit area.

REFERENCES

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[5.2] International Standard Organisation (ISO) No 2060.

[5.3] International Standard Organisation (ISO) No 6330,procedure C.

[5.4] International Standard Organisation (ISO) No 7211.

[5.5] International Standard Organisation (ISO) No 3810.

[5.6] Munden, D. L., J. Textile Inst. 50, T448-T471 (1959).

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Part Four: Results and Discussion

CHAPTER 6

RESULTS OF GEOMETRICAL ANALYSIS OF KNITTED FABRICS AND EVALUATION OF "PROKNIT" SYSTEM

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6.1. Introduction

Before we proceed with the presentation and analysis of the obtained results, it is necessary to provide some clarifications concerning the experimental work that has been done so far and the way the results have been presented in this chapter.

The whole experimental work was divided into different steps, which were followed in order to complete the puzzle of information and make "proKNIT" system operational. After designing "proKNIT" it was necessary to create our database of information, which was going to be used for determining fabric mass. The database was set up using the non-dimensional parameters, which were calculated from two sets of fabrics. One set of fabrics was analysed-tested for courses and wales per unit length and for loop length determination in dry and wet-relaxed states. The second set of fabrics was steamed and mild washed before the same tests were carried out. Thus based on the results obtained, the non-dimensional parameters of all mentioned fabrics were calculated and the values fed into "proKNIT" system. All the results obtained from this part of the project are analytically presented on appendix tables.

In this chapter, the non-dimensional variables obtained for the above knitted structures are compared with those obtained by previous workers and some very useful conclusions have been drawn. From the analysis of the results, to name but one example, it became apparent that the steaming process used on knitted fabrics has a direct effect on the fabric shrinkage behaviour, a practical widely used by the garment industry today.

After entering the non-dimensional variables to "proKNIT" system, it was necessary to evaluate its accuracy on predictions of fabric mass. Therefore,

a new set of fabrics was produced following the same knitting procedure on the same knitting machine, using also the same types of yarns. These new fabrics produced were called "reference fabrics", were tested only for loop length and fabric mass. All actual fabric masses were compared with the predicted ones by "proKNIT" system and the results of which are analysed bellow.

The main conclusion that can be drawn from this experimental work is that the system itself is indeed in a position to offer quick and largely reliable results, which means that there is potential for expansion in the future to include a wider range of yarns, which, in any case, was taken into consideration when designing the program in the first place.

6.2. Yarn composition and quality

At the beginning of the project it was decided to obtain as many different kinds of yarns as possible to carry out the tests for determining the non-dimensional variables, which would be used in "proKNIT" system. However, it was soon realised that the information compiled for such a variety number of yarn samples was going to be enormous and thus difficult to manage on an experimental level. It was decided, therefore, to choose the most commercial wool yarns existing on market, which, from a small investigation in the knitting section, turn out to be wool blends. As far as, the Greek knitting industry is concerned 80% wool blended yarns and about 20% wool yarns are used for the production of pullovers and cardigan alone. The reason behind this is that wool blend yarns are of better quality, in terms of

durability, fastness, and stability characteristics, apart from being cheaper compared to 100% wool yarns, which need additional treatments in order to present stable dimensional properties. Therefore, it was decided to proceed with the project using commercial wool blended yarns.

It is a well-known fact that the main, most popular man-made fibre used in wool blends is acrylic (Table 6.1). "Dralon" being the commercial name for an acrylic fibre also found often on the market. The percentage of acrylic fibre in the yarns used varied from 30-70% according to the yarn composition. However, when a lighter and shinier colour to the yarn is required some yarns containing viscose fibres produced from wood are used.

The codes presented on first column of Table 6.1 represent the yarn details in terms of yarn title and fibre content, i.e. yarn Count is Nm 2/28, yarn composition is 50% Wool Merinos / 50% Dralon, thus the abbreviation is 2/28-50Wme50D-d. The last letter "d" indicates that this yarn is dyed. These codes are also given to fabrics knitted in order to observe their behaviour during relaxation procedures. In the Appendix these codes are always used to describe each fabric together with the values of machine cam settings. The total yarn count in tex is that which was used on the knitting machine for the fabric production.

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TABLE 6.1 Yarn composition and codes used during the experimental procedure

Yarn code	Yarn composition	Nm	Total yarn count (tex)
2/28-50A50W	50% Acrylic / 50% Wool extra fine (undyed)	2/28	218.4
2/28-70A30W	70% Acrylic /30% Wool (undyed)	2/28	218.1
2/17-50A25V25W	50% Acrylic / 25% Viscose / 25% wool (undyed)	2/17	234.4
2/28-50WMe50D-d	50% Wool Merinos / 50% Dralon (dyed blue)	2/28	219.6
2/28-DR70W30A-d	Dry Relaxed 70% Wool / 30% Acrylic (dyed brown)	2/28	218.4
2/17-50A25V25W-d	50% Acrylic 25% Viscose 25% Wool (dyed beige)	2/17	256.8

6.3. Estimation of non-dimensional parameters

Table 6.2 presents a small sample of values obtained from the tests carried out for the determination of K parameters, which are considered to be a certain factor in the calculation of fabric mass. Also, on the same table the values of wales per centimeter (wpc) are given with a slash and a value of 2 (i.e. 4.0/2) for all double jersey fabrics (1X1 rib, 2X2 rib and interlock). This value refers to the number of wales on the back of the fabric. Therefore, the estimation of K values has been reached by multiplying courses and wales per centimeter shown on the face of the fabric by the loop length respectively. This way of calculating K values has been adopted, on the one hand, in order to facilitate comparison of the non-dimensional constants obtained with the values found by previous researchers and on the other,

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because in industry the analysis of a knitted fabric is, in fact, done on the face of the fabric and then the number of wales per unit width is doubled. The logic of the structural knitted cell (SKC) used by Knapton et al [6.4] has not been adopted in the calculations of K values, because the outcome is the same. The small differences, in tenths of a hundred, observed in loop length between dry and wet or finished/steamed relaxed states have to be ignored because they do not affect the final values of non-dimensional parameters (K), nor the cover factor of the fabrics.

TABLE 6.2 Estimation of non-dimensional parameters used on "proKNIT" system.

Fabric type	cpc	wpc	ℓ (mm)	K_c	K_w	K_s	R
Plain knit 12.5 undyed (Dry)	5.3	4.1	9.50	50.3	39.0	1950	1.29
Plain knit 12.5 undyed (Wet)	5.7	4.3	9.50	54.1	40.9	2213	1.32
Purl knit 14.5 undyed (Dry)	5.6	2.9	12.20	68.3	35.4	2418	1.93
Purl knit 14.5 undyed (Fin/St)	5.6	3.0	12.28	68.8	36.9	2539	1.87
1X1 rib 10.5 undyed (Dry)	5.3	4.0/2	8.52	45.2	34.1	1541	1.33
1X1 rib 10.5 undyed (Wet)	5.9	3.7/2	8.51	50.2	31.5	1581	1.59
2X2 rib 13.2 undyed (Dry)	4.0	3.1/2	12.25	49.0	37.9	1857	1.29
2X2 rib 13.2 undyed (Wet)	4.3	2.9/2	12.21	52.5	35.4	1859	1.48
Interlock 12.5 undyed (Dry)	4.2	3.9/2	11.57	48.6	45.0	2187	1.08
Interlock 12.5 undyed (Wet)	4.5	3.7/2	11.60	52.2	42.9	2239	1.22

6.4. Tightness factor values

According to stitch cam settings used during fabric production, the tightness factor was kept within the reason of ±18% of the recommended average value of 1.46, since various authors [6.6], [6.7], [6.8], [6.9] have commented that the so-called " non-dimensional constants" K_c, K_w and K_s do not remain constant over a wide range of tightness factors. The values presented on

Table 6.3 indicate the above mentioned percentage variation of tightness factor.

TABLE 6.3 Variation of tightness factor

Type of fabric	tex	ℓ (mm)	Tightness Factor
Plain knit 12.5 undyed (dry-relaxed)	218.4	9.50	1.56
Plain knit 12.5 undyed (wet-relaxed)	218.4	9.50	1.56
Purl knit 14.5 undyed (dry-relaxed)	218.4	12.20	1.21
Purl knit 14.5 undyed (wet-relaxed)	218.4	12.28	1.21
1X1 rib 10.5 undyed (dry-relaxed)	218.4	8.52	1.74
1X1 rib 10.5 undyed (wet-relaxed)	218.4	8.51	1.74
2X2 rib 13.2 undyed (dry-relaxed)	218.4	12.25	1.21
2X2 rib 13.2 undyed (wet-relaxed)	218.4	12.21	1.21
Interlock 12.5 undyed (dry-relaxed)	218.1	11.57	1.27
Interlock 12.5 undyed (wet-relaxed)	218.1	11.60	1.27

6.5. Non-dimensional parameters used on "proKNIT" system

Using the values obtained for courses and wales per centimeter and loop length in millimeters as the basis, the values of K_c, K_w, K_s and R were calculated for all knitted fabrics using wool-blended yarns for their production. Analytically, all values are presented in the Appendix tables. The mean values of non-dimensional constants of all produced fabrics are given on Table 6.4. These values have been entered into "proKNIT" software in order for the system to be operational and capable of predicting the fabric mass. The prediction of fabric mass per unit area is a result of these non-dimensional parameters (constant K values) in conjunction with yarn linear density, loop length and tightness factor.

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TABLE 6.4 Mean values of the obtained non-dimensional variables used on "proKNIT" software

Type of fabric	Process	K_c	K_w	K_s	R
Plain knit undyed yarn	Dry	50.0	38.8	1940	1.29
Plain knit dyed yarn	Dry	50.0	39.5	1975	1.27
Plain knit undyed yarn	Wet	54.0	41.0	2214	1.32
Plain knit dyed yarn	Wet	53.0	40.0	2120	1.32
Plain knit undyed yarn	Steamed	52.0	40.0	2080	1.30
Plain knit dyed yarn	Steamed	53.2	40.0	2128	1.33
Purl fabric undyed yarn	Dry	68.8	36.2	2490	1.90
Purl fabric dyed yarn	Dry	71.2	37.0	2585	1.90
Purl fabric undyed yarn	Wet	Not Av	Not Av	Not Av	Not Av
Purl fabric dyed yarn	Wet	Not Av	Not Av	Not Av	Not Av
Purl fabric undyed yarn	Steamed	70.0	37.0	2590	1.89
Purl fabric dyed yarn	Steamed	72.4	38.3	2773	1.89
1x1 Rib undyed yarn	Dry	44.0	34.0	1500	1.30
1x1 Rib dyed yarn	Dry	45.0	34.0	1530	1.32
1x1 Rib undyed yarn	Wet	50.0	31.5	1575	1.58
1x1 Rib dyed yarn	Wet	50.0	32.5	1625	1.54
1x1 Rib undyed yarn	Steamed	46.5	30.0	1400	1.55
1x1 Rib dyed yarn	Steamed	47.5	32.0	1520	1.48
2x2 Rib undyed yarn	Dry	49.0	38.0	1862	1.29
2x2 Rib dyed yarn	Dry	50.0	38.0	1900	1.31
2x2 Rib undyed yarn	Wet	52.4	35.5	1860	1.50
2x2 Rib dyed yarn	Wet	53.0	36.0	1908	1.47
2x2 Rib undyed yarn	Steamed	47.2	33.2	1567	1.42
2x2 Rib dyed yarn	Steamed	47.5	33.4	1591	1.42
Interlock undyed yarn	Dry	48.0	45.0	2160	1.06
Interlock dyed yarn	Dry	48.8	45.8	2235	1.07
Interlock undyed yarn	Wet	51.6	42.7	2203	1.21
Interlock dyed yarn	Wet	52.4	43.3	2270	1.21
Interlock undyed yarn	Steamed	49.6	42.0	2083	1.18
Interlock dyed yarn	Steamed	51.0	43.0	2193	1.18

The values of the non-dimensional parameters (K_C, K_w, K_s and R) presented on Table 6.4 are significantly dependent on the relaxing conditions (dry, wet and steamed) as well as the type of yarn used, dyed or undyed. Looking

specifically at the values of the Ks parameters, which indicate an overall view of the fabric behaviour, it appears that plain-knit fabric has shrunk in both directions, length and width following wet treatment compared to dry relaxed state, the K_s values have increased after wet relaxation. However, the values of K_s obtained once the fabrics were first steamed and washed afterwards are not significantly different from those of wet relaxed. We can say that they are a fraction lower than those obtained following wet treatment. Also, on plain-knit fabric the ratio values (R) indicate that there is more fabric contraction in lengthwise than in width wise because the R values increase.

This fabric behaviour is more pronounced for the other types of knitted constructions, i.e. purl, 1X1 rib, 2X2 rib and interlock. It is clear that there is a distinct reduction in K_s values even for the dry relaxed case. For example, 1X1 rib structure produced by undyed yarn in dry relaxed state has shown a K_s value equal to 1500 while after steaming and washing this value has been reduced to 1400. A similar tendency exists for 2X2 rib and interlock structures. The explanation for this behaviour lies in the steaming process, which has steamed-set the fabrics. The yarns used for the production of these fabrics are wool blends of more than 50% man-made fibres. Therefore, these fabrics can be easily dimensionally stabilised (set) by heat or steam since the temperature of the steam is close to boiling point. The washing process after steaming does not improve the shrinkage behaviour of the fabrics. Therefore, steaming is used to stabilise the dimensions of the knitted fabric so as to avoid further garment shrinkage during use, which probably explain why knitted fabrics are steamed in industry.

In wet process for purl structure there are no values available because during the test agitation was applied by accident to the samples, which presented felting. As far as purl structure is concerned, it follows from

Chapter 1.3 that it presents a high contraction lengthwise, thus the face loops are hidden within the contracted structure giving out a high ratio value (1.9), which has not been affected by steaming process. This unchangeable ratio value also indicates that the fabric has been proportionally contracted in lengthwise as well as widthwise.

From observations of the values compiled, it follows that an increase in courses per centimetre is accompanied with a decrease in wales per centimetre as the relaxation process moves from dry to wet state. This behaviour applies to all double jersey structures (ribs and interlock). It has been mentioned by previous workers [6.1], [6.2], [6.3] that the dry relaxation process does not result to a minimum energy state since the fabric stitches rearrange themselves within the structure and reach a minimum energy state after tumble-drying. However, it is well known that tumble-drying creates felting on woollen knits if the yarns have not had an adequate shrink-resist treatment. That is why, in order to avoid felting it was decided, in this experimental work that after wet treatment and mild agitation during water hydro extraction that the fabrics would be allowed to relax enough for the mass of the fabric to be easily predicted in this state.

In dry relaxed state for interlock structure the ratio between courses and wales per unit length is about equal to unity, however, after wet relaxation the value of R increases since there is a higher level of shrinkage in length direction compared to width direction where extension appears. Looking at K_s values can be generally said that the loops rearrange themselves inside the fabric structure in order to achieve a minimum energy position. This stitch rearrangement gives out similar values of K_s, which are close to 2.200 units. Similarities in behaviour also exist for rib structures, as the K_s values, between dry and wet relaxed states, do not demonstrate any significant difference.

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6.6. Comparison of non-dimensional parameters

It has already been mentioned that the recommended length unit for courses and wales per unit length in SI units is the centimetre and that of stitch length is the millimetre. Consequently K_s values, found by previous workers, have to be multiplied by 100 while those of K_c and K_w by 10, in order to be comparable with the values presented on Table 6.4. The ratio value R is, naturally, not affected. If the loop length is given in centimeters then the non-dimensional values presented above are similar to those presented by the other researchers (Table 6.5). The comparison with previous workers will be limited, however, only to values obtained in dry and wet relaxed state, since none of them has produced any evidence for the finished/steamed process.

TABLE 6.5 Comparison of K parameters of plain-knit fabrics

Fabric state	Parameters			
	K_c	K_w	K_s	R
Dry-relaxed (Munden) [6.6]	5.0	3.8	19.0	1.31
Dry-relaxed (Postle) [6.3]	4.7	4.0	18.0	1.16
Dry-relaxed (Knapton et al) [6.5]	4.7	3.9	18.3	1.20
Dry-relaxed (Thesis)	5.0	3.9	19.4	1.29
Wet-relaxed (Munden)	5.3	4.1	21.6	1.29
Wet-relaxed (Postle)	5.4	4.2	22.8	1.28
Wet-relaxed (Knapton et al)	5.2	4.1	21.3	1.27
Wet-relaxed (Thesis)	5.4	4.1	22.1	1.32

Looking at the non-dimensional parameters presented on Table 6.5 it can be deducted that there is no significant differences as far as the values

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obtained in wet relaxed state are concerned. Significant differences exist only in the values for dry relaxed state where the fabrics have yet not reached a minimum state of energy. In dry relaxed state the values obtained by Postle do not exhibit significant differences compared to those obtained by Knapton et al. On the contrary Mundens' values are closely related to those obtained in this project. Then comparing the non-dimensional parameters (K values) obtained in this project with those presented by Munden, it becomes clear that in dry-relaxed state for undyed wool the values of K parameters are about the same. The K values obtained in the present work have been estimated separately for dyed and undyed yarns in order to have a higher accuracy or small deviations when determining the theoretical fabric mass in correlation with real fabric mass. When determining the average K values, which result from both yarns, dyed and undyed, in wet-relaxed state, it is apparent that there is a very close correlation with K values presented by Munden i.e. K_c= 5.35, K_w = 4.05, K_s = 21.6 and R = 1.32.

On the other hand, for plain-knit fabrics in dry-relaxed state, the K values presented by Postle and Knapton et al do not approach either those obtained by Munden or those produced in this project. On the contrary, in wet relaxed state there is a clearer picture as far as the non-dimensional parameters are concerned. All values of wet-relaxed state presented on Table 6.5 appear to have negligible differences. More specifically, we can say that Postle's K values are very close to those presented on this project for undyed yarns; however, the ratio of K_c to K_w is lower, something which is probably related to the tightness factors used by Postle and Knapton et al.

As far as double knitted fabrics are concerned, or 1x1 Rib in particular, Smirfitt [6.1] analysed this structure using the logical path of plain knit fabrics and thus produced the non-dimensional parameters of K values presented

on Table 6.6. Comparing these values with those obtained in this work, a very close relation exists between them. Knapton et al also presented a set of K values for dry and wet relaxed states using the logic of structural knitted cell (SKC) for 1X1 rib structure. The results as they have been presented do not agree with those listed on Table 6.6 and this is because the logic behind the calculation is different. However, by recalculating the values presented by Knapton et al [6.4}, so as to be more easily comparable to the rest of the values presented on the Table, it appears that they do not differ significantly from those obtained by the author.

