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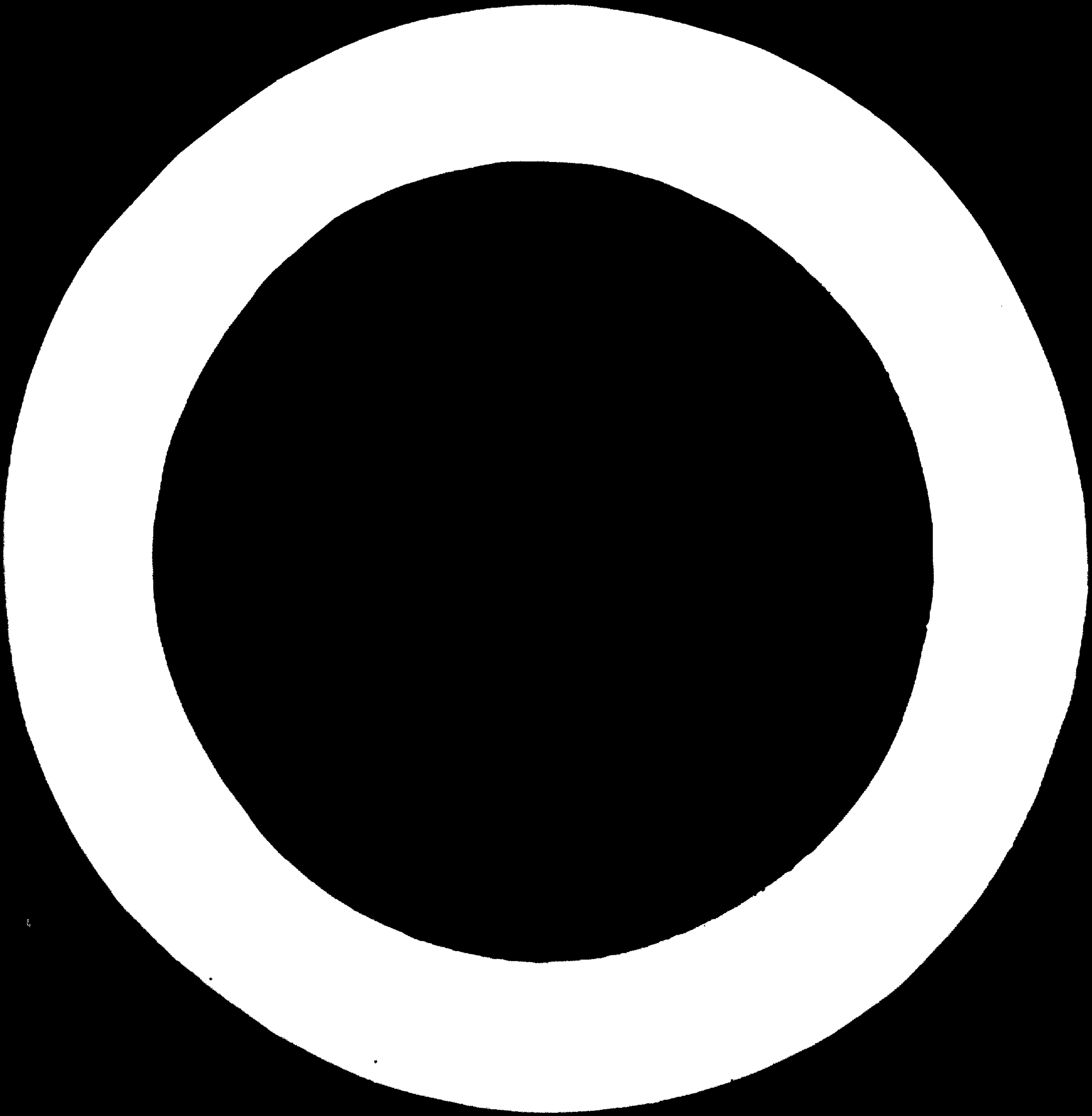
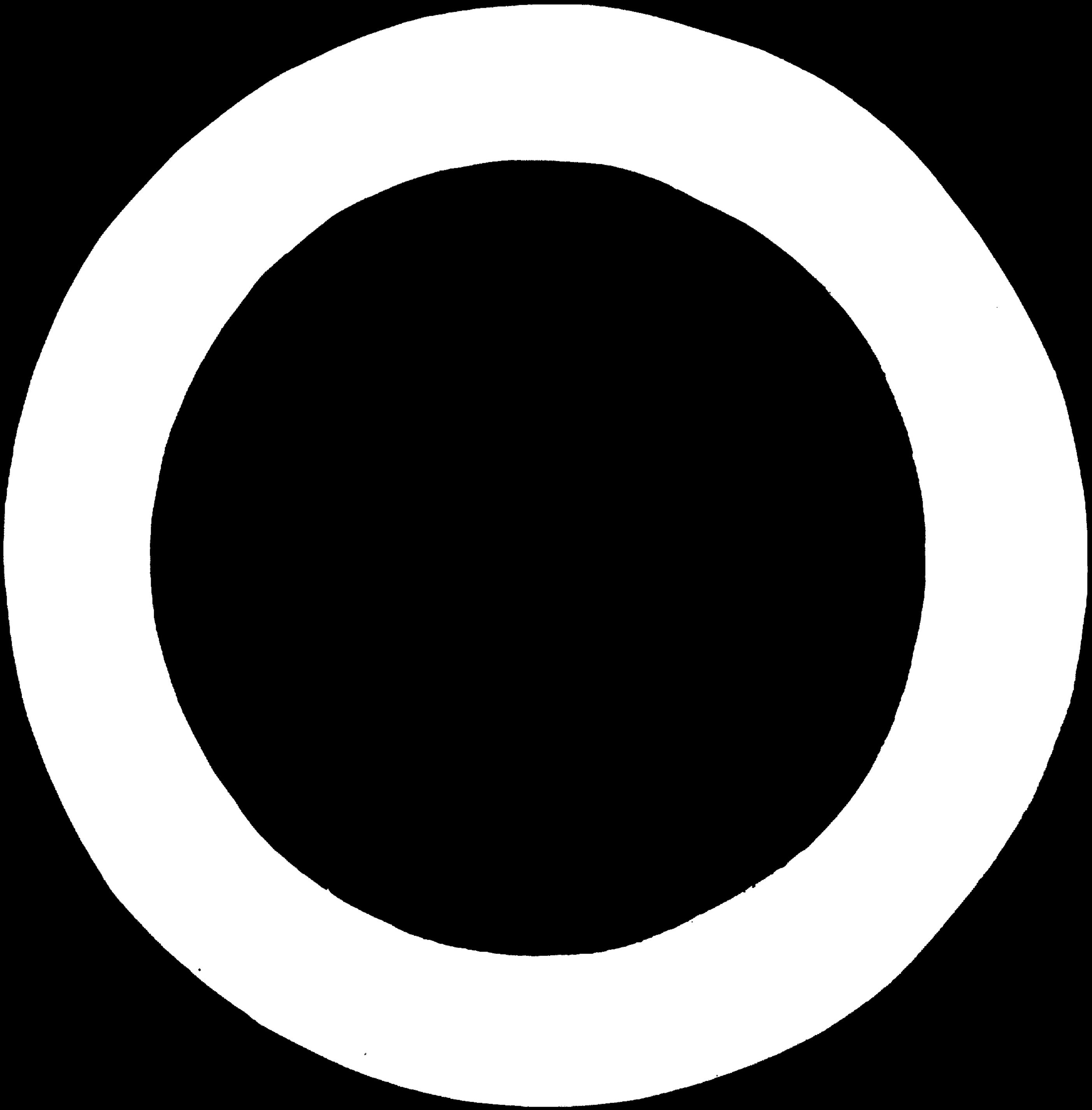
TRAINING FOR INDUSTRY SERIES NO. 3

THE
ŁÓDŹ TEXTILE SEMINARS

3. Knitting

UNITED NATIONS





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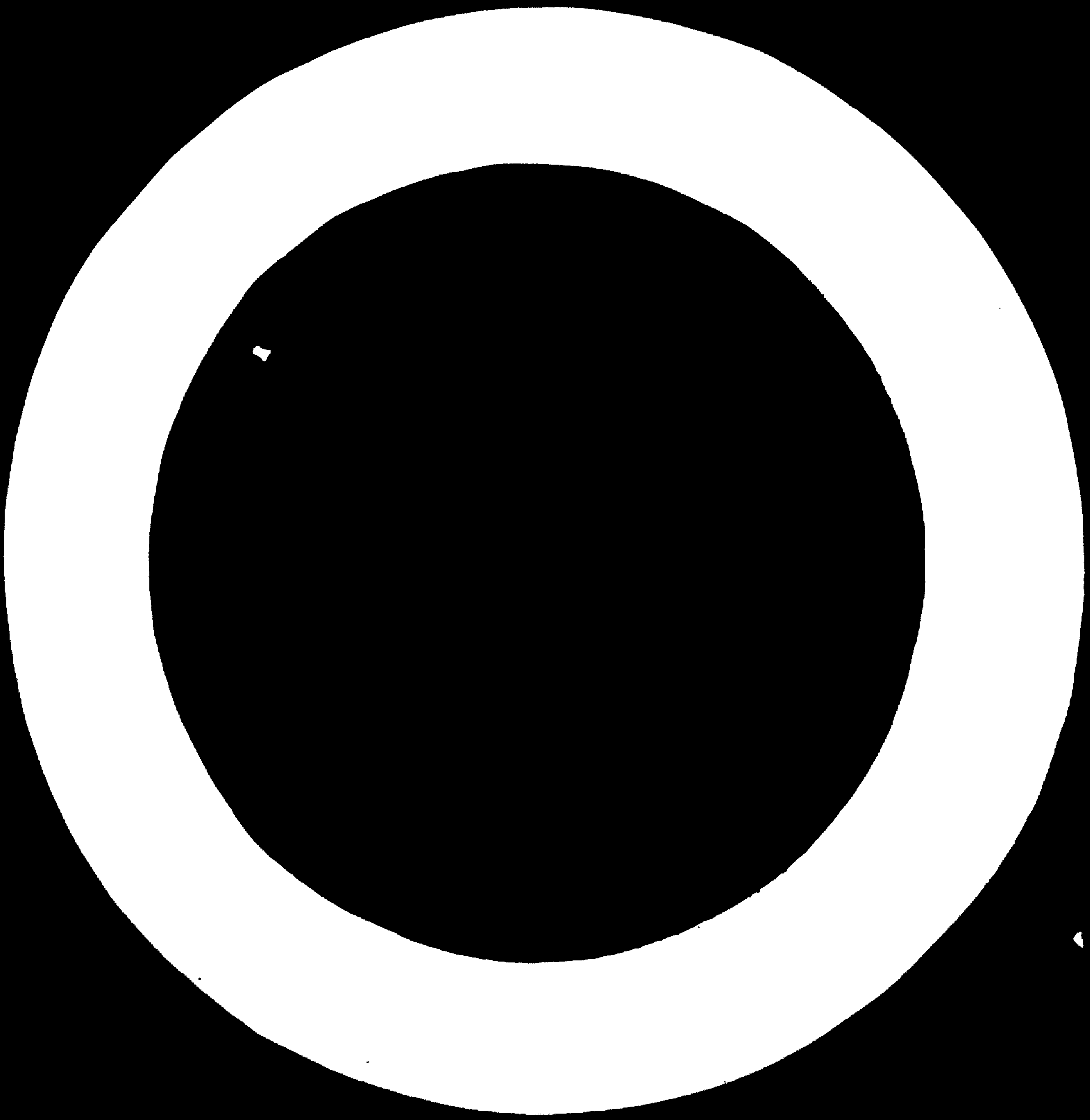

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

TRAINING FOR INDUSTRY SERIES No. 3

THE ŁÓDŹ TEXTILE SEMINARS

3. Knitting

UNITED NATIONS
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FOREWORD

This publication is the third of a series devoted to textile engineering and closely related fields. It is part of the Training for Industry Series published by the United Nations Industrial Development Organization (UNIDO).

Rapid world-wide increases in population and industrialization are reflected in the textile and allied industries. In any ranking of human needs, fibres and textiles for clothing and industrial purposes are second only to food-stuffs. The continuing quantitative and qualitative changes in textile production require the broadest and most complete dissemination of information in this important area.

The purpose of the present series is to make available to the developing countries the most recent scientific and technical information in order to help them to establish textile industries or to improve the effectiveness and economic viability of existing textile industries that are still in the earlier stages of economic development.

At the suggestion of UNIDO, with the support of the authorities of the Polish People's Republic, a post-graduate in-plant training course in textile industries was held in Łódź from May through September 1967. The course was repeated from May through October 1968, and its content was modified and up-dated on the basis of experience and new information. It was repeated again in 1969 and it is planned to continue this programme, up-dating its subject matter and improving its usefulness to the textile industries of the developing countries. It is on these courses that the present series is based.

The courses were organized by the Textile Research Institute in Łódź with the object of training a group of already highly qualified specialists in all branches of industry relating to textiles. Under normal conditions, such training would require work in mills and in research and development over a period of several years.

