THE DIMENSIONAL PROPERTIES OF
RASCHEL KNITTED FABRICS CONSTRUCTED
FROM WOOL YARNS

A thesis presented to the University of Leeds
for the
degree of Doctor of Philosophy
by
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Being an account of the work carried out in the Department of Textile Industries under the supervision of Mr. D. L. Munden, B.Sc., F.T.I.

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Finally, to my wife, my grateful thanks for all the typing and her continuous support throughout this work.

ABSTRACT

The thesis is a report of an investigation into the relationships between fabric dimensions and the stitch length of single bar warp knitted constructions under various conditions of relaxation. The dimensions are described in terms of the k_c, k_w, k_s and k_r values of the fabrics.

It has been found that the ultimate fabric dimensions are independent of yarn count but the relationship between c.p.i. and stitch length on the machine is count dependent. Two loop models have been proposed for relaxed and machine state fabrics and the felting properties of the 1 x 1 closed lap construction have also been investigated.

CONTENTS

CHAPTER II HISTORICAL SURVEY OF WARP KNITTING 27

Page No.

CHAPTER III PREVIOUS WORK ON THE PHYSICAL AND GEOMETRICAL PROPERTIES OF KNITTED FABRICS 50

CHAPTER IV DETAILS OF MACHINE USED FOR EXPERIMENTAL WORK AND INITIAL INVESTIGATION INTO EFFECTS OF MACHINE VARIABLES ON THE DIMENSIONAL PROPERTIES OF THE FABRIC ... 69

PART I - RELAXATION RESULTS

CHAPTER I

INTRODUCTION - PRINCIPLES OF WARP KNITTING

I. PREAMBLE

Knitted fabrics are constructed by bending a yarn into a loop and passing this loop through a previously formed loop so that the latter hangs on the former. Thus a knitted construction is one in which the basic unit is a loop, the loops hanging on each other as illustrated in Fig.1.

To form a fabric, these loops are arranged to make vertical and horizontal rows, a vertical row being termed a 'wale' and a horizontal row being called a 'course', (Fig.2).

Two distinct classes of knitted fabric exist, weft knitted and warp knitted. Weft knitted constructions are produced from threads running across the fabric (weft-wise), a simple weft knitted structure being illustrated in Fig.2. Machine produced weft knitted fabric is an exact copy of hand knitted fabric. The yarn is fed to the needles successively, but the loops may be formed collectively as on a Cottons Patent Machine, or successively as on the circular or flat bed machine.

Warp knitted fabrics are formed from a multiplicity of ends (warp), the ends passing down a length of the fabric as they form loops. Generally speaking, yarns must traverse from wale to wale to connect the wales together to form a fabric. A simple warp knit construction is shown in Fig.3. The nearest

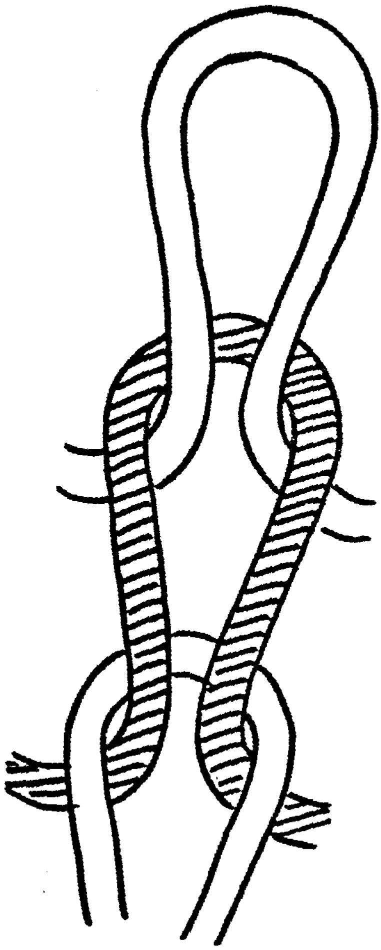


Fig. 1

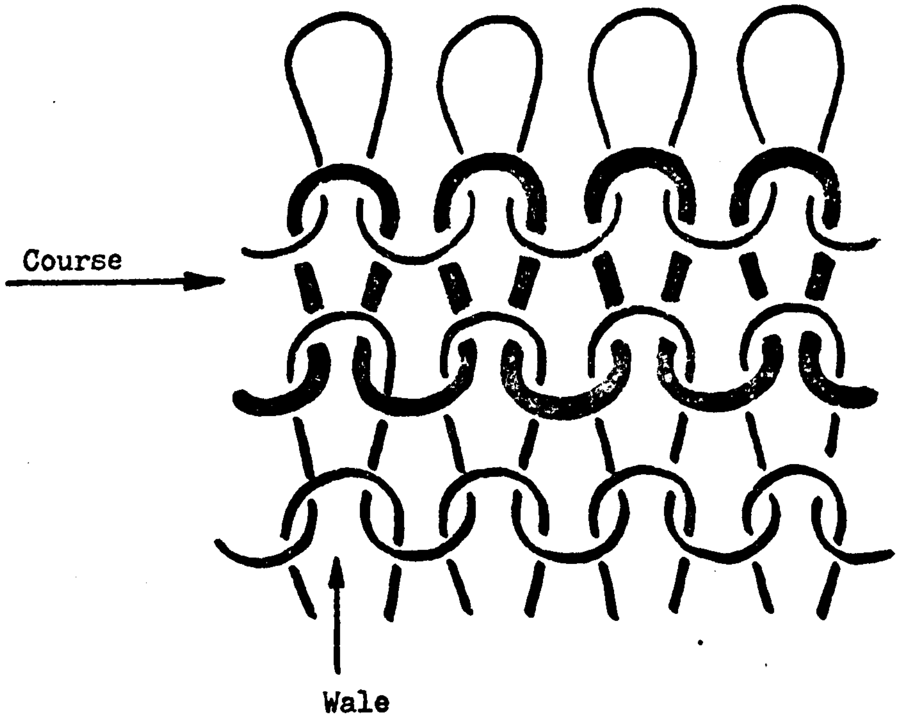


Fig. 2

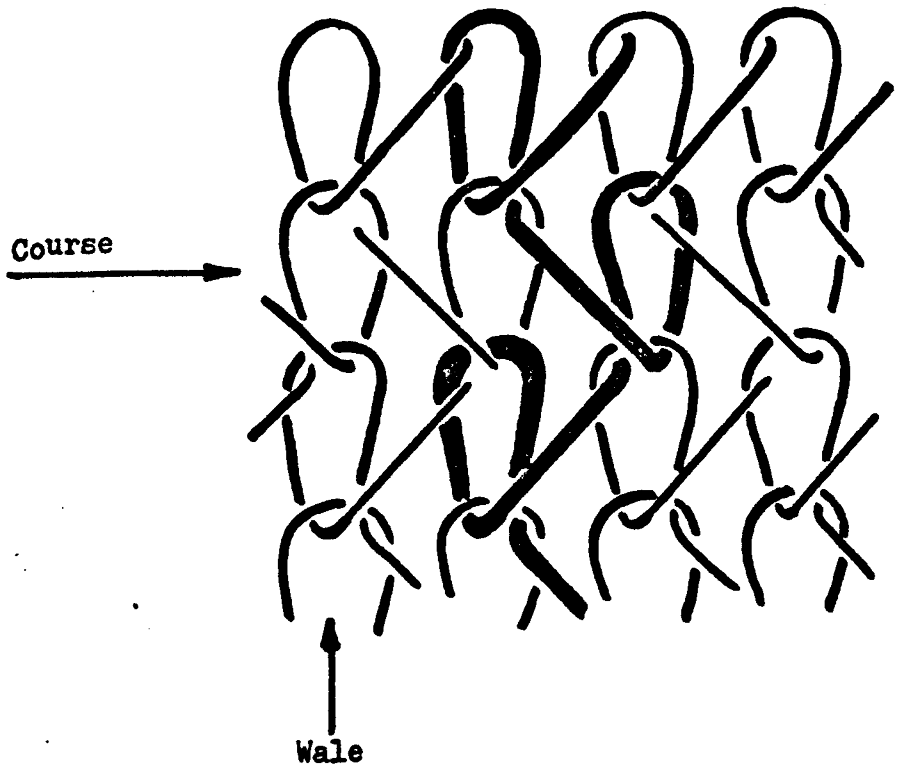


Fig. 3

hand product to a machine produced warp knitted construction is crochet work. In warp knitting the yarns are fed to the needles collectively and the stitches are formed simultaneously by all needles.

II. WARP KNITTING MACHINES

Warp knitted fabrics are divided into two groups according to the type of machinery on which they are produced. These are tricot and Raschel machines characterised by the manner in which the fabric is taken from the needles. (See later notes page 20).

The fundamental difference between Raschel machines and tricot machines is in the lay-out of the knitting elements and in the knitting action during loop formation. This difference is such that each machine is suitable for a different range of fabrics.

The bearded needle machine is a direct development of the original action used in the hand-frame and the lay-out of the knitting elements is shown in Fig.4. They consist of (i) bearded needles - mounted vertically to form the knitted loops, (ii) guides to lay the yarn round the needles, (two guides are shown in the diagram), (iii) presser to close the needle beards and (iv) sinkers which have four distinct functions, (a) to hold the fabric at the correct height, (b) to hold the fabric down while the needles rise, (c) to land the old loop during pressing and (d) to push the old loop clear of the ascending needle after knock-over.

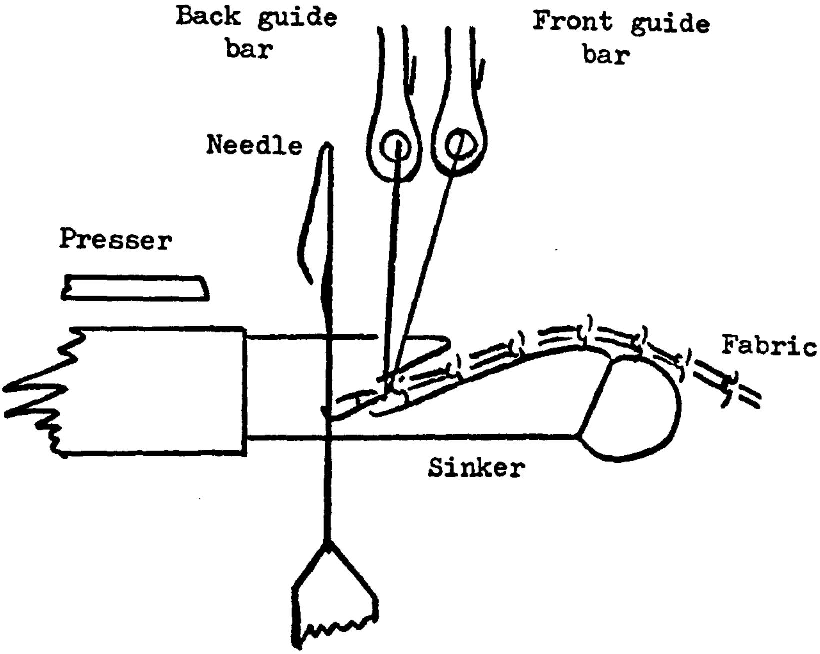

Back guide bar
Front guide bar
Needle
Presser
Fabric
Sinker

Fig. 4

1. Knitting action of a tricot machine

The knitting action of a bearded needle machine may be described with reference to Fig. 4a to 4h.

4a. Rest Position. This is so termed because the needles halt momentarily during their rise from forming the last course. The sinkers are forward holding the fabric down, the presser back, and the guides at the front of the machine.

On modern machines the needles halt at a position which is two-thirds of its total movement from the bottom position. On very old machines, (prior to about 1924), this distance is approximately half and the needle had a longer stroke.

4b. Overlap. The guides swing to the beard side of the needle, (towards the back of the machine), to form the overlap which is a movement parallel to the needle bar, generally one needle space. Occasionally a two needle movement may be used, or the movement may be omitted, e.g. when laying-in. The movement of each bar is completely independent although on the more common two bar constructions, the overlaps of each bar are generally in opposition to each other.

4c. Return Swing. The guides now swing through the needles to return to the front of the machine laying the thread around the needle across the beard.

4d. Second Rise. The needles rise to their full height allowing the thread placed across the beard to fall onto the stem.