TABLE 6.6 Comparison of K parameters of 1X1 rib structure

Fabric state	Parameters			
	K_c	K_w	K_s	R
Dry-relaxed (Smirfitt) [6.1]	4.5	3.3	14.9	1.36
Dry-relaxed (Knapton et al) [6.4]	4.5	3.2	14.4	1.41
Dry-relaxed (cotton) [6.10]	4.1	2.8	11.5	1.46
Dry-relaxed (cotton blend) [6.10]	4.1	3.1	12.7	1.32
Dry-relaxed (Thesis)	4.4	3.4	15.0	1.30
Wet-relaxed (Smirfitt)	5.0	3.3	16.3	1.53
Wet-relaxed (Knapton et al)	4.9	3.1	15.2	1.58
Wet-relaxed (cotton) [6.10]	4.8	2.9	13.9	1.65
Wet-relaxed (cotton blend) [6.10]	4.4	3.1	13.6	1.42
Wet-relaxed (Thesis)	5.0	3.1	15.7	1.58

Poole and Brown [6.10] also presented a set of values for cotton and cotton blend yarns using the logic of structural knitted cell (SKC). Their values have also been recalculated and presented on Table 6.6. In dry relaxed state the values they obtain have a distinct difference from the rest. In wet-relaxed state, however, the numerical difference from the other values has been reduced approaching but not quite reaching the values of the other

researchers. This is probably a sign that yarn composition may affect the non-dimensional parameters of the 1X1 rib structure, something which comes in contrast with the theory developed by other researchers that the yarn composition has no effect on the values of non-dimensional variables [6.12].

TABLE 6.7 Comparison of K parameters of 2X2 rib structure

Fabric state	Parameters			
	K_c	K_w	K_s	R
Dry-relaxed (Knapton et al) [6.4]	4.8	3.7	17.76	1.30
Dry-relaxed (Thesis)	4.9	3.8	18.62	1.29
Wet-relaxed (Knapton et al)	5.1	3.5	17.97	1.46
Wet-relaxed (Thesis)	5.2	3.5	18.60	1.50

The values obtained for 2X2 rib fabric in a dry and wet-relaxed state, however, are of particular interest since the ratio between courses and wales per centimeter increases as the process passes from dry to wet state, although, the non-dimensional variable (K_s) has not been affected at all. However, an increase in the K_c value does not necessarily mean that there will be a proportionate increase in K_w value, which, in fact, decreases. The rearrangement of loop position inside the structure results in giving out negligible differences in K_s values. This structural behaviour is presented on Table 6.7. Knapton et al have also shown this tendency of loop rearrangement in 2X2 rib structure. The K_s values they obtain in the two relaxed states, dry and wet, do not change distinctly but remain more or less the same, while at the same time there is an increase in ratio values. All constant values presented by Knapton et al are lower than those recorded by the author, therefore, it is precarious to use any of these values for determining fabric mass.

TABLE 6.8 Comparison of K parameters of interlock

Fabric state	Parameters			
	K_c	K_w	K_s	R
Dry-relaxed (Knapton/Fong) [6.11]	4.2	2.6	10.92	1.61
Dry-relaxed (Thesis)	4.8	4.5	21.60	1.06
Wet-relaxed (Knapton/Fong)	4.4	2.6	11.45	1.69
Wet-relaxed (Thesis)	5.2	4.3	22.30	1.21

The values presented on Table 6.8 concern interlock structure. Comparing the author's values with those presented by Knapton and Fong [6.11] in dry and wet relaxed states, we can conclude that there is no correlation between them. The differences between the two sets of values are vast and the reason behind these differences probably lies in error measurements.

Finally, for purl structure there are no available values for comparison since none of the previous researchers has worked on this structure for predicting the non-dimensional parameters.

6.7. Evaluation of "proKNIT" system

In order to compare the theoretical fabric mass predicted by "proKNIT" system with that of actual fabric mass, new samples were knitted by the same knitting machine, Stoll CMS 411 selectanit electronic –V- bed-knitting machine having a gauge of 7 needles per inch. The knitting machine was programmed according to the data used for the first experimental trials for determining the non-dimensional parameters. The reference fabrics were

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knitted using the available yarns of the first trials and the stitch cams were set according to the values given on Table 4.3. All new knitted fabrics produced were relaxed in dry, wet and finished states and then the fabric mass in grams per square meter as well as the loop length of each of them were determined in a standard atmosphere. The tightness factor for each fabric was calculated using the values of loop length and yarn count.

Then the values of machine gauge, yarn count and tightness factor were entered into "proKNIT", which processed the data given and produced the estimated loop length, courses and wales per centimetre and theoretical fabric mass. The results obtained by these procedures are presented on Tables 6.9 – 6.11. In each table there are the following columns:

- The first column gives the fabric and yarn quality details as well as the "proKNIT" estimation.

- The second one is concerned with the state of relaxation.

- The third and forth column is for courses and wales per cm respectively as calculated by "proKNIT".

- The fifth column is for the values of stitch density shown by "proKNIT".

- The sixth column lists the values of loop length measured and those predicted by "proKNIT".

- The seventh column shows the fabric mass found during testing.

- The eighth column gives the values of fabric mass predicted by "proKNIT".

- The last two columns refer to the values of tightness factor and yarn count respectively.

The target of this project is to predict the knitted fabric mass in grams per square meter in different relaxing conditions, therefore, by making a simple overall comparison of the figures presented on Tables 6.9 – 6.11, between theoretical and actual fabric mass, it appears that "proKNIT" system has predicted the fabric mass per unit area with a divergence of not more than 7%. More specifically the following commends can be deducted:

1. Only 2% of the predicted fabric masss have shown a difference greater than 5% from the actual fabric mass, thus for 98% of the predicted fabric masses the difference falls below of 5% difference.

2. 83% of the predicted fabric masses fall below 3% difference. In other words, 17% of the predicted fabric masses have shown a difference of 3% or above.

3. Only 66% of the predicted fabrics have achieved a difference below 2%. This means that two knitted fabrics out of three have achieved less than 2% difference.

Therefore, it follows from the above observations that 98% of the predicted values of fabric mass demonstrate a divergence of less that 5%, which is not greater than the standards/specifications set by private textile companies as well as the Public Knitting Sector, although it is common practice not to express this divergence from the expected average mass in percentages but rather by giving the minimum and maximum values allowed of the requested mass.

TABLE 6.9 Comparison between predicted and actual fabric mass

Fabric Type	State of Relaxation	cpc	wpc	S	ℓ (mm)	Act. Fab. mass (g/m^2)	Est. Fab. mass (g/m^2)	K_f	Tex used
Plain-knit undyed 2/28-50A50W12.5	Dry				9.50	455		1.55	218.4
"proKNIT" Estimation	Dry	5.24	4.07	21.34	9.50		444.3		
Plain-knit undyed 2/28-50A50W12.5	Wet					508			
"proKNIT" Estimation	Wet	5.66	4.30	24.36			507.1		
Plain-knit undyed 2/28-50A50W12.5	Fin/St					485			
"proKNIT" Estimation	Fin/St	5.45	4.20	22.88			476.4		
Purl knit undyed 2/28-50A50W 14.5	Dry				12.32	435		1.20	218.4
"proKNIT" Estimation	Dry	5.59	2.94	16.42	12.32		442.0		
Purl knit undyed 2/28-50A50W 14.5	Fin/St					447			
"proKNIT" Estimation	Fin/St	5.68	3.00	17.08			463.0		
1X1 rib undyed 2/17-50A25V25W11.5	Dry				10.41	699		1.47	234.4
"proKNIT" Estimation	Dry	4.23	3.27/2	13.83	10.41		675.0		
1X1 rib undyed 2/17-50A25V25W11.5	Wet					710			
"proKNIT" Estimation	Wet	4.80	3.03/2	14.54			709.6		
2X2 rib undyed 2/28-50A50W13.5	Dry				12.21	662		1.21	218.4
"proKNIT" Estimation	Dry	4.01	3.11/2	12.48	12.21		665.9		
2X2 rib undyed 2/28-50A50W13.5	Wet					673			
"proKNIT" Estimation	Wet	4.29	2.91/2	12.47			665.3		
Interlock undyed 2/28-70A30W12.5	Dry				11.54	830		1.28	218.1
"proKNIT" Estimation	Dry	4.16	3.90/2	16.23	11.54		816.6		
Interlock undyed 2/28-70A30W12.5	Wet					841			
"proKNIT" Estimation	Wet	4.47	3.70/2	16.55			833.0		
Interlock undyed 2/28-70A30W12.5	Fin/St					776			
"proKNIT" Estimation	Fin/St	4.30	3.64/2	15.65			787.5		

TABLE 6.10 Comparison between predicted and actual fabric mass

Fabric Type	State of Relaxation	cpc	wpc	S	ℓ (mm)	Act. Fab. mass (g/m^2)	Est. Fab. mass (g/m^2)	K_f	Tex used
Plain-knit dyed 2/17-50A25V25W14.5	Dry				12.82	370		1.25	256.8
"proKNIT" Estimation	Dry	3.90	3.08	12.02	12.82		395.6		
Plain-knit dyed 2/17-50A25V25W14.5	Wet					416			
"proKNIT" Estimation	Wet	4.13	3.12	12.90			424.6		
Plain-knit dyed 2/28-DR70W30A12.5	Wet				9.53	499		1.55	218.4
"proKNIT" Estimation	Wet	5.56	4.20	23.32	9.53		485,6		
Plain-knit dyed 2/28-DR70W30A12.5	Fin/St					497			
"proKNIT" Estimation	Fin/St	5.58	4.20	23.41			487.4		
Purl dyed 2/28-DR70W30A14.5	Dry				12.74	432		1.16	218.4
"proKNIT" Estimation	Dry	5.59	2.90	16.23	12.74		447.7		
Purl dyed 2/28-DR70W30A14.5	Fin/St					470			
"proKNIT" Estimation	Fin/St	5.65	3.01	17.08			471.2		
1X1 rib dyed 2/28-50Wme50D10.5	Dry				8.32	852		1.78	219.6
"proKNIT" Estimation	Dry	5.40	4.08/2	22.10	8.32		806.3		
1X1 rib dyed 2/28-50Wme50D10.5	Fin/St					820			
"proKNIT" Estimation	Fin/St	5.70	3.84/2	21.89			800.8		
1X1 rib dyed 2/28- DR70W30A11.5	Wet				9.92	715		1.49	218.4
"proKNIT" Estimation	Wet	5.04	3.27/2	16.51	9.92		715.3		
1X1 rib dyed 2/28- DR70W30A11.5	Fin/St					660			
"proKNIT" Estimation	Fin/St	4.79	3.22/2	15.45			669.4		

TABLE 6.11 Comparison between predicted and actual fabric mass

Fabric Type	State of Relaxation	cpc	wpc	S	ℓ (mm)	Act. Fab. mass (g/m^2)	Est. Fab. mass (g/m^2)	K_f	Tex used
2X2 rib dyed 2/28-DR70W30A13.2	Dry				11.82	691		1.25	218.4
"proKNIT" Estimation	Dry	4.23	3.21/2	13.59	11.82		701.9		
2X2 rib dyed 2/28-DR70W30A13.2	Wet					714			
"proKNIT" Estimation	Wet	4.48	3.04/2	13.65			704.9		
Interlock dyed 2/28-50Wme50D13.5	Dry				12.56	787		1.18	219.6
"proKNIT" Estimation	Dry	3.89	3.65/2	14.17	12.56		781.6		
Interlock dyed 2/28-50Wme50D13.5	Wet					816			
"proKNIT" Estimation	Wet	4.17	3.45/2	14.39			793.5		
Interlock dyed 2/28-50Wme50D13.5	Fin/St					760			
"proKNIT" Estimation	Fin/St	4.06	3.42/2	13.90			766.9		
Interlock dyed 2/17-50A25V25W12.5	Dry				12.23	929		1.31	256.8
"proKNIT" Estimation	Dry	3.99	3.74/2	14.94	12.23		938.3		
Interlock dyed 2/17-50A25V25W12.5	Wet					956			
"proKNIT" Estimation	Wet	4.28	3.54/2	15.16			952.6		
Interlock dyed 2/17-50A25V25W12.5	Fin/St					896			
"proKNIT" Estimation	Fin/St	4.17	3.52/2	14.66			920.7		

What also becomes clear looking closely at the results presented on the tables is the effect the steaming process has on fabric dimensions, which have been stabilised at a certain level, eventually giving a lighter fabric. Since the yarns used in this project were wool blends of over 50% man-made fibres, the steaming process had a greater effect on them. Therefore, the mild wash, which followed the steaming operation, did not distinctly alter the dimensions of the fabrics. In all cases of double knits the steamed fabric mass appears lighter even than the fabrics of dry-relaxed state.

It appears from Table 7.9 that the plain-knit produced from undyed yarn using a tightness factor of 1.55 showed an increase in mass from dry to wet relaxed state of 53 g/m^2 for the tested fabric and 63 g/m^2 for "proKNIT" system. In other words, the increase in mass for dry to wet relaxation of the tested fabric is 11.6% and 12.4% for the theoretical values predicted by "proKNIT". The difference between the two percentage values is 0.8%, a value that can be considered as negligible. However, if we move to purl fabric, this difference increases to 1% and to 3% for 1X1 rib structure, while for the rest of the fabrics appearing on this table the percentage difference is also negligible. In the next Table, 6.10, the increase in mass per unit area from dry to wet for the measured plain-knit fabric is 11% while for the estimated by "proKNIT" fabric mass is 6.8% giving a difference in values of over 4%. Also the difference between the values of actual and estimated fabric mass for purl knit is approximately 4%, i.e. for the measured fabric there is an increase in mass per unit area of 8.8%, while for the predicted values the increase in mass is 5%. These percentage differences can be reduced by customizing the fabrics' tightness factor in smaller groups and developing the appropriate non-dimensional parameters.

6.8. Fabric mass predictions

Using "proKNIT" system the estimated fabric mass for each reference fabric was predicted simply by entering the values of machine gauge, yarn count and tightness factor. The predicted values of fabric mass were plotted against the real values of fabric mass and the graphs of Figures 6.1, 6.2 and 6.3 were produced.
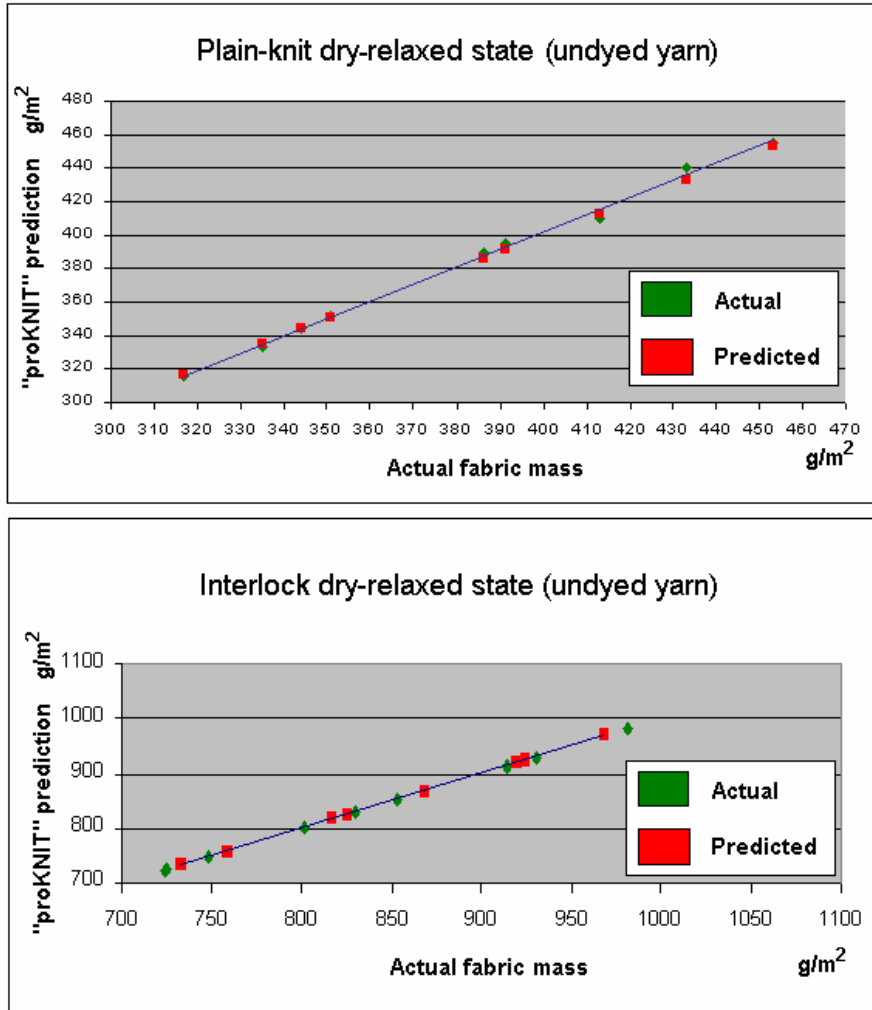
Fig. 6.1 Comparison between predicted and actual fabric mass in dry relaxed state (plain-knit and interlock)

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The first graphs of Fig. 6.1 show the alignment of the results obtained from a plain-knit structure produced from undyed yarn. The red dots show the values of the fabric mass estimated by "proKNIT" system and the green ones the fabric mass found after testing. It is clear that the red dots largely coincide with the green ones along the line, which means that the deviation is extremely small. The second graph of the same figure, which represents estimations for the interlock structure, presents a similar picture where most of the dots coincide with each other, giving out small differences between the predicted and the actual fabric mass.

In Fig. 6.2, there are two more graphs presenting variations in fabric mass of 1X1 and 2X2 rib structures. For 1X1 rib structure, in particular, there is a small deviation of the fabric mass values in the range of 680 – 750 g/m^2 where only one predicted fabric mass coincides with the actual fabric mass. However, for the remaining values there is a convergence in the values of the predicted and actual fabric masses.

In the second graph of Fig. 6.2 where the values of 2X2 rib are presented, it is observed that three values out of four plotted above of 900 g/m^2, for actual fabric mass, deviate from with predicted ones. The reason for having these differences lies mainly in the tightness factor as well as the fabric structure, which is highly elastic.