The courses give the participants an opportunity to become acquainted and to do actual work in conjunction with some of Poland's leading research centres and industrial enterprises, and to discuss with experts problems connected with techniques, technology, economics, organization and research in the field of textiles. In organizing the courses, the Textile Research Institute endeavours to co-ordinate the content of theoretical lectures, technical discussions and practical studies in laboratories and mills, covering all the fundamental problems of textile industries.

The main object of the seminars is to adapt the broad range of problems presented by Polish specialists to the direct needs of the developing countries. Lectures by the research workers of the Institute formed the core of the programme. The lectures do not review or repeat the basic problems usually studied at technical colleges and high schools in the course of normal vocational training; rather, they deal with subjects most often of concern to the management and technical staff of a textile enterprise.

The lectures, as presented in this series, have been grouped in eight parts: textile fibres; spinning; knitting; weaving and associated processes; non-conventional methods of fabric production; textile finishing; testing and quality control; and plant and power engineering.

It is hoped that the experience gained from these courses, as presented in this series, will contribute to the improvement of textile industries everywhere, and particularly in the developing countries.

The views and opinions expressed in this publication are those of the individual authors and do not necessarily reflect the views of the secretariat of UNIDO.

CONTENTS

EXPLANATORY NOTES

References are indicated in parenthesis in the text, by name of author and year of publication. The full references are listed, alphabetically by author, at the end of each article.

References to "tons" indicate metric tons and to "dollars" ($), United States dollars, unless otherwise stated.

The following abbreviations have been used:

cpi means "courses per inch".
Denier (den) is the weight in grams of 9,000 metres of yarn.
gg is "gauge".
kcal is kilocalorie.
Metric count (Nm) is the number of kilometres of yarn per kilogram.
A nanometer (nm) is 10^{-6} mm.
rev/min is revolutions per minute.
Tex is the weight in grams of 1,000 metres of yarn; millitex (mtex) is 0.001 tex.
wpi is "wales per inch".
Worsted count is the number of 560-yard lengths per pound of yarn.

THE STRUCTURE OF KNITTED FABRICS

by

K. Natkański

This paper presents a brief description of theoretical investigations on knitted fabric structures. Particular attention is given to work carried out in the last two decades.

The first account of a systematic study of the properties and dimensions of knitted fabrics was published by Tompkins (1914). He proposed the first law of knitted-fabric geometry, which states that the product of the number of wales and courses per inch of a fabric is a constant and is independent of the distortion of the fabric. He also found that the linear dimensions of plain-knit and rib-knit fabrics are dependent on yarn thickness.

The next important contribution to knitted-fabric research was made by Dutton (1944), who published the results of a large number of experimental observations on knitted fabrics, concerning their dimensional changes after knitting. These results indicated that the quality and regularity of a plain-knit fabric are dependent upon many factors, for example, the type of yarn and its package; the type of machine used and its speed; fabric storage conditions, such as the temperature and humidity of the yarn storage room, knitting room and fabric storage room; and the nature of the finishing and washing treatments.

Dutton suggested that dimensional changes in knitted fabrics are caused by recovery from strains imparted to the fabric during knitting. He also found that the differences in fabric dimension recovery are not equal and depend upon the type of relaxation treatment applied and the degree of distortion of the fabric before finishing.

The results of these investigations suggested that it was necessary to create a satisfactory physical model of the knitted fabric structure in order to explain the causes and effects of the dimensional changes observed. From such a model it might be possible to predict the final equilibrium state of the knitted structure.

Geometrical analysis of the plain-knitted structure

The first attempt to create a model of the plain-knitted structure was made by Chamberlain (1926), who found that a theoretically balanced loop (figure 1) is composed of an upper curved circular portion, two lower curved, also circular, portions and two diagonal straight portions that link the upper and lower curved

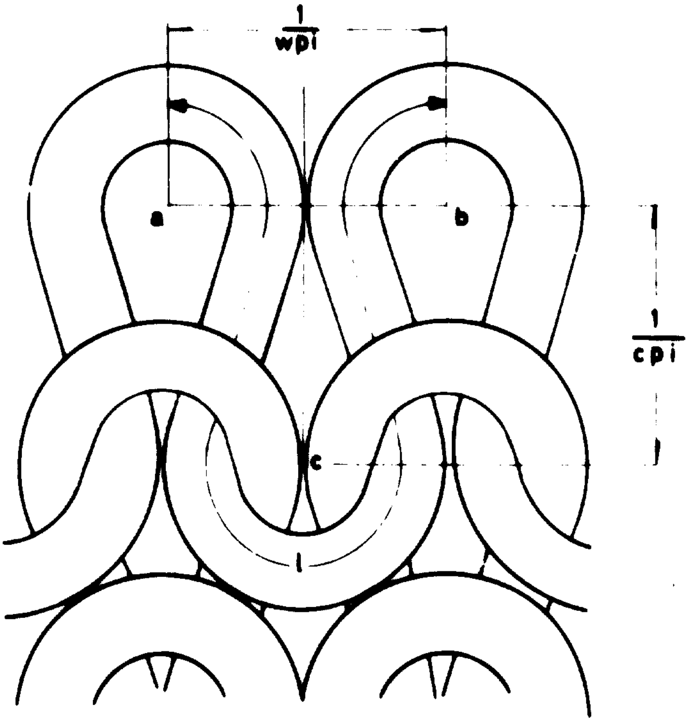


Figure 1. Chamberlain's plain stitch model (see text)

portions, one on either side. In Chamberlain's model, the loops of adjacent courses and wales are in contact, and the position of the maximum width of one loop coincides with the position of minimum width of the interlocking loop. By means of geometry, Chamberlain determined some characteristic values according to his model (cpi is "courses per inch"; wpi is "wales per inch"; *d* is the diameter of the yarn).

$$\frac{1}{\text{cpi}} = \frac{\sqrt{3}}{2\text{wpi}},$$

and

$$\frac{1}{\text{wpi}} = 4d.$$

Further,

$$\frac{\text{cpi}}{\text{wpi}} = \frac{2}{\sqrt{3}} = 1.15$$

and

$$\frac{\text{cpi}}{\text{wpi}} = \frac{3\pi + 2\sqrt{3}}{4\ \text{wpi}}.$$

It can be concluded from Chamberlain's equations that any change in loop length will involve a change in length of the fabric. The width of the fabric will not change, as it is governed by yarn diameter (d) only.

Chamberlain concluded his theoretical considerations in a very pessimistic vein: "In practice, however, there are so many other factors involved, that the results obtained theoretically do not agree with those obtained practically . . .".

Chamberlain considered only the case of a two-dimensional model of a knitted fabric of maximum cover. In fact, however, a plain-stitch loop is a three-dimensional structure, and fabrics with different covers can be obtained. Chamberlain's formulae did not consider these cases.

Peirce (1947) tried to generalize Chamberlain's loop model. Peirce created a three-dimensional model of a plain-stitch loop by laying it on the surface of a circular cylinder whose generators were parallel to the line of courses. Peirce's model also took into account changes introduced by changes in loop length for a given yarn diameter by adding extra straight portions across the top and bottom of the loops and in the diagonal straight portions.

The geometry of Peirce's loop was expressed by the following equations:

Wale spacing is

$$\frac{1}{\text{wpi}} = d(4 + 2\epsilon);$$

Course spacing is

$$\frac{1}{\text{cpi}} = d(3.364 + 2\xi)$$

where ϵd and ξd are the added straight sections inserted in circular and straight sections.

Thus, loop length (l) is

$$l = \frac{2}{\text{cpi}} + \frac{1}{\text{wpi}} + 5.94d.$$

Dalidovitch (1949) published the results of theoretical investigations of various knitted structures. He considered a two-dimensional and a three-dimensional plain-stitch model (figure 2) and obtained the following expressions for stitch length:

For the two-dimensional model,

$$l = \frac{1.57}{\text{wpi}} + \frac{2}{\text{cpi}} + d$$

and for the three-dimensional model,

$$l = \pi\sqrt{\left(\frac{1}{4\text{wpi}}\right)^2} + \frac{d}{\text{wpi}} + 2d^2 + 2\sqrt{\frac{1}{\text{cpi}} + 2d^2}.$$

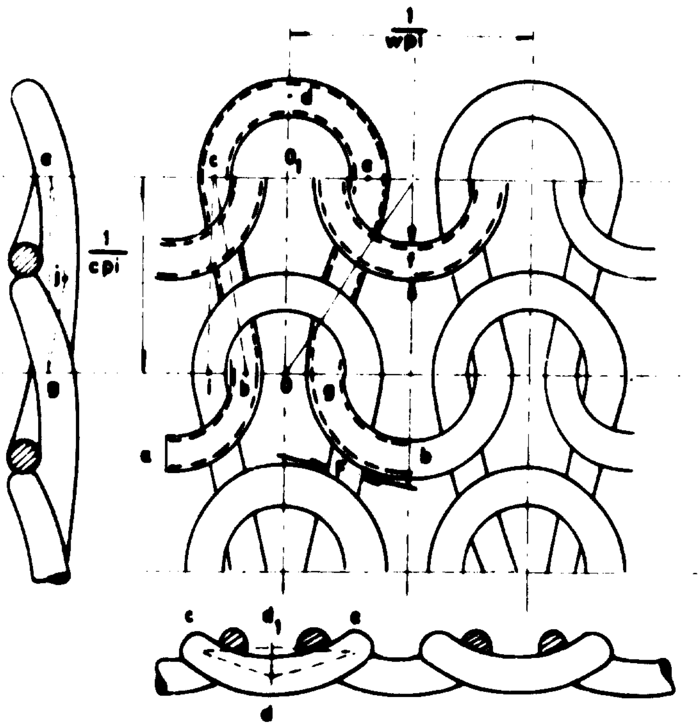


Figure 2. Dalidovitch's plain stitch model (see text)

Moreover, Dalidovitch distinguishes between the different states of loop shape, according to the type of fabric-finishing treatment.

Shinn (1955) considered a two-dimensional plain-stitch loop model, which led to the same loop-characteristic values as those of Chamberlain's model, the basic principles of his considerations being the same.

Leaf and Glaskin (1955) criticized Peirce's model. These investigators showed that, in reality, Peirce's model could not represent a stable fabric. According to their calculations, there were discontinuities of torsion at certain locations in Peirce's model that would cause the loop to change its shape after relaxation.

This criticism holds for other loop models. There are no physical reasons for some parts of the yarn in a loop to remain straight. The curvatures of the yarn would therefore change and, consequently, the shape of the loop would also change.

Leaf and Glaskin proposed another three-dimensional plain-stitch loop model. Its central axis in the plane of the fabric lies on the surface of three cylinders, which are perpendicular to the plane of the fabric. This model is satisfactory with respect to strain continuity.

Doyle (1953) had observed, when investigating the dimensional properties of plain-knitted fabrics, that, for a wide range of fabrics, the product of the number of courses and wales in unit area is dependent solely upon loop length, the relationship being of the form

$$S = \frac{k_s}{l^2}$$

where S = stitch density,

l = length of yarn knitted in the stitch,

k_s = constant.

Subsequently, it was shown that when fully relaxed, a plain-knitted structure also obeyed the following relationships:

$$\text{cpi} = \frac{k_c}{l}$$

$$\text{wpi} = \frac{k_w}{l}\,.$$

Hence,

$$\text{stitch density} = \text{cpi} \times \text{wpi} = \frac{k_c}{l} \times \frac{k_w}{l} = \frac{k_s}{l^2}.$$

Also,

$$\frac{\text{cpi}}{\text{wpi}} = \frac{k_c}{k_w} = k_r,$$

where k_c, k_w, k_s and k_r are constants called "fabric dimensional parameters".

These formulae can be considered as the basic laws of knitted-fabric structure, in that they indicate the dimensions towards which any plain-knitted structure tends in order to reach the state of equilibrium or minimum internal energy when knitted and removed from the machine. Further, they indicate that there is only one factor that governs the dimensions of a knitted fabric, namely, the length of the yarn knitted in the stitch. These experimental relationships have been recognized and accepted by subsequent researchers in this field and used as basic principles for further investigations.

Munden's investigations on knitted fabrics and their tendency to reach a characteristic state of energy equilibrium have led to the realization that there are two basic equilibrium states for the knitted fabric, depending upon the treatment of the fabrics after knitting (Munden, 1959). These two states are known as the dry-relaxed state and the wet-relaxed state.

If, after knitting, a fabric has been allowed to lie freely for a sufficient length of time, it may reach a stable state of equilibrium. This state is called a "dry-relaxed state". The state of equilibrium reached by a fabric after static relaxation in water and subsequent drying is called a "wet-relaxed state".

Munden estimated the k-values for both dry- and wet-relaxed states of a plain fabric as follows:

TABLE 1.

k-Value	*Dry-relaxed state*	*Wet-relaxed state*
k_c	5.0	5.3
k_w	3.8	4.1
k_s	19.0	21.6

From these values it is clear that the cpi/wpi ratio or k_c/k_w ratio is 1.3 for both dry- and wet-relaxed fabrics. This k_r-value may be looked upon as a loop-shape factor.

Leaf (1960) proposed a different geometrical loop shape for the plain-knit loop structure. The knitted loop in the fabric plane was considered to be composed of two joined, identical elasticas (figure 3). He adopted the elastica because its shape is mathematically determinable and because its configuration is similar to that of a knitted loop.