4e. Pressing. The needles fall until the beard is in line with the

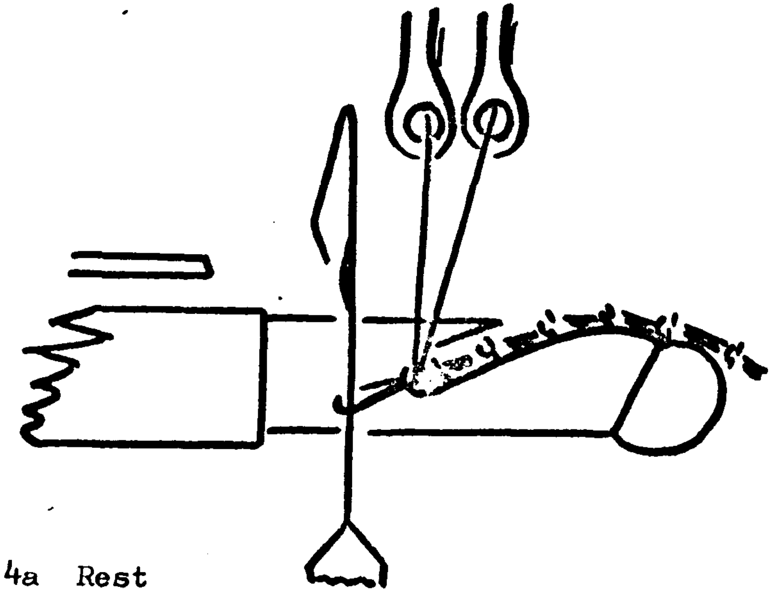


Fig. 4a Rest

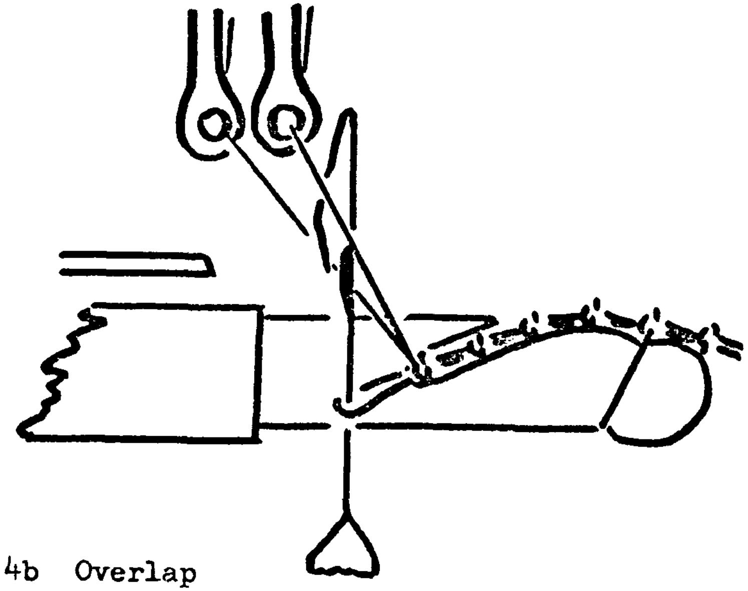


Fig. 4b Overlap

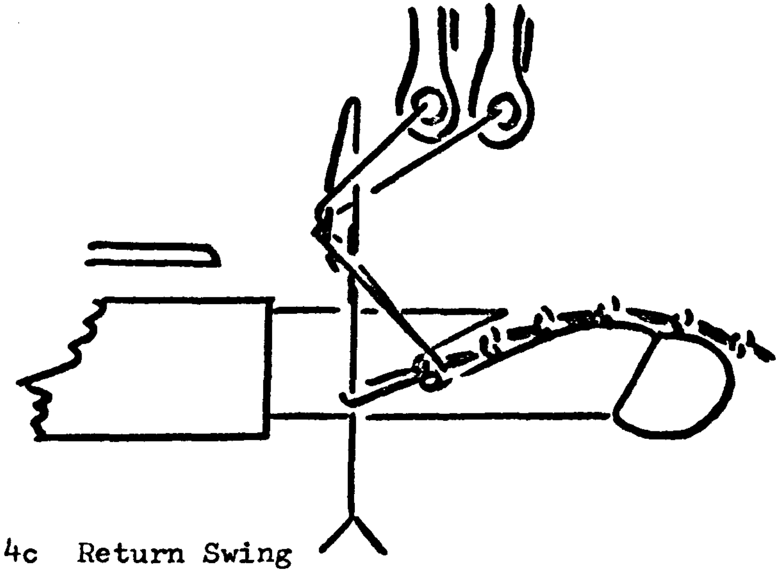


Fig. 4c Return Swing

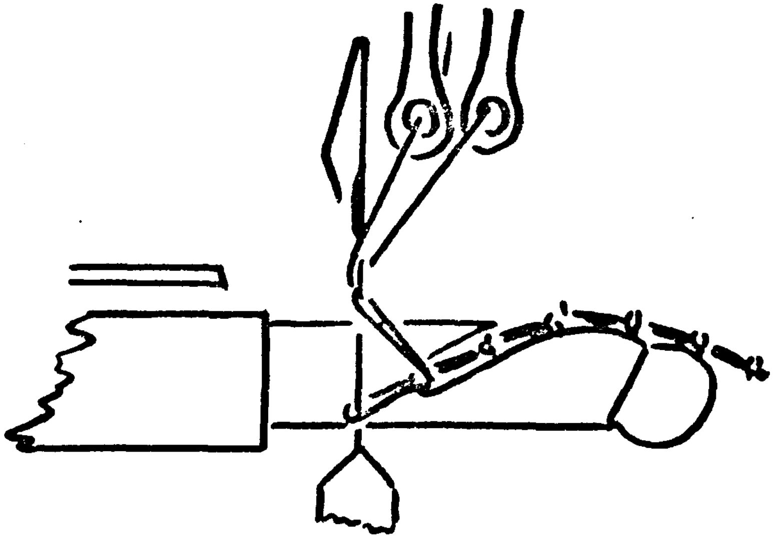


Fig. 4d Second Rise

presser. In this position the threads are under the beard and the old loop outside it on the needle stem. The presser moves forward and closes the beard.

4f. Landing. The sinker now moves back, the shape of the sinker belly forcing the fabric loop up onto the closed beard.

4g. Knocking Over. The needles now descend thus drawing the new threads through the fabric loop and forming a new loop or, conversely, the old loop is knocked over the head of the needle onto the new threads.

4h. Holding down. The sinkers now advance pushing the old fabric loop away from the ascending needle and holding the fabric down while the needles rise to the rest position to repeat the knitting action. At a point between pressing and landing and knocking over, (depending upon the type of machine), the guide bars make a second endwise movement parallel to the needle bar. This is the underlap. Its magnitude may be any number of needle spaces in either direction dependent upon the fabric structure being produced. As in the case of the overlap, each bar is completely independent in this movement.

2. Knitting action of a Raschel Machine

The knitting elements of a Raschel machine are shown in Fig.5 and consist of the following - (i) latch needles to form the loops, (ii) guides to lay the yarn round the needles, (iii) sinkers to hold the fabric down while the needles rise, and (iv) trickplate to support the fabric.

The knitting action of the Raschel machine may be described

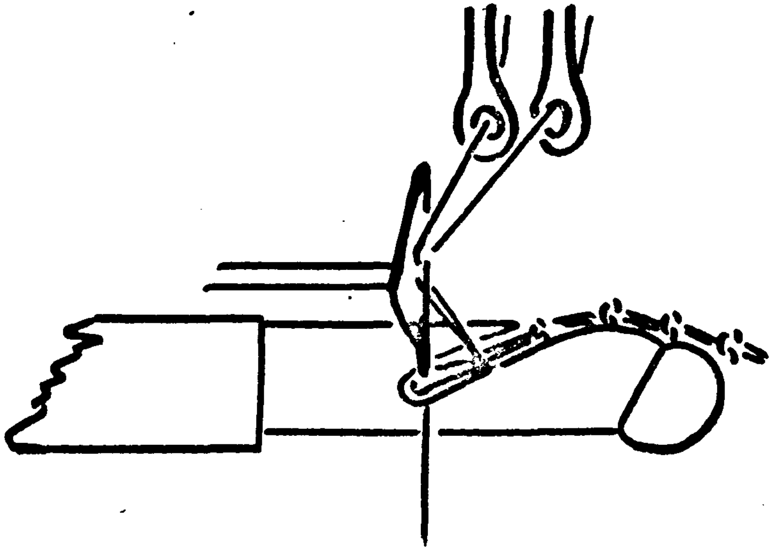


Fig. 4e Pressing

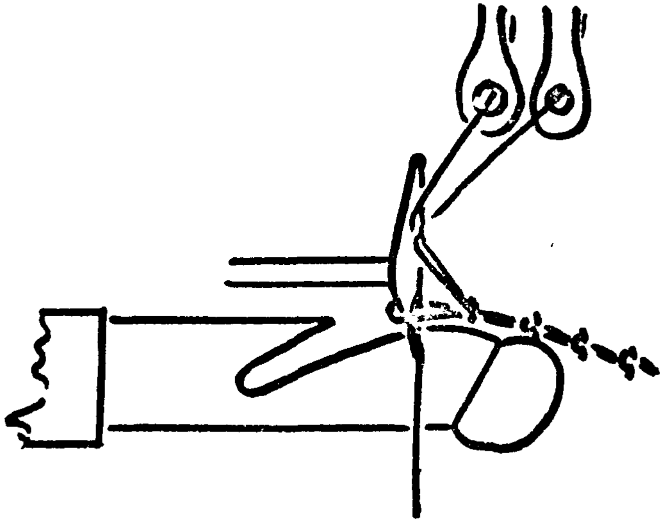


Fig. 4f Landing

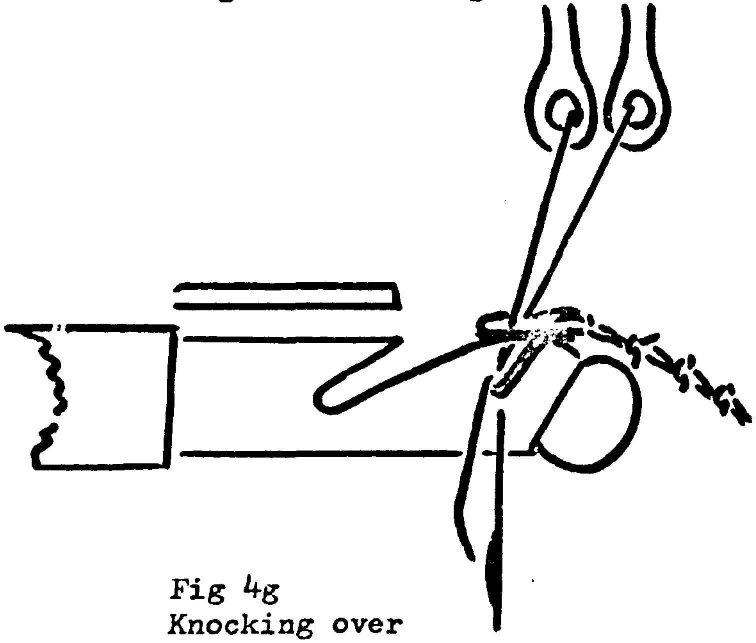


Fig 4g
Knocking over

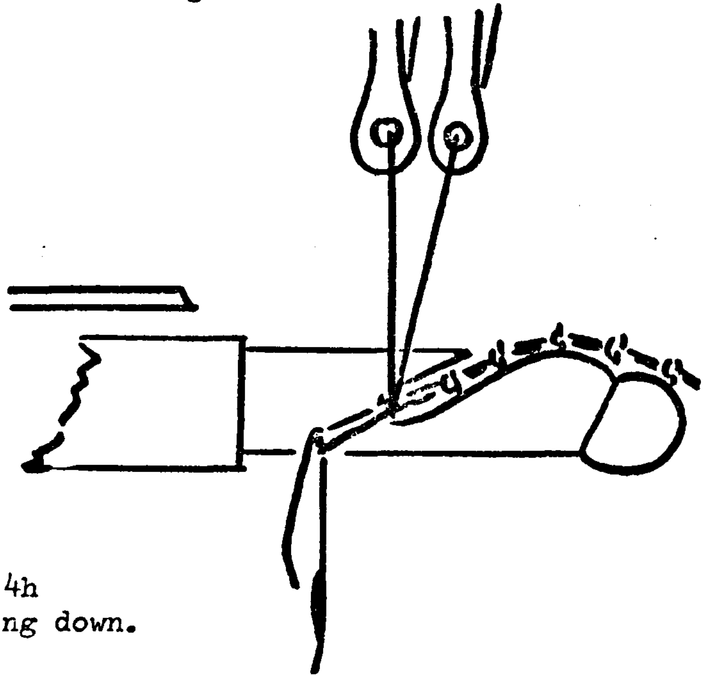


Fig. 4h
Holding down.

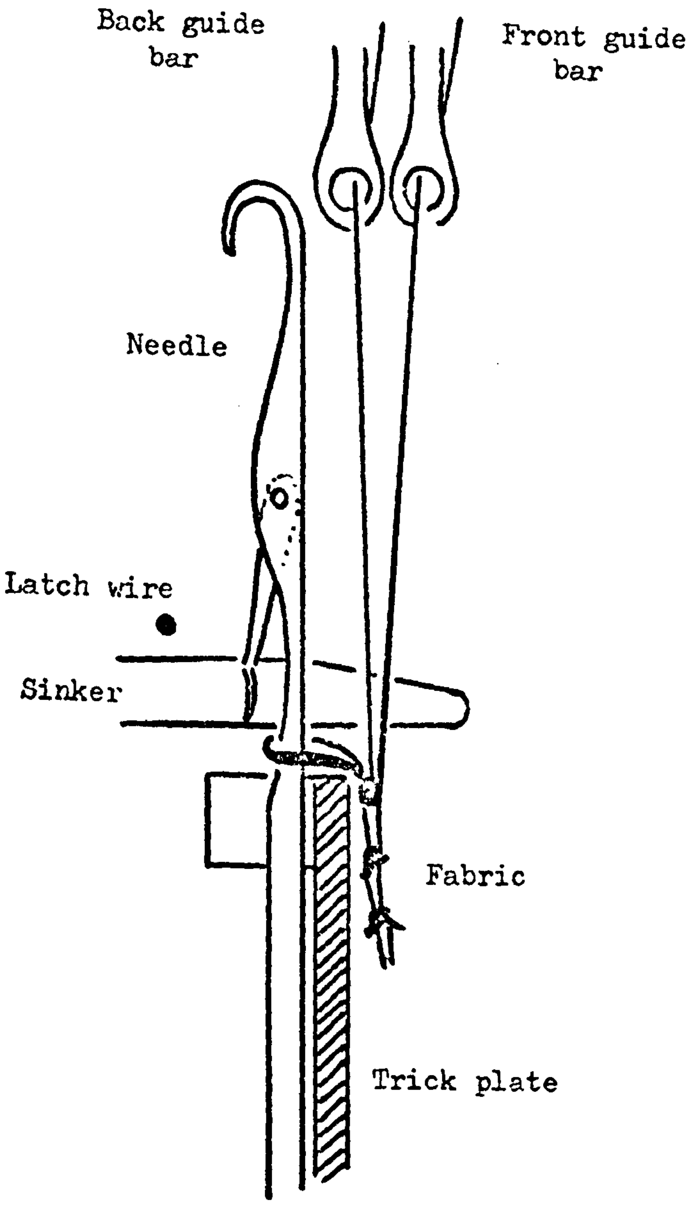

Back guide bar
Front guide bar
Needle
Latch wire
Sinker
Fabric
Trick plate

Fig. 5

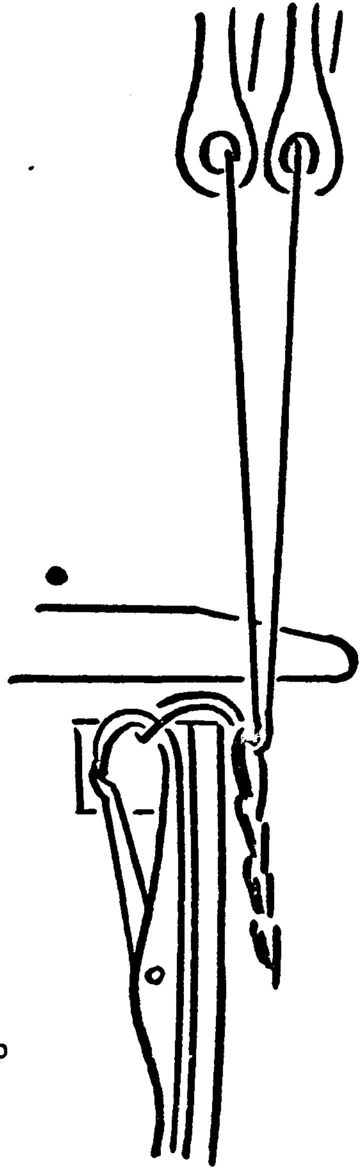


Fig. 5a
Underlap

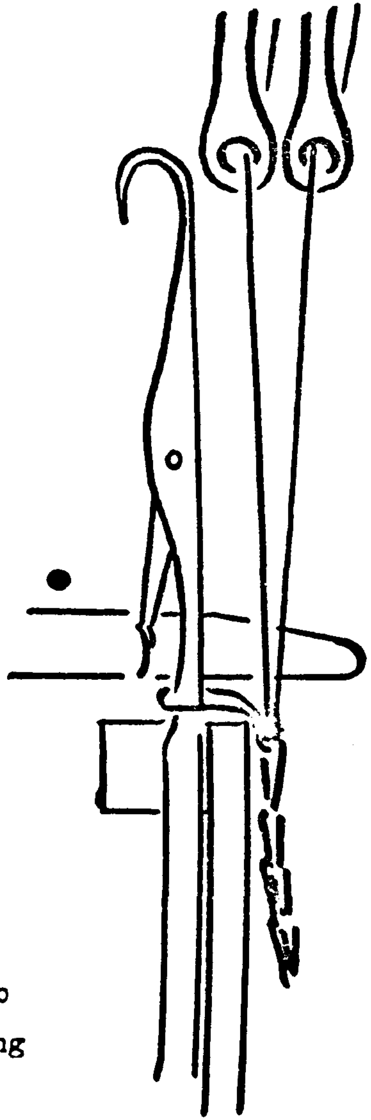


Fig. 5b
Clearing

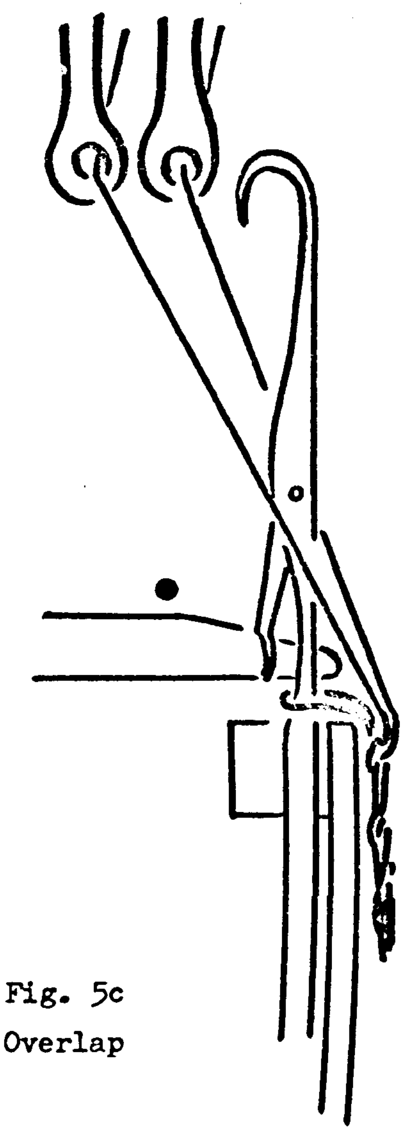


Fig. 5c
Overlap

with reference to diagrams 5a to 5f as follows -

5a. Holding Down. The sinkers move forward over the trick plate to hold the fabric down while the needles rise to the rest position.