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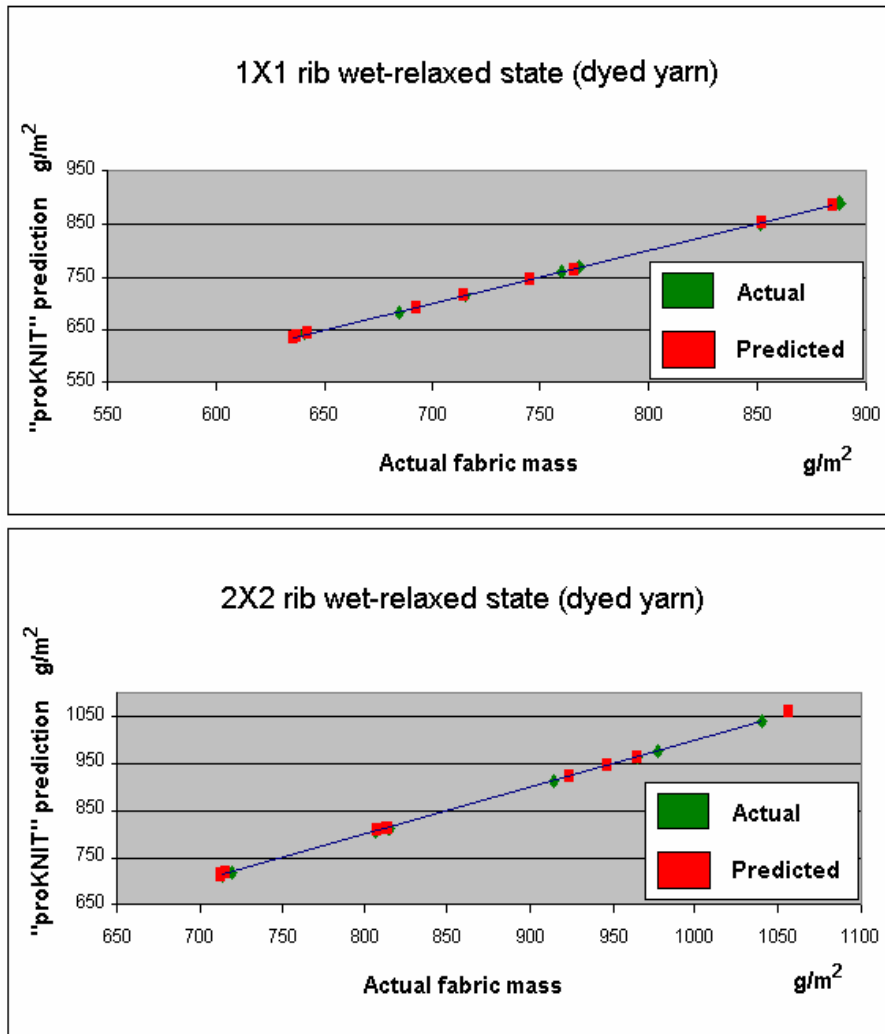
Fig. 6.2 Comparison between predicted and actual fabric mass in wet-relaxed state (1X1 and 2X2 rib)

What can be deduced from the purl structure graph in Fig. 6.3 is that, contrary to the 1X1 rib graph, Fig. 6.3, which presents mass values scattered along the line where numerical deviations are present, there is a high concentration of values along the line in three fabric mass regions. One is around $450g/m^2$, the second is around the mass of $520 \ g/m^2$ and the third one is around $600g/m^2$. This behaviour probably arises from the three

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different tightness factors, which were used during fabric production. The small deviation present between actual and predicted fabric masses is also characteristic.
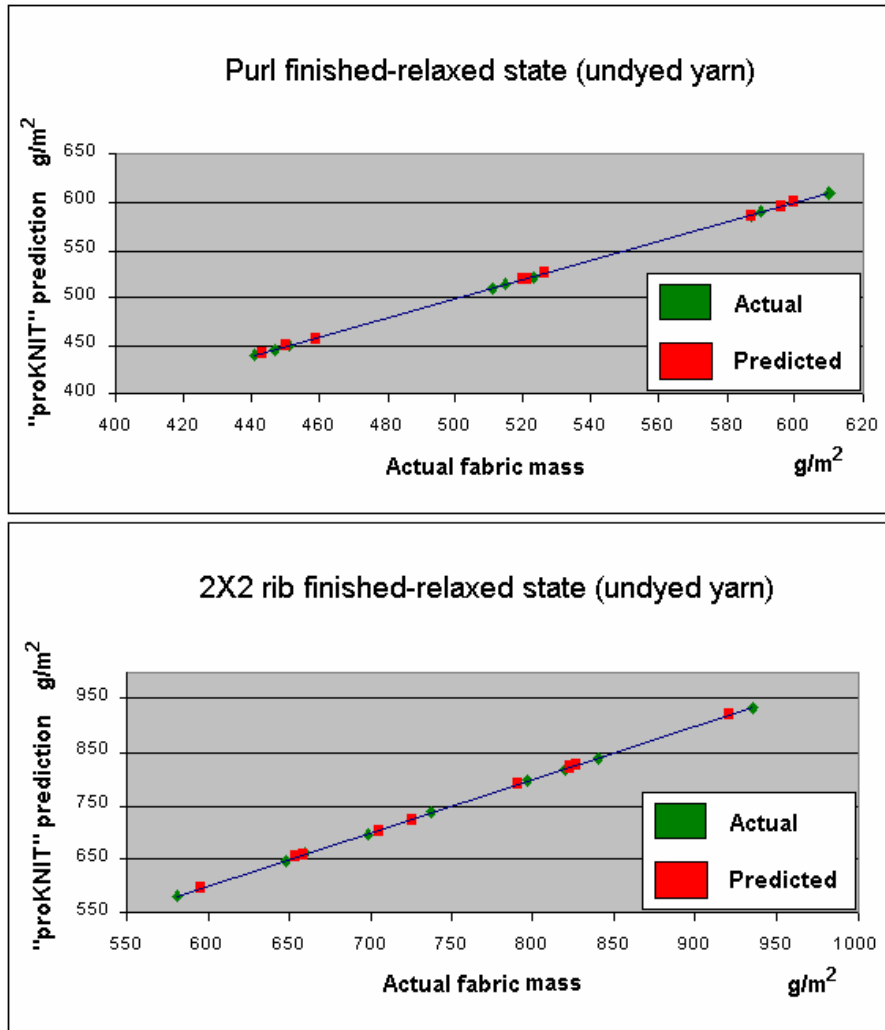
Fig. 6.3 Comparison between predicted and actual fabric mass in finished – steamed relaxed state (purl knit and 2X2 rib)

6.9. Discussion and Conclusions

An attempt to predict the knitted fabric mass per unit area has been made on commercial wool blended yarns using a newly developed software called "proKNIT". The fabric mass predictions took place on five primary base structures – plain, rib (1X1 and 2X2), interlock and purl – that were produced on a flat –V- bed knitting machine. The calculations involved for the estimation of the fabric mass were based on machine gauge, yarn count, state of relaxation, tightness factor and the non-variable parameters found in the produced fabrics.

The first attempt to predict fabric mass for wool mixture yarns was successful and the predictions did not show significant differences from actual fabric mass. The small deviation present in the different samples is a consequence of the time required by each fabric to relax (i.e. open structures need more time to relax in dry state) and on tightness factor.

However, the following need to be pointed out:

1. This project covered only a small range of tightness factor and only one category of yarn type, wool blends.

2. The estimation of fabric mass using "ProKNIT" system has been based on fabric geometry of weft knitted fabrics.

3. Courses and wales per unit length and loop density derived from the non-dimensional variables (K_s, K_w and K_s).

At the start of this project "proKNIT" system was intended to be used for research only. However, it soon became obvious 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 on fabric

production but rather easy to operate as it does not demand a high level competence in computer use. Extensive experimentation with "proKNIT" has shown that although the system is indeed in a position to produce reliable results, at the same time there is potential for further development in the future. Before the system can be fully operational further research should take the following considerations into account:

1. The non-dimensional parameters must be classified into small categories according to tightness factor so as to cover all existing values, i.e. from 0.9 to 2.0, when loop length is in mm.

2. The relaxation procedures must be justified with accuracy and be maintained throughout the experimental procedure of determining the non-dimensional variables.

3. The calculations for determining courses and wales per unit length can also be done through the non-dimensional values of K_s and R (the courses/wales ratio).

4. The non-dimensional variables must be determined for each category of yarn separately i.e. cotton yarn, wool yarn, man-made yarns etc.

Finally, once the developed system is replenished with more data in order to cover a much wider variety of yarns so it can become more flexible and errors kept to a minimum.

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APPENDIX

VISUAL BASIC PROGRAMMING

LANGUAGE

An Outline

A1. Introduction to Visual basic

Visual Basic programming language originates from BASIC (Beginner's All-purpose Symbolic Instruction Code), which was developed by John Kemery and Thomas Kurtz in Dartmouth College in the middle of the 1960s. Visual Basic provides a graphical environment in which we can visually design the forms and controls that become the building blocks of our application. It supports many useful tools that will help someone to be more productive. These include, but are not limited to:

- projects,

- forms,

- class objects,

- templates,

- custom controls and

- database managers.

When using Visual Basic, the most important skill every one needs is to be comfortable with using the development environment. Without the integrated tools in the environment, Visual Basic programming would be less flexible and much more difficult. All design would need to be done on graph paper and flow charts, and it would need to be typed in line by line. Fortunately, Visual Basic contains many integrated tools to make the application development process simpler. This collection of tools makes up the integrated Development Environment (IDE)

Visual Basic has been also specifically designed to utilise the internet. It comes with several controls that allow us to create Web-based applications, called Active X executables. Using this new style of application, we can revise our existing Visual Basic applications and distribute them through the Internet.

Also, Visual Basic continues to provide the Explorer-style development environment, modelled after Windows Explorer. This characteristic makes easy for a computer user to jump right into creating applications with Visual Basic. Almost all the objects and tools on screen can be manipulated through a right-click. Therefore, it is possible for some one to set properties, add controls, and even view context-sensitive help with this single action.

A.2. Visual Basic environment

When we start Visual Basic for the first time, the Project Wizard will open, and we will notice the New Project dialog box (Fig. 1). According to this window it is possible for someone to select from several types of projects that will give him/her a head start on developing his or her applications. This window has three tabs:

- New

- Existing and

- Recent.

The Existing tab allows us to select an existing project. This could be a sample project included with Visual Basic, or it could be a project we have worked in the past. The Recent tab allows us to select from the most recently used projects. This tab is similar to the existing tab, but when it is chosen, it presents a list of the existing projects, which we have worked on recently, instead of all of the existing projects.
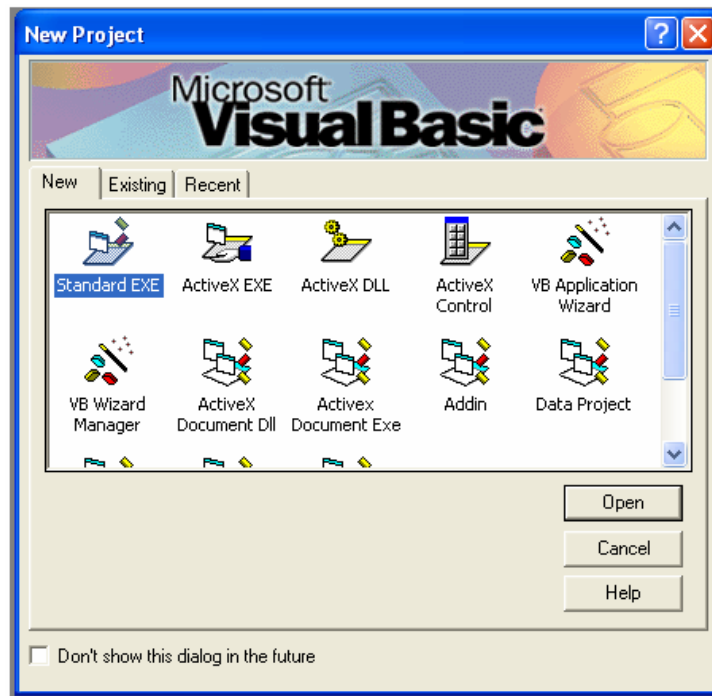
Fig. 1 The New Project dialog box

By selecting a project template from the New tab, we let Visual Basic create the foundation of our application. This can save us a lot of time designing an application. The New tab present us with several project templates:

❑ Standard EXE

❑ ActiveX EXE

❑ ActiveX DLL

❑ ActiveX Control

❑ VB Wizard Manager

❑ Data Project

❑ IIS Application

❑ Add-In

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❑ ActiveX Document DLL

❑ ActiveX Document EXE

❑ DHTML Application

❑ VB Enterprise Edition Controls

We can use any of these tabs to help getting started on a project in Visual Basic.

A.3. Learning the IDE features

Now let's take a close look at the Visual Basic Integrated Development Environment (IDE). Behind the Project Wizard window lies the IDE (Fig. 2). The IDE is an important part of Visual Basic; it is the environment where we spend most of the time creating the appropriate applications. IDE is a term commonly used in the programming world to describe the interface and environment we use to create our applications. It is called integrated because we can access virtually all of the development tools we need from one screen, called an interface. The IDE is also used commonly referred to as the design environment, the program or just the IDE.

The visual Basic IDE is made up of a number of components:

➢ Menu Bar

➢ Toolbar

➢ Project Explorer

➢ Properties window

➢ Form Layout window

➢ Toolbox

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> ➢ Form Designer
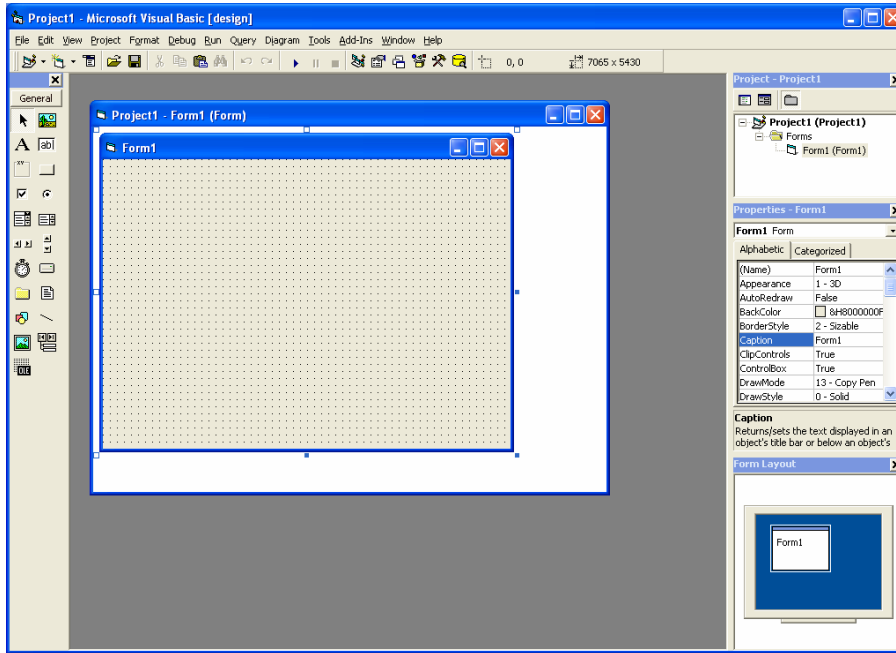
Fig. 2 Visual Basic's Integrated Development Enviroment (IDE)

It is important for anyone to get familiarised with IDE before jumping into coding without becoming comfortable with the Integrated Developing Environment.

A.4. The Menu Bar

The menu bar is the line of text that lies across the top of the Visual Basic window (Fig. 3). It is very much like menus, which have seen in other Windows applications. This menu gives access to many features within the development environment.
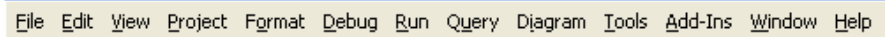
Fig. 3: The Menu Bar

The first on the left is the File menu. From this menu someone can work with actual files that make up the applications. It is possible to create, open print and save projects. Next to file is the Edit menu. From here it is possible for a person to use the functions to store controls as well as code. In addition it is possible for someone to have access to the Find facilities in the IDE. Using this menu it is possible the search for text throughout a procedure, a module, or an entire project.

From the View menu we can view various components and tools. We can view a form and a code module, as well as other utilities that help make our development time more productive.

The Project menu is the heart of our project. From here we can add to and remove forms, code modules, user controls property pages as well as ActiveX designers from our projects. In addition we can add and remove custom controls and OLE (Object Linking and Embedding) references. Right-clicking the Toolbox or Project Explorer can access many of these menu options. The options on the Format menu deal specially with the size and placement of controls and forms.

When we are debugging our applications, you will become very familiar with the Debug menu. From here we can start and stop our applications, set watches and breakpoints, and perform other tasks to help monitor our application's progress. Using Run menu it is possible for someone to start and stop applications, as well as break in the middle of program's execution and then start again. Break and Resume are handy when it comes time to debug.

The next two menus, Query and Diagram are new and have been introduced to Visual Basic 6. The commands in Query menu simplify the creation of SQL (Structured Query Language) queries. The Diagram menu is used for building database applications. It especially helps when editing database diagrams.

From the Tools menu we can add procedures and set procedure properties. In addition we can access the Menu Editor. It is also possible for someone to choose Options from the Tools menu to set preferences for IDE.

The Add-Ins menu contains additional utilities called Add-Ins. By default we should have an option for Visual Data Manager and another for the Add-In Manager. Visual Data Manager is a simple but useful tool that allows us to design and populate a database in many popular formats, including Microsoft Access. The Add-In Manager allows us to select other Add-In utilities to be added to the Add-Ins menu.

The Window menu gives us options to tile and cascade windows within the IDE. We can also arrange the icons for minimized forms. However, perhaps the most important option is the window list at the bottom of the menu. This list allows us to quickly access open windows in the IDE. Finally, the Help menu is an assistant one for more information concerning the applications.

A.5. The toolbar

Immediately below the menu bar lies the Visual Basic tool bar (Fig. 4). In case that the user can not see the toolbar, the sequence to follow for its appearance is: View►Toolbars►Standard.

It is possible to control the whole Visual Basic environment from the menu bar, but the toolbar gives easy access to the menu-bar commands, which will be used more frequently. It would be noticed that when moving the mouse over the buttons they appear to raise themselves up from the toolbar.

Fig. 4 The Visual Basic toolbar

The available buttons of the toolbar together with their function are given on Table 1.

TABLE 1: Toolbar buttons

Button	Title/Function
	Add Standard EXE: it adds a Standard EXE project.
	Add Form: It adds a new form in the project
	Menu Editor: It starts the Menu Editor.
	Open Project: It opens an existing project.
	Save Project: It saves the entire project.
	Cut: It is used during Code Editor for cutting part of the project

		Copy: It is used to copy part of the code.
		Paste: It is used to paste a part into the code.
		Find: It is used to find characters or line of characters
		Undo: It is used to cancel the last functions
		Redo: It is used to bring back the part which has been cancelled.
		Start: It is used to start the existing project
		Break: It is used to stop the execution of a project in order to be checked for existing errors.
		End: It stops the execution of a project
		Project explorer: The project explorer window appears on the screen.
		Properties Window: The Properties Window appears on the screen.
		Form Layout Window: The Form Layout window appears on the screen.
		Object Browser: The Object Browser window appears on the screen.
		Toolbox: The Toolbox appears on the screen.
		Data view Window: A window for all databases appears on the screen.

It is possible to move some buttons around on the Visual Basic toolbar in order to make them more easily accessible. Also, in case that the toolbar does not contain the necessary shortcuts or it is necessary for someone to add another menu item, then it is possible to customise further by selecting the appropriate Commands tab.

A.6. The Project Explorer

On the right side of the screen, just under the tool bar, is the Project Explorer window (Fig. 5). The Project Explorer is a quick reference to the various elements-forms, classes and modules- of a project.
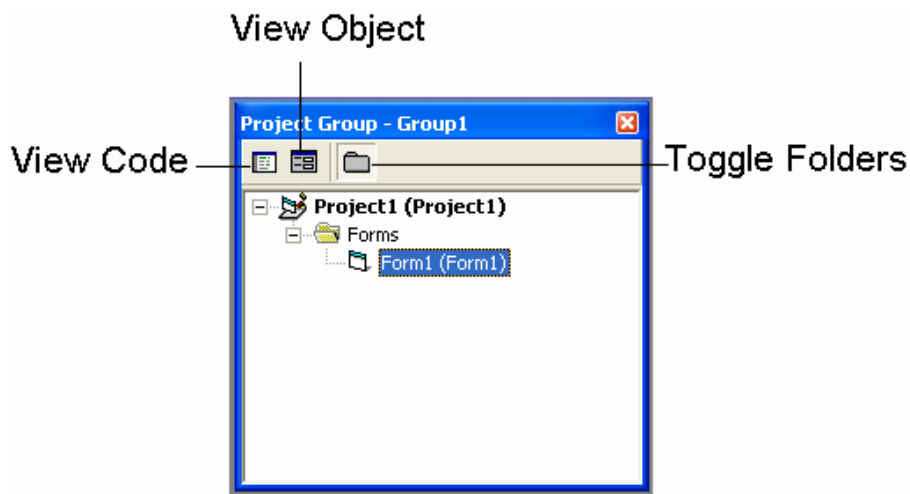
Fig.5 The Project Explorer window

The Project Explorer window is much like Window Explorer in that it allows us to expand and collapse the subfolders. All of the objects that make up our application are packaged in a project. If we save it for later use, testing, debugging, or improvement, Visual Basic provides the default file extension. A simple project will typically contain one form, which is the window used by our application. In addition to forms, the Project Explorer window also lists

code modules and classes. Larger applications will often have a number of forms, modules and classes.