The model was made three-dimensional by causing the elasticas to be bent out of the plane of the fabric into two different surfaces. In the first model, the elasticas were placed on the surface of a cylinder, as Peirce did. It was found that this model could be fitted to Munden's experimental results for wet-relaxed fabrics but not to the dry-relaxed fabrics.

In his search for another model that would fit both the wet- and dry-relaxed states, Leaf proposed a second model. The third dimension was assumed to be a sine wave. The second model is more complicated mathematically, but it provided a model that would fit the experimental relationship between cpi, wpi and stitch length for both the wet- and dry-relaxed states. However, both of Leaf's models are

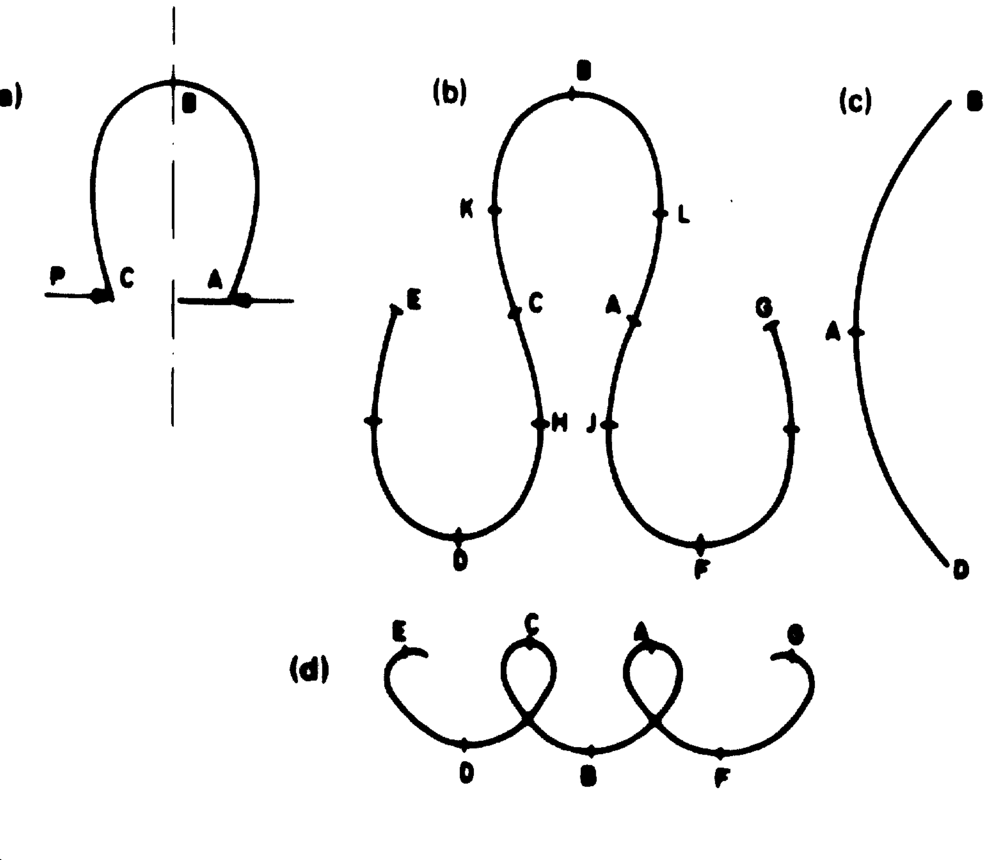


Figure 3. Leaf's plain-stitch model: (a) original elastica, (b) loop model in plane and (c), (d) its projections (see text)

physically unrealistic, because the proposed elasticas would only be produced if external forces acted on the yarn at those places on the knitted loop where there are no external forces. In addition, these models take no account of the effect of a given loop on its neighbouring interlocking loops.

It is to be noted that the loop shape of these models is determined by the experimental values obtained by Munden. They can thus be considered only as possible models that fit the observed experimental results.

Munden (1960) created a plain-knitted loop model by assuming a simplified two-dimensional system of forces in which he considered the interaction of neighbouring loops on the configuration of the individual loop. He suggested that the knitted loop was held in a loop configuration by forces acting upon it by neighbouring loops. In its simplest form, these forces could be represented by forces *P* acting on the loop at its widest and narrowest portions, as shown in figure 4.

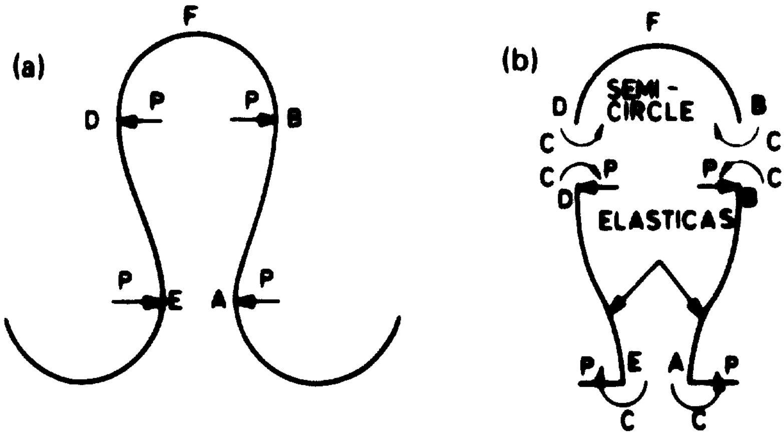


Figure 4. Munden's plain-stitch model: (a) loop model, (b) forces and couples layout (see text)

Munden's main assumptions in analysing this model were as follows:

(a) The narrowest portion of a given loop coincides with the widest portion of the subsequent loop.

(b) The external forces act horizontally; that is, they have no vertical components and act on the vertical portions of the loop only. They are also considered to act at the widest and narrowest portions of the loop.

(c) A two-dimensional model only was considered.

In the mathematical analysis of this model, the loop was divided into sections, and the forces acting on the sections were as shown in figure 4. Thus, the central section of the loop took the form of a semicircle, and the vertical sections were elasticas.

An infinite range of loop shapes was obtainable with this model, differing in the ratio of the widest to the narrowest part of the loop. For each loop shape, the appropriate *k*-values could be calculated, and Munden found that *k*-values in reasonable accord with those obtained experimentally were obtained for loop shapes when the yarns at the narrowest part of the loop touched each other. For this case, the ratio of the widest to the narrowest part of the loop was 3:1.

These findings suggest that a loop can be considered as a force-determined configuration in which the forces are applied at the loop-interlocking points and that, to a reasonable approximation, these forces can be localized at these interlocking points.

In the years 1963 to 1965, Postle (1965) tried to generalize Munden's model and used two basic geometrical parameters in his analysis; namely, the loop angle and the interlocking angle (figure 5). The latter is a parameter that indicates a lack of coincidence of both the widest and the narrowest parts of the loops.

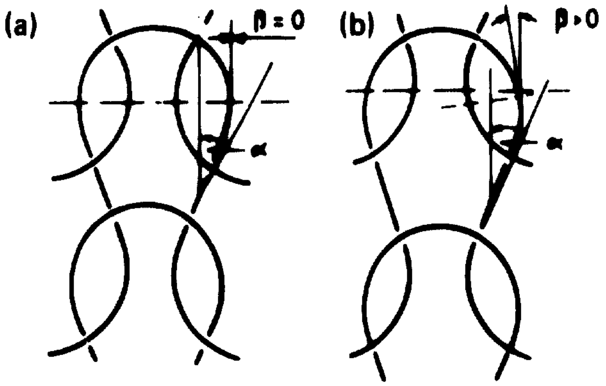


Figure 5. Postle's plain-stitch models: (a) special model (β = 0), (b) general model (β > 0) α = loop angle, β = interlocking angle (see text)

Applying forces acting perpendicularly to the plane of the fabric, Postle created a three-dimensional model. He found that, with this method (that is, independently considering the bending of the loop in the two planes at right angles to each other), it was impossible to relate the loop structure to a condition of minimum bending force. In his general summary, he suggested that, to achieve this, a more general approach involving a one-stage analysis of a three-dimensional loop would be required.

Geometry and structure of 1 X 1 rib fabrics

The theoretical investigations of the 1 X 1 rib basic structure are not as rich in the variety of conceptions as those of the plain-knitted structure. Here, also, the first recorded systematic investigation of the factors affecting the dimensions of 1 X 1 rib fabrics is that of Tompkins (1914). However, his results were empirical, and he did not propose a geometrical model to fit the experimental findings.

Dalidovitch (1949) proposed a 1 X 1 rib structure model, built on the assumption that a loop made from an elastic yarn such as wool had the same radius of curvature in every part. He thus assumed that the loop shape could be considered as a circle that had been cut at the bottom and the two cut ends twisted out of the fabric plane.

In the general case,

$$\frac{1}{\text{wpi}} = D + d,$$

where D and d are loop and yarn diameters, respectively. As D in this formula is equal to l/π where l is the loop length,

$$\frac{1}{\text{wpi}} = \frac{l}{\pi} + d.$$

Course spacing is assumed to be,

$$\frac{1}{\text{cpi}} = D - d;$$

thus,

$$\frac{1}{\text{cpi}} = \frac{l}{\pi} - d.$$

Also,

$$\frac{\text{cpi}}{\text{wpi}} = \frac{D + d}{D - d}.$$

Dalidovitch suggests that, for an elastic thread, the specific loop configuration is given by 1/wpi = $4d$; thus $D + d = 4d$; and $D = 3d$.

Dalidovitch also states that the loop shape is different when made from less elastic yarn and changes during wearing and, especially, washing, with an increase in length until both faces of the 1 X 1 rib structure resemble the face side of the plain-knitted structure. Therefore, under these circumstances, the following formula for the plain-knitted structure applies:

$$l = \frac{1.57}{\text{wpi}} + \frac{2}{\text{cpi}} + \pi d$$

and the cip/wpi ratio is 1.156. In practice, the most common value obtained is approximately 1.4 for dry-relaxed fabrics.

Smirfitt (1964) described the results of a series of experiments designed to determine the factors controlling the dimensions of relaxed 1 X 1 rib fabrics. Using worsted yarns and the following range of worsted counts–2/10's, 2/16's, 2/20's, 2/24's, 2/32's, 2/40's, and 2/56's,–he showed that the geometrical properties of worsted 1 X 1 rib fabrics can be described by means of k-values similar to those used for plain-knitted fabrics. Smirfitt found that k_r-values for a wide range of fabrics made from these yarns were independent of yarn count and had the following numerical values:

For dry-relaxed fabrics	$k_s = 15.0$
For wet-relaxed fabrics	
measured after drying	$k_s = 16.3$
measured under water	$k_s = 16.2$
tumble-dried	$k_s = 16.5$

However, when considering the influence of number of ends of yarn knitted into a fabric, Smirfitt mentioned mean k_s-values as follows:

For 1/12's (one end)	$k_s = 17.0$
For 2/24's (one end)	$k_s = 17.2$
For 1/24's (two ends)	$k_s = 17.0$
For 2/48's (two ends)	$k_s = 17.6$

These figures refer to the wet-relaxed state but "are similar to those obtained in other relaxed states" (Smirfitt, 1964).

Smirfitt advocates using $k_s = 16.0$ for the wet-relaxed condition. It is surprising that the results for the single yarns mentioned above were not included in experiments aimed at obtaining the average k_s-value. Smirfitt did not comment on these differences, but it has been suggested that these were probably caused by inexact and inefficient relaxation techniques. Thus, Nutting (1961) stated that standard wet relaxation did not produce complete relaxation of the fabric and that a better result can be obtained by more intensive treatment.

Smirfitt attempted to explain his results in terms of a geometrical model of the 1 X 1 rib structure based on Leaf's model of the plain-knitted structure (figure 3). In accordance with this assumption, he considered a 1 X 1 rib structure to consist of two adjacent loops, meshed in opposite directions and linked by short lengths of yarn that pass through the fabric. The assumption is that the adjacent loops along the

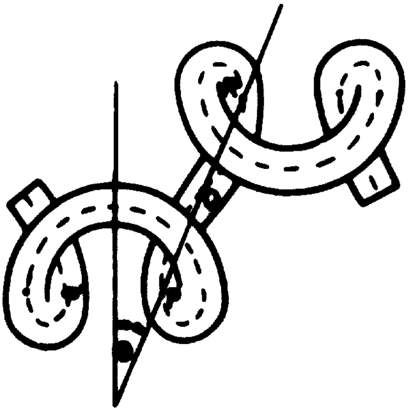


Figure 6. Smirfitt's 1×1 rib-stitch model

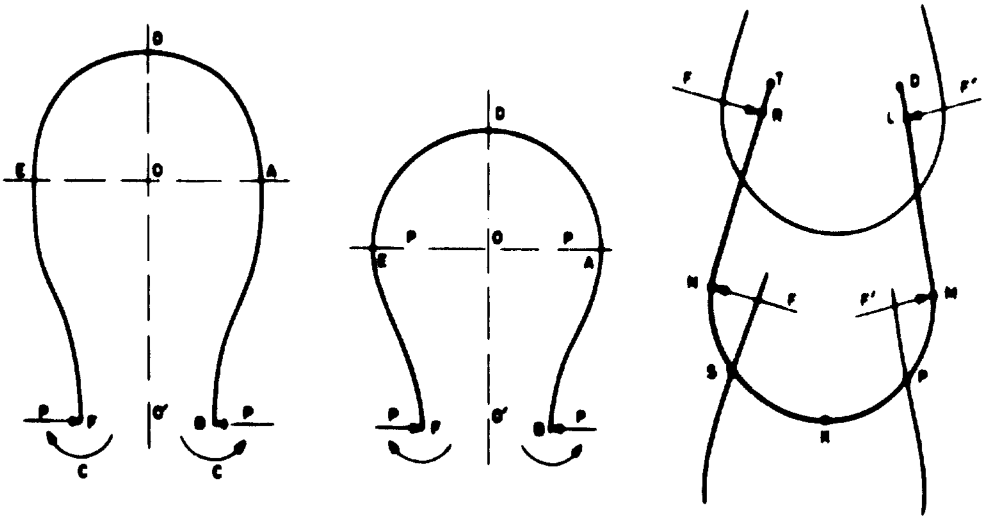
same course are not in contact, nor are the individual loops closed at their necks. Smirfitt found that this model would produce results in accord with those observed experimentally when the length of yarn passing through the fabric was inclined at an angle $\theta = 23^\circ$ (figure 6). However, this model is subject to the same criticisms as those previously levelled against the Leaf model of the plain-knitted structure (figure 3).