5b. Rest Position. The needles rise from forming the last course and in so doing rise through the old fabric loop. This opens the latch and the loop passes off the latch onto the needle stem. The latch wire prevents the latch from flicking to the closed position due to the tension in the loop as the latter passes from latch to stem. The needles, having reached their highest position rest, or halt, for lapping.

5c. Overlap. The guides swing through the needles onto the hook side and in that position form the overlap which is exactly the same as an overlap on a tricot machine. The sinkers now withdraw.

5d. Return Swing. The guides return to the front of the machine leaving the threads in the needle hook or across the stem above the latch. The needles now fall taking the threads in the hook, the old loop passing at the back of the latch.

5e. Latch closing. The continued descent of the needle causes the old loop to close the latch.

5f. Knocking-over. The needles continue their uninterrupted downward movement pulling the new yarns through the old fabric loop and forming a stitch. During knocking over, the underlap is made which is the second endwise movement of the guide bars and is the same as the underlap on tricot machines.

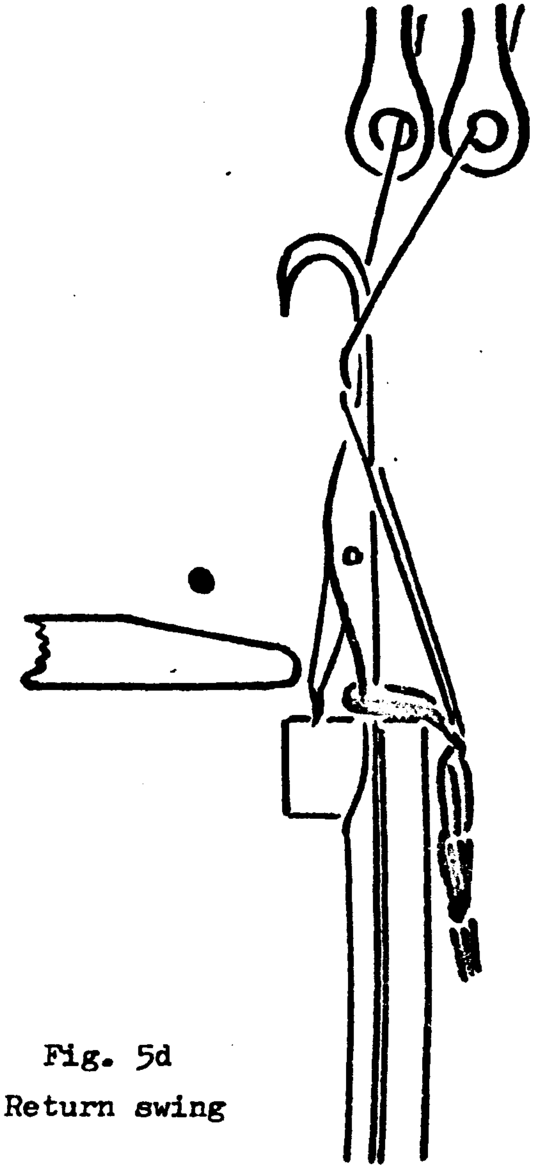


Fig. 5d
Return swing

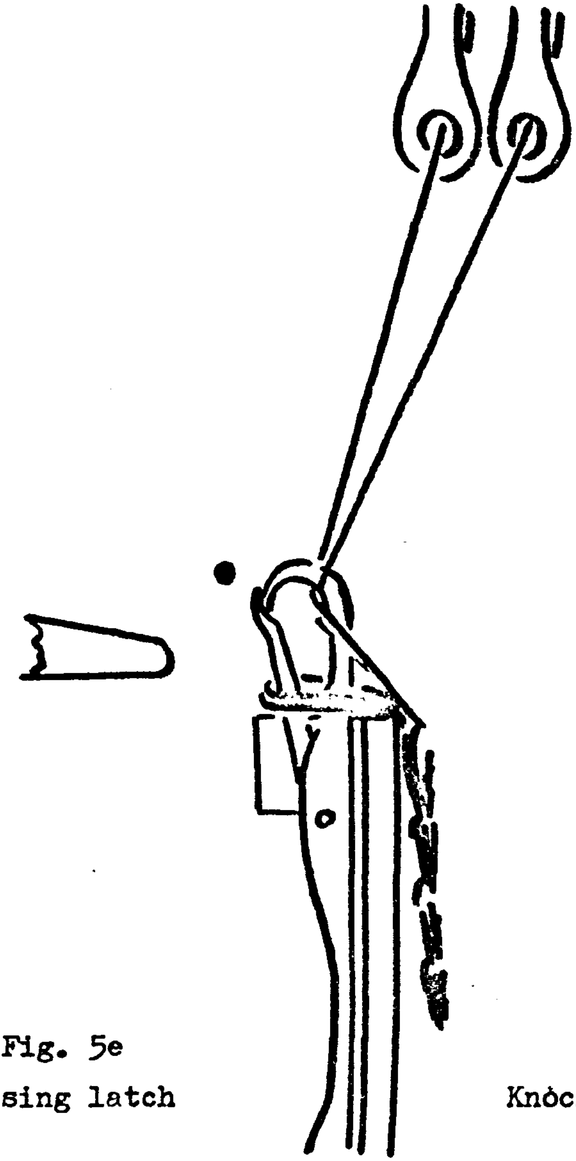


Fig. 5e
Closing latch

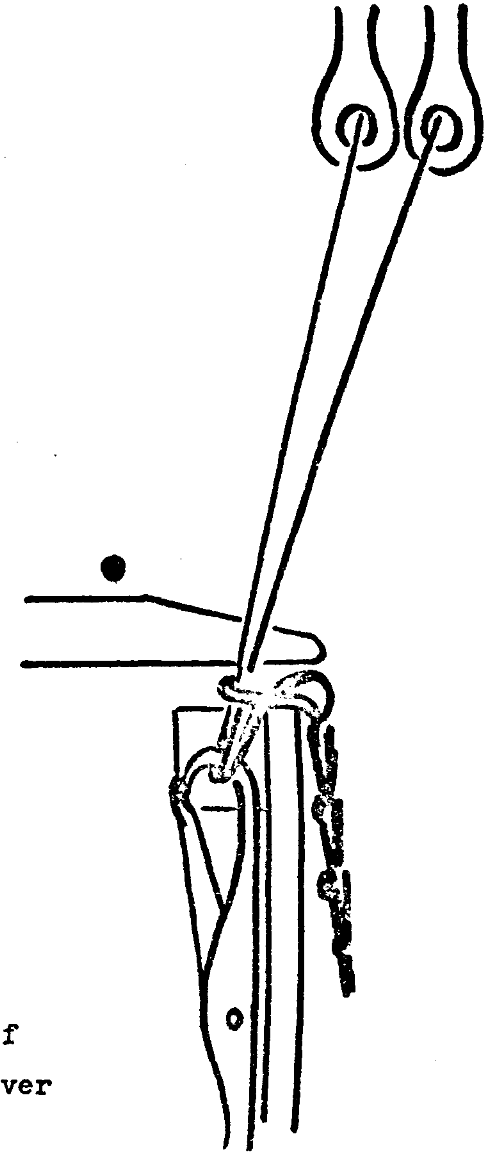


Fig. 5f
Knocking over

All warp knitting machines whether tricot or Raschel have the same fundamental construction and consist of the following sections:-

(1) The knitting elements to form the fabric (as described previously.)

(2) The pattern drum mechanism to determine the pattern and fabric construction.

(3) The warp let-off mechanism to control the delivery of the yarn.

(4) The fabric take-up mechanism to take the fabric from the knitting elements.

(5) Patterning mechanisms - additional mechanisms to produce special constructions.

3. The Pattern Drum Mechanism

The structure of the fabric is dependent upon the direction and magnitude of the overlap and underlap and these are established by the pattern drum. These movements determine the fabric structure as may be seen by reference to Fig.6. The guides swing between the needles (a), form the overlap (b), and return to the front of the machine (c). While the needles descend to form the loop, underlap (d) is formed. This produces one course. The action is repeated on the next course, swing (e), overlap (f), return swing (g), and underlap (h).

The actual pattern drum mechanism consists of a metal drum with tracks or grooves cut in it, one track for each guide bar. Onto this drum are placed chains constructed of links, one chain