To view a form, it is necessary to select it in the Project Explorer and then click View Object button. Any code associated with the form can be viewed in its own window by clicking the View Code button. If we right-click in the Project Explorer, we are presented with a pop-up menu that offers many options specific to that particular window. For instance, we can add, remove, and print forms and code modulus from the pop-up menu. If we want to remove an object from our project, right-click the name of the object in the Project Explorer window and we select Remove. The name of the control will be listed after the Remove command.

A.7. The Properties Window

Right under the Project Explorer window is the Properties window. The Properties window exposes the various characteristics or properties of the selected objects. To clarify this concept, consider that each and every form in an application is an object. Each and every control (a command button, for example) that appears on a form is also an object. Now, each object in Visual basic has characteristics such as colour and size. Other characteristics affect not just the appearance of an object but the way it behaves, too. All these characteristics of an object are called the properties. Thus, a form has properties and any controls placed on the form have properties too. All of these properties are displayed in the Properties window (Fig. 6).

In the Properties window, we will see a list of the properties belonging to an object. There are quite a few of them, and we may have to scroll to see them

all. Fortunately, many of the properties are self –explanatory (Caption, Height, Width and so on), but some of the others are rarely used. If we are not sure what a specific property does, we can highlight it and look at the brief description at the bottom of the Properties window. Besides scrolling to view properties, we can also view properties either alphabetically or by category, by clicking the appropriate tab. Whichever method we use is a matter of preference.
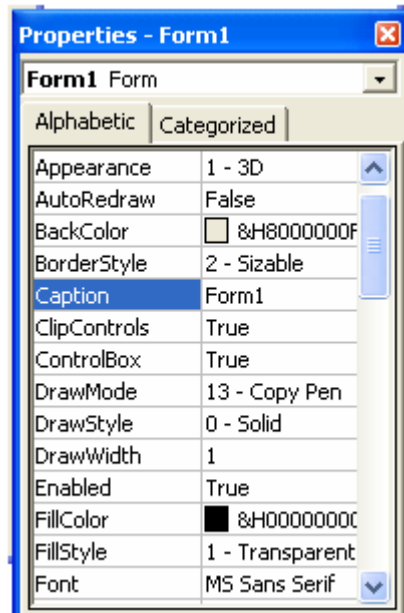
Fig. 6 The Properties window

When a control such as a command button, for example, is put on a form, the properties window shows the properties for that control when it is selected. We can see the properties for different objects, including the underlying form, by clicking each object in turn. Alternatively, we can use the drop-down list at the top of the Properties window to select the control and display its properties. Most properties are set at design time, although many can be changed at run time.

Most of the time, properties are set directly from the Properties window when we are creating an application. When we are working in the IDE, it is referred to as working in "design time" because we are still designing our program. Sometimes we need to change properties while a program runs. We may want to disable a command button, for example. We can do this by writing a code that changes the property. This is done at "run time", when our program is actually running.

The way to change a property setting depends on the range and type of values it can hold. Since the Visual Basic IDE is a visual environment, we will set most properties at design time. This technique saves us time by not requiring us to write the code to achieve the same results. Below are some of the most common types of properties:

- ❑ Boolean Value Properties

- ❑ Predefined Value Properties (it is also called enumerated list)

- ❑ String Value properties (when it is required text)

- ❑ Hexadecimal Value Properties

- ❑ Filename Properties

- ❑ Size Properties

A.8. The Form Layout Window

The Form Layout window is a simple but useful tool (Fig. 7). It appears at the bottom left side of the IDE window. Its purpose is to simply give us an overall view of the current form, show us what it looks like and how it is positioned on the screen at run time. The Form Layout window can be removed from its initial position, it can be increased in size or it can be closed. It can also appear again by the tab View from Menu Bar.

The Form Layout window is useful for determining what screen space our form will use when our application is running. To use the Form Layout window, it is necessary to do the following:

1. Click the form in the form Layout window and move it to the centre of the monitor graphic in the middle of the window.
2. Run the program by selecting Run►Start.
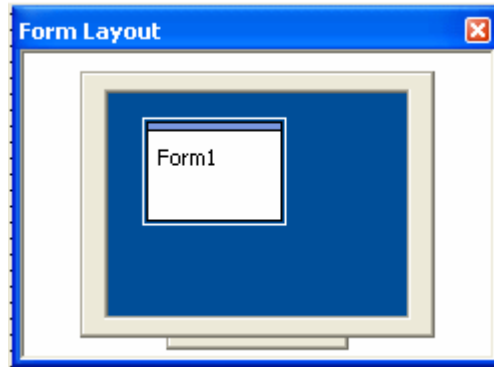
Fig. 7 The Form Layout window

A.9. The Toolbox

As the name implies, the Toolbox contains the bits and pieces we need to build our application interface. All the tools shown in Figure 8, with the exception of the pointer at the top left, correspond to the objects, or items, we might want to place on a form in our application. These tools or objects are referred to as Controls. Most of them are part of Visual Basic and are called build-in or standard controls. Depending on Visual Basic set-up, there may be a few more controls in the Toolbox. Table 2 presents analytically each one of the tools.

The Toolbox is more or less the same for most of the Visual Basic versions. It allows us to define tabs, which we can then use to organise our controls. To remove a control, we simply turn off the appropriate check box in the Custom Controls dialog box. It is important to know that we can't add or remove the build-in controls from the Toolbox, so controls such as command button will always be present.

Fig. 8 The Visual Basic Toolbox with the custom controls

TABLE 2: Toolbar buttons

Control/Button	Title/ Function
	Pointer: It can be used when it is necessary to move a control or to add another control.

	Picture Box: It is similar to image controls. It often displays graphs, e.g. bitmaps, icons, JPEGs and GIFs.
	Label control: It is similar to a text box control where a Caption is displaced.
	Text box: It is commonly used for accepting user input or for entering data. Nearly every Visual Basic project involves at least one text box control.
	Frame control: It is not particularly useful. The controls normally placed in a frame are option buttons and check boxes. It has the effect of grouping them together so that when the frame is moved, the other controls move too.
	Command button: It is one of the most common controls found in windows application. It can be used to elicit simple responses from the user or to invoke special functions on forms.
	Check box: It is rather similar to option button, below.
	Option button: It is also called radio button, and is used to allow the user to select one, and only one, option from a group of options.
	Combo box: The name comes from "combination box". It combines the features of both a text box and a list box.
	List box: It is an ideal way of presenting users with a list of data.
	Horizontal scroll bar: It is typically used to increase or decrease a value.
	Vertical scroll bar: The function is similar to Horizontal scroll bar.

	Timer control: It is one of the few controls always hidden at run time. It checks the system clock and acts accordingly.
	Drive list: It is normally used in conjunction with the directory list and the file list controls. It allows the user to select a file in a particular directory on a particular drive.
	Directory list box: It is used in conjunction with the drive control and file control. The user can select a directory on the current drive from the directory list.
	File list box: This comes at the end of the drive-directory-file chain. It is used to list the actual filenames that are in the directory specified by the Path property.
	Shape object: It is used for object drawing.
	Line object: It is used for drawing lines.
	Image object: It is another equivalent to the picture box control. But unlike the picture control, the image control can't act as a container for other objects.
	Data control: It is used for connection with a database.
	OLE control: It is used for OLE (Object Linking and Embedding) references.

A.10. The Form Designer

In the centre of the screen there is the Former Designer. This is the workspace where we actually design the visual layout of the form and the controls that lie on it. It is basically a window that we can add different elements to in order to create a complete application. Every application we can see on the screen is based on some type of form.

In the Visual Basic IDE, we will see either one form at a time, or the Code window. The Code window is discussed later in this chapter. To create a new form, we open Visual Basic and select File ► New Project ► Standard EXE; we will see the various parts of a single form object, as shown in Fig. 9. It is seen from Fig. 9 that the form has little black dots in the centre of each side. These boxes are called anchors. We can drag an anchor with the mouse to resize the form. If we increase the size of the Form over the Project Explorer and Properties windows then it will lie under the Project Explorer and Properties windows. We can use scroll bars at the right and bottom of the Form Designer to uncover the hidden portion of the form.
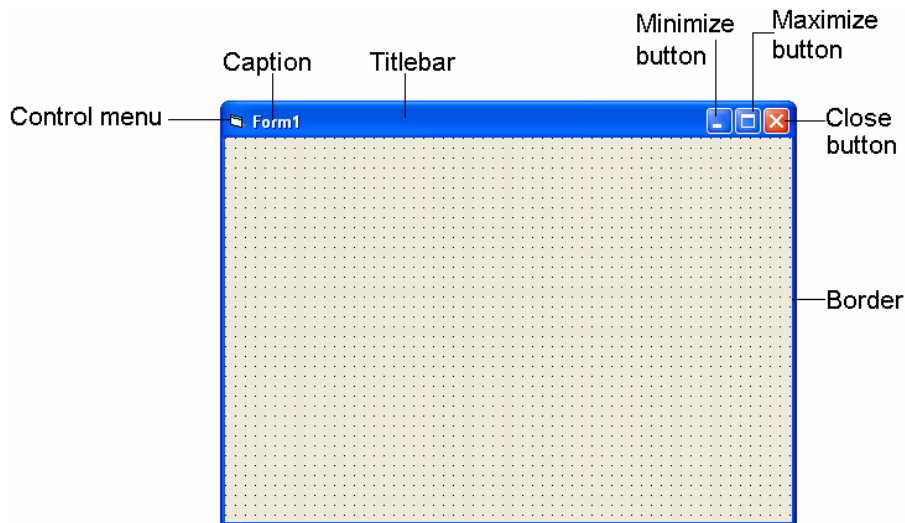
Fig. 9 The Form Designer

On each form there are the following elements:

- **The border:** The form's border is what gives the form its elasticity. Depending on the type of form we want to display, we can program the border to be fixed, sizable or even nonexistent. These features can be set with the Border-Style property.

- **The Title Bar:** The title bar is the coloured bar on the top of most forms. If owr desktop colour scheme is set to Windows default scheme, this bar will be blue. We can use the title bar to drag the window around the screen. In addition, double-clicking it will alternately maximize and restore the form.

- **The Caption:** The form's caption is the next we see in the form's title bar. It can be used to identify the name of the application, the current function of form or as a status bar. What we put in the caption depends on what our program is trying to achieve.

- **The Control Menu:** This is a simple menu that allows us to restore, move, resize, minimize, maximize and close a form. To enable this button on our form, we set the form's Control Box property to True in the form's Properties window.

- **The Minimize Button:** This is used to minimize the current form that is, move it out of the way, to the Windows Taskbar. To enable this button on our form, we set the form's MinButton property to True in the form's Properties window.

- **The Maximize Button:** The maximize button has two purposes. If the form is in its normal size, we can click the Maximize button to automatically expend the current form to the size of the screen or container of the form. A form's container is also known as Multiple Document Interface (MDI) form. If the form is maximised, we can click this button again to restore the form to its original size. To

enable this button on our form, we set the form's MaxButton property to True in the properties window.

❑ **The Close Button:** Its purpose is to close the current window. In Visual Basic we can control whether the Close button is visible to the user with the Control Box property. The Close button will not be visible if the Control box is not visible.

A.11. Working on Form Designer

The different controls are placed on the Form Designer in two ways. The simplest way is by double-click on the required "control" and it is automatically transferred to the form. The other way is by a single click on the "control", then we place the pointer of the mouse on the position of the form requiring setting and while we are pressing the left button of the mouse we drag the mouse to the required dimensions. When we are changing the control dimensions, a set of numbers appears, which define the size in twips. To verify our example let us put the "Label Control" on the top left part of the form and we can change its dimensions using the mouse. The form with "Label Control" will be according to Fig. 10. At the bottom there is a set of numbers, which define the size of the control in twips.
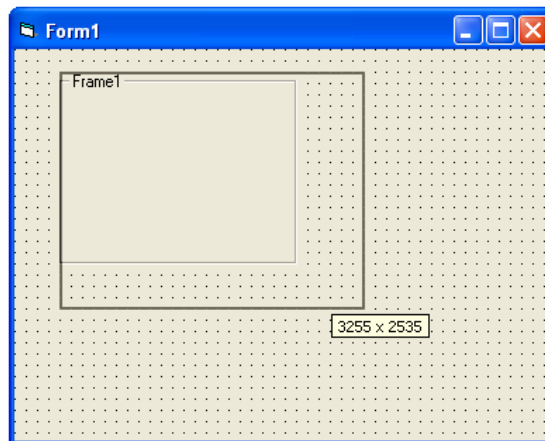
Fig. 10 Placing Label Control on the form

It is possible to change the title of the Label using the Properties Window. To do so it is therefore necessary to have the appropriate command, which is lbl in front of the name. Thus, we give the name lblTest to this Control. This command is shown on Fig. 11. Now we have to change the Caption property. This property defines the Label Control, which will appeal on the form. We assume that we want to write, "Welcome to Visual Basic". This can be done simply by putting this sentence as a value of Caption property. It is possible also in a similar way to change fonts, style and size of letters.
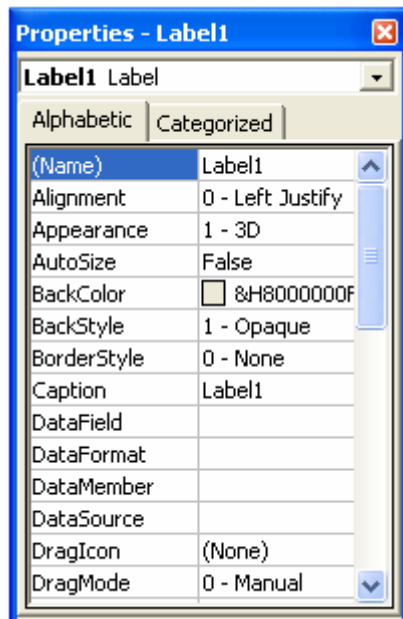
Fig. 11 Change property Name

The result of our trial is shown in Fig. 12. Apart from the changes that will take place on the Property Window, it is also necessary to develop the appropriate Code, which will give real meaning to the whole application.

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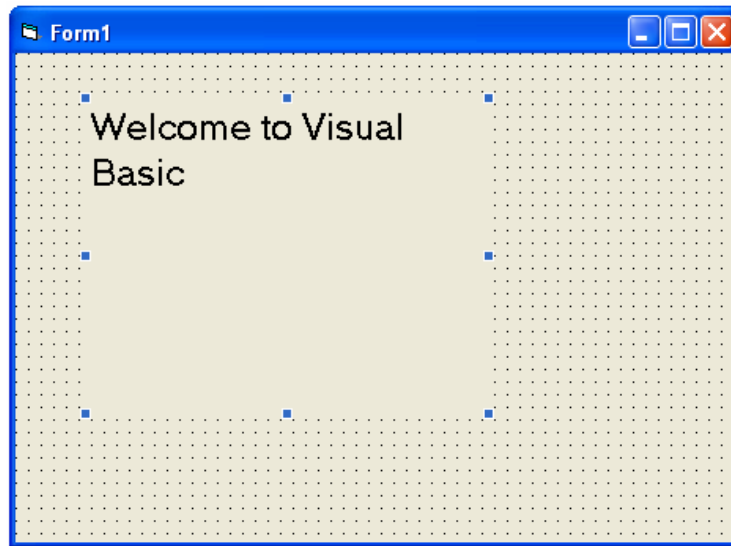
Fig. 12 The final appearance of the form

A.12. Code Window

In Visual Basic, the editor is called the "Code Window". It is actually a turbo-charged text editor with many productivity tools built in. This is the window where we will do most of our work. We can open the Code window by double-clicking a form or control in the Form Layout window. If we double-click a form, we will be taken to a procedure for the form. Open the form by double-clicking in the Project explorer window, or select View Code button in the Project Explorer. If we double-click a control, we will be taken to a procedure for that control. Once the Code window is open we can go to any procedure for any object on the selected form (Fig. 13). A procedure is a collection of lines of codes that are grouped together to perform a set of related tasks.

The Code window contains two lines of codes. The first one has a combination of the object name and the event or default event (Form_Load()). On this command the word Load() is an event, which takes place when loading the form. In the case that we want to change Load() event with Click() event, therefore the first line will become: Private Sub Form_Click(). This means that it will be activated by click of the mouse.
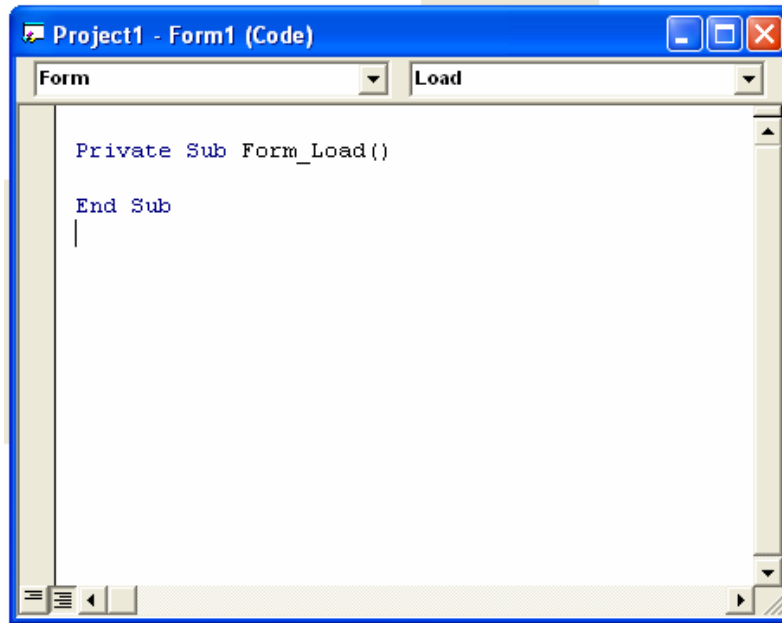
Fig. 13 Code window

Last is the line "End Sud" which defines the end of the procedure. It is also necessary between these two code lines to add the appropriate code that will give meaning to the whole project. Depending on how we set our IDE options, we can have our Code window display multiple procedures at one time.

A.13. Visual Basic project

Every procedure in Visual Basic is defined and saved as a project. A project consists of files, which contain modulus (codes), objects and a reference file, which contains the ending .vbp. Therefore, we can say that a project contains a combination of objects and guidance instructions for the behaviour of the objects.