From 1965 through 1967, Natkański (1967) investigated the 1 X 1 rib-knitted structure. He corrected the experimental k-values found by Smirfitt for this stitch and gave the dimensional parameters for four different relaxation states of 1 X 1 rib-knitted fabrics.

When analysing the results of investigations of the actual fabrics, he found that the linear dimensional properties of 1 X 1 rib fabrics and the appropriate dimensional parameters k_c and k_w are affected by the loop length and yarn thickness (yarn count). Only the k_s-value can be considered as a factor independent of the yarn thickness, for its effect on the number of loop per unit area is so small as to be negligible.

Natkański has also shown that, in a simplified analysis of the 1 X 1 rib structure, it is possible to obtain the dimensional relationship in the form of cpi $= k_c/l$ and wpi $= k_w/l$, and to neglect the yarn count effect. Nevertheless, in a general case the yarn-count effect must be considered in any analysis of the linear dimensional parameters of a 1 X 1 rib structure.

Natkański has given two theoretical models of 1 X 1 rib-knitted fabrics. One of them applies to the knitted fabrics after dry-relaxation treatment (ordinary drying or tumble-drying), and the second model applies to the fabrics after wet-relaxation treatments (wetting or washing).



(a) (b) (c)

Figure 7. Natkański's 1 X 1 rib-stitch plane model: (a) dry relaxed, (b) wet relaxed, (c) in the third dimension

The dry-relaxed structure model has been assumed to be similar to an elastic rod bent by a plane system of forces and couples applied to its ends (figure 7a). The shape of the second model was obtained by means of a plane system of forces and couples acting at the widest and narrowest dimensions of the bend formed, which has the shape of a knitted loop (figure 7b).

The plane models obtained in this manner can be made three-dimensional by the application of forces acting in the plane perpendicular to that of the fabric (figure 7c).

Natkański emphasized the fact that, in the analysis of a knitted structure, and especially of a knitted structure of the rib type, one must take into account its three-dimensional nature. Moreover, he has indicated that, in a three-dimensional theoretical model of a knitted structure, the flattening of the yarn must be considered. He has shown that, in a rib structure, the yarn-flattening ratio is a comparatively high value $d_1/d_2 \approx 2$, where d_1, and d_2 are the widths of the yarn cross-section in two perpendicular planes; all of the theoretical models that have been considered thus far were assumed to be made from a yarn with circular cross-section $d_1/d_2 = 1$.

Geometry and structure of rib variants

It is evident that the more complicated the knitted structure becomes, the more difficult it is likely to be to explain the effects observed. Variant rib structures have been investigated by Dalidovitch (1949), who applied the same reasoning to obtain the geometrical relationships for these more complicated structures as he did for his rib and plain models. As was the case with other early workers in this field, his models were based on geometrical considerations and not on physical principles.

In order to calculate the characteristic values for the half-cardigan and full cardigan structures, Dalidovitch divided these structures into two components, namely the knitted loops and the tuck loops (see figure 8, indexes 1 and 2). Dalidovitch estimated the stitch length in the full cardigan as follows:

in the knitted loop,

$$l = \frac{\pi D_1}{2} + \frac{2}{\text{cpi}} + \frac{\pi D_2}{2}$$

where D_1 and D_2 are the arc diameters of the upper and the lower parts of the loop, respectively;

in the tuck loop,

$$2 = \frac{\pi D_3}{2}$$

where D_3 is the arc diameter of the upper part of the tuck loop.

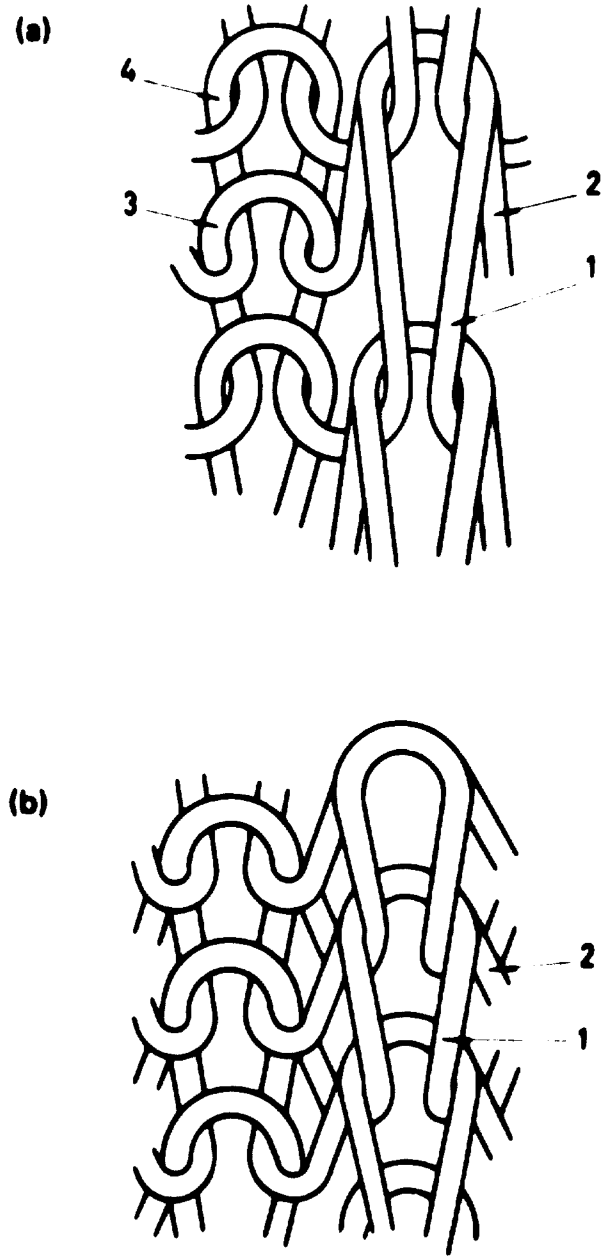


Figure 8. Dalidovitch's half-cardigan (a) and full cardigan (b) models (see text)

In the half-cardigan stitch, Dalidovitch distinguished knitted loops of three different sizes (figure 8, indexes 1, 3 and 4), whose stitch lengths were:

in loop 1,

$$1 = \frac{\pi D_1}{2} + \frac{2}{\text{cpi}} + \frac{\pi D_2}{2},$$

in loop 3,

$$3 = \frac{\pi D_4}{2} + \frac{2}{\text{cpi}} + \frac{\pi D_2}{2},$$

in loop 4,

$$4 = \pi D_5$$

where D_4 and D_5 are the arc diameters of the upper parts of the loops, respectively, and D_1, D_2 and D_3 are as in the previous equations. In the half-cardigan stitch, the length of the tuck loop is described by the same formula as for the full cardigan stitch.

In analysing these models, Dalidovitch obtained relationships to express the *D*-values in terms of yarn diameter, and from these relationships obtained the cpi/wpi ratios for half-cardigan and full cardigan as 1.64 and 1.92, respectively.

In relating loop length to fabric dimensions, Dalidovitch obtained the following formulae for cotton (c) and rayon (r) interlock structure, respectively:

$$c = \frac{18}{\text{wpi}} + \frac{20}{\text{cpi}} + 3.6d,$$

and

$$r = \frac{18}{\text{wpi}} + \frac{20}{\text{cpi}} + 1.5d.$$

His model consisted basically of the plain-stitch structure, with some correction made for the length of yarn between the front and back faces of the fabric.

He also obtained experimental results for interlock fabrics made from cotton yard, bleached and unbleached, and from regenerated cellulose, from which he obtained the following empirical relationships:

for unbleached cotton fabrics,

$$\frac{1}{\text{wpi}} = 3d + \frac{d\delta\sqrt[6]{N}}{36};$$

for bleached cotton fabrics,

$$\frac{1}{\text{wpi}} = 3d + \frac{d\delta\sqrt[8]{N}}{33};$$

and for rayon fabrics,

$$\frac{1}{\text{wpi}} = 3d + \frac{d\delta\sqrt[8]{N}}{28}$$

where

δ = cover factor $\left(\frac{l}{d_{\text{min}}}\right)$,

N = metric yarn count,

d = effective yarn diameter,

d_{min} = yarn diameter in compressed state (calculated from the specific density of the fibre).

Dalidovitch's geometrical models permit the estimation of some properties of knitted fabrics with great accuracy but, unfortunately, they do not elucidate the laws that govern the behaviour of knitted fabrics.

Hurt (1964) investigated experimentally the dimensional properties of cotton interlock fabrics and obtained empirical results for the dimensions of fabrics of this structure after dry relaxation and washing. He attempted to interpret these results on a model, basically the Leaf plain-stitch model (figure 3), modified to allow for the cross-links necessary to produce alternate loops on the opposite faces of the fabric. The wale spacing was derived from further drawings of interlock fabric cross-sections.

Investigations of the dimensional properties of jacquard-knitted fabrics have also been carried out by Dalidovitch (1949). He has described a wide variety of these fabrics and formed many formulae that describe their properties. The more complicated their structure, the more complicated and less precise are the formulae concerned.

All of Dalidovitch's formulae are based on simple geometrical loop shapes and do not take into consideration the important physical factors considered in the work of investigators who worked five to ten years later; for example, considerations of elasticity and energy.

It should be noted that, until the present, none of these attempts have succeeded in creating a satisfactory, physically realistic theoretical model of knitted fabric structure. Many researchers are still working on this problem, and it is to be expected that, in the near future, their efforts will meet success, because more accurate and reliable methods and devices are increasingly available.

In recent years the researchers in this field have been assisted by the most modern scientific tool—the computer. With it, the research carried out in the laboratories has become broader in range and scope and less time-consuming, and the prospects of achieving the aim more realistic.

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THE PRODUCTION OF KNIT GOODS FROM YARNS CONTAINING MAN-MADE FIBRES

by

A. Nawrocki

The principles of yarn processing in the preparatory divisions

The special characteristics of man-made fibres necessitate proper preparation and maintenance of definite processing conditions. Different batches of yarn should be carefully separated as the properties of yarns can differ from batch to batch and from supplier to supplier. In consequence, their mixing may bring about deformation of the fabric structure, uneven dyeing and the like. The delivered yarn must be carefully and constantly inspected for its count and twist.

The count deviation should not exceed 5 per cent. During storage, precautions must be taken against yarn damage. Cones with damaged or deformed packages should be eliminated.

The unpacking of cones from their protective paper should be done immediately before they are placed on the machine. Man-made filament yarns intended for producing warp-knitted fabrics are wound onto the beams.

It is necessary to give particular attention to maintaining a constant and unidirectional tension on all of the threads during warping. This is particularly true of yarn made from polyvinyl chloride fibres, which stretch even during a small increase in tension. This stretching can cause imperfections in the form of deformation or uneven colouration in knitted fabrics.

In this case it is advisable to apply compensatory tension devices with central adjustment. The value of yarn tension during warping should amount to 0.1 to 0.2 g/den (0.9 to 1.8 g/tex).

With textured yarns, this tension should not exceed the value necessary to straighten it (0.1 g/den or 0.9 g/tex). In conventional yarns, speeds from 150 m/min up to 250 m/min are employed. For polyvinyl chloride yarns or for yarns made from polyester fibres, the speed cannot exceed 120 m/min.

The surfaces of all machine elements that come into contact with the yarn - primarily the holders and tension devices - must be kept smooth and clean. Worn or damaged elements that might cause stresses on or damage to man-made filament yarns, which have high tenacity, should be replaced.

The bobbins should be placed on the creel in such a way that the distance between the eye and the top of the bobbin should be equal to the diagonal of a bobbin's cone, and a guiding eyelet should be placed on the prolongation of the cone axis. Setting-up in this way keeps the yarn from sliding on the surface of the package during unwinding. The distance between the bobbins on the creel and the beam during warping should be as small as possible, and the number of intermediate elements that induce additional stress should be limited to the utmost.