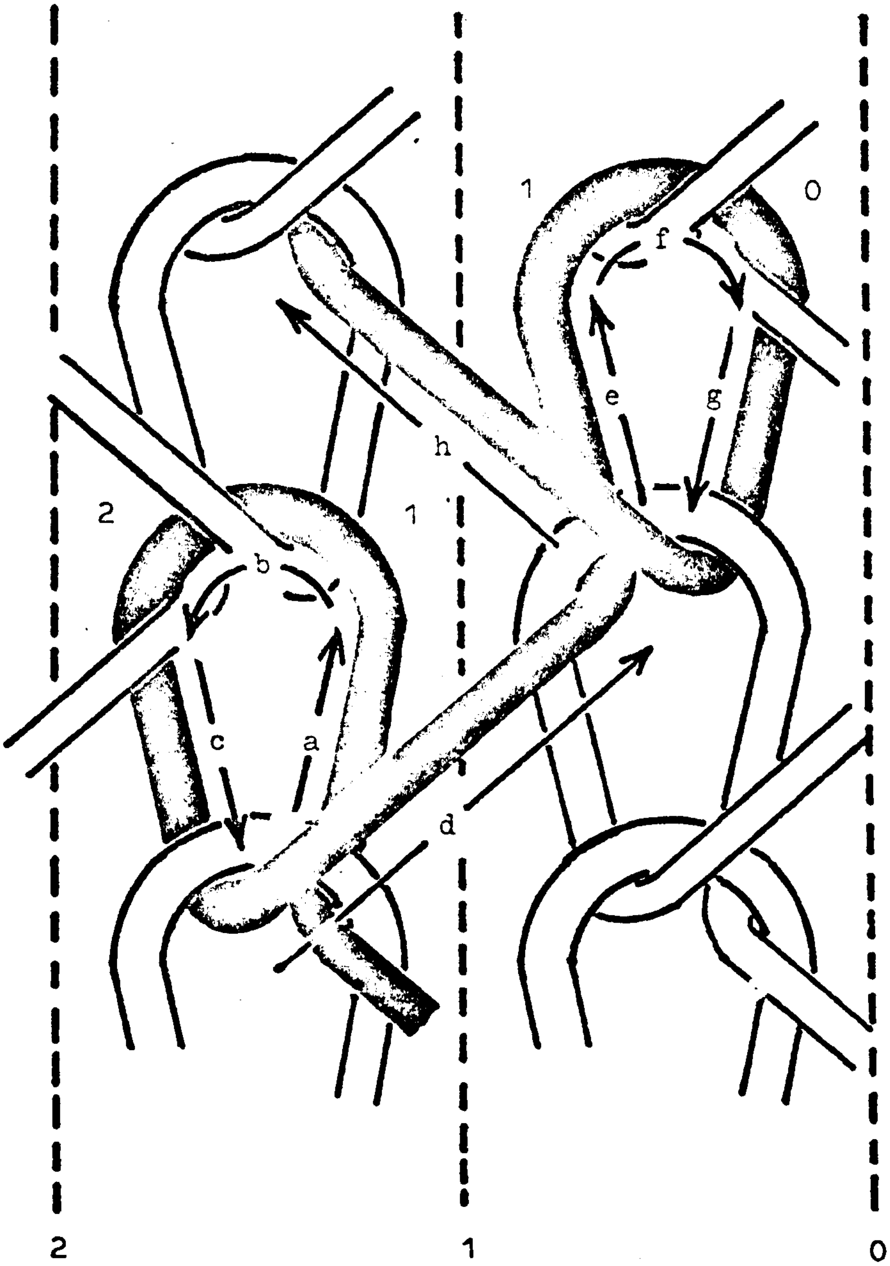


Fig. 6

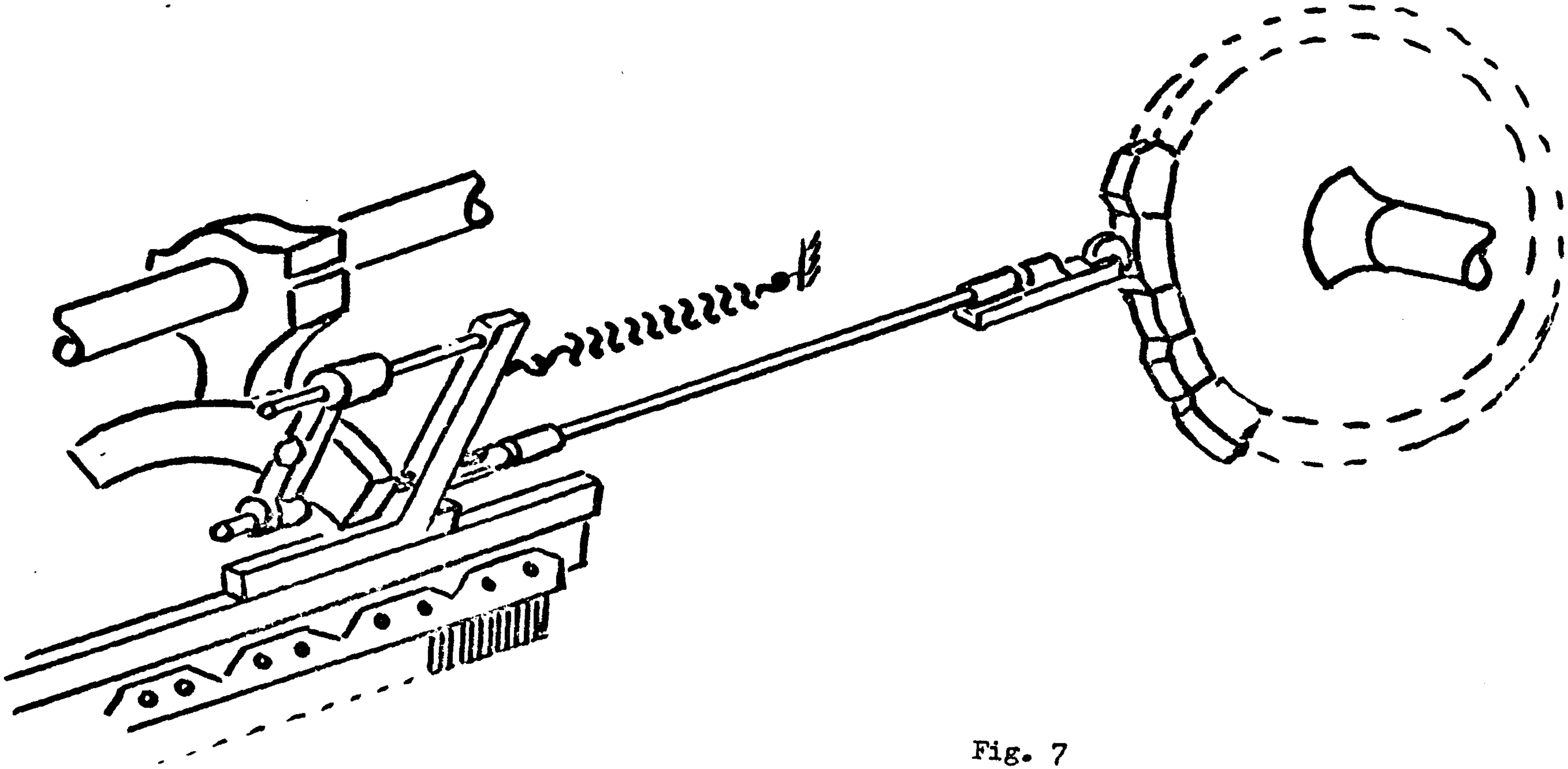


Fig. 7

Pattern Drum Motion

for each guide bar. The end of the guide bar is kept in contact with the chain via a push rod and roller, (Fig.7), by means of a return spring. Thus, the periphery of the chain will determine the position of the guide bar. As a higher link is presented to the roller, the guide bar will move to the left by a positive movement and conversely a lower link will allow the bar to move to the right by the return spring. This is a negative movement. The pattern drum may be placed on either side of the machine, although it is generally placed on the right.

Various heights of link are available for fabric construction and are numbered representing the needle spaces from the lowest link zero. The difference in height between two consecutive links will be $\frac{1''}{\text{n.p.i.}}$.

4. Representation of fabric structure by chain links

Consider the structure in Fig. 6. All threads make the same movement, so one thread only need be considered. The needle spaces which are used by that thread are numbered, 0 being placed on the same side as the pattern drum, in this case on the right, and the remaining spaces numbered consecutively from this. Consider the knitting action: the guide enters at space 1 and forms the overlap leaving via space 2. The overlap is thus formed 1 - 2. On the second course, the guide enters height 1, forms the overlap and swings back on height 0, so the overlap is formed 1 - 0. It is only necessary to read off the overlaps, the underlaps automatically fall into place. Thus, if the chain links are arranged in the

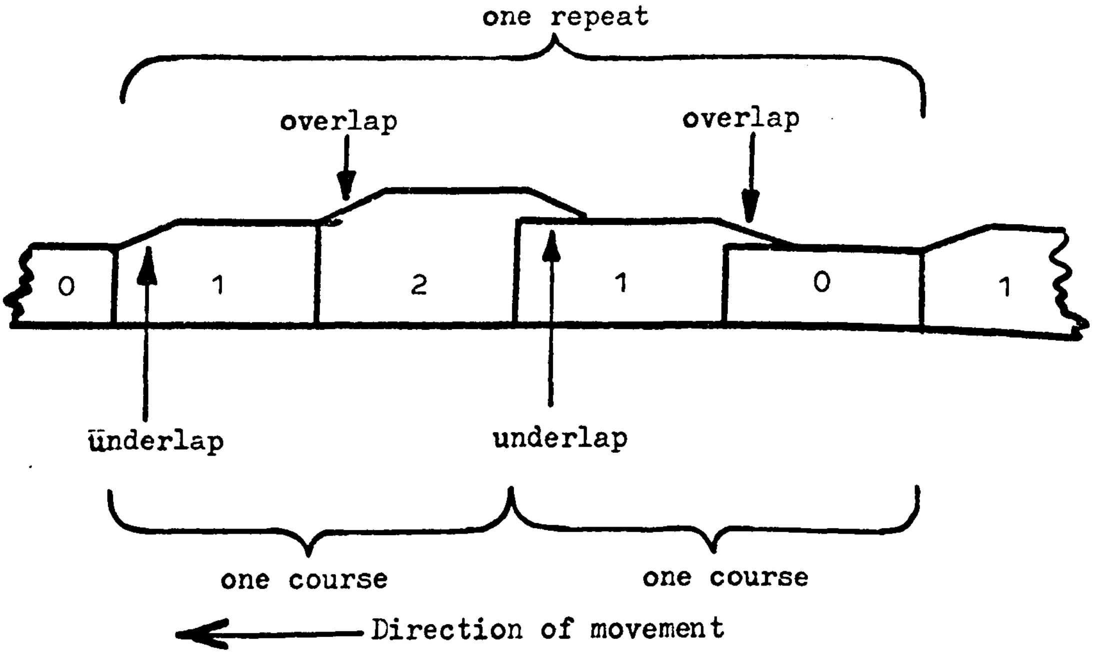


Fig. 8a

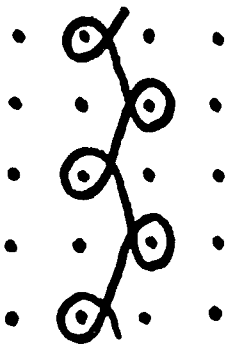


Fig. 8b

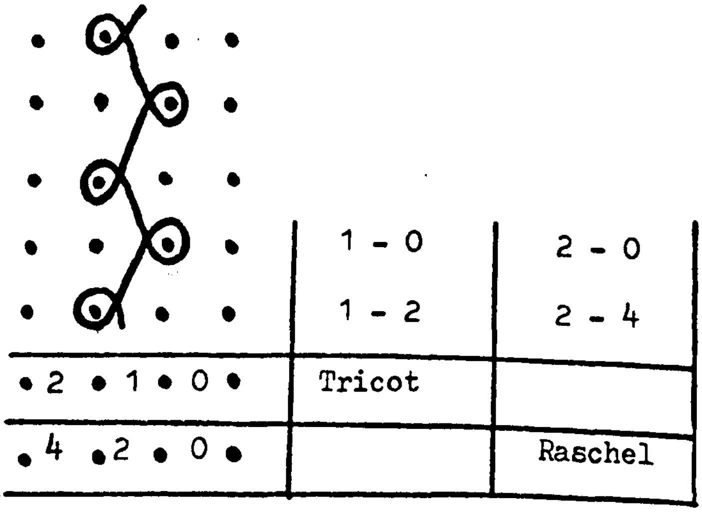


Fig. 8c Fig. 8d

Fig. 8

order 1 - 2 / 1 - 0, the fabric illustrated in Fig. 6, (1 x 1 closed lap), will be produced. The chain construction for this fabric is shown in Fig. 8a, it being noted that two links are required for the formation of each course.

5. Point paper representation (Draft).

It is not possible to illustrate each fabric construction by drawing a loop structure in each case so that a shortened version is used. This is referred to as the lapping movement and consists of drawing the paths of the threads without drawing the loop. This is drawn on special point paper which consists of vertical and horizontal rows of dots representing the position of the needle heads on successive courses. The 1 x 1 closed lap is illustrated in this manner in Fig. 8b.

From this lapping movement, it is possible to obtain the chain construction by numbering the needle spaces in the same manner that the needle spaces were numbered on the loop structure. In this case the '0' is placed on the right, and each space numbered consecutively from this. The chain construction is then read off by reading the overlap as in Fig. 8c.

Tricot and Raschel drafting is performed in exactly the same manner. The chain construction is, however, slightly different as the needle spaces on a Raschel machine are numbered in twos. The equivalent Raschel chain is shown in Fig. 8d.

III FABRIC CONSTRUCTION.

The number of guide bars used on the machine determines the

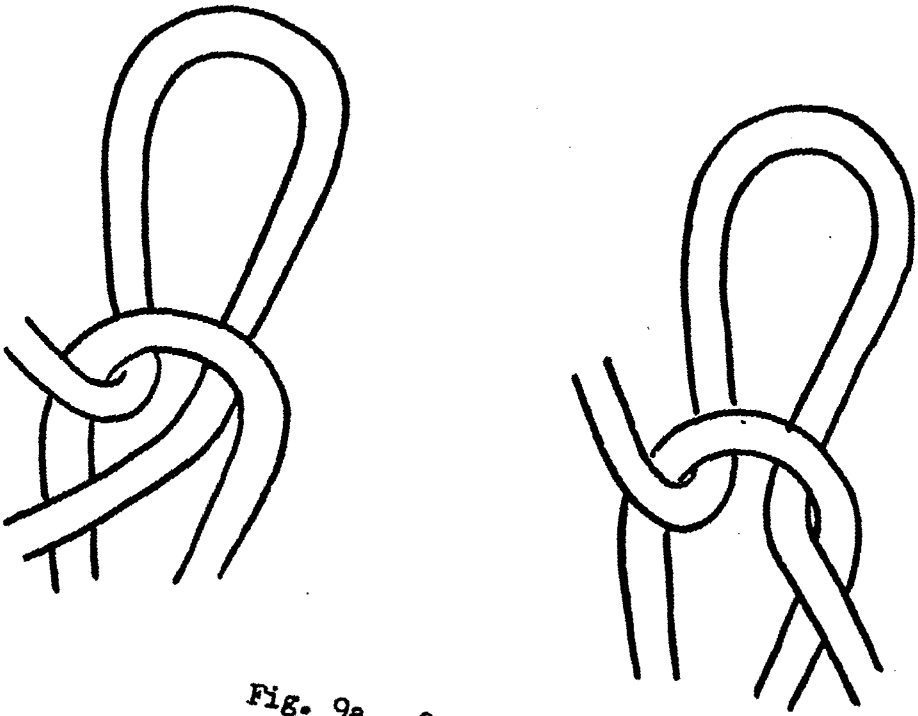


Fig. 9a Open loops

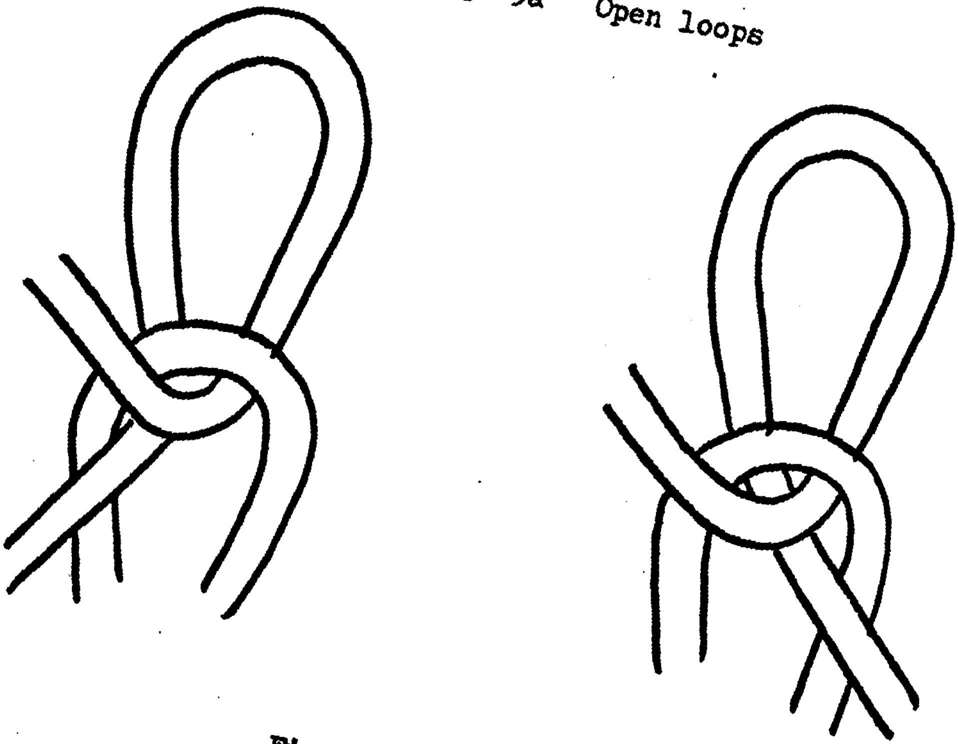


Fig. 9b Closed loops

complexity, type and properties of the fabric which can be produced. For this reason, machines are available with 1 to 42 guide bars, although the majority of machines have 2, 4 or 6 guide bars. Fabrics are generally classified according to the number of guide bars used.

Before considering the actual movements of the guide bars, the following points should be noted.

may

Open and closed laps. During knitting, the needle many be lapped in one of two ways, either so that the base of the loop is left open, or so that the threads are crossed to close the loop. The former is referred to as an open lap and the latter as a closed lap. They are illustrated in Fig. 9a and 9b respectively.

Face and Back. Warp knitted fabrics may be used commercially so that either side is the face or the effect side. To distinguish the two sides of a fabric from a technical point of view, they are referred to as the technical face and the technical back.

Technical face. This is the side which shows the 'v' shaped loops and the fabric is considered to be the right way up when the point of the 'v' is down. This is illustrated in Fig. 10a.

Technical back. The technical back of the fabric is the side which shows the underlaps, (Fig. 10b). The fabric is produced with this side uppermost on the machine. It is for this latter reason that fabrics are always considered in this way when designing, drafting, performing fabric analysis and drawing loop structures.