Every project has one file, which has .vbp ending and at least one file that is connected to the project with ending .frm. If the Form contains pictures, apart from the file with ending .frm, it is necessary to have one more binary file with an .frx ending. Table 3 shows different types of files, which can be used in a project.

TABLE 3: Visual Basic type of files

File type	Ending	Description
Basic Module	.bas	To save every module code
Class Module	.cls	To save every class module
Form Module	.frm	To save every form
Binary	.frx	To save icons
log	.log	Saving file for miss loading
Resource	.res	File for saving binary and numerical data
Project	.vbp	To save the project
Workspace	.vbw	To save the working area

A.14. Creating a simple Visual Basic project

In order to create a project using Visual Basic programming language it is necessary to follow a number of steps. These steps have the following order:

- A. Defining the project task

- B. Creating of the visual layout or the interface

- C. Developing the logic behind the code

- D. Project verification

Let us assume that we want to create a project, which will appear on the visual layout the title "Hello World!". Therefore, we have to follow the above sequences.

A. Define the project task

In this case the project task is a simple one. We want the words "Hello World!" to appear on the top part of the Form and the application to be terminate by pressing a button on the lower part of the form.

B. Creation of the visual layout or the interface

In order to develop the appropriate visual layout environment it is necessary to load the Visual Basic Integrated Development Environment (IDE) as show on Fig. 2. Afterwards, we have to decide which tools are required. Therefore, for writing the words "Hello World!" it is necessary to use the Tool "Label" and the Tool "Command Button" to stop the application.

Now to create this application it is necessary to follow these steps:

1. Click File ► New Project

2. If it is not already visible, open the Form Layout window by selecting View ► Form Layout Window.

3. Double-click the Label control in the toolbox to create the label on the form. Drag the label so it sits just below the top of the form. Resize the label so it is roughly the height of one line of text and wide enough to contain the text "Hello World!".

4. Double-click the Command Button control in the toolbox to create a command button of default size in the centre of the form. Drag the button near the bottom centre of the form. Our form should now look similar to the one shown on Fig. 14.
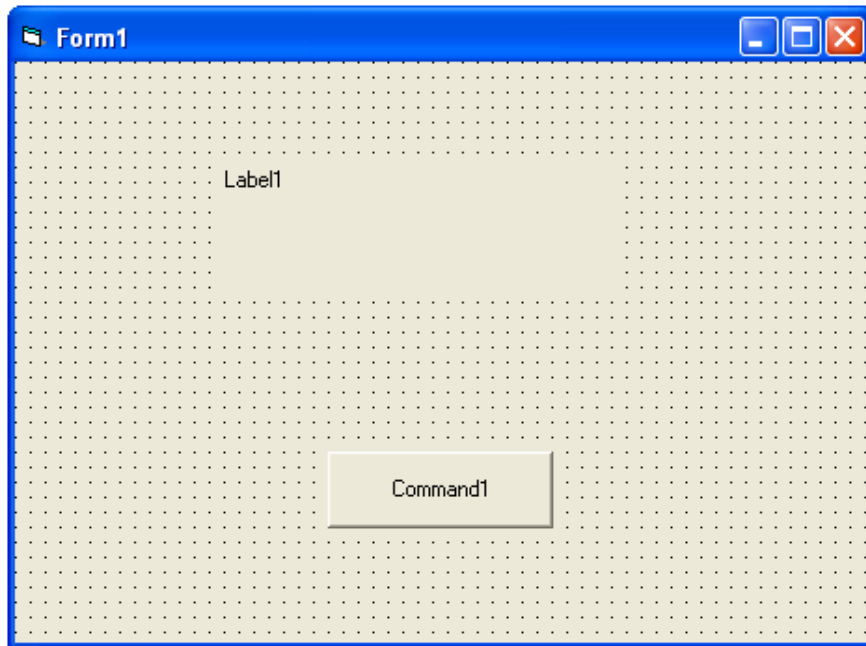
Fig. 14 Apperance of the Form

5. Now, click the form once to select it. We can tell that the form, as opposed to any of the controls, is selected because its properties are listed in the Properties window.

6. Set the following two properties for the form by typing in the text under the setting column in the appropriate property field:

Property	Setting
Name	FrmWorld
Caption	First Application

7. Now, click the label and set the next two properties:

Property	Setting
Name	lblWorld
Caption	Hello World!

8. Click the Command button and set its properties as follows:

Property	Setting
Name	cmdExit
Caption	Exit

This time the Caption property appears as the text on the button.

C. Developing the logic behind the code

Once we have finished with the program of the visual layout environment, the next move is the development of the logic using the appropriate code. In order to develop the code for the above Form it is necessary to follow the next steps:

1. Double-click the cmdExit button. Double-clicking a control, or a form, opens the Code window at the default event for the control. The default event for a command button is the Click() event. This is seen in the code window Fig. 15. The Private Sub is a prefix, the important point is the name of the procedure which is: cmdExit. This

means that any code entered in the procedure will be executed when the user clicks the cmdExit button.

2. Type the following line of code between the Private Sub and End Sub lines. Here, the only command that we type is the word "End". When the user clicks the cmdHelloWorld! button, the cmdExit_Click() event occurs. This event tells the form to unload itself, because this is the only form in the application. It also tells the application to end.
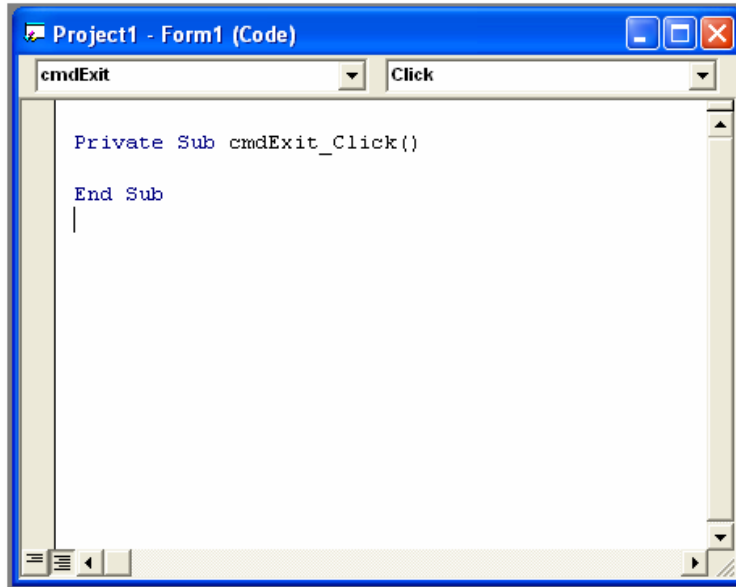
Fig. 15 The procedure in the Code window

D. Project verification

As soon as we finish with code, it is necessary to verify the procedure of the project. The present example is a simple project, thus it is not of vital importance to verify its correct operation. Finally, it is necessary to save the project by following the steps:

1. Click File ► Save Project. Enter World.frm as the name of the form and World.vbp as the name of the project.

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2. Click Run ► Start. We can see a form similar to the one in Fig. 16, which simply says "Hello World!".

3. Click the Exit button to end terminate the application.

Fig. 16 First application Hello World!

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[A.3] Dimopoulos K., Applications Visual Basic 6 (Dromon 2002).

[A.4] Balena F., Programming Microsoft Visual Basic 6 (Microsoft Press 1999).

[A.5] Perry G., Sams Teach Yourself Visual Basic 6 in 21 Days (Macmillan Computer Publishing 1998).

[A.6] Holzner S., Visual Basic 6 Black Book (The Coriolis Group 1998).

PROGRAMMING CODES

frmMain (Form1.frm)

```
Private Sub Form_Load()
Form2.Hide
Form3.Hide
Form4.Hide
Form5.Hide
Form6.Hide
Form7.Hide
Form8.Hide
Form9.Hide
Form10.Hide
End Sub

Private Sub Image1_Click()
q = frmMain.Left
w = frmMain.Top
Unload frmMain
Form2.Show
End Sub
```

Form2 (Form2.frm)

```
Private Sub Command1_Click()
q = Form2.Left
w = Form2.Top
Unload Form2
Form3.Show
End Sub

Private Sub Form_activate()
Form2.Left = q
Form2.Top = w
End Sub
```

Form3 (Form3.frm)

```
Private Sub Command1_Click()
```

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```
Dim Msg2 As String
q = Form3.Left
w = Form3.Top
If Option1.Value = True Then
cotton = True
Form3.Hide
Form4.Show
ElseIf Option2.Value = True Then
wool = True
Form3.Hide
Form4.Show
ElseIf Option3.Value = True Then
cm = True
Unload Form3
Form4.Show
ElseIf Option4.Value = True Then
wm = True
Unload Form3
Form4.Show
ElseIf Option5.Value = True Then
'ccy = True
Msg2 = MsgBox("No data available.", 0, "proKNIT System")
ElseIf Option6.Value = True Then
'wcy = True
Msg2 = MsgBox("No data available.", 0, "proKNIT System")
ElseIf Option7.Value = True Then
'ccm = True
Msg2 = MsgBox("No data available.", 0, "proKNIT System")
ElseIf Option8.Value = True Then
wcm = True
Unload Form3
Form4.Show
Else
Dim Msg1 As String
Msg1 = MsgBox("Please make a selection.", 32, "proKNIT System")
End If
End Sub

Private Sub Form_activate()
Form3.Left = q
Form3.Top = w
Option1.Value = False
Option2.Value = False
Option3.Value = False
Option4.Value = False
Option5.Value = False
Option6.Value = False
Option7.Value = False
```

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```
Option8.Value = False
End Sub
```

Form4 (Form4.frm)

```
Private Sub Command1_Click()
q = Form4.Left
w = Form4.Top
If Option1.Value = True Then
fab = 10630
doub = 1
sjplain = True
fabtype = "Single Jersey Plain Knit"
Unload Form4
Form5.Show
ElseIf Option2.Value = True Then
fab = 10630
doub = 1
sjpurl = True
fabtype = "Single Jersey Purl Knit 1x1"
Unload Form4
Form5.Show
ElseIf Option3.Value = True Then
fab = 8860
doub = 2
djrib = True
fabtype = "Double Jersey 1x1 Rib"
Unload Form4
Form5.Show
ElseIf Option4.Value = True Then
fab = 8860
doub = 2
dkrib = True
fabtype = "Double Knit 2x2 Rib"
Unload Form4
Form5.Show
ElseIf Option5.Value = True Then
fab = 8860
doub = 2
dkinter = True
fabtype = "Double Knit Interlock"
Unload Form4
```

```
Form5.Show
Else
Dim Msg1 As String
Msg1 = MsgBox("Please make a selection.", 32, "proKNIT System")
End If
End Sub

Private Sub Command2_Click()
cotton = False
wool = False
cm = False
wm = False
ccy = False
wcy = False
ccm = False
wcm = False
Unload Form4
Form3.Show
End Sub

Public Sub Form_Load()
Form4.Left = q
Form4.Top = w
Option1.Value = False
Option2.Value = False
Option3.Value = False
Option4.Value = False
Option5.Value = False
End Sub

Private Sub Image1_Click()
Img1.Show
End Sub

Private Sub Image2_Click()
Img2.Show
End Sub

Private Sub Image3_Click()
Img3.Show
End Sub

Private Sub Image4_Click()
Img4.Show
End Sub

Private Sub Image5_Click()
Img5.Show
```

End Sub

Form5 (Form5.frm)

```vb
Private Sub Command1_Click()
est = Val(Text2.Text)
If Text2.Text = "" Then
Dim msg5 As Integer
msg5 = MsgBox("Please make a selection.", vbOKOnly, "proKNIT System")
Else
Dim Msg2 As Integer
Dim msg3 As Single
Dim msg4 As Single
Msg2 = MsgBox("Do you wish to keep the estimated Yarn Count?", 36, "proKNIT
System")
   If Msg2 = 7 Then
      msg3 = InputBox("Enter new Yarn Count:", "proKNIT System", est)
      If msg3 > y Then
      msg4 = MsgBox("The value you have entered is not valid.", vbOKOnly,
"proKNIT System")
      ElseIf msg3 < x Then
      msg4 = MsgBox("The value you have entered is not valid.", vbOKOnly,
"proKNIT System")
      ElseIf StrPtr(msg3) = 0 Then
      MsgBox "!"
      Else
      Tex = msg3
      gau = Val(Text1.Text)
      Unload Form5
      Form6.Show
      End If
   Else
   Tex = Val(Text2.Text)
   gau = Val(Text1.Text)
   Unload Form5
   Form6.Show
   End If
End If
End Sub

Private Sub Command2_Click()

fab = 0
sjplain = False
sjpurl = False
djrib = False
```

```
dkrib = False
dkinter = False
Unload Form5
Form4.Show
End Sub

Private Sub Form_Load()
Form5.Left = q
Form5.Top = w
Dim est As Single

Option1.Value = False
Option2.Value = False
Option3.Value = False
Option4.Value = False
Option5.Value = False
Option6.Value = False
Option7.Value = False
Option8.Value = False
Option9.Value = False
Option10.Value = False
Option11.Value = False
Option12.Value = False
Option13.Value = False
Option14.Value = False
Option15.Value = False
Option16.Value = False
Option17.Value = False
Option18.Value = False
Option19.Value = False
End Sub

Private Sub Option1_Click()
Text1.Text = Option1.Caption
Text2.Text = Format(fab / 4 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 248 - 680"
x = 248
y = 680
Else
Text3.Text = "Tex 413 - 590"
x = 413
y = 590
End If
End Sub

Private Sub Option10_Click()
Text1.Text = Option10.Caption
```

```
Text2.Text = Format(fab / 15 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 36 - 56"
x = 36
y = 56
Else
Text3.Text = "Tex 31 - 42"
x = 31
y = 42
End If
End Sub

Private Sub Option11_Click()
Text1.Text = Option11.Caption
Text2.Text = Format(fab / 16 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 31 - 50"
x = 31
y = 50
Else
Text3.Text = "Tex 27 - 37"
x = 27
y = 37
End If
End Sub

Private Sub Option12_Click()
Text1.Text = Option12.Caption
Text2.Text = Format(fab / 18 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 25 - 42"
x = 25
y = 42
Else
Text3.Text = "Tex 25 - 28"
x = 25
y = 28
End If
End Sub

Private Sub Option13_Click()
Text1.Text = Option13.Caption
Text2.Text = Format(fab / 20 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 23 - 33"
x = 23
y = 33
Else
```

```
Text3.Text = "Tex 20 - 25"
x = 20
y = 25
End If
End Sub

Private Sub Option14_Click()
Text1.Text = Option14.Caption
Text2.Text = Format(fab / 22 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 20 - 28"
x = 20
y = 28
Else
Text3.Text = "Tex 17 - 21"
x = 17
y = 21
End If
End Sub

Private Sub Option15_Click()
Text1.Text = Option15.Caption
Text2.Text = Format(fab / 24 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 17 - 25"
x = 17
y = 25
Else
Text3.Text = "Tex 14 - 18"
x = 14
y = 18
End If
End Sub

Private Sub Option16_Click()
Text1.Text = Option16.Caption
Text2.Text = Format(fab / 26 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 14 - 23"
x = 14
y = 23
Else
Text3.Text = "Tex 12 - 17"
x = 12
y = 17
End If
End Sub
```

```
Private Sub Option17_Click()
Text1.Text = Option17.Caption
Text2.Text = Format(fab / 28 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 12 - 20"
x = 12
y = 20
Else
Text3.Text = "Tex 11 - 14"
x = 11
y = 14
End If
End Sub

Private Sub Option18_Click()
Text1.Text = Option18.Caption
Text2.Text = Format(fab / 30 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 8 - 17"
x = 8
y = 17
Else
Text3.Text = "Tex 10 - 12"
x = 10
y = 12
End If
End Sub

Private Sub Option19_Click()
Text1.Text = Option19.Caption
Text2.Text = Format(fab / 32 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 7 - 14"
x = 7
y = 14
Else
Text3.Text = "Tex 8 - 11"
x = 8
y = 11
End If
End Sub

Private Sub Option2_Click()
Text1.Text = Option2.Caption
Text2.Text = Format(fab / 4.5 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 205 - 547"
x = 205
```

```
y = 547
Else
Text3.Text = "Tex 354 - 472"
x = 354
y = 472
End If
End Sub

Private Sub Option3_Click()
Text1.Text = Option3.Caption
Text2.Text = Format(fab / 5 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 169 - 500"
x = 169
y = 500
Else
Text3.Text = "Tex 295 - 413"
x = 295
x = 413
End If
End Sub

Private Sub Option4_Click()
Text1.Text = Option4.Caption
Text2.Text = Format(fab / 6 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 124 - 338"
x = 124
y = 338
Else
Text3.Text = "Tex 180 - 270"
x = 180
y = 270
End If
End Sub

Private Sub Option5_Click()
Text1.Text = Option5.Caption
Text2.Text = Format(fab / 7 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 100 - 260"
x = 100
y = 260
Else
Text3.Text = "Tex 150 - 260"
x = 150
y = 260
End If
```

```
End Sub

Private Sub Option6_Click()
Text1.Text = Option6.Caption
Text2.Text = Format(fab / 8 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 84 - 169"
x = 84
y = 169
Else
Text3.Text = "Tex 120 -180"
x = 120
y = 180
End If
End Sub

Private Sub Option7_Click()
Text1.Text = Option7.Caption
Text2.Text = Format(fab / 10 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 56-113"
x = 56
y = 113
Else
Text3.Text = "Tex 60 - 120"
x = 60
y = 120
End If
End Sub

Private Sub Option8_Click()
Text1.Text = Option8.Caption
Text2.Text = Format(fab / 12 ^ 2, "###")
If fab = 10630 Then
Text3.Text = "Tex 49 - 84"
x = 49
y = 84
Else
Text3.Text = "Tex 45 - 75"
x = 45
y = 75
End If
End Sub

Private Sub Option9_Click()
Text1.Text = Option9.Caption
Text2.Text = Format(fab / 14 ^ 2, "###")
If fab = 10630 Then
```

```
Text3.Text = "Tex 42 - 72"
x = 42
y = 72
Else
Text3.Text = "Tex 36 - 49"
x = 36
y = 49
End If
End Sub
```