It is necessary to maintain parallel winding of yarn on the spool, and package density should be uniform along the entire length of the beam. Depending on their end-use man-made staple yarns undergo warping or winding processes. During winding, a constant uniform tension of all the yarns is required. This can be attained by the use of tension devices with central adjustment installed on the winding machines. In case of yarn break, when winding is done on drum winding machines, the spindle must be automatically drawn away from the drum to avoid ruffling and entangling of the package.

Since there is considerable stretching and weakening of the yarn in the sector before a break, the broken end should be tied only after unwinding and cutting off 1 or 2 cm of yarn from the cone. Winding speed should not exceed 200 m/min, particularly with polyvinyl chloride fibres.

Uniform hardness of the package is required to ensure the correct and uniform structure of the knitted fabric. Values from 30 to 40 (Durometer reading "O") for package hardness are acceptable. If yarn has been stored for a considerable period, rewinding before knitting is advisable.

During winding, the yarn is coated with paraffin or undergoes a process of surface improvement by means of a special, easily removed preparation that facilitates processing on the knitting machines. The warping of man-made staple yarns requires the same conditions as for man-made filament fibres. The distance between the bobbins and the eyeboard should be at least 15 cm.

Because of the low humidity and associated electrostatic qualities of synthetic fibres, the maintenance of definite conditions in the production areas is necessary. The ambient air should have a relative humidity of 65 per cent and a temperature of 20° to 24°C.

Knitting conditions

Before knitting, it is necessary to examine carefully the conditions and functional correctness of all elements of the machine that come into contact with the yarn or that participate in the loop-forming process. This particularly concerns the cams, needles, guides and yarn holders. Here too, damaged or imperfectly working elements should be replaced. The surfaces of needles, guides and holders should be smooth, so as to avoid snagging the yarn passing through them.

These precautions are especially important in the knitting of textured and high-bulk yarns, which have a strong tendency to snag. Good results can be obtained by the use of chromium guides, which are twice as resistant to damage as the conventional guides.

The uniformity and stability of yarn tensions in all working systems of machines are of great importance in the processing of man-made fibres. Good results may be obtained by using compensatory feeding devices with central adjustments. The optimum yarn tension measured near the yarn feeder during the knitting process should not exceed 0.1 to 0.2 g/den (0.9 to 1.8 g/tex).

The fibrous dust given off from the yarn during processing must be removed from the machine by means of a pneumatic installation such as a membrane compressor, which prevents it from settling on neighbouring machines. The condition of the ambient air should be as given above.

When air humidity is below 40 per cent, fibre rigidity and fragility increase simultaneously with a decrease in its processibility.

Knitting fabrics from regenerated cellulosic (viscose and acetate) fibres

The technological parameters of regenerated cellulosic staple yarn processing do not differ in principle from those accepted for natural yarns, because the properties of the fibres as well as the structure and properties of the yarn are similar.

Yarns of rayon staple are usually knitted on circular or flatbed latch-needle machines or on loop-forming sinker-web machines. The yarn counts and application trends of such yarns are the same as for cotton or wool yarns.

Continuous rayon yarns from 40 to 225 den (4.5 to 25 tex) can be processed on nearly all types of equipment except flatbed machines of coarse gauges. Warp-knitted fabrics for ladies' underwear and for gloves are the fundamental products.

Knitting fabrics from synthetic yarns

Polyamides

With yarn containing polyamide staple fibres, the technological parameters do not differ in principle from those that have been adopted for natural yarns. As a rule, the polyamide fibres content in blends with natural fibres does not exceed 25 per cent. These yarns can be knitted on circular or flatbed latch-needle machines and on Terrot machines. The range of yarn counts and their application are the same as for yarns made from natural fibres (cotton, wool).

Polyamide filament yarns are usually knitted on warp knitting machines, on machines of the Cotton's Patent type and on seamless hosiery machines. On 26-gauge knitting warp machines, yarns ranging from 20 to 80 den (2.2 to 8.9 tex) are generally used.

On machines of the Cotton's Patent type, yarn from 7 to 60 den (0.78 to 6.67 tex) is used. On the seamless hosiery machines, yarns of 7 and 20 den (0.78 and 2.2 tex) are usually processed. Ladies' underwear, shirts and stockings make up the basic assortment of end-products.

Polyacrylonitrile (standard)

Yarns made from standard polyacrylonitrile fibres should be somewhat finer (about 10 per cent) than woollen yarns, since their specific weight is lower than that of wool. This must be done if knitted fabrics of similar covering properties are to be obtained. The specific weight of knitted polyacrylonitrile fabric is thus lower than that of a woollen fabric. In the knitting of standard polyacrylonitrile yarns, the machine should be adjusted for a somewhat greater stitch density than is used with woollen yarn, because the elasticity of polyacrylonitrile yarns is smaller than that of woollen yarns. Consequently, in polyacrylonitrile knitted fabrics, the loop length, during loop formation as well as in the knitted fabric after its removal from the machine, will be approximately the same.

With woollen yarn, the loop length in a knitted fabric is smaller than during loop formation. Polyacrylonitrile yarns can be knitted on all types of machines other than warp knitting machines. Outerwear garments form the basic product assortment.

Polyester

In the case of yarns containing polyester fibres, the technological parameters are the same as those for knitted woollen fabrics.

There is a tendency to use polyester yarns that are somewhat finer than woollen yarns used for the same purpose. This results from the greater strength of the polyester fibres as compared with woollen fibres, as well as from the fact that an increase in the yarn count is usually associated with an increased twist factor, which can produce a decrease in the pilling tendency. Yarns that contain polyester staple fibres can be knitted on nearly all types of machines. Interlock plain and piqué knitted fabrics intended for outerwear are the fundamental products.

Polyester filament yarns are usually knitted on warp knitting machines. The range of yarn count is from 40 to 70 den (4.5 to 7.8 tex). The basic product assortment consists of ladies' underwear and shirts.

Polyvinyl chloride

Yarns made from polyvinyl chloride, ranging from 12 to 60 Nm, may be knitted on almost all types of machines, with the exception of warp knitting machines. The same yarn counts as for woollen yarn are employed. The loop length in the knitted fabrics destined for anti-rheumatic underwear is usually 10 to 15 per cent greater than in woollen fabrics. In the knitting industry, polyvinyl chloride filament yarns in range from 45 to 120 den (5 to 13.3 tex) are used. Yarns of 45 and 75 den (5 and 8.3 tex) are used for the production of warp-knitted fabrics destined for use in underwear. Yarns of 75 and 120 den are processed on interlock machines of 20 gg or finer. They are used primarily for outerwear.

Polypropylene

The parameters adopted for fabrics knitted from natural fibres can be used with polypropylene fibres. In designing knitted fabrics containing polypropylene fibres, the change of yarn diameter that results from their small specific weight (0.91 g/cm^3) must be taken into consideration. Accordingly, a finer count of polypropylene yarn must be used to obtain a knitted fabric of the same thickness and covering properties as when natural fibres are used.

Until this time, polypropylene filament yarns have not been generally used in the production of knitted underwear or outerwear. Knitted knotless fishing nets, packing materials and knitted shoe fabrics are the chief products.

Polyvinyl alcohol

The parameters of the knitting process for these yarns are analogous to those used with natural-fibre yarns. Polyvinyl alcohol yarns are used in underwear, outerwear and socks.

Polyurethane

Polyurethane staple fibres are mainly used in blends with polyacrylonitrile fibres such as Courtelle and Orlon. The share of polyurethane fibres in these blends ranges from 5 to 15 per cent. These yarns are used in elastic knitwear and socks. Continuous polyurethane fibres are used in the forms of monofilament and multifilament yarns. The range of yarn counts applied for the knitting purposes is very wide. For Verene fibre the range is from 90 to 1,660 den (10 to 185 tex), and for Lycra fibre from 70 to 1,120 den (7.8 to 124.5 tex).

Polyurethane yarns can be knitted either as they are or with single or double coatings. Polyurethane yarns are usually covered with polyamide and cotton yarns. Core-spun yarns with a polyurethane fibre core and coverings of cotton, wool, polyacrylonitrile or polyamide fibres also can be used. Polyurethane yarns are mainly used to produce interlock and warp-knitted fabrics from the Raschel machine. These yarns are usually knitted in combination with Helanca yarns. The fundamental assortment of garments made from them consists of bathing suits, elastic stockings and corsets.

Knitted fabrics made from modified yarns

High-bulk yarns

High-bulk yarns are most often made from polyacrylonitrile fibres. Bulked yarns adapted for knitting are used either in shrunk or non-shrunk form. The metric yarn counts range from 18 to 36 Nm and, for the most part, doubled yarns are used. If non-shrunk yarn is used, the yarn count after shrinkage will be from 14 to 18 per cent lower than the initial count.

With previously shrunk high-bulk yarns, the density of the fabric should be from 15 to 20 per cent lower than for standard yarns, taking into account the increase in yarn thickness after shrinkage.

However, when non-shrunk high-bulk yarns are used, the raw fabric should be about 40 per cent looser than the knitted fabric produced from standard yarns, because, as a consequence of shrinkage, the stitch density of the knitted fabric will increase about 25 per cent. The residual density compensates for the increase in yarn diameter after shrinkage. During the knitting of rib trimmings, the stitch density must be from 15 to 20 per cent greater than in the body of the fabric. High-bulk yarns are used in the production of knitted fabrics on machines of the Cotton's Patent type, and on flatbed and circular latch-needle machines. These knitted fabrics are intended for use in outerwear.

Textured yarns

The changes of yarn structure caused by texturing processes cause an increase in volume. This increase differs according to the kind of yarn and the process used. The highest values are achieved with Helanca yarn and the lowest value with undulated (Agilon) and looped (Taslan) yarns. Because of this increase in volume after the texturing process, it is necessary to correct the factors relating to the yarn count, taking into consideration the requirements connected with the cover factor. In tables 1 and 2, the typical values of yarn denier (tex) are given for the textured yarns most frequently used with several types and gauges of knitting machines. Outerwear, bathing suits and hosiery constitute the essential assortment of products made from textured yarns.

TABLE 1. DATA FOR KNITTING PROCESSES FOR HELANCA, ELASTIL AND BAN-LON-TYPE STUFFER-CRIMPED YARN

		Resulting yarn size		
Machine type	*gg*	*den*	*tex*	*Stitch*
Interlock	10	250—300	27.8—33.3	Interlock
	12	200—250	22.2—27.8	
	14	150—200	16.7—22.2	
	16	150	16.7	
	18	100	11.1	
	20	70—100	7.8—11.1	
	24	55—70	6.1—7.8	
RTR	10	300	33.3	Interlock
Circular rib machine	12	300	22.2	Rib
	14	150	16.7	
	16	150	16.7	
	18	100	11.1	
	20	100	11.1	
	24	70	7.8	
Terrot machine	18	100	11.1	Plain
	20	70—100	7.8—11.1	
	22	70	7.8	
Latch-needle machine	7	600—900	66.7—100	Plain
	8	450—600	50.0—66.7	
	10	300—400	33.3—44.5	
	12	200—300	22.2—33.3	
	14	150—200	16.7—22.2	
	16	150	16.7	
Cotton's Patent type machine (full-fashion)	12	500	55.6	Plain
	15	400—500	44.5—55.6	
	18	400—420	44.5—46.7	
	21	300—400	33.3—44.5	
	24	230—300	27.8—33.3	
	28	200—250	22.2—27.8	
	36	100	11.1	
	39	70	7.8	

Machine type	*gg*	*Resulting yarn size*		*Stitch*
		den	*tex*	
	42	70	7.8	
	45	55—70	6.1—7.8	
	48	55	6.1	
	51	30	3.33	
Double-cylinder hosiery machine	6	270	30	Plain
	14	180—210	20—23.3	
	18	180—210	20—23.3	

TABLE 2. DATA FOR KNITTING PROCESSES FOR BI-STABILIZED YARNS OF THE CRIMPLENE TYPE

Machine type	*gg*	*Resulting yarn size*		*Stitch*
		den	*tex*	
Interlock	14	150—300	16.7—33.3	Interlock
	16	150—250	16.7—27.8	
	18	100—250	11.1—27.8	
	20	75—250	8.35—27.8	
	28	75—100	8.35—11.1	
RTR	10	600	66.7	
Circular rib machine	12	200—400	22.2—44.5	Rib
	14	150—300	16.7—33.3	
	16	150—200	16.7—22.2	
	18	100—150	11.1—16.7	
Flatbed machine	7	600—1,200	66.7—133.4	Plain
	8	450—900	50.0—100.0	
	10	300—600	33.3—66.7	
	12	225—450	25.0—50.0	
	14	200—300	22.2—33.3	

Making up knit goods

The character of knit goods, and above all their aesthetic properties, depend in great measure on the methods used in manufacturing them. This problem becomes particularly important in the case of knitted fabrics produced from yarns containing man-made fibres. Modification of traditional methods of manufacture is required because of the special properties of man-made fibres.

Knitted fabrics should always be fully shrunk before being made up. This is particularly true of those produced from modified yarns (high bulk, textured) that are easily deformed. Such clothing supplements as linings, stiffenings and inserts must be decatized before manufacture to avoid later deformation of the finished goods.