1. Single Bar Fabrics

These have little or no commercial application owing to their

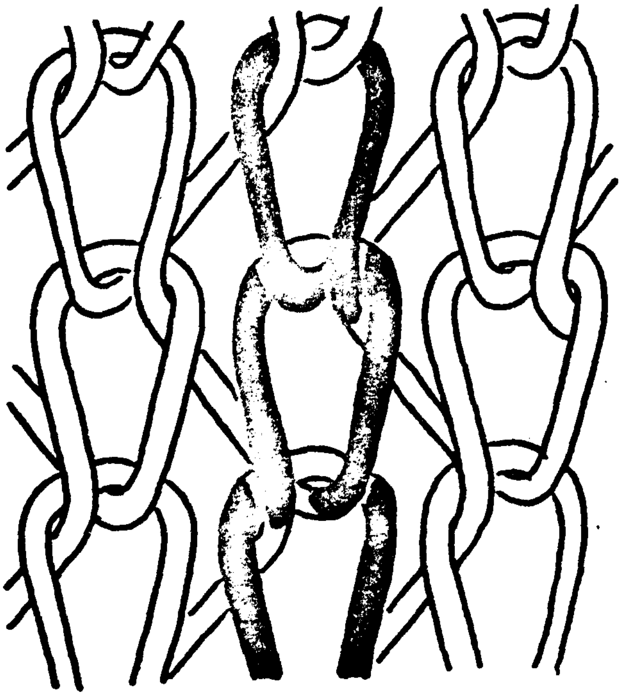


Fig. 10a

Technical Face

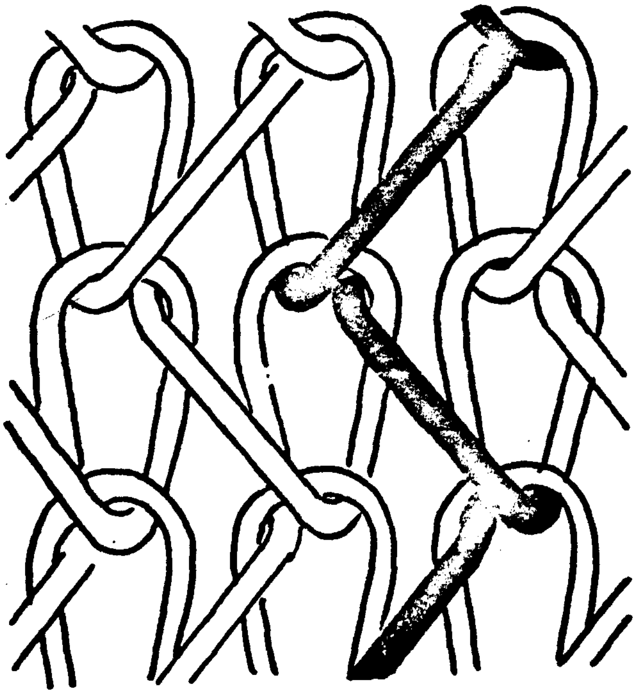
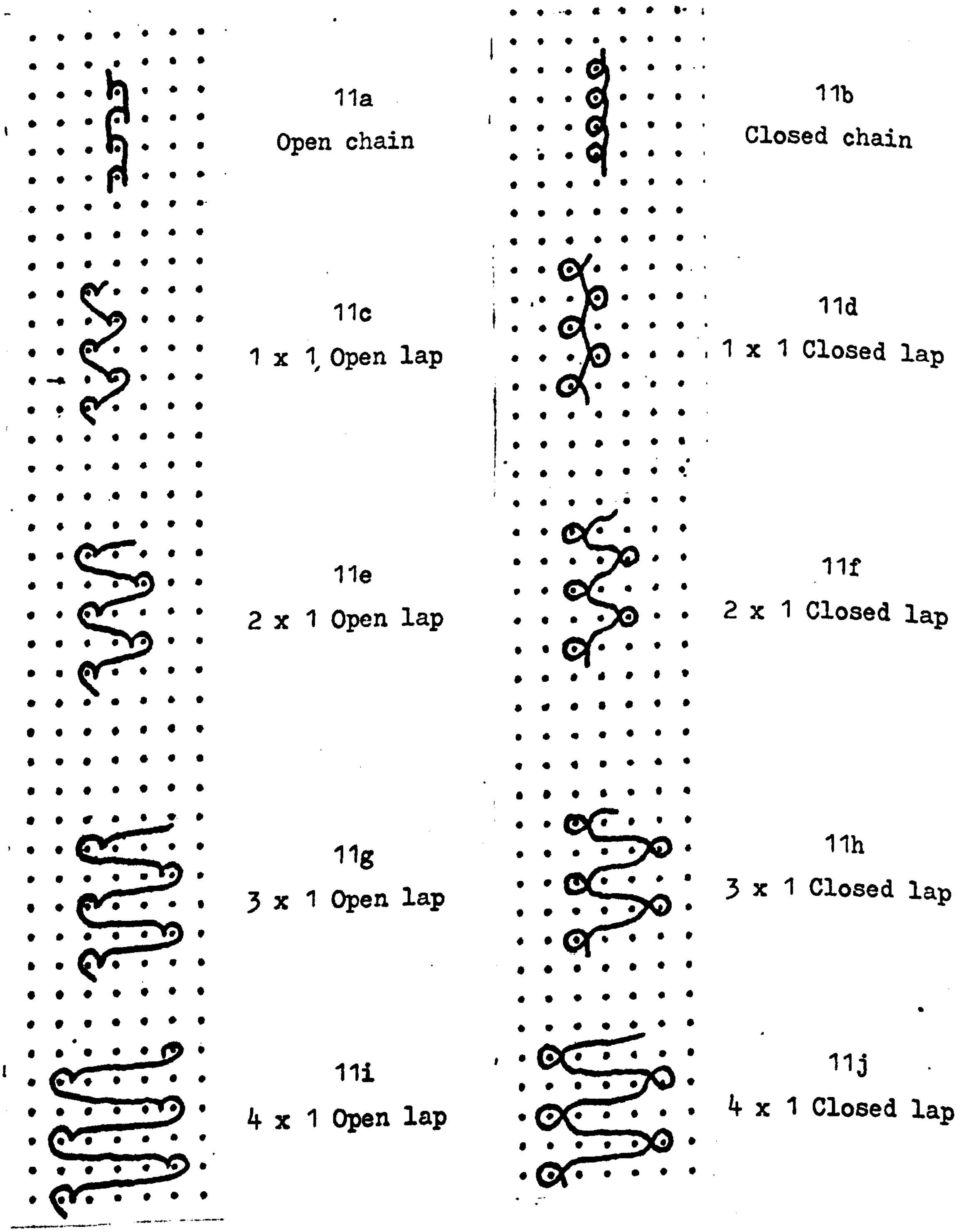


Fig. 10b

Technical Back



11a
Open chain

11b
Closed chain

11c
1 x 1 Open lap

11d
1 x 1 Closed lap

11e
2 x 1 Open lap

11f
2 x 1 Closed lap

11g
3 x 1 Open lap

11h
3 x 1 Closed lap

11i
4 x 1 Open lap

11j
4 x 1 Closed lap

Fig. 11

limitations in pattern and properties. However, they serve to illustrate the basic lapping movements used in the more complex 2 and 3 bar constructions.

(a) Chaining construction

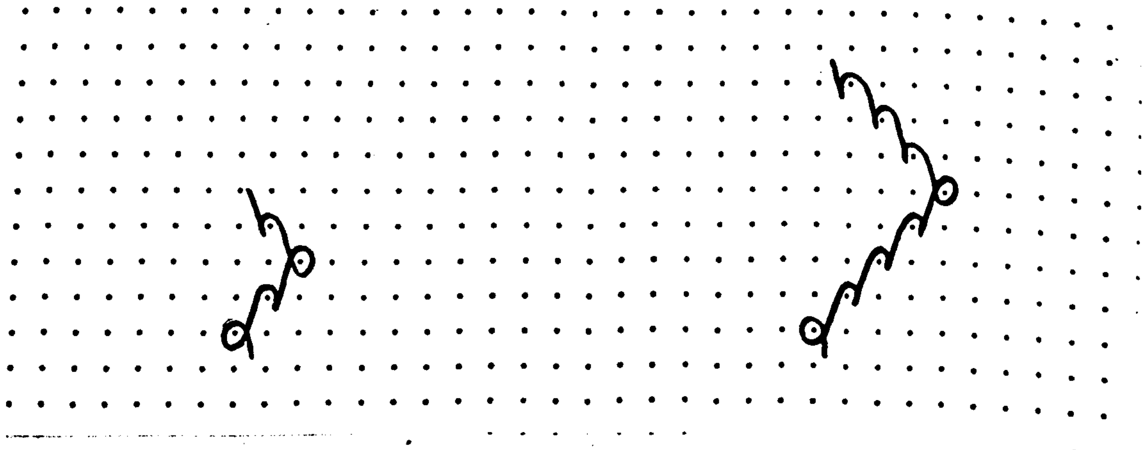
The simplest construction is the chaining movement, (Figs. 11a and b) which in itself will not form a fabric, but may be used in conjunction with other guide bars to do so. The movement may be formed with overlaps only to make an open lap, (Fig. 11a), or with overlaps and underlaps to give a closed lap, (Fig. 11b).

(b) Simple regular constructions

To form a fabric with one guide bar using full set threading, (one thread for each needle in the knitted width), it is necessary to form an underlap to connect the wales together. A single needle underlap results in a 1 x 1 movement which is nearest to the plain weft knitted construction. It may be produced in either open lap, Fig. 11c, or closed lap Fig.11d. This structure suffers from the disadvantage that it will split from top to bottom should a thread break and is only used in conjunction with other guide bars.

Other basic movements are produced by extending the underlap to give 2 x 1, 3 x 1 and 4 x 1 constructions, (first figure indicates underlap and the second figure the overlap), which are illustrated as open and closed versions in Figs. 11e to 11j.

Each of these constructions are simple regular movements repeating on two courses. They are devoid of pattern being perfectly plain in appearance. All suffer from the fact that the loops lie

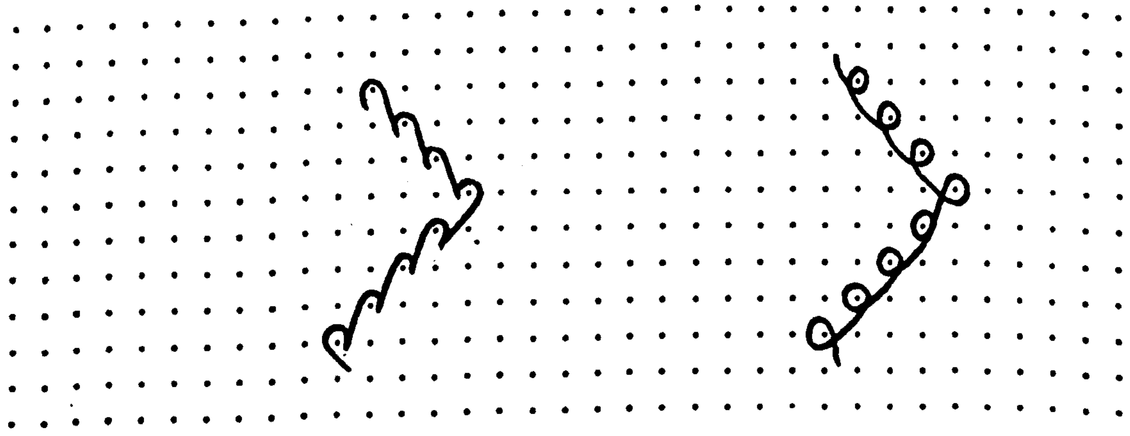


12a

4 Course Atlas

12b

8 Course Atlas



12c

8 Course Atlas
(Open laps)

12d

8 Course Atlas
(Closed laps)

Fig. 12 Atlas Laps

at an angle in the fabric, odd courses leaning in one direction and even courses leaning in the opposite direction. As the length of the underlap increases, the fabric weight, loop inclination, opacity, thickness and lustre on the technical back of the fabric increases, but the fabric stability decreases.

(c) Atlas movements

In this class of fabric the guide bars move for a number of courses in one direction one needle at a time and then return in the same manner, a simple example being shown in Fig. 12. An atlas movement is described by stating the total number of courses for the repeat. Fig. 12a shows a 4 course atlas and Fig. 12b an 8 course atlas. Atlas movements are generally made open laps closed on the turn as Fig. 12a and 12b, but they may be made all open as Fig. 12c or all closed as in Fig. 12d.

Atlas fabrics are often referred to as shadow stripe fabrics because as the guide bars move in one direction, the loops lie at an angle, this being reversed when the guide bar moves in the opposite direction. This gives a difference in light reflection resulting in a horizontal shadow stripe effect.

(d) Fancy atlas movements

Variations in the plain atlas movement offer considerable scope for patterning, particularly when used in conjunction with other guide bars and/or coloured warps. The possibilities are endless and a few of the simpler constructions are illustrated in Fig. 13. Checks, diagonal lines, chevrons and fancy zig-zag effects are the more popular motifs.

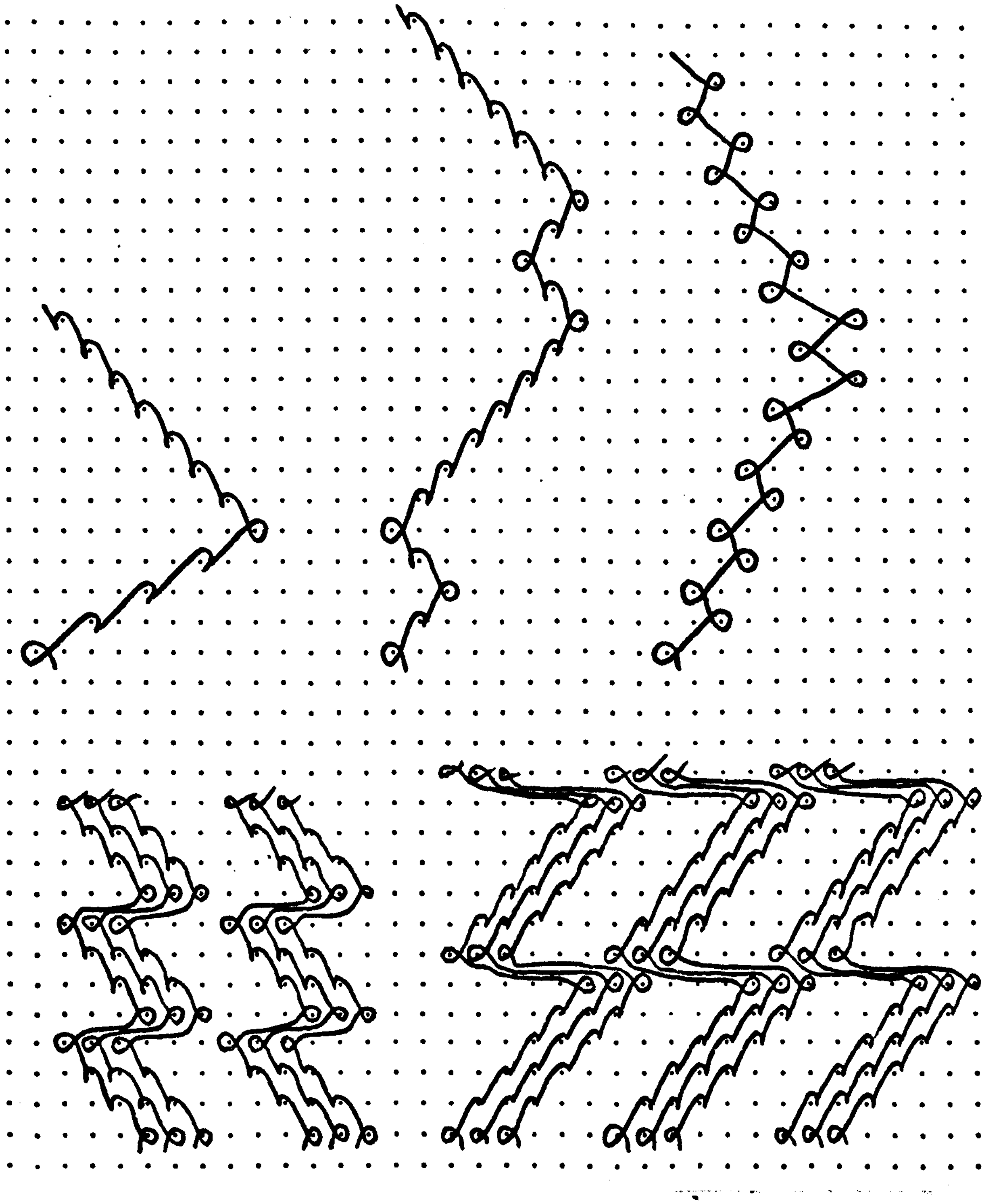


Fig. 13

Fancy Atlas Constructions

2. Two Bar Fabrics Full Set Threading.

The use of two guide bars gives a wider scope for the engineering of fabrics both from the point of view of structural properties and patterning than is available with one guide bar. It is evident that the movement of the two bars must be different, otherwise the equivalent of a single bar construction would be obtained, but with two threads in each loop. It is equally obvious that to obtain the same degree of fullness of fabric, it is necessary for the count of the threads in each guide bar to be half that of the single bar equivalent.