Form6 (Form6.frm)

```
Private Sub Command1_Click()
If Option1.Value = True Then
mm = 10
Else
mm = 1
End If
Unload Form6
Form7.Show
End Sub

Private Sub Command2_Click()
Dim Msg2 As Integer
kf = Val(Text1.Text)
If kf < test1 Then
Msg2 = MsgBox("The value you have entered is not valid.", vbOKOnly, "proKNIT
System")
ElseIf kf > test2 Then
Msg2 = MsgBox("The value you have entered is not valid.", vbOKOnly, "proKNIT
System")
Else
kf = Val(Text1.Text)
Label6.Visible = True
Text2.Visible = True
Label6.Caption = "The value of loop length (l) is"
el = (Sqr(Tex) / kf)
Text2.Text = Format(el, "#0.00")
Label8.Caption = el
Command1.Visible = True
End If
End Sub

Private Sub Command3_Click()
```

```
el = 0
kf = 0
Unload Form6
Form5.Show
End Sub

Private Sub Form_Load()
Option1.Value = False
Option2.Value = False
Dim a As Single
Dim b As Single
Label1.Caption = ""
Label2.Caption = ""
Label3.Caption = ""
Label4.Visible = False
Label5.Caption = ""
Label6.Caption = ""
Text1.Visible = False
Text2.Visible = False
Line2.Visible = False
Line3.Visible = False
Command1.Visible = False
Command2.Visible = False
Label7.Visible = False
End Sub

Private Sub Option1_Click()
test1 = 8
test2 = 20
Label1.Caption = "Range of Tightness Factor (Kf) when loop length (l) is in cm"
Label2.Caption = "Tightness Factor (Kf) 8 - open structure"
Label3.Caption = "Average value of (Kf) is 14.6"
Label4.Visible = True
Label4.Caption = "8 - 20"
Label5.Caption = "Choose the value of Tightness Factor (Kf)"
Command2.Visible = True
Text1.Visible = True
End Sub

Private Sub Option2_Click()
test1 = 0.8
test2 = 2
Label1.Caption = "Range of Tightness Factor (Kf) when loop length (l) is in mm"
Label2.Caption = "Tightness Factor (Kf) 0.8 - open structure"
Label3.Caption = "Average value of (Kf) is 1.46"
Label4.Visible = True
Label4.Caption = "0.8 - 2.0"
Label5.Caption = "Choose the value of Tightness Factor (Kf)"
```

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```
Command2.Visible = True
Text1.Visible = True
End Sub
```

Form7 (Form7.frm)

```
Private Sub Command1_Click()
If Check1.Value = 0 And Check2.Value = 0 And Check3.Value = 0 Then
Dim Msg1 As String
Msg1 = MsgBox("Please make a selection.", 32, "proKNIT System")
ElseIf Check1.Value = 1 And Check2.Value = 1 And Check3.Value = 1 Then
Dim Msg2 As String
Msg1 = MsgBox("Please select one or two relaxed states.", 32, "proKNIT System")
Else
   If Check1.Value = 1 Then
   dry = True
   dry2 = True
   End If
   If Check2.Value = 1 Then
   wet = True
   wet2 = True
   End If
   If Check3.Value = 1 Then
   fin = True
   fin2 = True
   End If
Unload Form7
Form8.Show
End If
End Sub

Private Sub Command2_Click()
el = 0
Unload Form7
Form6.Show
End Sub

Private Sub Form_Load()
Check1.Value = 0
Check2.Value = 0
Check3.Value = 0
End Sub
```

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Form8 (Form8.frm)

```
Private Sub Command1_Click()
Text1.Visible = True
Text2.Visible = True
Text3.Visible = True
Text4.Visible = True
If dry = True Then
Label1.Caption = "Courses per cm (c) in Dry-relaxed state"
Label2.Caption = "Wales per cm (w) in Dry-relaxed state"
Label3.Caption = "Loop density (S) in Dry-relaxed state"
Label4.Caption = "Loop shape (R)"
   If cotton = True Then
   ks = 1900
   kc = 50
   kw = 38
   r = 1.31
   Text1.Text = Format(kc / (mm * el), "#0.00")
   Text2.Text = Format(kw / (mm * el), "#0.00")
   dryc = kc / (mm * el)
   dryw = kw / (mm * el)
   Text3.Text = Format(dryc * dryw, "#0.00")
   sdry = dryc * dryw
   Text4.Text = Format(dryc / dryw, "#0.00")
   dry = False
      If dry = False And wet = False And full = False And fin = False Then
      Command1.Caption = "Next >>"
      End If
   ElseIf wool = True Then
   ks = 1900
   kc = 50
   kw = 38
   r = 1.31
   Text1.Text = Format(kc / (mm * el), "#0.00")
   Text2.Text = Format(kw / (mm * el), "#0.00")
   dryc = kc / (mm * el)
   dryw = kw / (mm * el)
   Text3.Text = Format(dryc * dryw, "#0.00")
   sdry = dryc * dryw
   Text4.Text = Format(dryc / dryw, "#0.00")
   dry = False
      If dry = False And wet = False And full = False And fin = False Then
```

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```
    Command1.Caption = "Next >>"
    End If
ElseIf cm = True Then
ks = 1900
kc = 50
kw = 38
r = 1.31
Text1.Text = Format(kc / (mm * el), "#0.00")
Text2.Text = Format(kw / (mm * el), "#0.00")
dryc = kc / (mm * el)
dryw = kw / (mm * el)
Text3.Text = Format(dryc * dryw, "#0.00")
sdry = dryc * dryw
Text4.Text = Format(dryc / dryw, "#0.00")
dry = False
    If dry = False And wet = False And full = False And fin = False Then
    Command1.Caption = "Next >>"
    End If
ElseIf wm = True Then
    If sjplain = True Then
    ks = 1940
    kc = 50
    kw = 38.8
    r = 1.29
    ElseIf sjpurl = True Then
    ks = 2490
    kc = 68.8
    kw = 36.2
    r = 1.9
    ElseIf djrib = True Then
    ks = 1500
    kc = 44
    kw = 34
    r = 1.3
    ElseIf dkrib = True Then
    ks = 1862
    kc = 49
    kw = 38
    r = 1.29
    Else
    ks = 2160
    kc = 48
    kw = 45
    r = 1.06
    End If
Text1.Text = Format(kc / (mm * el), "#0.00")
Text2.Text = Format(kw / (mm * el), "#0.00")
dryc = kc / (mm * el)
```

```
        dryw = kw / (mm * el)
        Text3.Text = Format(dryc * dryw, "#0.00")
        sdry = dryc * dryw
        Text4.Text = Format(dryc / dryw, "#0.00")
        dry = False
           If dry = False And wet = False And full = False And fin = False Then
           Command1.Caption = "Next >>"
           End If
        ElseIf wcm = True Then
           If sjplain = True Then
           ks = 1975
           kc = 50
           kw = 39.5
           r = 1.27
           ElseIf sjpurl = True Then
           ks = 2585
           kc = 71.2
           kw = 37
           r = 1.9
           ElseIf djrib = True Then
           ks = 1530
           kc = 45
           kw = 34
           r = 1.32
           ElseIf dkrib = True Then
           ks = 1900
           kc = 50
           kw = 38
           r = 1.31
           Else
           ks = 2235
           kc = 48.8
           kw = 45.8
           r = 1.07
           End If
        Text1.Text = Format(kc / (mm * el), "#0.00")
        Text2.Text = Format(kw / (mm * el), "#0.00")
        dryc = kc / (mm * el)
        dryw = kw / (mm * el)
        Text3.Text = Format(dryc * dryw, "#0.00")
        sdry = dryc * dryw
        Text4.Text = Format(dryc / dryw, "#0.00")
        dry = False
           If dry = False And wet = False And full = False And fin = False Then
           Command1.Caption = "Next >>"
           End If
        End If
     ElseIf wet = True Then
```

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```
Label1.Caption = "Courses per cm (c) in Wet-relaxed state"
Label2.Caption = "Wales per cm (w) in Wet-relaxed state"
Label3.Caption = "Loop density (S) in Wet-relaxed state"
Label4.Caption = "Loop shape (R)"
  If cotton = True Then
  ks = 2180
  kc = 53
  kw = 41
  r = 1.29
  Text1.Text = Format(kc / (mm * el), "#0.00")
  Text2.Text = Format(kw / (mm * el), "#0.00")
  wetc = kc / (mm * el)
  wetw = kw / (mm * el)
  Text3.Text = Format(wetc * wetw, "#0.00")
  swet = wetc * wetw
  Text4.Text = Format(wetc / wetw, "#0.00")
  wet = False
    If wet = False And full = False And fin = False Then
    Command1.Caption = "Next >>"
    End If
  ElseIf wool = True Then
  ks = 2180
  kc = 53
  kw = 41
  r = 1.29
  Text1.Text = Format(kc / (mm * el), "#0.00")
  Text2.Text = Format(kw / (mm * el), "#0.00")
  wetc = kc / (mm * el)
  wetw = kw / (mm * el)
  Text3.Text = Format(wetc * wetw, "#0.00")
  swet = wetc * wetw
  Text4.Text = Format(wetc / wetw, "#0.00")
  wet = False
    If wet = False And full = False And fin = False Then
    Command1.Caption = "Next >>"
    End If
  ElseIf cm = True Then
  ks = 2180
  kc = 53
  kw = 41
  r = 1.29
  Text1.Text = Format(kc / (mm * el), "#0.00")
  Text2.Text = Format(kw / (mm * el), "#0.00")
  wetc = kc / (mm * el)
  wetw = kw / (mm * el)
  Text3.Text = Format(wetc * wetw, "#0.00")
  swet = wetc * wetw
  Text4.Text = Format(wetc / wetw, "#0.00")
```

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```
wet = False
   If wet = False And full = False And fin = False Then
   Command1.Caption = "Next >>"
   End If
ElseIf wm = True Then
   If sjplain = True Then
   ks = 2214
   kc = 54
   kw = 41
   r = 1.32
   ElseIf sjpurl = True Then
   ks = 2736
   kc = 72
   kw = 38
   r = 1.89
   ElseIf djrib = True Then
   ks = 1575
   kc = 50
   kw = 31.5
   r = 1.58
   ElseIf dkrib = True Then
   ks = 1860
   kc = 52.4
   kw = 35.5
   r = 1.5
   Else
   ks = 2203
   kc = 51.6
   kw = 42.7
   r = 1.21
   End If
Text1.Text = Format(kc / (mm * el), "#0.00")
Text2.Text = Format(kw / (mm * el), "#0.00")
wetc = kc / (mm * el)
wetw = kw / (mm * el)
Text3.Text = Format(wetc * wetw, "#0.00")
swet = wetc * wetw
Text4.Text = Format(wetc / wetw, "#0.00")
wet = False
   If wet = False And full = False And fin = False Then
   Command1.Caption = "Next >>"
   End If
ElseIf wcm = True Then
   If sjplain = True Then
   ks = 2120
   kc = 53
   kw = 40
   r = 1.32
```

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```
         ElseIf sjpurl = True Then
         ks = 2800
         kc = 73.5
         kw = 38.1
         r = 1.92
         ElseIf djrib = True Then
         ks = 1625
         kc = 50
         kw = 32.5
         r = 1.54
         ElseIf dkrib = True Then
         ks = 1908
         kc = 53
         kw = 36
         r = 1.47
         Else
         ks = 2270
         kc = 52.4
         kw = 43.3
         r = 1.21
         End If
      Text1.Text = Format(kc / (mm * el), "#0.00")
      Text2.Text = Format(kw / (mm * el), "#0.00")
      wetc = kc / (mm * el)
      wetw = kw / (mm * el)
      Text3.Text = Format(wetc * wetw, "#0.00")
      swet = wetc * wetw
      Text4.Text = Format(wetc / wetw, "#0.00")
      wet = False
         If wet = False And full = False And fin = False Then
         Command1.Caption = "Next >>"
         End If
      End If
   End If
ElseIf fin = True Then
Label1.Caption = "Courses per cm (c) in Finished & Full-relaxed state"
Label2.Caption = "Wales per cm (w) in Finished and Full-relaxed state"
Label3.Caption = "Loop density (S) in Finished and Full-relaxed state"
Label4.Caption = "Loop shape (R)"
   If cotton = True Then
   ks = 2410
   kc = 56
   kw = 43
   r = 1.3
   Text1.Text = Format(kc / (mm * el), "#0.00")
   Text2.Text = Format(kw / (mm * el), "#0.00")
   finc = kc / (mm * el)
   finw = kw / (mm * el)
   Text3.Text = Format(finc * finw, "#0.00")
```

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```
sfin = finc * finw
Text4.Text = Format(finc / finw, "#0.00")
fin = False
Command1.Caption = "Next >>"
ElseIf wool = True Then
ks = 2300
kc = 56
kw = 42.2
r = 1.32
Text1.Text = Format(kc / (mm * el), "#0.00")
Text2.Text = Format(kw / (mm * el), "#0.00")
finc = kc / (mm * el)
finw = kw / (mm * el)
Text3.Text = Format(finc * finw, "#0.00")
sfin = finc * finw
Text4.Text = Format(finc / finw, "#0.00")
fin = False
Command1.Caption = "Next >>"
ElseIf cm = True Then
ks = 2410
kc = 56
kw = 43
r = 1.3
Text1.Text = Format(kc / (mm * el), "#0.00")
Text2.Text = Format(kw / (mm * el), "#0.00")
finc = kc / (mm * el)
finw = kw / (mm * el)
Text3.Text = Format(finc * finw, "#0.00")
sfin = finc * finw
Text4.Text = Format(finc / finw, "#0.00")
fin = False
Command1.Caption = "Next >>"
ElseIf wm = True Then
   If sjplain = True Then
   ks = 2080
   kc = 52
   kw = 40
   r = 1.3
   ElseIf sjpurl = True Then
   ks = 2590
   kc = 70
   kw = 37
   r = 1.89
   ElseIf djrib = True Then
   ks = 1400
   kc = 46.5
   kw = 30
   r = 1.55
```

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```
      ElseIf dkrib = True Then
      ks = 1567
      kc = 47.2
      kw = 33.2
      r = 1.42
      Else
      ks = 2083
      kc = 49.6
      kw = 42
      r = 1.18
      End If
   Text1.Text = Format(kc / (mm * el), "#0.00")
   Text2.Text = Format(kw / (mm * el), "#0.00")
   finc = kc / (mm * el)
   finw = kw / (mm * el)
   Text3.Text = Format(finc * finw, "#0.00")
   sfin = finc * finw
   Text4.Text = Format(finc / finw, "#0.00")
   fin = False
   Command1.Caption = "Next >>"
   ElseIf wcm = True Then
      If sjplain = True Then
      ks = 2128
      kc = 53.2
      kw = 40
      r = 1.33
      ElseIf sjpurl = True Then
      ks = 2773
      kc = 72.4
      kw = 38.3
      r = 1.89
      ElseIf djrib = True Then
      ks = 1520
      kc = 47.5
      kw = 32
      r = 1.48
      ElseIf dkrib = True Then
      ks = 1591
      kc = 47.5
      kw = 33.4
      r = 1.42
      Else
      ks = 2193
      kc = 51
      kw = 43
      r = 1.18
      End If
   Text1.Text = Format(kc / (mm * el), "#0.00")
```

```
    Text2.Text = Format(kw / (mm * el), "#0.00")
    finc = kc / (mm * el)
    finw = kw / (mm * el)
    Text3.Text = Format(finc * finw, "#0.00")
    sfin = finc * finw
    Text4.Text = Format(finc / finw, "#0.00")
    fin = False
    Command1.Caption = "Next >>"
    End If
Else
Unload Form8
Form9.Show
End If
End Sub

Private Sub Command2_Click()
dryc = 0
dryw = 0
sdry = 0
drywe = 0
wetc = 0
wetw = 0
swet = 0
wetwe = 0
finc = 0
finw = 0
sfin = 0
finwe = 0
dif = 0
dry = False
dry2 = False
wet = False
wet2 = False
fin = False
fin2 = False
Unload Form8
Form7.Show
End Sub

Private Sub Form_activate()
If dry = True Then
Label1.Caption = "Courses per cm (c) in Dry-relaxed state"
Label2.Caption = "Wales per cm (w) in Dry-relaxed state"
Label3.Caption = "Loop density (S) in Dry-relaxed state"
Label4.Caption = "Loop shape (R)"
ElseIf wet = True Then
Label1.Caption = "Courses per cm (c) in Wet-relaxed state"
Label2.Caption = "Wales per cm (w) in Wet-relaxed state"
```

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```
Label3.Caption = "Loop density (S) in Wet-relaxed state"
Label4.Caption = "Loop shape (R)"
ElseIf fin = True Then
Label1.Caption = "Courses per cm (c) in Finished & Full-relaxed state"
Label2.Caption = "Wales per cm (w) in Finished and Full-relaxed state"
Label3.Caption = "Loop density (S) in Finished and Full-relaxed state"
Label4.Caption = "Loop shape (R)"
Else
End If
End Sub
```

Form9 (Form9.frm)

```
Private Sub Command2_Click()
Unload Form9
Form10.Show
End Sub

Private Sub Command3_Click()
dryc = 0
dryw = 0
sdry = 0
drywe = 0
wetc = 0
wetw = 0
swet = 0
wetwe = 0
finc = 0
finw = 0
sfin = 0
finwe = 0
dif = 0
dry = False
dry2 = False
wet = False
wet2 = False
fin = False
fin2 = False
Unload Form9
Form7.Show
End Sub
```

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```vb
Private Sub Form_activate()
Text1.Text = ""
Text2.Text = ""
Text3.Text = ""
If dry2 = True Then
Text1.Visible = True
Label1.Caption = "Fabric mass (g/m2) in dry-relaxed state"
Text1.Text = Format((sdry * el * mm * Tex) * doub / 100, "#0.00")
drywe = (sdry * el * mm * Tex) * doub / 100
Else
Text1.Visible = False
End If
If wet2 = True Then
Text2.Visible = True
Label2.Caption = "Fabric mass (g/m2) in wet-relaxed state"
Text2.Text = Format((swet * el * mm * Tex) * doub / 100, "#0.00")
wetwe = (swet * el * mm * Tex) * doub / 100
Else
Text2.Visible = False
End If
If fin2 = True Then
Label4.Caption = "Fabric mass (g/m2) in finished and full-relaxed state"
Text4.Text = Format((sfin * el * mm * Tex) * doub / 100, "#0.00")
finwe = (sfin * el * mm * Tex) * doub / 100
Else
Text4.Visible = False
Label4.Caption = ""
End If


If dry2 = True And wet2 = True Then
Label3.Caption = "% Difference of fabric mass between dry and wet state"
Text3.Visible = True
Text3.Text = Format((wetwe - drywe) / wetwe * 100, "#0.00")
dif = (wetwe - drywe) / wetwe * 100
ElseIf dry2 = True And fin2 = True Then
Label3.Caption = "% Difference of fabric mass between dry and finished/full
relaxed state"
Text3.Visible = True
Text3.Text = Format((finwe - drywe) / finwe * 100, "#0.00")
dif = (finwe - drywe) / finwe * 100
ElseIf wet2 = True And fin2 = True Then
Label3.Caption = "% Difference of fabric mass between wet and finished/full
relaxed state"
Text3.Visible = True
Text3.Text = Format((finwe - wetwe) / finwe * 100, "#0.00")
dif = (finwe - wetwe) / finwe * 100
Else
Label3.Caption = ""
```

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```
Text3.Visible = False
End If
End Sub
```

Form10 (Form10.frm)

```
Private Sub Command1_Click()
dryc = 0
dryw = 0
sdry = 0
drywe = 0
wetc = 0
wetw = 0
swet = 0
wetwe = 0
finc = 0
finw = 0
sfin = 0
finwe = 0
dif = 0
Label7.Caption = ""
Label8.Caption = ""
Label9.Caption = ""
Label10.Caption = ""
Label11.Caption = ""
Label20.Caption = ""
Label21.Caption = ""
Label22.Caption = ""
Label23.Caption = ""
Label24.Caption = ""
Label25.Caption = ""
Label26.Caption = ""
Label27.Caption = ""
Label28.Caption = ""
Label29.Caption = ""
Label30.Caption = ""
Label31.Caption = ""
Label33.Caption = ""
dry = False
dry2 = False
wet = False
wet2 = False
```