Cutting

The low elasticity of knitted fabrics produced from man-made fibres requires the exact adaptation of garment patterns to the structure and shape of the body. It is suggested that the patterns be made in such a way that long seam sectors should not be parallel to courses or wales, but rather run diagonally across them. Such oblique seams are more durable and less exposed to deformation.

Stretching of knitted fabric must be avoided during marking because it may cause deformation. Only tailors' chalk should be used to mark patterns. If the fibres melt during cutting, the number of layers cut at a time must be reduced, the speed of the knife or band-knife should be decreased or, if possible, agents for cooling the cutting elements should be used.

The surface of the knife, its base and other elements that come into contact with knitted fabrics should be smoothed and polished. This is of particular importance with knitted fabrics made from continuous yarns and especially from curled ones, since their component fibres separate and cause dragging of the stitches. The proper pressure and speed of the knife are also of great significance, since their excessive increase can cause melting of the knitted fabrics. The speed should not exceed 500 rev/min with a band knife or 1,800 rev/min with a hand knife.

Sewing

During the sewing of knitted fabrics constructed of man-made fibres, the three following essential problems arise: *(a)* proper preparation of the machine, *(b)* decrease of intensity of needle heating and *(c)* suitable selection of the sewing threads.

The pressure foot of the sewing machine determines the correct leading of the seam. The optimum pressure must be selected to secure the rythmic shift of knitted fabrics by the conveyor. The conveyor shift should be longer than when sewing knitted fabrics made from natural yarns. The stitch panel hole must be precisely fitted to the needle diameter. If the hole is too large, there will be deformation of the lower layer of the knitted fabrics during punching by the needle. Both layers of knitted fabric must be arranged with care under the binding unit in order to prevent them from puckering.

During sewing, the edges being sewn together should be stretched equally; they should never be pushed under the pressure foot. The knitted fabrics should be slightly stretched in the direction of the seam so as to flatten it. All elements of the machine that come into contact with the knitted fabrics, such as the stitch plate, the pressure foot and some parts of the machine table must be smoothed and polished so as to minimize the adhesion of knitted fabrics produced from man-made fibres, and especially from filament fibres.

However, the heat generated by the resistance of fibre in contact with the needle is the most important problem in the sewing-up of knitted fabrics constructed from man-made fibres. When there are very many strokes per time unit, the heat generated cannot be diffused quickly enough by natural circulation, and needle temperature may rise as high as 400°C, at which temperature man-made fibres begin to melt. The permissible temperatures of the needles for the several basic synthetic materials are as follows: for polyvinyl-chloride fibres, 100°C; for polyamide fibres, 230°C and for polyester and polyacrylonitrile fibres, up to 280°C. The magnitude of friction force and the intensity of needle heating connected with it depend in great measure on the form of the fibres and on the density of the knitted fabrics.

Friction magnitude reaches the optimum value with knitted fabrics made from filament yarns, which are characterized by high stitch compression. The magnitude of friction force is comparatively low for knitted fabrics of low density produced from staple yarns. These yarns permit, at each moment, an access of fresh air actuated by the sewing thread that takes away from the needle a part of heat generated by friction.

Experiments with some synthetic materials have confirmed the observation made concerning the sewing of cotton and silk articles that there is a considerable increase in needle temperature when the sewing thread breaks; that is, at the moment when the needle, moving with the same speed, produces no seam.

There are several methods of decreasing needle heat, four of the most effective of them being the following: *(a)* decrease of friction force by the use of needles with modified shapes and surfaces, *(b)* decreasing the friction by the use of a lubricant, *(c)* cooling by means of fluids and *(d)* cooling by means of compressed air.

The Schmetz needle is a typical example of modification of needle shape. In this case the needle diameter is increased by about 15 per cent immediately behind the needle point, with the result that the hole punched in the knitted fabrics is greater than the diameter of the needle shank, which freely passes across the knitted fabrics without friction. The reduced heating of such needles permits their use at higher speeds. Good results are also obtained by using chrome-finished needles, which are more useful than nickle-finished needles because of their lower tendency to heating as well as less adhesion of melted fibre particles.

Good results are also obtained when sewing threads are impregnated with a special preparation that is melted by needle heat and covers the thread surfaces, thus reducing the friction coefficient. As noted, another solution to this problem is to cool the needle with liquids. This is done by supplying the needle regularly with a set amount of a liquid characterized by a low boiling point so that it may be removed by evaporation. This fluid must not produce spots on the knitted fabrics that are difficult to remove.

Cooling by the use of compressed air is the most efficient way to decrease needle temperature. The air can either flow through the needles or through pipes mounted next to them. In the first case the hollowed needle shank is employed as a cylinder in which a little high-speed piston pumps down compressed air when the needle is lifted. A channel is milled on the outer surface of the needle, running along its entire length. In this channel, the air blown near the needle point can pass along the needle to its shank. With this method, high speeds are obtainable that permit a 25 per cent increase in the sewing speed. In the second case, air is pressed continuously through pipes with outlets in the form of thin sprayers near the needles. The sewing thread is also subject to the quick heating caused by friction. Special precautions must be taken when threads made from filament fibres are used.

Even when the continuous filament thread is sufficiently strong, pieces of its component fibres may break off and form small balls that can cause serious difficulties. Also, sewing threads may shrink upon cooling and thus deform seams made with them.

The sewing thread must have the same strength, shrinkage and colour as the yarn used for producing the knitted fabrics that are sewn with it. All clothing supplements, such as linings, the bands of zip-fasteners and stiffening inserts must be fully shrunk before being sewn in.

Seam stitching should be fairly loose so as to preserve the primary shape of the garment after washing. With curled yarns, seam elasticity should be not less than 25 per cent. Cotton and nylon threads can be used for the sewing of buttons and button-hole edging. The linking of garments made from Ban-Lon yarn must be done immediately after knitting, before the stitches are shrunk. The stitch density must be adapted to that of the knitted fabrics so as to obtain an equal surface of knitted fabrics near the place of linking.

For linking pullovers from full-fashion Cotton's Patent machines and circular latch-needle machines, the same count of yarn should be used as in knitting. Similarly, if the rib trim is made of yarn coarser than that used in the body of the fabric, it is necessary to use, for linking, yarn of the same count as was used in the rib trim.

Pressing

During the pressing of fabrics knitted from yarns containing man-made fibres, the possibility of direct contact of the fabrics with the hot metallic surface must be eliminated. The surface of a knitted fabric that undergoes pressure at a high temperature becomes shiny and less fluffy. Good results may be obtained with machines in which pressing is associated with steaming. Such types of pressing machines may be used successfully with knit goods made from polyacrylonitrile fibres.

The installation of a flexible cover on the machine table is indispensable for proper pressing. This covering must be changed as soon as the first deformations appear. Hard covers of pressing heads are to be avoided, and the pressing head must never be left in a lowered position. Supports under the head panel are used to prevent strong mechanical pressure.

Wet pressing should be avoided. For hand pressing, irons equipped with rheostats are recommended so as to maintain the pressing temperature appropriate for individual types of fibres. Only the reverse side of fabrics can be pressed, and in some cases a wet pressing cloth can be used if great care is taken. Special precautions must be taken in the pressing of ribbed and interlock fabrics.

NEW USES FOR KNITTED FABRICS

by

A. Nawrocki and J. Grębowski

Because of their high efficiency and wide variety, knitting machines are being employed increasingly for the production of many types of fabrics, not only for the production of garments but for technical purposes, haberdashery and even for medical purposes, that were not previously made by knitting. Some of the more interesting of these products are described below.

Knitted garments

Knitted imitation chamois leather

Knitted fabrics that resemble chamois leather are made by modifying the knitted fabric by a proper selection of raw materials, knitted structures and finishing treatments. The raw material is a blended yarn that contains highly shrinkable (40 to 50 per cent) polyvinyl chloride fibres and normally shrinkable polyamide or polyacrylonitrile fibres. From this yarn an interlock fabric is knitted as tightly as possible. This knitted fabric shrinks considerably in the finishing process, which consists of operations such as washing, dyeing with shrinking, polishing, shearing and water-proof finishing.

During shrinking, the polyvinyl chloride fibres migrate to the inside of knitted structure, forming a kind of core. Most of the normally shrinking polyamide or polyacrylonitrile fibres remain on the fabric surface, where they mainly determine the appearance and useful properties of the fabric.

Knitted chamois leather-like fabrics have very valuable hygienic properties (thermal insulation, air permeability) and aesthetic qualities (dimensional stability, wrinkle resistance) that surpass those of natural chamois leather. They can be used to produce clothing and some items of haberdashery that were formerly made only from natural chamois or velour leathers.

It seems possible to employ knitted fabrics of these kinds in the production of some goods in which fabrics woven of pure wool have been dominant up to now. In outerwear such as coats, the thermal insulating power of chamois leather-like fabrics is greater than that of fabrics woven from pure wool. The production cost of these knitted fabrics is approximately 30 per cent less than the average production cost of natural chamois and velour leathers and 50 per cent less than those of woven coat fabrics that contain 80 to 100 per cent wool.

Knitted fabrics with a woven appearance

Depending on the methods of production used and the end-uses envisioned, knitted fabrics of woven appearance can be light or heavy. In either case, these knitted fabrics are produced on warp knitting machines, usually from synthetic filament yarns, with the use of stable stitches (that is, stitches with limited extensibility). The warp stitches are tricots(1.0/1.2, 1.0/2.3, 1.0/3.4 or 1.0/4.5), the weft being laid in the courses and wales. After proper finishing, these knitted fabrics are made up into dress shirts, waterproof coats, tarpaulins and the like.

As compared with woven fabrics, these knitted textiles are distinguished by high resistance to crushing and wrinkling, easy care and good aesthetic appearance. Worthy of special note are knitted fabrics that require no ironing; shirts made from them are superior to those made of woven poplin.

Heavy knitted fabrics with a woven appearance are produced on a single needle-bar Raschel machine, using a stable stitch, and can be plain or patterned. In these knitted fabrics as in warp-knitted ones, limitation of stitch extensibility is obtained by laying the weft in the courses and wales. Raschel machines are usually equipped with at least six needle-bars, and it is therefore possible to obtain a wide range of relief designs while preserving the limited extensibility of the stitches.

As an example, the set-up for a patterned knitted fabric made on a 24-gg Raschel machine and the yarns used are given below:

In guide bars I and II: polyacrylonitrile staple yarn 48/2 Nm;
In guide bars III and IV: polyacrylonitrile staple yarn 24/2 Nm;
In guide bar V: polyamide yarn 200 den (22.22 mtex).

The guide bars are threaded as follows:

```
I     I  I  I  II I  I  I  I  I  I  I
II    I  I  I  II I  I  I  I  I  I  I
III   .  .  .  .. .  I  I  I  I  I  I
IV    I  I  I  II I  .  .  .  .  .  .
V     I  I  I  II I  I  I  I  I  I  I
```

The chain links are set out as follows:

I 88/00//
II 00/00/00/22//
III 68/20/68/66 68/20/68/66/68/66/68/66/68/66/68/66/68/66/68/
66/68/66/68/66//
IV 68/66/68/66/68/66/68/66/68/66/68/66/68/20/68/66/68/20/68/
66/68/66/68/66//
V 22/24/22/20//

After appropriate finishing, these knitted fabrics are used to upholster furniture and for decorative elements in automobile interiors.

Knitted fabrics with a plain, stable stitch are produced with the aid of four guide bars, one of which forms the basic stitch, the second laying the weft in the wales, and the other two placing the weft in a direction opposite to that of the courses. This stitch structure imparts to the knitted fabric a compact, multilayer construction that is particularly useful for protective garments such as fire-proof clothing. The inner layers of such fabrics are constructed of core-spun yarns with glass-fibre centres, sheathed with polyvinyl chloride fibres; the outer layers are constructed of man-made fibres such as the modified acrylic Kanekalon (Japan). Protective clothing made from these knitted fabrics possess resistance not only to heat but to hot metal splinters. Their hygienic properties are also satisfactory.

Knitted fabrics for technical purposes

Knotless fishnets

Knotless fishnets are made from polyamide yarns on Raschel machines with one or two needle-bars, using a chain stitch and a periodically alternating tricot stitch. Weft threads may be laid between the wales of the chain stitch. Figure I shows an entry of a typical stitch used for the production of knotless nets on a 24-gg Raschel machine.

Many kinds of netting can be produced on a single needle-bar Raschel machine by using yarns of different counts for the weft and chain stitches and by changing the number of wefts or weft and chain-stitch interloopings at the joint points of the net loops. With a double needle-bar machine, different kinds of nets can be obtained by changing the number of guide bars, the number of interlacings in the joint points of the loops and by application of the weft between the stitches formed by needles of both needle-bars. Research has proved that such nets fulfil all the requirements for equipment for this fishing technique. Research is being extended into the use of knotless fishnets in active fishing.

Among the advantages of knotless fishnets produced on Raschel machines are the following: *(a)* decrease in the consumption of raw material, *(b)* shortening the technical process of net production, *(c)* durability of net form and structure and *(d)* improvement of conditions for fishery exploitation.