(a) Commercial fabrics full set threading

Two bar fabrics with full set threadings form the backbone of the commercial warp knitting trade being produced mainly in continuous filament yarn.

The simplest two bar construction is tricot with a front bar movement of 1 - 0 / 1 - 2 and a back bar movement of 1 - 2 / 1 - 0, but this is of little use commercially as it will split should one loop break.

It should be noted that tricot is a generic term used to refer to all types of fabric produced on tricot machines and the trade associated with the production of these fabrics. It is also used to describe a specific single bar construction using a 1 x 1 lap open or closed, and also a two bar construction using two 1 x 1 laps in opposition, again open or closed.

There are a number of basic fabric constructions in common commercial use. These are locknit, reverse locknit, satin, loop raised, sharkskin and queenscord. The constructions of these fabrics are given below. Their lapping movements are illustrated in Fig.14. The loop structure of locknit is shown in Fig.15, that of loop raised in Fig.16 and sharkskin in Fig.17.

Locknit

Front bar	2 - 3 / 1 - 0
Back bar	1 - 0 / 1 - 2

Reverse Locknit

Front bar	1 - 0 / 1 - 2
Back bar	2 - 3 / 1 - 0

Loop Raised

Front bar	1 - 0 / 3 - 4
Back bar	0 - 1 / 2 - 1

Satin

Front bar	1 - 0 / 3 - 4 (or 1 - 0 / 4 - 5)
Back bar	1 - 2 / 1 - 0

Sharkskin

Front bar	1 - 0 / 1 - 2
Back bar	3 - 4 / 1 - 0
or	4 - 5 / 1 - 0

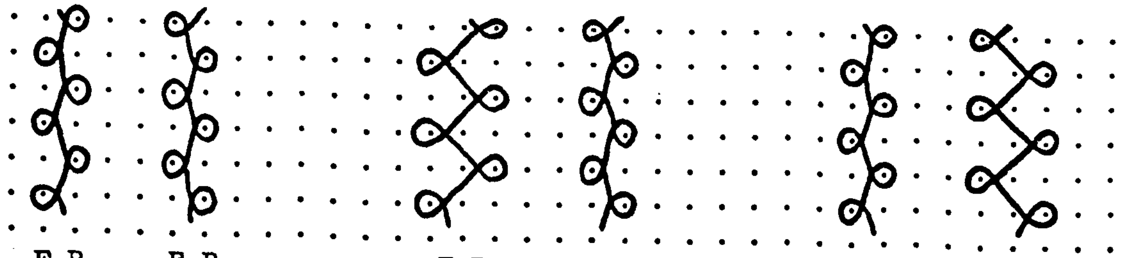
Queens Cord

Front bar	1 - 0 / 0 - 1
Back bar	3 - 4 / 1 - 0
	(or 4 - 5 / 1 - 0)

To understand the characteristics of two bar fabrics it is necessary to know the lay of the yarn in the fabrics and the relative movements of the two bars as these, together with the actual lapping movements employed, determine the final properties.

(b) Lay of yarns in the fabric

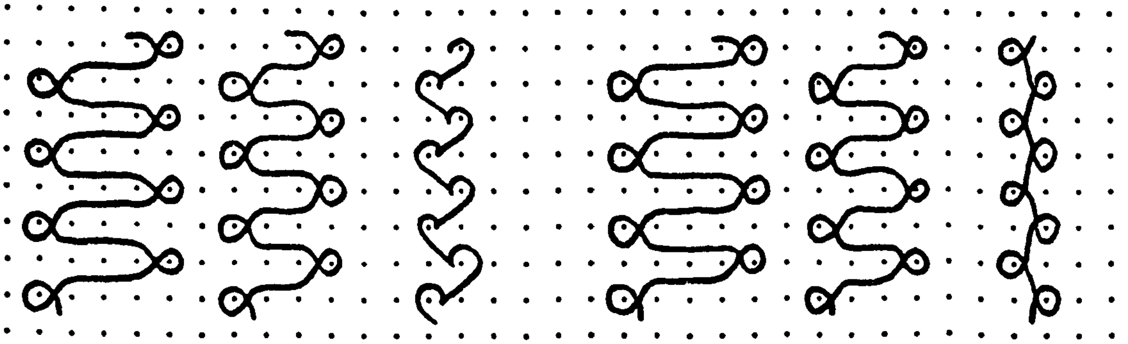
The loops lie on the technical face of the fabric and these loops contain two yarns, one from each guide bar. The underlaps from the back guide bars lay across the back of these loops and the underlaps of the front guide bars lay on top of these underlaps. Therefore, the loops are prominent on the technical face of the fabric, the underlaps of the front bar lie on the top on the