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```
fin = False
fin2 = False
Unload Form10
Form7.Show
End Sub

Private Sub Command2_Click()
    Dim frm As Form
    For Each frm In Forms
        Unload frm
        Set frm = Nothing
    Next frm
End Sub

Private Sub Form_Load()
Label7.Caption = ""
Label8.Caption = ""
Label9.Caption = ""
Label10.Caption = ""
Label11.Caption = ""
Label20.Caption = ""
Label21.Caption = ""
Label22.Caption = ""
Label23.Caption = ""
Label24.Caption = ""
Label25.Caption = ""
Label26.Caption = ""
Label27.Caption = ""
Label28.Caption = ""
Label29.Caption = ""
Label30.Caption = ""
Label31.Caption = ""
Label33.Caption = ""
Label7.Caption = gau
Label8.Caption = Tex
Label9.Caption = fabtype
Label10.Caption = kf
Label11.Caption = Format(el, "#0.00")
If dryc = 0 Then
Label20.Caption = ""
Else
Label20.Caption = Format(dryc, "#0.00")
End If
If dryw = 0 Then
Label21.Caption = ""
Else
Label21.Caption = Format(dryw, "#0.00")
End If
```

```
If sdry = 0 Then
Label22.Caption = ""
Else
Label22.Caption = Format(sdry, "#0.00")
End If
If drywe = 0 Then
Label23.Caption = ""
Else
Label23.Caption = Format(drywe, "#0.00")
End If
If wetc = 0 Then
Label24.Caption = ""
Else
Label24.Caption = Format(wetc, "#0.00")
End If
If wetw = 0 Then
Label25.Caption = ""
Else
Label25.Caption = Format(wetw, "#0.00")
End If
If swet = 0 Then
Label26.Caption = ""
Else
Label26.Caption = Format(swet, "#0.00")
End If
If wetwe = 0 Then
Label27.Caption = ""
Else
Label27.Caption = Format(wetwe, "#0.00")
End If
If finc = 0 Then
Label28.Caption = ""
Else
Label28.Caption = Format(finc, "#0.00")
End If
If finw = 0 Then
Label29.Caption = ""
Else
Label29.Caption = Format(finw, "#0.00")
End If
If sfin = 0 Then
Label30.Caption = ""
Else
Label30.Caption = Format(sfin, "#0.00")
End If
If finwe = 0 Then
Label31.Caption = ""
Else
```

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```
Label31.Caption = Format(finwe, "#0.00")
End If
If dif = 0 Then
Label33.Caption = ""
Else
Label33.Caption = Format(dif, "#0.00")
End If
If mm = 10 Then
Label34.Caption = "cm"
Else
Label34.Caption = "mm"
End If
End Sub
```

Global Variables

```
Public q As Long
Public w As Long

Public cotton As Boolean
Public wool As Boolean
Public cm As Boolean
Public wm As Boolean
Public ccy As Boolean
Public wcy As Boolean
Public ccm As Boolean
Public wcm As Boolean

Public fab As Single
Public doub As Single
Public fabtype As String

Public sjplain As Boolean
Public sjpurl As Boolean
Public djrib As Boolean
Public dkrib As Boolean
Public dkinter As Boolean

Public gau As Single
Public Tex As Single
Public el As Single
Public x As Single
Public y As Single
```

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```
Public mm As Single
Public loopp As Single

Public kf As Single

Public dry As Boolean
Public wet As Boolean
Public fin As Boolean

Public ks As Single
Public kc As Single
Public kw As Single
Public r As Single

Public dryc As Single
Public dryw As Single
Public drywe As Single
Public wetc As Single
Public wetw As Single
Public wetwe As Single
Public finc As Single
Public finw As Single
Public finwe As Single
Public dif As Single