Knitted fabrics for sacking

Knitted fabrics are used to produce sacks for shipping potatoes and other agricultural products. Such sacking materials can be produced on single needle-bar Raschel machines, using stitches similar to those employed in the production of knotless fishnets. The raw materials used to produce knitted sack fabrics are polypropylene or polyvinyl alcohol staple yarns. The weight per square metre of these fabrics is about 73 g, and a sack with dimensions of 60 X 105 cm weighs 100 g. Sacking knitted from polypropylene yarn is four times lighter than sacking made from woven flax or hemp yarns. The strength of knitted sacks packed with potatoes, as estimated by the number of times they can be dropped from a height of 1 m, is eight times greater than that of woven sacks.

Furthermore, the output of sacking by Raschel knitting machines is far greater than that of looms. While a loom can produce nearly 18 running metres of woven sack fabric per hour, from which 9 sacks can be made, the output of a Raschel machine is 400 running metres per hour at an operating speed of 350 rev/min. This high rate of machine productivity results from the use of an open-work stitch that permits the production of knitted fabrics in the form of "shawls". From 12 to 18 of these shawls can be knitted simultaneously on the working width of the machine. After removal from the machine, the width of the shawls corresponds to the desired width of a sack. From 400 running metres of the knitted fabric, 180 sacks can be

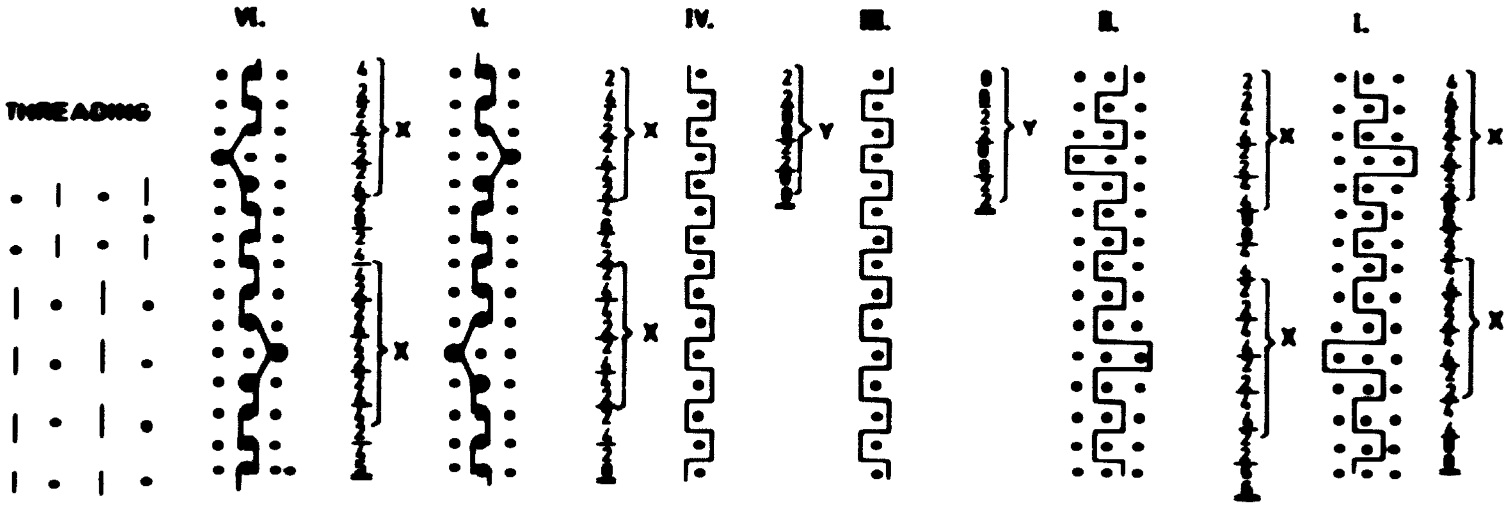


Figure 1. Diagram of the movements of the guide bars and of their threading and set-out of the chain links during the production of knotless fishnets on the single-needle bar Raschel machine. (Note: lengths x and y depend upon the required size of the net openings)

made. The productivity of the Raschel machine is thus tenfold greater than that of a loom, and the production cost of knitted sacks is considerably lower than that of woven sacks.

Knitted fabrics for water-cooling units

Cooling towers with fan coolers are the best-known means of cooling water in a closed cycle. Water discharged from a heat exchanger at a temperature of 30° 40°C is cooled in the cooler to 20° - 30°C.

The basic elements of the cooler are a water-distributing device and a sprinkler formed of trickling blocks. Until quite recently, the trickling units were made from wood (pine) or from asbestos-cement cardboard.

Investigations carried out in the Textile Research Institute in Łódź have shown that knitted fabrics of special construction could be used in the cooling towers. The use of knitted fabrics as a water-distributing element facilitates heat exchange in the cooler, thus increasing the cooling effect. A trickling unit made from knitted fabric having a volume of 1 m^3 and weighing 25 kg has 50 m^2 of trickling surface, whereas the conventional block constructed of wooden panels, with a volume of 1 m^3 and weighing 150 kg has only 32 m^2 of trickling surface. The use of knitted fabrics gives a remarkable cooling efficiency and makes possible the reduction of the cooler dimensions by about 30 per cent, thus permitting substantial savings in installation and operation costs.

Knitted fabrics for medical use

Artificial blood-vessels

Artificial blood-vessels are produced from textured polyester yarn on the latch-needle knitting machine. Advanced knitting technology permits the production of artificial straight and bifurcated vessels of any length and of diameters of 4 mm or more. After removal from the knitting machine, these artificial blood-vessels are finished by processes such as cleaning, shrinking, forming and heat-setting. In the forming process a definite bellows form is given to the vessel; this shape is stabilized in the next finishing phase.

The most important properties of artificial blood-vessels produced in Poland are high resistance, flexibility and elasticity. Furthermore, they are well absorbed by the organism, cause no inflammatory reaction and are resistant to chemical agents. Their special bellows shape permits them to maintain their circular cross-section even during intensive bending. The inner surfaces of their walls are perfectly smooth, thus ensuring undisturbed flow of the blood. Since these artificial blood-vessels do not fray, they can be cut with scissors or scalpels, and apertures can be also cut into their sides for branch anastomosis.

These artificial blood-vessels can be sterilized repeatedly without deterioration. These Polish-made prostheses are greatly appreciated by the most distinguished surgeons, as is amply documented in the medical literature.

Dressing bands

Dressing bands serve primarily to secure essential dressings to wounds or other injuries. Knitted dressing bands are made from viscose staple yarns on 26-gg warp-knitting machines. The structure of the knitted fabrics is formed of loop chain stitches and weft, with incomplete (1 × 1 or 1 × 2) threading of the guide bars. The density of the knitted fabric is 140 courses per 10 cm, and its weight is 50 to 60 g/m^2. The bands can be as wide as desired.

Knitted dressing bands, in contrast to woven ones, are constructed of threads that are little subject to unravelling. They also have great elasticity and do not fray. Bandages made from them have a good appearance, fit comfortably, do not slip from the wound and hold the dressing securely. When knitted bandages are used to secure wound dressings, only 50 to 60 per cent as many bandage layers are needed as when conventional gauze bandages are used. They do not deteriorate significantly even after several washings. In obstetrics knitted bandages are better than the woven ones employed up to now. Knitted bandaging fabrics can be used for operation wraps, setons and the like.

Orthopaedic stiffening bandages

Until recently, the dressings and stiffening appliances employed in orthopaedy, in the treatment of Heine-Medina disease, in spinal injuries, after limb amputation and in neurosurgery, were made of gypsum, leather, plastics and the like.

In trauma surgery, gypsum has the important advantage of hardening quickly. However, this advantage is less important in orthopaedy, as evidenced by the successful use of leather in certain appliances. Gypsum dressings are used only temporarily, and their value lies in the possibility of executing them on the patient immediately and in their low cost.

Orthopaedic appliances made from plastics, leather, wood and metal can be constructed only on the basis of positive gypsum casts previously prepared by highly qualified technicians in well-equipped workshops. However, orthopaedic workshops cannot execute the appliances rapidly; the patients must sometimes wait for many months to receive them, and such delay may be very harmful. For example, after Heine-Medina disease, children must wear corsets or other appliances made of leather reinforced with metal. Until he receives his appliance, the child must wear a heavy gypsum corset, and this can affect the growth of his spine adversely.

If stiffening bandages must be changed frequently, leather appliances cannot be used; only gypsum ones can be employed. If too much time elapses between the amputation of a limb and the fitting of a prosthesis, permanent changes such as muscular atrophy may occur. In this situation, not only will the period of rehabilitation be prolonged, but the artificial limb may become useless. Another prosthesis is then required, causing still further increases in costs and prolongation of rehabilitation. These considerations are particularly important for patients who have lost either or both of their legs. These patients are immobile, and they may become depressed, and the recovery period may be prolonged still further.

These difficulties can be eliminated, to a great extent, by the use of knitted stiffening bandages made from polyamide and acetate yarns on the Raschel machine, using a chain stitch and weft laid in with two fully threaded guide bars. To produce such appliances or prostheses, the following are needed: a solvent and a positive plaster cast of the part of body where the appliance is to be fitted, and some lightly rolled bandages. The bandages, soaked in the solvent, are wound around the plaster cast, which has been rubbed smooth. The acetate fibres are dissolved by the solvent and first become a sticky mass that hardens into a solid and elastic crust when the solvent evaporates. The undissolved polyamide fibres form a framework of the appliance so that it holds its form. After about 24 hours, when the bandage has dried completely, it is cut along an appropriate line, removed from the cast and placed on the patient. It can be secured by a slight wrapping with ordinary flat bandage. If frequent removal and re-installation of the appliance is necessary, small hooks to permit lacing-up can be mounted on it. When a temporary artificial limb is being made in this way, appropriate metal elements are inserted between the layers of bandage. When the solvent has dried, the outer layers of bandage are bonded inseparably to the crust that originated from the innermost bandage.

Appliances made in this way can be of many different shapes and of considerable size; they can therefore be used in amputations, immobilization of the spine and the like. They are light and elastic and absorb X-rays to a minimal degree, making it possible to obtain good radiographs without removing them. However, they are easily removable, making it possible to maintain the hygiene of the immobilized part of the body as well as of the appliance itself, which can be washed with cold water. Furthermore, they may be perforated (that is, punched with 5-mm holes), to facilitate the circulation of air, without weakening them appreciably.

Stiffening bandages of this kind may be used to construct insertion sockets for provisional and permanent artificial limbs, splints for thigh bones, Schantz's collars to immobilize the jugular vertebrae, and the like. Orthopaedic appliances made in this way bond excellently to metal, wood and plastics. Very importantly, neither highly qualified technicians nor elaborately equipped workshops are needed for their execution.

Other medical articles

In Poland, research directed toward developing new products for medical use, made by knitting techniques, has already yielded many results, the value of which is well recognized in the world of medicine. The following merit special mention: bronchial barriers, artificial tendons and ligaments, surgical threads, artificial external ears and artificial oesophagi. Research is in progress to produce substitute articles for ophthalmology, heart surgery, thoracic surgery, plastic surgery, laryngology and urology. Synthetic yarns are the most important raw materials for the production of all of these articles.

Thus, products produced by knitting not only cover, adorn and decorate the human body, but are also used within it to form substitute organs that fulfil definite functions in its complex mechanism.

AUTOMATION IN THE KNITTING INDUSTRY

by

A. Nawrocki

The rapid development of the knitting industry has been associated with a constant increase in the automation of the machines and processes used, for it is automation that ensures the fulfilment of the conditions for this development.

In general, automation of knitting processes has the following advantages:

(a) Preservation of the optimum knitting conditions by maintaining the uniform functioning of machine components;

(b) Exploitation of the optimum operating conditions of machines that produce a variety of knitted fabrics with different features;

(c) Improvement of fabric quality by reducing breakages of needles and yarns;

(d) Shortening the production process and increasing of machine efficiency by eliminating some technical operations;

(e) More efficient use of factory space by reducing the area occupied by the machines (especially in the case of continuous lines); and

(f) Reduction of labour input and reduction of production costs.

Two types of automation can be distinguished: that of a single machine and that of a set of two or more machines that produce the same thing. In the first case, automation refers to two basic units of the machine, namely, a stop-motion unit that ensures the correct operation of the machine, and a programming unit for operations performed by particular parts of it.

Automation of the first (stop-motion) unit is aimed at improving the control of: *(a)* yarn feeding, by stopping the machine in case of yarn breakage, excessive knots in the yarn, excessive tension and the like; *(b)* working elements that take direct part in knitting (cams, needles, and the like) and *(c)* fabric quality, that is eliminating the causes of defects in the fabric such as variations in tightness.

Yarn tension control and the signalling of yarn breakage are performed on the yarn section between the bobbin and the feeding unit. Between the furnishing reels unit and the feeder, yarn control is taken over by another set of stop-motion units that control yarn tension and feeding speed and signal yarn breakages before the yarn reaches the needles. These stop-motion units operate on mechanical or electromechanical principles.

The yarn-controlling element is a set of balanced levers. A yarn breakage unbalances it, causing the emission of a light signal that indicates the fault and shuts off the motor.