Tricot

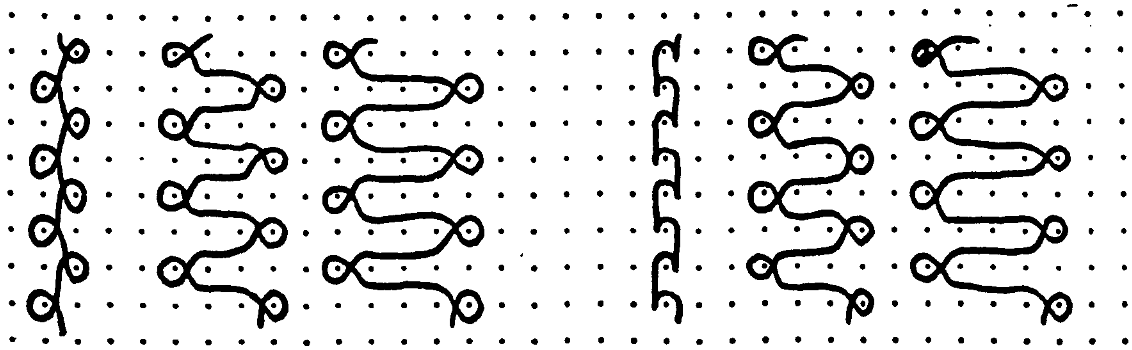
Locknit

Reverse locknit



Loop raised

Satin



Sharkskin

n Queen's cord

Fig. 14
Two bar constructions full set threading

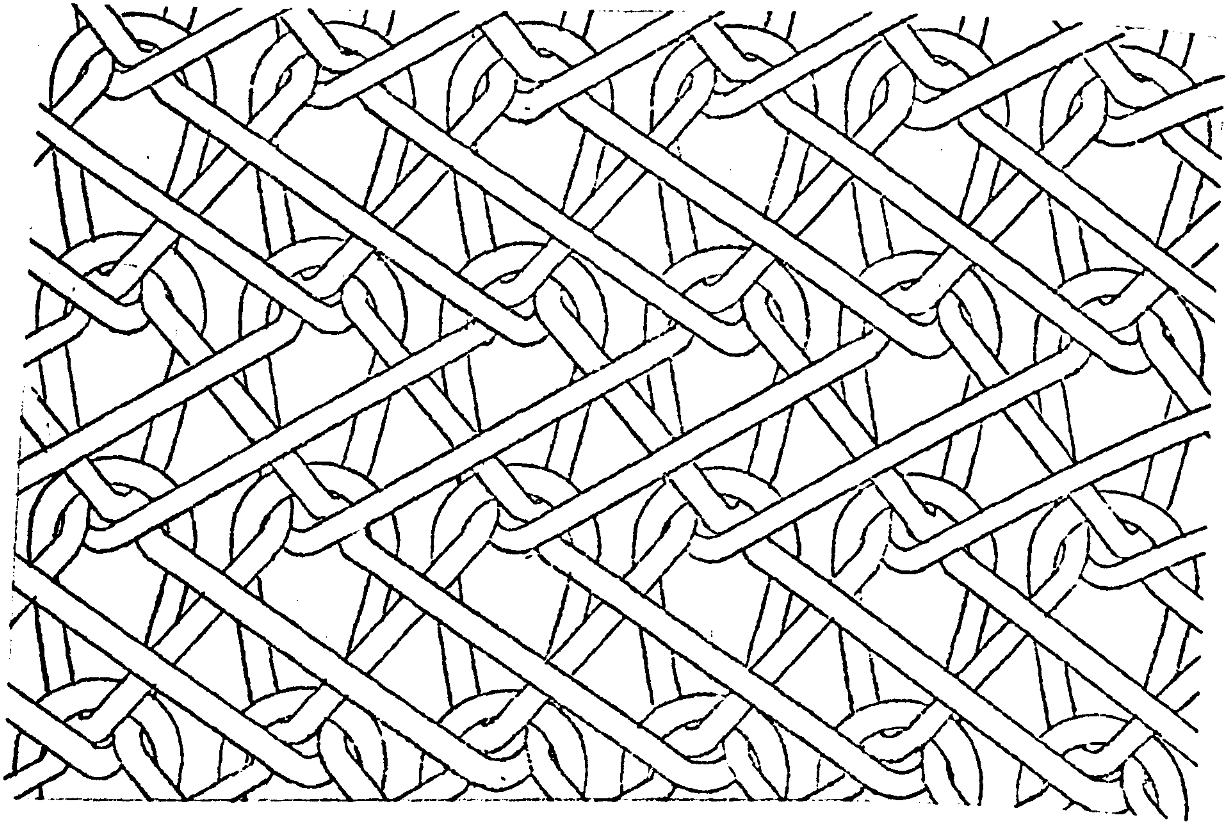


Fig. 15 Locknit

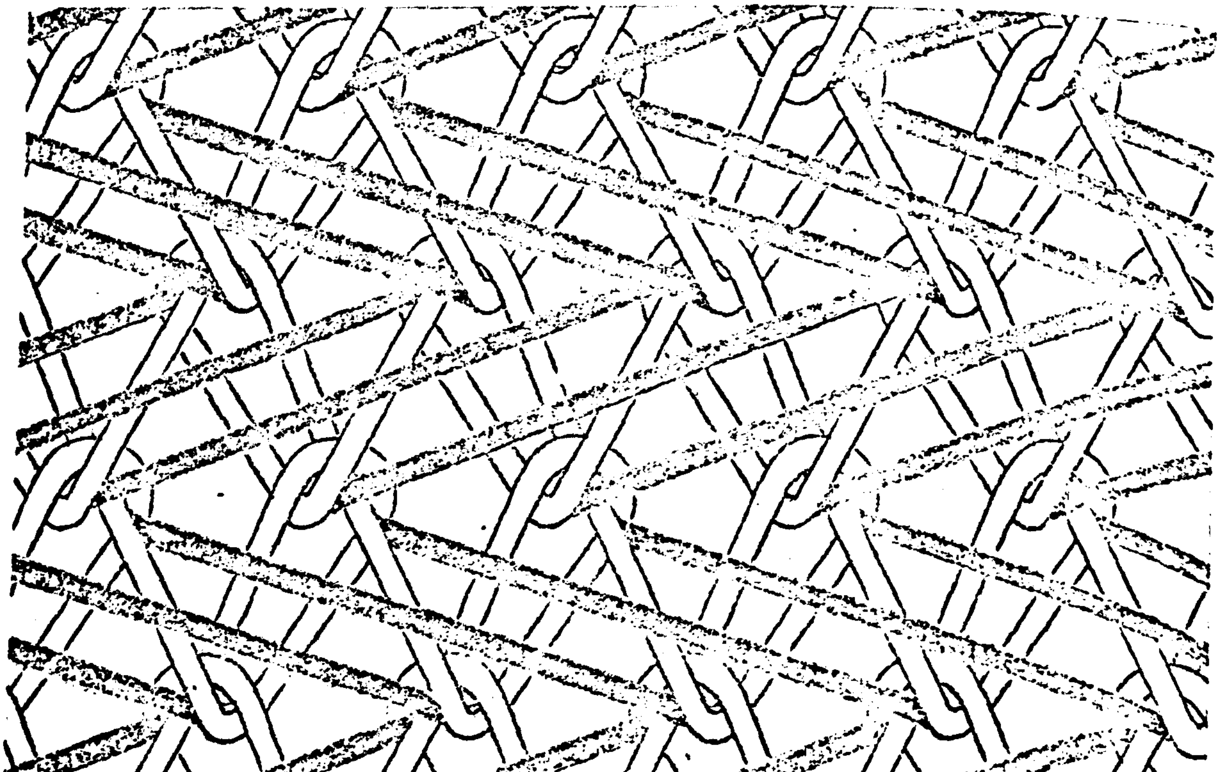


Fig. 16 Loop raised

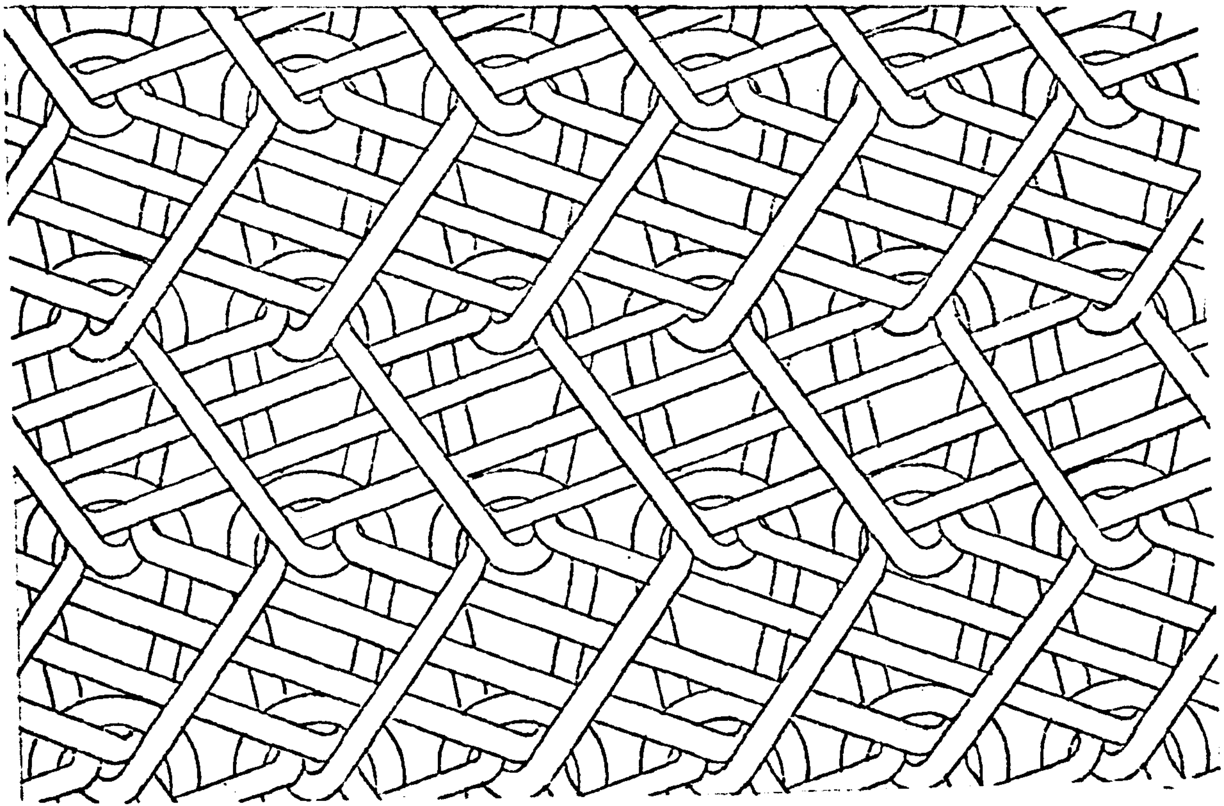
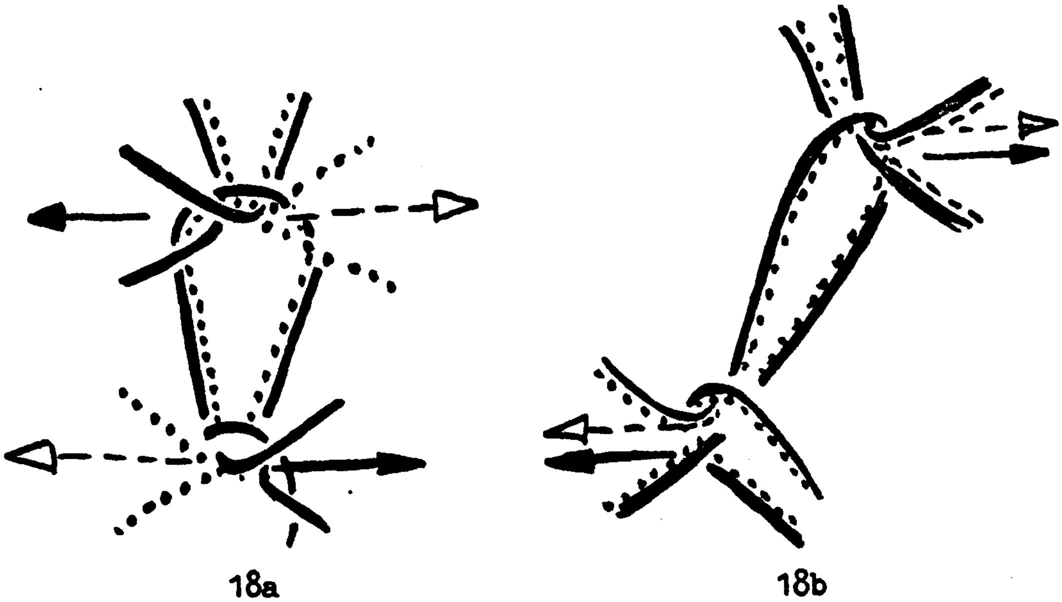


Fig. 17 Sharkskin



18a

18b

Fig. 18

technical back of the fabric. The underlaps of the back bar are sandwiched in the centre of the fabric.

(c) Relative movement of guide bars

The effect of the relative movements of the guide bars is summarised in the following rules.

i. If the underlaps of the two bars move in opposition, the loops will lie straight in the fabric as the forces exerted by the underlaps of one bar will be balanced by the forces exerted by the underlaps of the other bar, (Fig. 18a). Examples of fabrics in which this occurs are locknit and sharkskin. The relative size of the underlaps, e.g. 1 x 1, 2 x 1, 3 x 1, etc. are not important as the run-in of the yarn and, therefore, the tension in knitting is the predominant factor affecting the balance of the loop.

ii. If the underlaps of the two bars move together, the loops will lie at an angle in the fabric, the direction of inclination depending on the direction of the underlaps, Fig. 18b. An example is the loop raised construction.

iii. If a large underlap is used on the front bar with a short movement on the back bar, the bars moving in opposition, the fabric will contain widthwise elasticity, e.g. locknit.

iv. If the underlaps of the front bar are over 3 or 4 needle spaces, the technical back of the fabric will be of a lustrous nature, e.g. satin. This is because the underlaps lie almost straight and a large amount of light is reflected in one plane. These

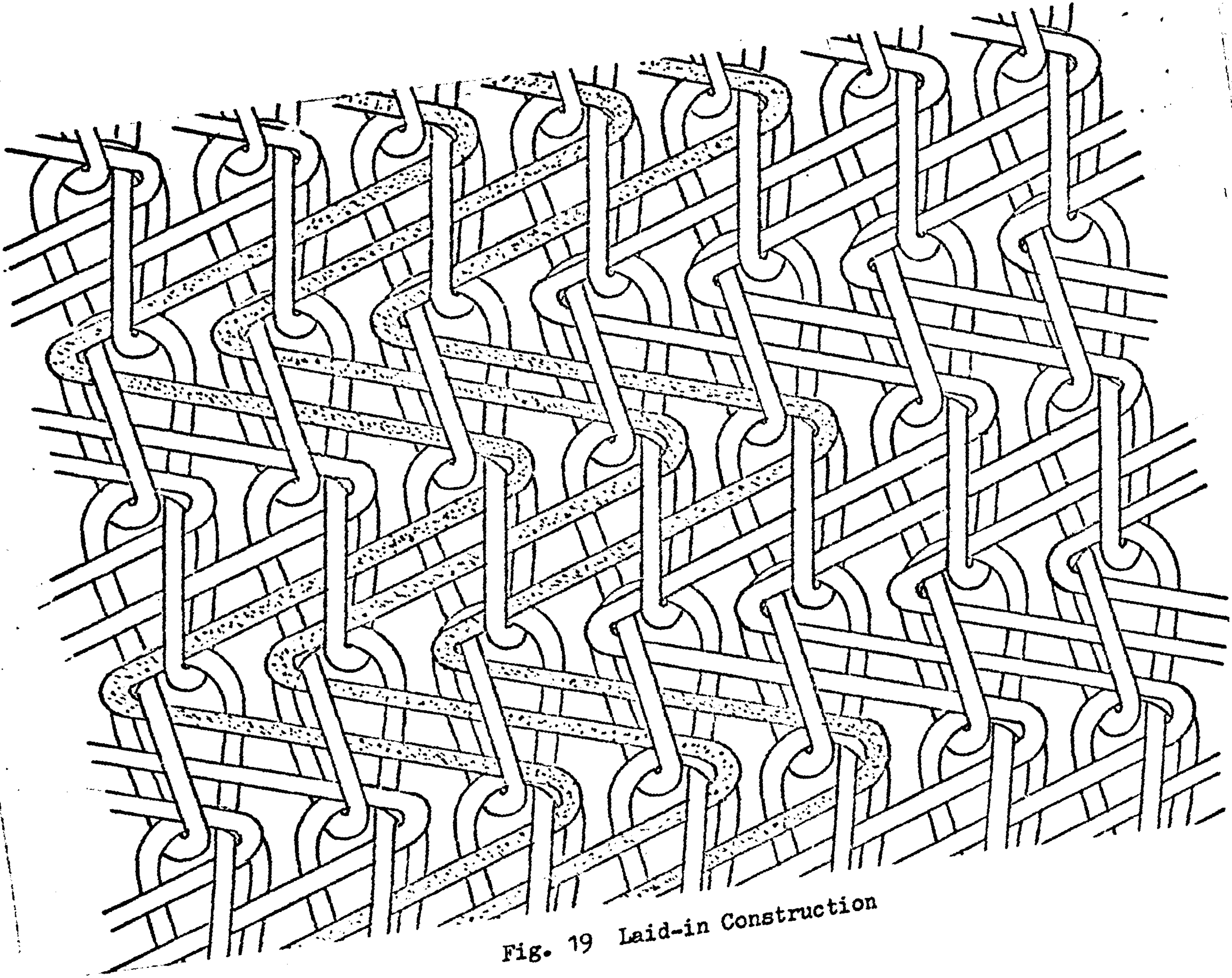


Fig. 19 Laid-in Construction

underlaps may be brushed as in a loop raised construction.

v. If a large underlap is used on the back bar and a short one on the front as in sharkskin and queens cord, a stable fabric is produced. This is because the long underlaps of the back bar are trapped in the centre of the fabric, thus restricting thread movement. The elasticity of any knitted fabric is dependent upon free transfer of yarn within the loop. It is for this reason that weft knitted constructions are more elastic than warp knitted constructions and why a sharkskin and queens cord fabric are very stable.

(d) Laid-in fabrics

When using more than one guide bar, it is possible to cause the back bar threads to connect into the fabric by forming underlaps only. In other words the overlap, and therefore the loop, is omitted. This results in a range of constructions which are suitable for a variety of fabrics and differ in appearance and properties from those obtained when both bars are knitting. Generally speaking, these fabrics are stable in construction and lighter in weight than the equivalent fabric in which two bars are knitting. The laying-in technique is also used extensively for the introduction of ornate designs. Typical examples of these are dress fabrics, Raschel laces and curtain nets.

One common fabric produced with two guide bars, with full set threading on each bar, consists of chaining on the front bar and laying in over three needles on the back bar. This is illustrated in Fig. 19.

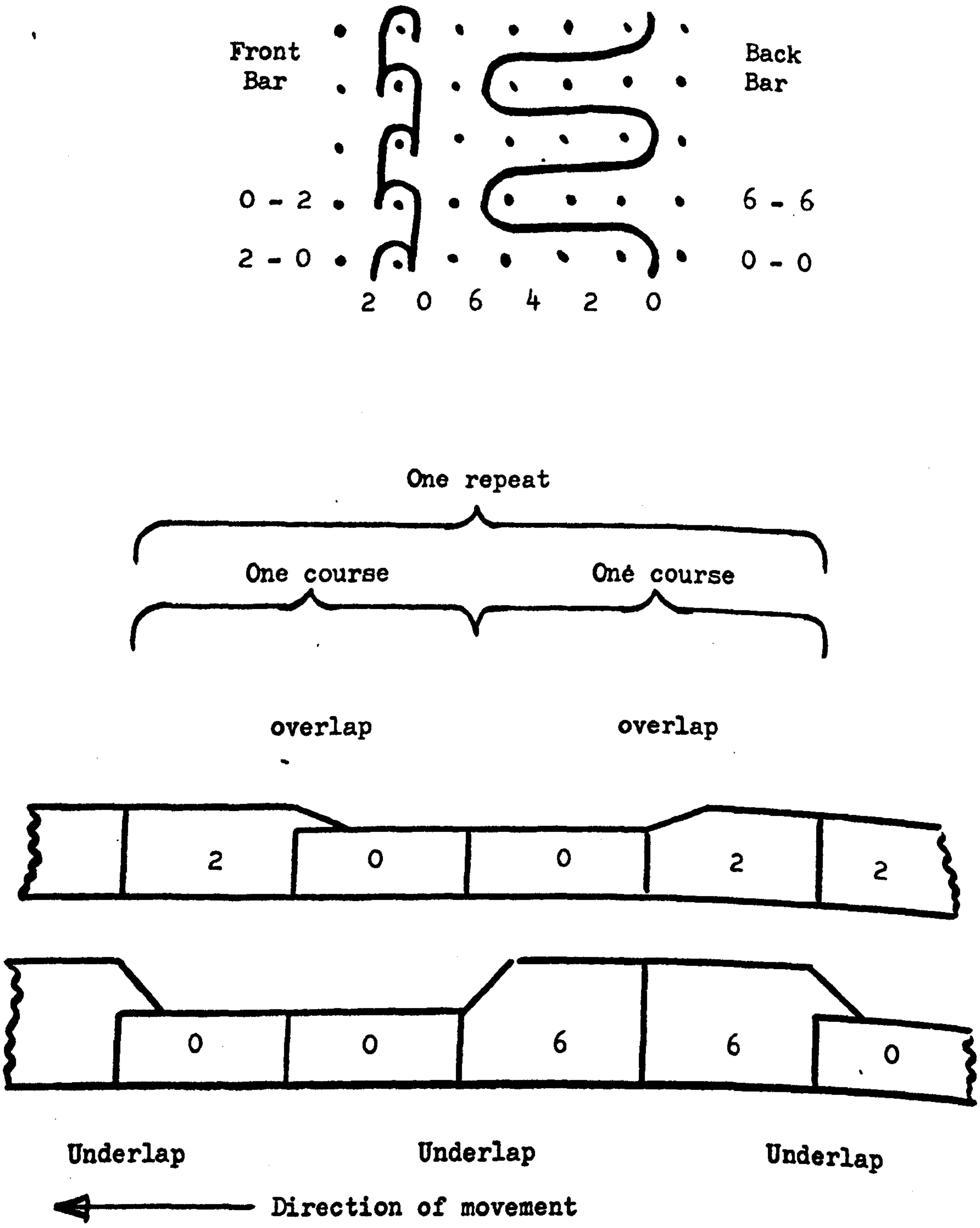


Fig. 20

Lapping movement and chain construction for the laid-in structure in Fig. 19.

The lapping movements for laid-in constructions are obtained by plotting the threads as they appear in the fabric and then reading off the chain in the same way as that for a knitted stitch. Two consecutive links will be of the same size, however, as no overlap is formed. Both lapping movement and chain construction for Fig. 19 are illustrated in Fig. 20 giving the link arrangement for a Raschel machine.

Other basic constructions are openwork and net fabrics formed with one knitting bar and one laid-in bar, using a full set threading on both bars. The basic construction is, as with all nets, that no side connection is made between adjacent wales for a number of consecutive courses. The loop distortion thus caused, together with suitable yarn counts, results in an openwork construction, the two most common of which are marquisette, Fig.21, and tulle, Fig. 22.