Public sdry As Single
Public swet As Single
Public sfin As Single

Public dry2 As Boolean
Public wet2 As Boolean
Public fin2 As Boolean

Public test1 As Single
Public test2 As Single
```

TABLES OF RESULTS

TABLE A1 : Specifications of wool blended yarns used on the production of the knitted fabrics

Yarn/fabric code	Yarn Composition	Yarn count		No of ends used	Theoretical total count used (tex)	Actual total count used (tex)
		Nm	**tex**			
2/28-50A50W	50% Acrylic / 50% Wool extra fine **undyed**	2/28	2/35.7	3	214.2	218.4
2/28-70A30W	70% Acrylic /30% Wool **undyed**	2/28	2/35.7	3	214.2	218.1
2/17-50A25V25W	50% Acrylic / 25% Viscose / 25% wool **undyed**	2/17	2/58.8	2	235.2	234.4
2/28-50WMe50D-d	50% Wool Merinos / 50% Dralon **dyed (Blue)**	2/28	2/35.7	3	214.2	219.6
2/28-DR70W30A-d	Dry Relaxed 70% Wool / 30% Acrylic **dyed (Brown)**	2/28	2/35.7	3	214.2	218.4
2/17-50A25V25W-d	50% Acrylic 25% Viscose 25% Wool **dyed (Beige)**	2/17	2/58.8	2	235.2	256.8

TABLE A2: Analysis for plain-knit fabric using undyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 12.5	5.3	4.1	9.50	21.73	50.3	39.0	1961	1.29
2/28-50A50W 13.5	4.6	3.6	10.80	16.56	49.7	38.9	1933	1.28
2/28-50A50W 14.5	4.1	3.1	12.41	12.71	50.9	38.5	1960	1.32
2/28-70A30W 12.5	5.1	4.0	9.72	20.40	49.6	38.9	1930	1.28
2/28-70A30W 13.5	4.5	3.5	11.20	15.80	50.4	39.2	1976	1.29
2/28-70A30W 14.5	4.0	3.1	12.40	12.40	49.6	38.5	1910	1.29
2/17-50A25V25W 13.5	4.5	3.5	11.20	15.75	50.4	39.2	1976	1.29
2/17-50A25V25W 14.5	3.9	3.0	12.80	11.70	49.9	38.4	1916	1.30
2/17-50A25V25W 15.5	3.5	2.7	14.30	9.45	50.0	38.6	1930	1.20
		Average Value			**50.09**	**38.8**		
		Used Value			**50.0**	**38.8**	**1940**	**1.29**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

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TABLE A3: Analysis for purl knit fabric using undyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 12.5	7.1	3.8	9.70	26.98	68.9	36.9	2542	1.88
2/28-50A50W 13.5	6.3	3.2	11.21	20.16	70.6	35.9	2532	1.96
2/28-50A50W 14.5	5.6	2.9	12.20	16.24	68.3	35.4	2418	1.93
2/28-70A30W 12.5	7.1	3.7	9.74	26.27	69.1	36.0	2490	1.92
2/28-70A30W 13.5	6.1	3.2	11.23	19.52	68.5	35.9	2462	1.91
2/28-70A30W 14.5	5.5	2.9	12.65	15.95	69.6	36.7	2554	1.90
2/17-50A25V25W 13.5	6.0	3.3	11.16	19.80	67.0	36.8	2466	1.82
2/17-50A25V25W 14.5	5.3	2.8	12.92	14.84	68.5	36.2	2480	1.89
2/17-50A25V25W 15.5	4.8	2.5	14.30	12.00	68.6	35.8	2456	1.92
		Average Value			68.79	36.18		
		Used Value			68.8	36.2	2490	1.90

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A4: Analysis for 1X1 rib knit fabric using undyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 10.5	5.3	4.0/2	8.52	21.20	45.2	34.1	1541	1.33
2/28-50A50W 11.5	4.6	3.5/2	9.75	16.10	44.9	34.1	1531	1.32
2/28-50A50W 12.5	4.0	3.1/2	10.77	12.40	43.1	33.4	1440	1.29
2/28-70A30W 10.5	5.2	4.0/2	8.50	20.80	44.2	34.0	1503	1.30
2/28-70A30W 11.5	4.6	3.5/2	9.65	16.10	44.4	33.8	1500	1.31
2/28-70A30W 12.5	4.0	3.1/2	10.78	12.40	43.1	33.4	1440	1.29
2/17-50A25V25W 11.5	4.3	3.3/2	10.45	14.19	44.9	34.5	1549	1.30
2/17-50A25V25W 12.5	3.8	2.9/2	11.70	11.02	44.5	33.9	1510	1.31
2/17-50A25V25W 13.5	3.4	2.7/2	12.80	9.18	43.5	34.6	1329	1.26
		Average Value			44.20	33.98		
		Used Value			44.0	34.0	1500	1.30

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A5: Analysis for 2X2 rib knit fabric using undyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 11.2	5.4	4.2/2	9.12	22.68	49.2	38.3	1884	1.29
2/28-50A50W 12.2	4.6	3.6/2	10.60	16.56	48.8	38.2	1864	1.28
2/28-50A50W 13.2	4.0	3.1/2	12.25	12.40	49.0	37.9	1857	1.29
2/28-70A30W 11.2	5.4	4.2/2	9.09	22.68	49.0	38.2	1872	1.28
2/28-70A30W 12.2	4.7	3.6/2	10.40	16.92	48.9	37.5	1834	1.31
2/28-70A30W 13.2	4.0	3.1/2	12.20	12.40	48.8	37.8	1846	1.29
2/17-50A25V25W 11.2	5.6	4.3/2	8.79	24.08	49.2	37.8	1860	1.30
2/17-50A25V25W 12.2	4.6	3.6/2	10.60	16.56	48.8	38.2	1864	1.28
2/17-50A25V25W 13.2	3.9	3.0/2	12.62	11.70	49.2	37.9	1865	1.30
		Average Value			48.99	37.98		
		Used Value			49.0	38.0	1862	1.29

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A6: Analysis for interlock knit fabric using undyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 11.5	4.7	4.4/2	10.23	20.68	48.1	45.0	2165	1.07
2/28-50A50W 12.5	4.2	3.9/2	11.42	16.38	48.0	44.6	2141	1.08
2/28-50A50W 13.5	3.7	3.5/2	12.97	12.95	48.0	45.4	2179	1.06
2/28-70A30W 11.5	4.7	4.4/2	10.19	20.68	47.9	44.8	2148	1.07
2/28-70A30W 12.5	4.2	3.9/2	11.57	16.38	48.6	45.0	2187	1.08
2/28-70A30W 13.5	3.7	3.5/2	12.97	12.95	48.0	45.4	2179	1.05
2/17-50A25V25W 11.5	4.6	4.3/2	10.45	19.78	48.0	44.9	2155	1.07
2/17-50A25V25W 12.5	4.1	3.9/2	11.60	15.99	47.6	45.2	2152	1.05
2/17-50A25V25W 13.5	3.6	3.4/2	13.22	12.24	47.6	45.0	2142	1.06
		Average Value			**47.98**	**45.03**		
		Used Value			**48.0**	**45.0**	**2160**	**1.06**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A7: Analysis for plain-knit fabric using dyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 12.5	5.4	4.1	9.70	22.14	52.4	39.8	2085	1.32
2/28-50WMe50D-d 13.5	4.5	3.6	11.10	16.20	50.0	39.9	1995	1.25
2/28-50WMe50D-d 14.5	3.9	3.2	12.30	12.48	48.0	39.4	1890	1.22
2/28-DR70W30A-d 12.5	5.3	3.9	10.00	20.67	53.0	39.0	2067	1.36
2/28-DR70W30A-d 13.5	4.5	3.5	11.57	15.75	52.0	40.5	2106	1.28
2/28-DR70W30A-d 14.5	3.9	3.2	12.33	12.48	48.1	39.4	1895	1.22
2/17-50A25V25W-d 13.5	4.5	3.4	11.30	15.30	50.8	38.4	1951	1.32
2/17-50A25V25W-d 14.5	3.8	3.1	12.70	11.78	48.3	39.4	1903	1.23
2/17-50A25V25W-d 15.5	3.3	2.8	14.20	9.24	46.9	39.8	1867	1.18
		Average Value			**49.94**	**39.51**		
		Used Value			**50.0**	**39.5**	**1975**	**1.27**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A8: Analysis for purl fabric using dyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 12.5	7.2	3.8	9.80	27.36	70.6	37.2	2626	1.90
2/28-50WMe50D-d 13.5	6.3	3.3	11.20	20.79	70.6	37.0	2612	1.91
2/28-50WMe50D-d 14.5	5.6	2.9	12.42	16.24	69.6	36.0	2506	1.93
2/28-DR70W30A-d 12.5	7.3	3.9	9.70	28.47	70.8	37.8	2676	1.87
2/28-DR70W30A-d 13.5	6.1	3.2	11.42	19.52	69.7	36.5	2547	1.90
2/28-DR70W30A-d 14.5	5.4	2.9	12.74	15.66	68.8	37.0	2546	1.86
2/17-50A25V25W-d 13.5	5.9	3.2	11.76	18.88	69.4	37.6	2594	1.85
2/17-50A25V25W-d 14.5	5.4	2.8	13.25	15.12	71.6	37.1	2656	1.93
2/17-50A25V25W-d 15.5	4.8	2.5	14.70	12.00	70.6	36.8	2598	1.92
		Average Value			71.19	37.0		
		Used Value			71.2	37.0	2585	1.90

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

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TABLE A9: Analysis for 1X1 rib fabric using dyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 10.5	5.5	4.2/2	8.32	23.10	45.8	34.9	1600	1.31
2/28-50WMe50D-d 11.5	4.8	3.7/2	9.43	17.76	45.3	34.9	1581	1.30
2/28-50WMe50D-d 12.5	4.1	3.1/2	11.00	12.71	45.1	34.1	1538	1.32
2/28-DR70W30A-d 10.5	5.5	4.2/2	8.20	23.10	45.1	34.4	1651	1.31
2/28-DR70W30A-d 11.5	4.7	3.6/2	9.62	16.92	45.2	34.6	1565	1.31
2/28-DR70W30A-d 12.5	4.1	3.1/2	10.95	12.71	44.9	33.9	1522	1.29
2/17-50A25V25W-d 11.5	4.4	3.3/2	10.05	14.52	44.2	33.2	1427	1.33
2/17-50A25V25W-d 12.5	3.8	2.9/2	11.58	11.02	44.0	33.6	1478	1.31
2/17-50A25V25W-d 13.5	3.4	2.6/2	13.08	8.84	44.5	34.0	1513	1.31
				Average Value	**44.9**	**34.18**		
				Used Value	**45.0**	**34.0**	**1530**	**1.32**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A10: Analysis for 2X2 rib fabric using dyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 11.2	5.5	4.2/2	9.20	23.10	50.6	38.6	1953	1.31
2/28-50WMe50D-d 12.2	4.7	3.6/2	10.60	16.92	49.8	38.2	1902	1.31
2/28-50WMe50D-d 13.2	4.2	3.2/2	11.90	13.44	50.0	38.1	1905	1.31
2/28-DR70W30A-d 11.2	5.6	4.3/2	8.90	24.08	49.8	38.3	1907	1.30
2/28-DR70W30A-d 12.2	4.7	3.6/2	10.60	16.92	49.8	38.2	1902	1.31
2/28-DR70W30A-d 13.2	4.2	3.2/2	11.90	13.44	50.0	38.1	1905	1.31
2/17-50A25V25W-d 11.2	5.2	4.0/2	9.50	20.80	49.4	38.0	1877	1.30
2/17-50A25V25W-d 12.2	4.5	3.4/2	11.00	15.30	49.5	37.4	1851	1.32
2/17-50A25V25W-d 13.2	4.0	3.0/2	12.40	12.00	49.6	37.2	1845	1.33
		Average Value			49.83	38.01		
		Used Value			50.0	38.0	1900	1.31

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A11: Analysis for interlock fabric using dyed yarns (DRY- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 11.5	4.7	4.4/2	10.45	20.68	49.1	46.0	2259	1.07
2/28-50WMe50D-d 12.5	4.3	4.0/2	11.39	17.20	49.0	45.6	2234	1.08
2/28-50WMe50D-d 13.5	3.9	3.7/2	12.58	14.43	49.1	46.5	2283	1.05
2/28-DR70W30A-d 11.5	4.7	4.4/2	10.45	20.68	49.1	46.0	2259	1.07
2/28-DR70W30A-d 12.5	4.3	4.0/2	11.30	17.20	48.6	45.2	2197	1.08
2/28-DR70W30A-d 13.5	3.9	3.6/2	12.60	14.04	49.1	45.4	2229	1.08
2/17-50A25V25W-d 11.5	4.4	4.2/2	11.06	18.48	48.7	46.5	2265	1.05
2/17-50A25V25W-d 12.5	4.0	3.8/2	12.03	15.20	48.1	45.7	2198	1.05
2/17-50A25V25W-d 13.5	3.6	3.4/2	13.34	12.24	48.0	45.4	2179	1.06
		Average Value			**48.76**	**45.8**		
		Used Value			**48.8**	**45.8**	**2235**	**1.07**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A12: Analysis for plain-knit fabric using undyed yarns (WET- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 12.5	5.7	4.3	9.50	24.51	54.1	40.9	2213	1.32
2/28-50A50W 13.5	4.9	3.7	10.99	18.13	53.9	40.7	2194	1.32
2/28-50A50W 14.5	4.5	3.4	12.00	15.30	54.0	40.8	2203	1.32
2/28-70A30W 12.5	5.5	4.2	9.82	23.10	54.0	41.2	2225	1.31
2/28-70A30W 13.5	4.8	3.6	11.30	17.28	54.2	40.7	2206	1.33
2/28-70A30W 14.5	4.1	3.1	13.18	12.71	54.0	40.9	2209	1.32
2/17-50A25V25W 13.5	4.9	3.7	11.02	18.13	54.0	40.8	2203	1.32
2/17-50A25V25W 14.5	4.2	3.2	12.80	13.44	53.8	41.0	2206	1.31
2/17-50A25V25W 15.5	3.6	2.7	15.18	9.72	54.5	41.0	2234	1.33
		Average Value			54.0	40.87		
		Used Value			54.0	41.0	2214	1.32

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A13: Analysis for 1X1 rib fabric using undyed yarns (WET- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 10.5	5.9	3.7/2	8.51	21.83	50.2	31.5	1581	1.59
2/28-50A50W 11.5	5.1	3.2/2	9.83	16.32	50.1	31.5	1578	1.59
2/28-50A50W 12.5	4.4	2.8/2	11.25	12.04	49.5	31.5	1559	1.57
2/28-70A30W 10.5	5.8	3.7/2	8.65	21.46	50.2	32.0	1606	1.57
2/28-70A30W 11.5	5.0	3.2/2	9.90	16.00	49.5	31.7	1568	1.56
2/28-70A30W 12.5	4.3	2.7/2	11.67	11.61	50.2	31.5	1581	1.59
2/17-50A25V25W 11.5	4.8	3.0/2	10.42	14.40	50.0	31.3	1565	1.60
2/17-50A25V25W 12.5	4.3	2.7/2	11.50	11.61	49.5	31.1	1540	1.59
2/17-50A25V25W 13.5	3.9	2.4/2	12.95	9.36	50.5	31.1	1570	1.60
	Average Value				**49.97**	**31.47**		
	Used Value				**50.0**	**31.5**	**1575**	**1.58**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A14: Analysis for 2X2 rib fabric using undyed yarns (WET- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 11.2	5.9	4.0/2	8.90	23.60	52.5	35.6	1869	1.48
2/28-50A50W 12.2	5.0	3.4/2	10.52	17.00	52.6	35.8	1883	1.47
2/28-50A50W 13.2	4.3	2.9/2	12.21	12.47	52.5	35.4	1859	1.48
2/28-70A30W 11.2	6.0	4.0/2	8.83	24.00	53.0	35.3	1871	1.50
2/28-70A30W 12.2	5.0	3.4/2	10.50	17.15	52.5	35.7	1874	1.47
2/28-70A30W 13.2	4.3	2.9/2	12.23	12.47	52.6	35.5	1867	1.48
2/17-50A25V25W 11.2	6.0	4.1/2	8.75	24.60	52.5	35.9	1885	1.46
2/17-50A25V25W 12.2	5.0	3.4/2	10.40	17.00	52.0	35.4	1841	1.47
2/17-50A25V25W 13.2	4.4	3.0/2	11.74	13.20	51.7	35.2	1820	1.47
		Average Value			**52.4**	**35.53**		
		Used Value			**52.4**	**35.5**	**1860**	**1.50**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A15: Analysis for interlock fabric using undyed yarns (WET- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 11.5	5.4	4.4/2	9.65	23.76	52.1	42.5	2214	1.23
2/28-50A50W 12.5	4.5	3.7/2	11.35	16.65	51.1	42.0	2146	1.22
2/28-50A50W 13.5	4.0	3.3/2	12.87	13.20	51.5	42.5	2189	1.21
2/28-70A30W 11.5	5.1	4.2/2	10.10	21.42	51.5	42.4	2184	1.21
2/28-70A30W 12.5	4.5	3.7/2	11.60	16.65	52.2	42.9	2239	1.22
2/28-70A30W 13.5	4.0	3.3/2	12.85	13.20	51.4	42.4	2179	1.21
2/17-50A25V25W 11.5	5.1	4.3/2	10.10	21.93	51.5	43.4	2235	1.19
2/17-50A25V25W 12.5	4.3	3.6/2	11.98	15.48	51.5	43.1	2220	1.19
2/17-50A25V25W 13.5	3.8	3.2/2	13.55	12.16	51.5	43.4	2235	1.19
		Average Value			**51.59**	**42.7**		
		Used Value			**51.6**	**42.7**	**2203**	**1.21**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A16: Analysis for plain-knit fabric using dyed yarns (WET- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 12.5	5.7	4.3	9.35	24.51	53.2	40.2	2139	1.33
2/28-50WMe50D-d 13.5	5.0	3.8	10.53	19.00	52.7	40.0	2108	1.32
2/28-50WMe50D-d 14.5	4.2	3.2	12.62	13.44	53.0	40.4	2141	1.31
2/28-DR70W30A-d 12.5	5.6	4.3	9.45	24.08	52.9	40.6	2148	1.30
2/28-DR70W30A-d 13.5	4.7	3.6	11.23	16.92	52.8	40.4	2133	1.31
2/28-DR70W30A-d 14.5	4.1	3.1	12.95	12.71	53.1	40.2	2135	1.32
2/17-50A25V25W-d 13.5	4.6	3.5	11.53	16.10	53.0	40.4	2141	1.31
2/17-50A25V25W-d 14.5	4.2	3.1	12.62	13.02	53.0	39.1	2072	1.35
2/17-50A25V25W-d 15.5	3.7	2.8	14.32	10.36	53.0	40.1	2125	1.32
		Average Value			**52.97**	**40.16**		
		Used Value			**53.0**	**40.0**	**2120**	**1.32**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A17: Analysis for 1X1 rib fabric using dyed yarns (WET- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 10.5	6.2	4.0/2	8.13	24.80	50.4	32.5	1632	1.55
2/28-50WMe50D-d 11.5	5.2	3.4/2	9.60	17.68	49.9	32.6	1627	1.53
2/28-50WMe50D-d 12.5	4.5	2.9/2	11.21	13.05	50.4	32.5	1638	1.55
2/28-DR70W30A-d 10.5	6.0	3.9/2	8.34	23.40	50.0	32.5	1625	1.54
2/28-DR70W30A-d 11.5	5.0	3.3/2	9.90	16.50	49.5	32.7	1619	1.52
2/28-DR70W30A-d 12.5	4.5	2.9/2	11.15	13.05	50.4	32.3	1628	1.55
2/17-50A25V25W-d 11.5	4.6	3.0/2	10.80	13.80	49.7	32.4	1610	1.53
2/17-50A25V25W-d 12.5	4.2	2.7/2	11.90	11.34	50.0	32.2	1610	1.54
2/17-50A25V25W-d 13.5	3.8	2.5/2	13.08	9.50	49.7	32.7	1625	1.52
		Average Value			50.0	32.49		
		Used Value			50.0	32.5	1625	1.54

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A18: Analysis for 2X2 rib fabric using dyed yarns (WET- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 11.2	6.1	4.1/2	8.78	25.01	53.6	36.0	1930	1.49
2/28-50WMe50D-d 12.2	5.1	3.5/2	10.37	17.85	52.9	36.3	1920	1.46
2/28-50WMe50D-d 13.2	4.5	3.1/2	11.68	13.95	52.6	36.2	1904	1.45
2/28-DR70W30A-d 11.2	6.0	4.1/2	8.80	24.60	52.8	36.0	1901	1.46
2/28-DR70W30A-d 12.2	5.1	3.5/2	10.35	17.85	52.9	36.2	1915	1.47
2/28-DR70W30A-d 13.2	4.5	3.1/2	11.70	13.95	52.7	36.3	1913	1.45
2/17-50A25V25W-d 11.2	5.8	3.9/2	9.10	22.62	52.8	35.5	1874	1.49
2/17-50A25V25W-d 12.2	5.0	3.4/2	10.59	17.00	53.0	36.0	1908	1.47
2/17-50A25V25W-d 13.2	4.4	3.0/2	12.00	13.20	52.8	36.0	1901	1.47
		Average Value			**52.9**	**36.06**		
		Used Value			**53.0**	**36.0**	**1908**	**1.47**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A19: Analysis for interlock fabric using dyed yarns (WET- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 11.5	5.2	4.3/2	10.10	22.36	52.5	43.4	2279	1.21
2/28-50WMe50D-d 12.5	4.6	3.8/2	11.41	17.48	52.5	43.4	2279	1.21
2/28-50WMe50D-d 13.5	4.2	3.5/2	12.55	14.70	52.7	43.9	2314	1.20
2/28-DR70W30A-d 11.5	5.2	4.3/2	10.20	22.36	53.0	43.9	2327	1.21
2/28-DR70W30A-d 12.5	4.6	3.8.2	11.32	17.48	52.1	43.0	2240	1.21
2/28-DR70W30A-d 13.5	4.3	3.6/2	12.02	15.48	51.7	43.3	2239	1.19
2/17-50A25V25W-d 11.5	4.8	4.0/2	10.90	19.20	52.3	43.6	2280	1.20
2/17-50A25V25W-d 12.5	4.4	3.6/2	11.86	15.84	52.2	42.7	2229	1.22
2/17-50A25V25W-d 13.5	3.9	3.2/2	13.40	12.48	52.3	42.9	2244	1.22
		Average Value			52.37	43.34		
		Used Value			52.4	43.3	2270	1.21

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A20: Analysis for plain-knit fabric using undyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 12.5	5.5	4.2	9.50	23.10	52.3	39.9	2087	1.31
2/28-50A50W 13.5	4.8	3.7	10.83	17.76	52.0	40.0	2080	1.30
2/28-50A50W 14.5	4.2	3.2	12.40	13.44	52.1	39.7	2068	1.31
2/28-70A30W 12.5	5.5	4.2	9.48	23.10	52.1	39.8	2074	1.31
2/28-70A30W 13.5	4.7	3.6	11.09	16.92	52.1	39.9	2079	1.30
2/28-70A30W 14.5	4.0	3.1	12.94	12.40	51.8	40.1	2077	1.29
2/17-50A25V25W 13.5	4.9	3.8	10.60	18.62	51.9	40.3	2092	1.29
2/17-50A25V25W 14.5	4.3	3.3	12.12	14.19	52.1	40.0	2084	1.30
2/17-50A25V25W 15.5	3.6	2.8	14.28	10.08	51.4	40.0	2056	1.29
	Average Value				**51.98**	**39.97**		
	Used Value				**52.0**	**40.0**	**2080**	**1.30**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A21: Analysis for purl fabric using undyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 12.5	7.3	3.9	9.59	28.47	70.0	37.4	2618	1.87
2/28-50A50W 13.5	6.5	3.4	10.80	22.10	70.2	36.7	2576	1.91
2/28-50A50W 14.5	5.6	3.0	12.28	16.80	68.8	36.9	2539	1.87
2/28-70A30W 12.5	7.3	3.9	9.45	28.47	69.0	36.9	2546	1.87
2/28-70A30W 13.5	6.4	3.4	10.95	21.76	70.1	37.2	2604	1.88
2/28-70A30W 14.5	5.5	2.9	12.74	15.95	70.1	37.0	2594	1.90
2/17-50A25V25W 13.5	6.9	3.6	10.30	24.84	71.1	37.1	2638	1.92
2/17-50A25V25W 14.5	6.1	3.2	11.50	19.52	70.1	36.8	2580	1.91
2/17-50A25V25W 15.5	5.3	2.8	13.20	14.84	70.0	37.0	2590	1.89
		Average Value			**69.93**	**37**		
		Used Value			**70.0**	**37.0**	**2590**	**1.89**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A22: Analysis for 1X1 rib fabric using undyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 10.5	5.7	3.7/2	8.15	21.09	46.5	30.2	1404	1.54
2/28-50A50W 11.5	4.8	3.2/2	9.65	15.36	46.3	30.9	1431	1.50
2/28-50A50W 12.5	4.2	2.7/2	11.07	11.34	46.5	30.0	1395	1.56
2/28-70A30W 10.5	5.6	3.6/2	8.35	20.16	46.8	30.0	1404	1.55
2/28-70A30W 11.5	4.8	3.1/2	9.68	14.88	46.5	30.0	1395	1.55
2/28-70A30W 12.5	4.2	2.7/2	11.07	11.36	46.5	29.9	1390	1.55
2/17-50A25V25W 11.5	5.3	3.4/2	8.82	18.02	46.7	30.0	1401	1.56
2/17-50A25V25W 12.5	4.4	2.8/2	10.65	12.32	46.8	29.8	1395	1.57
2/17-50A25V25W 13.5	3.7	2.4/2	12.50	8.88	46.3	30.0	1389	1.54
		Average Value			46.54	30.09		
		Used Value			46.5	30	1400	1.55

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A23: Analysis for 2X2 rib fabric using undyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 11.2	5.7	4.0/2	8.30	22.80	47.3	33.2	1570	1.42
2/28-50A50W 12.2	5.0	3.5/2	9.50	17.50	47.5	33.3	1530	1.43
2/28-50A50W 13.2	4.5	3.2/2	10.40	14.40	46.8	33.3	1558	1.41
2/28-70A30W 11.2	5.7	4.0/2	8.28	22.80	47.2	33.1	1562	1.43
2/28-70A30W 12.2	4.9	3.4/2	9.70	16.66	47.5	33.0	1567	1.44
2/28-70A30W 13.2	4.1	2.9/2	11.48	11.89	47.1	33.3	1568	1.41
2/17-50A25V25W 11.2	5.9	4.2/2	7.91	24.78	46.7	33.2	1550	1.41
2/17-50A25V25W 12.2	5.1	3.5/2	9.45	17.85	48.2	33.1	1595	1.46
2/17-50A25V25W 13.2	4.3	3.0/2	10.89	12.90	46.8	32.7	1530	1.43
		Average Value			47.24	33.14		
		Used Value			47.2	33.2	1567	1.42

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A24: Analysis for interlock fabric using undyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50A50W 11.5	5.2	4.4/2	9.52	22.88	49.5	41.9	2074	1.18
2/28-50A50W 12.5	4.3	3.6/2	11.67	15.48	50.2	42.0	2108	1.19
2/28-50A50W 13.5	3.7	3.1/2	13.55	11.47	50.1	42.0	2104	1.19
2/28-70A30W 11.5	4.8	4.1/2	10.24	19.68	49.2	42.0	2066	1.17
2/28-70A30W 12.5	4.2	3.6/2	11.67	15.12	49.0	42.0	2058	1.17
2/28-70A30W 13.5	3.8	3.2/2	13.02	12.16	49.5	41.8	2069	1.19
2/17-50A25V25W 11.5	5.3	4.5/2	9.34	23.85	49.5	42.0	2079	1.18
2/17-50A25V25W 12.5	4.8	4.1/2	10.25	19.68	49.2	42.0	2066	1.17
2/17-50A25V25W 13.5	3.9	3.3/2	12.87	12.87	50.2	42.5	2134	1.18
		Average Value			**49.6**	**42.0**		
		Used Value			**49.6**	**42.0**	**2083**	**1.18**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A25: Analysis for plain-knit fabric using dyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 12.5	5.7	4.3	9.30	24.51	53.0	40.0	2120	1.33
2/28-50WMe50D-d 13.5	5.0	3.8	10.60	19.00	53.0	40.3	2136	1.32
2/28-50WMe50D-d 14.5	4.3	3.2	12.50	13.76	53.7	40.0	2148	1.34
2/28-DR70W30A-d 12.5	5.6	4.2	9.52	23.52	53.3	40.0	2132	1.33
2/28-DR70W30A-d 13.5	4.7	3.6	11.15	16.92	52.4	40.1	2103	1.31
2/28-DR70W30A-d 14.5	4.3	3.2	12.41	13.76	53.4	39.7	2120	1.34
2/17-50A25V25W-d 13.5	4.5	3.4	11.78	15.30	53.0	40.0	2120	1.32
2/17-50A25V25W-d 14.5	4.0	3.0	13.25	12.00	53.0	39.8	2109	1.33
2/17-50A25V25W-d 15.5	3.5	2.6	15.32	9.10	53.6	39.8	2133	1.35
		Average Value			**53.16**	**39.97**		
		Used Value			**53.2**	**40.0**	**2128**	**1.33**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A26: Analysis for purl fabric using dyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 12.5	7.5	4.0	9.67	30.00	72.5	38.7	2806	1.88
2/28-50WMe50D-d 13.5	6.6	3.5	10.94	23.01	72.2	38.3	2765	1.89
2/28-50WMe50D-d 14.5	5.5	2.9	13.18	15.95	72.5	38.2	2770	1.90
2/28-DR70W30A-d 12.5	7.2	3.8	10.07	27.36	72.5	38.3	2777	1.89
2/28-DR70W30A-d 13.5	6.3	3.3	11.50	20.79	72.4	38.0	2751	1.90
2/28-DR70W30A-d 14.5	5.7	3.0	12.76	17.10	72.7	38.3	2784	1.90
2/17-50A25V25W-d 13.5	6.2	3.3	11.60	20.46	71.9	38.3	2754	1.88
2/17-50A25V25W-d 14.5	5.5	2.9	13.18	15.95	72.5	38.2	2770	1.90
2/17-50A25V25W-d 15.5	5.1	2.7	14.22	13.77	72.5	38.4	2784	1.89
		Average Value			**72.41**	**38.3**		
		Used Value			**72.4**	**38.3**	**2773**	**1.89**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A27: Analysis for 1X1 rib fabric using dyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 10.5	5.7	3.9/2	8.30	22.23	47.3	32.4	1533	1.49
2/28-50WMe50D-d 11.5	4.9	3.3/2	9.74	16.17	47.7	32.1	1531	1.48
2/28-50WMe50D-d 12.5	4.3	2.9/2	11.05	12.47	47.5	32.0	1520	1.48
2/28-DR70W30A-d 10.5	5.5	3.7/2	8.66	20.35	47.6	32.0	1523	1.49
2/28-DR70W30A-d 11.5	4.7	3.2/2	10.05	15.04	47.2	32.2	1520	1.47
2/28-DR70W30A-d 12.5	4.0	2.7/2	11.87	10.80	47.5	32.0	1520	1.48
2/17-50A25V25W-d 11.5	4.3	2.9/2	11.00	12.47	47.3	31.9	1509	1.48
2/17-50A25V25W-d 12.5	4.0	2.7/2	11.87	10.80	47.5	32.1	1525	1.48
2/17-50A25V25W-d 13.5	3.5	2.4/2	13.65	8.40	47.8	32.7	1563	1.46
		Average Value			**47.49**	**32.15**		
		Used Value			**47.5**	**32.0**	**1520**	**1.48**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A28: Analysis for 2X2 rib fabric using dyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 11.2	5.9	4.2/2	8.05	24.78	47.5	33.8	1606	1.41
2/28-50WMe50D-d 12.2	4.8	3.4/2	9.90	16.32	47.5	33.7	1601	1.41
2/28-50WMe50D-d 13.2	4.3	3.0/2	11.02	12.90	47.4	33.1	1569	1.43
2/28-DR70W30A-d 11.2	5.9	4.1/2	8.05	24.19	47.5	33.0	1568	1.44
2/28-DR70W30A-d 12.2	4.9	3.5/2	9.68	17.15	47.4	33.9	1607	1.40
2/28-DR70W30A-d 13.2	4.3	3.0/2	11.05	12.90	47.5	33.2	1577	1.43
2/17-50A25V25W-d 11.2	5.6	3.9/2	8.59	21.84	48.1	33.4	1607	1.44
2/17-50A25V25W-d 12.2	4.9	3.4/2	9.69	16.66	47.5	33.0	1568	1.44
2/17-50A25V25W-d 13.2	4.4	3.1/2	10.68	13.64	47.0	33.1	1556	1.42
		Average Value			**47.49**	**33.36**		
		Used Value			**47.5**	**33.4**	**1591**	**1.42**

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.

TABLE A29: Analysis for interlock fabric using dyed yarns (FIN/ST- RELAXED STATE)

Fabric Code	cpc	wpc	Loop length in mm (ℓ)	Loop density (S)	K_c	K_w	K_s	R
2/28-50WMe50D-d 11.5	5.0	4.2/2	10.20	21.00	51.0	42.8	2183	1.19
2/28-50WMe50D-d 12.5	4.4	3.7/2	11.63	16.28	51.2	43.0	2202	1.19
2/28-50WMe50D-d 13.5	4.0	3.4/2	12.70	13.60	50.8	43.2	2195	1.18
2/28-DR70W30A-d 11.5	4.9	4.2/2	10.38	20.58	50.9	43.6	2219	1.17
2/28-DR70W30A-d 12.5	4.3	3.6/2	11.86	15.48	51.0	42.7	2178	1.19
2/28-DR70W30A-d 13.5	3.9	3.3/2	13.02	12.87	50.8	43.0	2184	1.18
2/17-50A25V25W-d 11.5	4.7	4.0/2	10.83	18.80	50.9	43.3	2204	1.18
2/17-50A25V25W-d 12.5	4.1	3.5/2	12.15	14.35	49.8	42.5	2117	1.17
2/17-50A25V25W-d 13.5	3.5	3.0/2	14.57	10.50	51.0	43.7	2229	1.17
		Average Value			50.82	43.09		
		Used Value			51.0	43.0	2193	1.18

The abbreviations cpc and wpc refer to courses and wales per centimetre respectively.