The yarn-feeding control unit is also composed of a set of levers. It operates on the basis of variations in yarn tension. When yarn tension increases, the unit causes the yarn-speed regulator to increase the speed of yarn feeding. When yarn tension slackens, the yarn-speed regulator reduces the speed of yarn feeding and brings the yarn tension back to the proper level.

Needle-operation control is performed by means of electromechanically operating stop-motion units. Defective needles deflect the stop-motion stud, thus closing the electrical circuit of the stop-motion unit and cutting off the electrical current to the motor.

A stop-motion unit acts in a similar way when the take-down tension is too low. The operating stud of this unit is situated in the gap between the dial needles and cylinder needles, just above the fabric. The fabric piled up on the needles pushes the stud from its position, closing the electrical circuit of the unit.

Control of the fabric being knitted is performed by means of mechanical contact devices and by devices with photoelectric cells. In circular knitting machines, such as rib or sinker-wheel machines, the controlling stud slides on the surface of the stretched fabric. If a hole appears in the fabric, the stud drops through it and is deflected from its position by the rotating fabric tube, cutting off the electrical current and stopping the machine.

In both interlock and warp-knitted fabrics, holes caused by yarn breaks are comparatively small, so a rather sensitive stop-motion device must be used to detect them. Photoelectric cell devices for this purpose have been introduced recently. The principle of operation of such a device consists in throwing a beam of light on the fabric. When a hole appears, the light passes through it and sets the photoelectric cell into operation. The photoelectric current, after amplification, switches off the electric motor and stops the machine.

In interlock machines, the light beam is thrown through the rotating fabric, and in warp-knitting machines the photoelectric cell passes over the entire width of the fabric, beneath which there is a mirror. When a hole in the fabric appears, the light is reflected, setting the photoelectric cell into operation.

Control of fabric tightness is performed by means of isotopic devices. Beta rays pass through the fabric and are absorbed in a control device that is coupled electrically with a cam and feeder-adjusting arrangement. The usefulness of such isotopic devices is limited, being restricted to the range of rather tight fabrics.

Automation of the programming unit concerns the operation of the main elements of the knitting machine, that is, needles, sinkers, presses, transfer needles, feeders and the like. An automatic programming unit consists of three functionally coupled basic elements: a control element, a transmitting element and an adjusting element. Mechanically operating control elements can consist of chains, tapes, discs, drums, and cams or of combinations of cams and drums, discs and drums, or tapes and drums. Control elements of this kind are suitable for the production of patterned fabrics with limited pattern area. The size of the pattern depends on the number of needle selectors that is appropriate to the size of the programming unit.

Recently, electronic programming elements have been introduced. The Moratronic machine, which is built by the Morat Company (Federal Republic of Germany) is an example of an electronically programmed knitting machine. In it, a film tape is used on which 26 rows of points are marked. A light beam is thrown through this tape onto a set of photodiodes in which an electrical current is generated. After amplification, this current is transformed into signals by potentiometers. After further amplification, the signals are used for the selection of needles in the cam boxes.

Another example of programming automation is the production of full-fashioned garments such as stockings. The desired shape of the garment is obtained by means of loop transfer (narrowing or widening) or by changing the number of needles working in the machine. Very complex patterns can be obtained by combining these two methods.

Narrowing and widening of the fabric by loop transfer is commonly used on full-fashioned and automatic V-bed machines. A special transfer mechanism is used for this purpose. Control impulses are transferred to the machine from a central control unit that consists of a drum and a chain.

Loop transfer is used to produce garments of relatively simple shape. If a more complicated shape is required, other knitting elements are used, namely, feeders and pressers.

Needle selection is also possible in flat and circular knitting machines. By means of jacks and needle selectors, some of the needles may be switched off while the others continue knitting. In this way the knitted fabric can be made to preselected shapes and sizes.

Programming of machine operation also can be done by cam control, which makes possible a variety of stitches, among them openwork stitches, loop courses for linking and welt stitches. Usually, in such cases, some control devices such as chains with studs, tapes, electromagnetic and electronic stop-motion units are used on the knitting machines.

The separation of socks produced one after another in a continuous line is another example of automation. The socks can be separated in different ways; as by temporary cutting off the yarn supply or switching off the feeder. After being cast off from the needles, the socks are transported to a container by a pneumatic transport tube.

The performance of operations by sets of machines that produce the same type of garment, eliminating some of the technical operations, constitutes another kind of knitting process automation. A typical example is a continuous line for the production of seamless stockings. In it, a number of knitting machines and control devices are connected by means of a pneumatic tube.

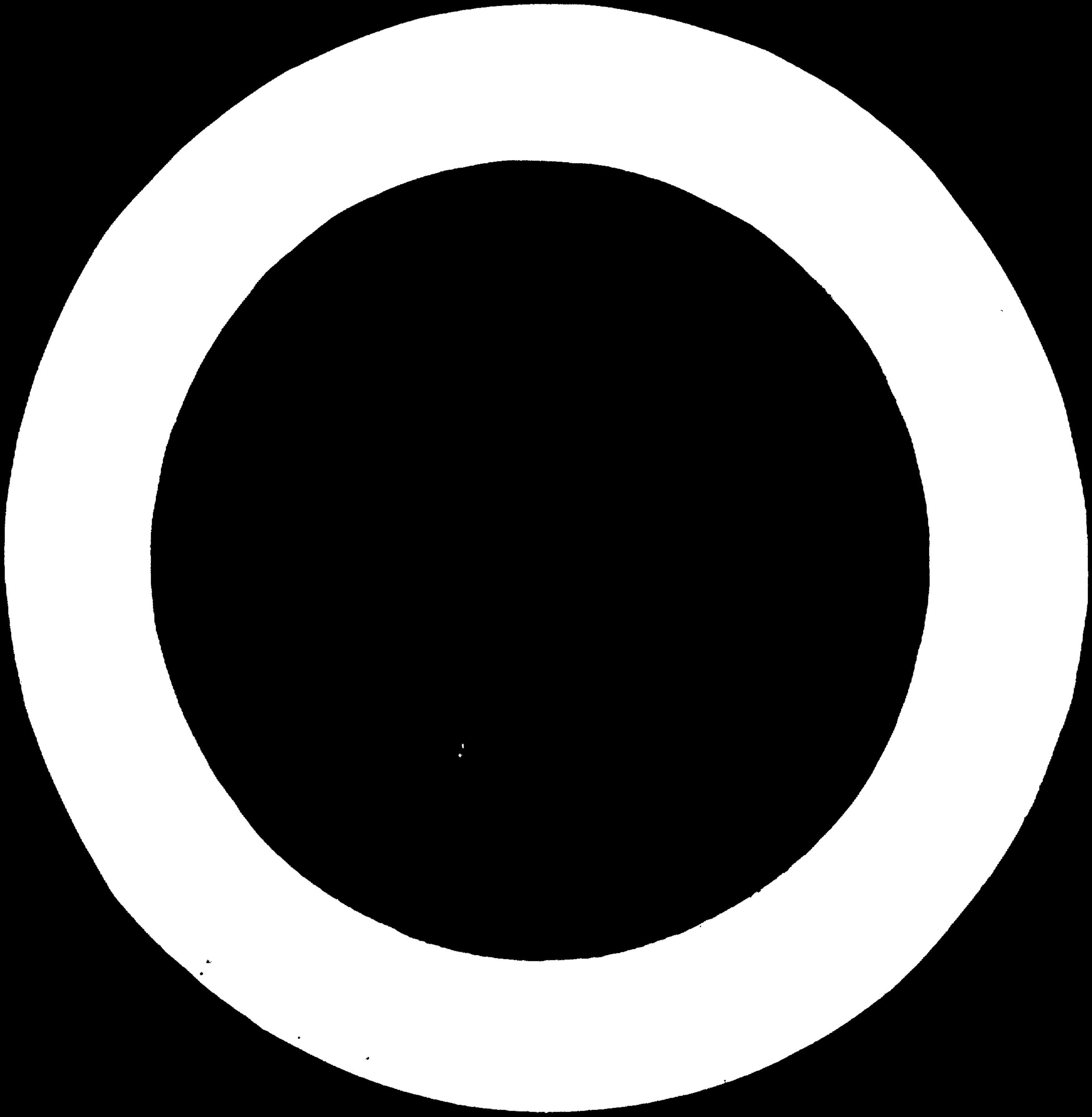
A very important feature of this continuous line is the fact that it is possible to stop any machine that produces a faulty stocking by simply pressing a button on the control board. When this is done, a light signal is switched on to inform the knitting machine operator.

A continuous line usually consists of 30 four-feeder or 90 to 120 one-feeder knitting machines. The continuous line is controlled electronically, according to an operation programme.

The next technical operation is the closing of the toe-end, after which the stockings are sent to the inspecting post, where the stockings are turned inside out after inspection and sent by means of pneumatic tube to the next operations (thermofixing and dyeing). Afterwards the stockings are automatically selected and paired.

These operations–inspection, thermofixing and dyeing, and selection– can be performed, respectively, on Inspectomatic (France), Colorplast (Federal Republic of Germany) or Teintofix (France), and Pair-O-Matic (France) machines.

The final operation in the continuous line is packaging. This is done on automatic machines that fold, label and pack the stockings. These operations can be performed on the Plipack G machine (France). This machine can fold the stockings in three different ways, any of which may be selected by a control lever. One, two or three pairs of stockings can be folded together.



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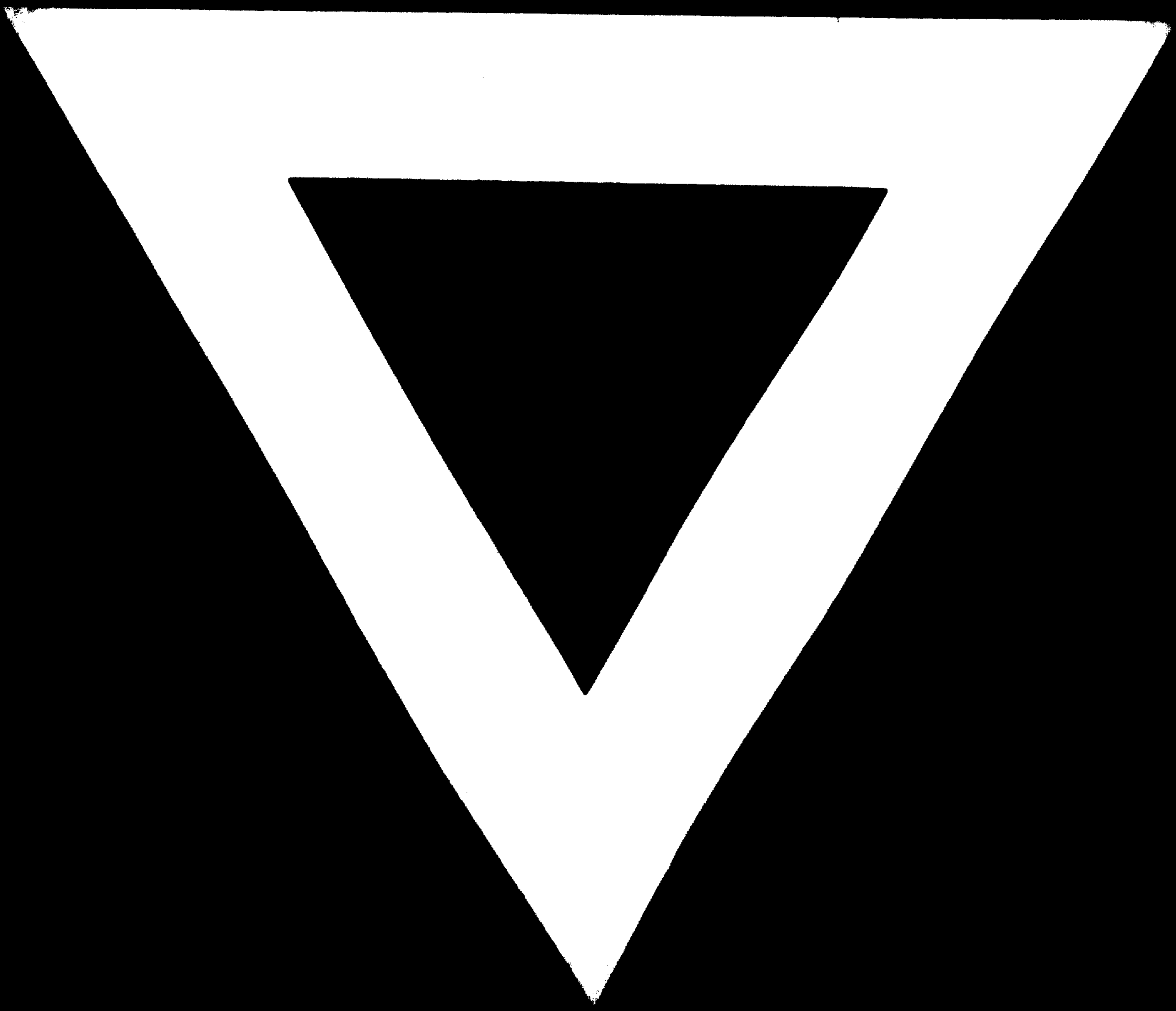

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