3. Three Bar Constructions.

The use of three guide bars obviously opens the field for the production of more complex fabrics and, generally speaking, the majority of these fabrics are ornate in nature. With such constructions, it is not possible to class them as standard types with the exception of one or two of the simpler fabrics. These fall into two groups, those in which all bars knit and those in which some bars lay in.

(a) Knitted constructions

The most common of these is the shirting, blouse and dress fabric in which all bars are full set threaded with 40 denier nylon

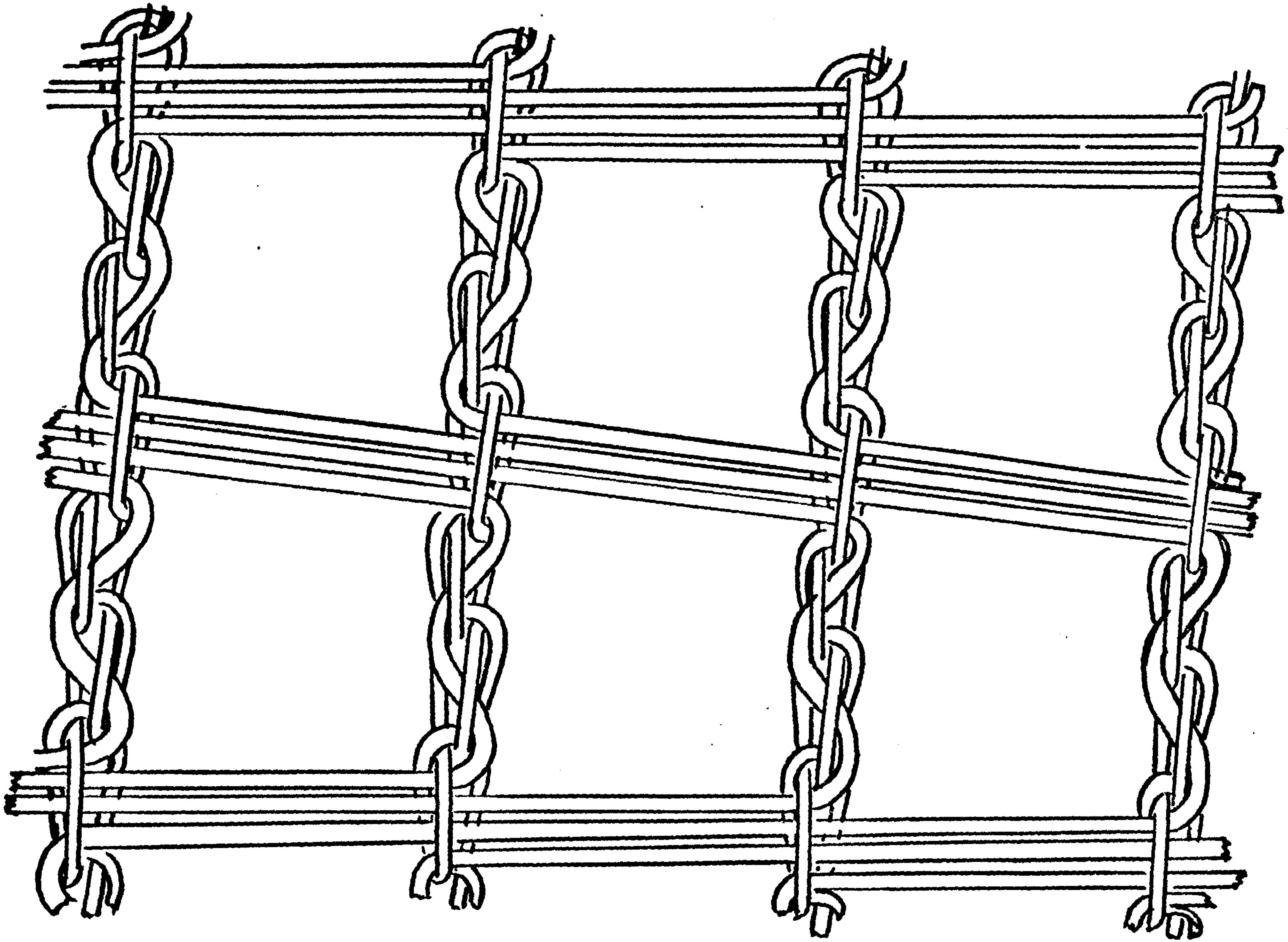


Fig. 21 Marquisette

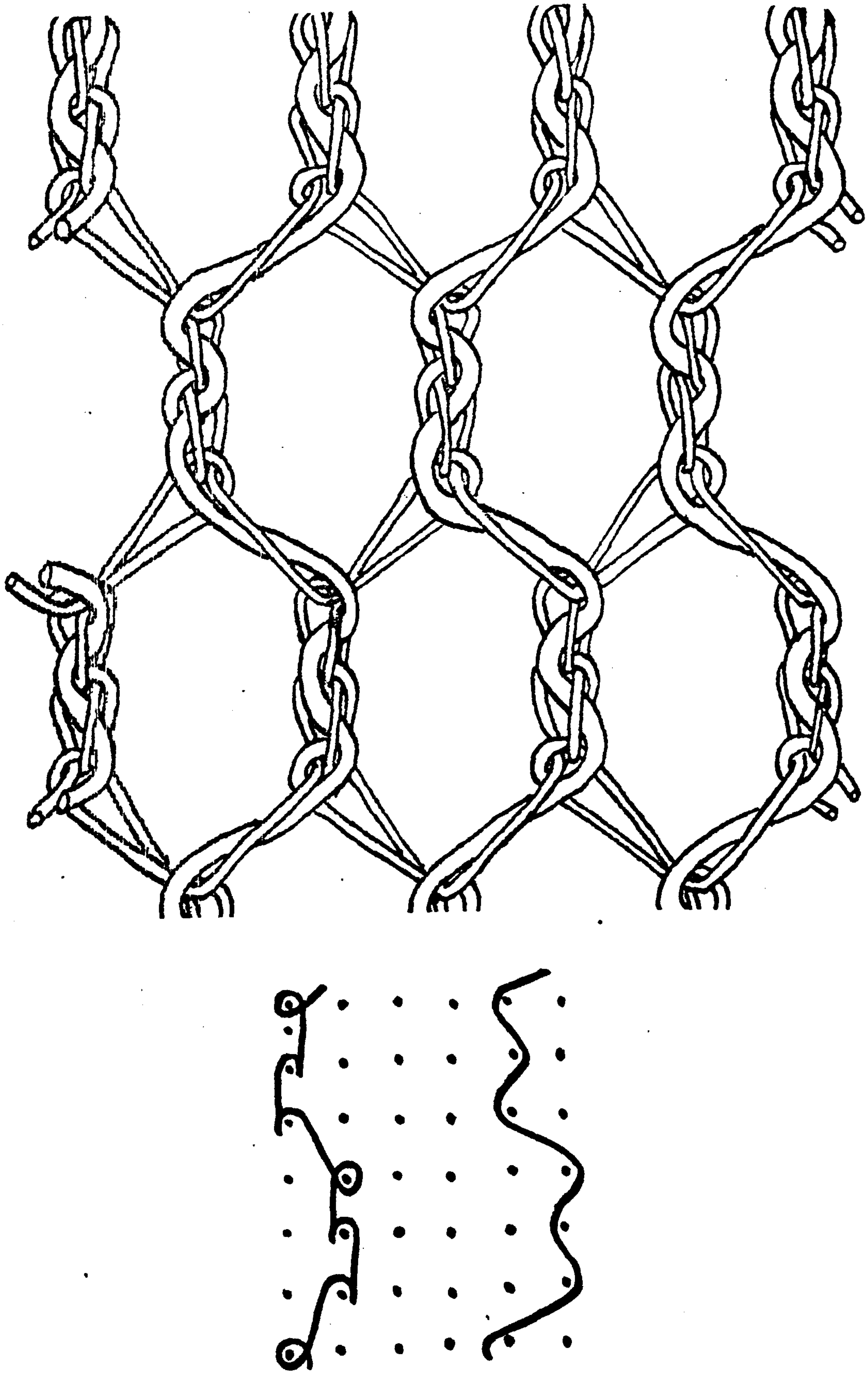


Fig. 22 Tulle

or Terylene and the movements are -

Front bar 1 - 0 / 0 - 1
Middle bar 1 - 2 / 1 - 0
Back bar 1 - 0 / 3 - 4 (Fig. 23a)

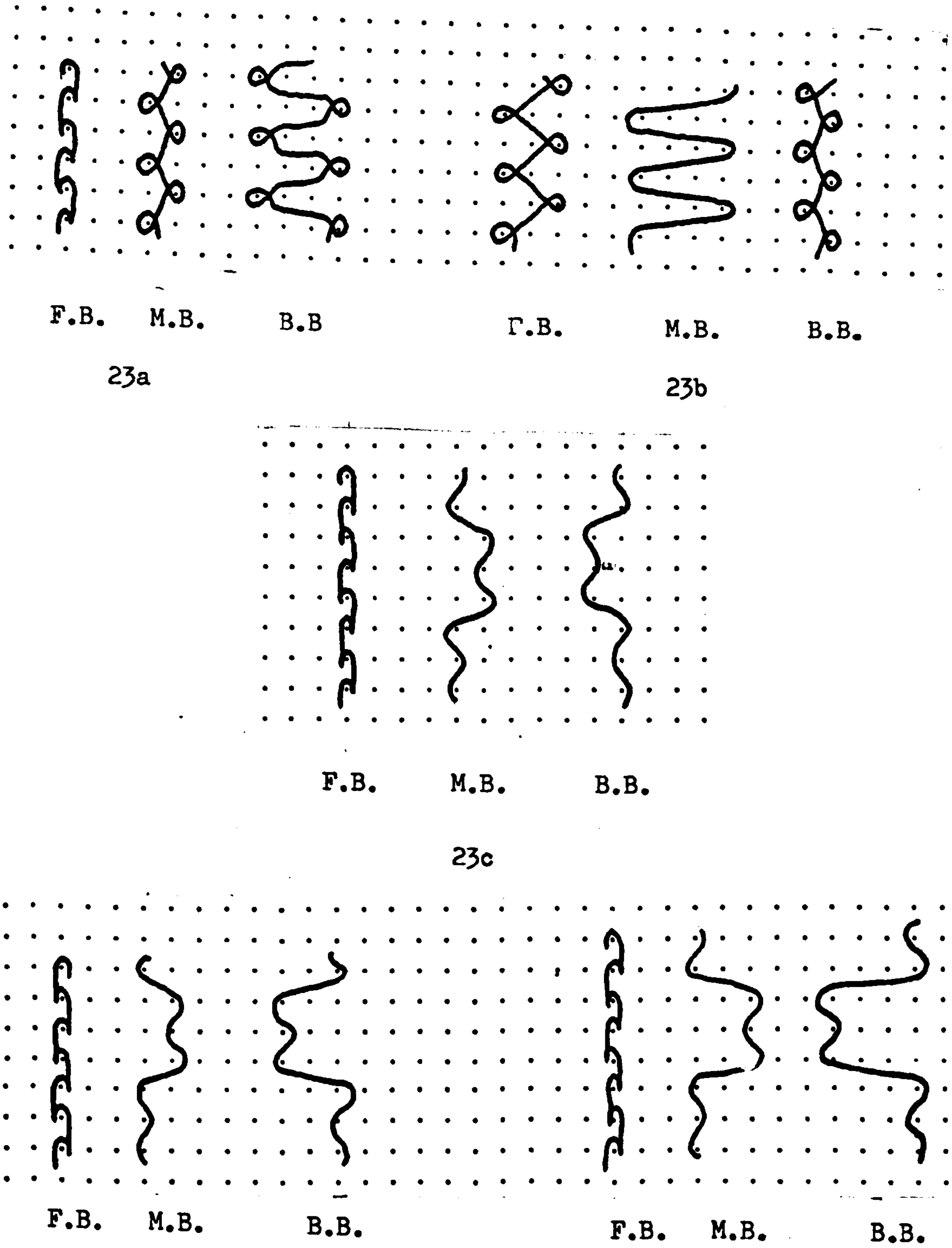
Three bar constructions have better stability, opacity and drape, but will obviously be heavier than their two bar equivalent.

Variations of this basic three bar construction are made for the introduction of pattern which is generally achieved by altering the movement of the back bar to give horizontal stripes, or alternatively, alteration of the front bar threading to give vertical stripes, or a combination of both to give check effects.

(b) Laid-in constructions

Two classes exist within this group; one produces a solid fabric and the other an open-work effect. The former is generally made by using locknit movements on the front and back bars and laying-in over three or four needles in the middle bar. By using a slack run-in on the middle bar, its threads can be caused to show on the technical back of the fabric. This principle is used to make two types of fabric, one by using a highly twisted yarn in the middle bar to give a crepe effect and the other by using a flat yarn with a large number of filaments to make a pile fabric after subsequent brushing during finishing. (Fig. 23b).

The second class in this group, openwork constructions, are generally marquisette or voile nets. The marquisette three bar version is only an extension of the two bar type. The third bar



23a

23b

23c

23d

FIG. 23

lays-in, in opposition to the second bar to give added stability and drape and prevent wale slippage. The three bar net is more common than the two bar version. The two laying-in bars are not generally equal in movement unless the least underlap is used as in Fig. 23c, which, although a commercial construction, is the lowest quality of this type of net. Other commercial constructions are shown in Fig. 23d.

4. Quality Control.

The quality of warp knitted fabrics is controlled on the machine by determining the courses per inch and the stitch length. The former is governed by the take-up mechanism, a set of change gears being provided to give different courses per inch. The latter is determined by the let-off mechanism which controls the speed of movement of the warp.

(a) Stitch length

Since it is impractical to measure one stitch on the machine, the required amount of yarn to produce 480 courses is measured. This is referred to as the 'run-in', or 'runner', or 'runner length'. 480 courses is termed 'one rack', therefore, if a fabric has a run-in of 67" per rack, it means that 67" of yarn are required to produce 480 courses, or the stitch length is $\frac{67}{480} = 0.140''$. Each warp requires a different run-in according to the lapping movement used.

(b) Run-in ratio

The run-in ratio or runner ratio is the ratio of yarn required between the various bars. e.g. If a locknit fabric has a run-in of 62" per rack on the front bar and 48" per rack on the back bar, the run-in ratio will be 64:48 or 4:3 or 1.33:1.00.

(c) Estimation of run-in

The usual means of estimating the run-in of a new fabric is by each designer using his own experience. Various formulae have been proposed, (see Chapter Three), but none have been able to calculate accurately the run-in required to produce a fabric at a given number of finished wales and courses per inch.

(d) Estimation of run-in ratios

The run-in ratio can be determined by empirical rules[1.2.3], but these again give only an approximate figure. The system used is as follows -

The lapping movement is divided into loops and underlaps and each are given a value according to the movement. Loops equal 2, underlaps 1 for each needle space traversed, vertical underlaps as in a chain stitch 0.75 and the underlap of adjacent loops formed by a two needle overlap 0.5. Thus locknit would be :-

Back bar		Total
Loops	2 2	4
	$\overbrace{1 - 2}^{2}\underbrace{\quad}_{1}\overbrace{1 - 0}^{2}\underbrace{\quad}_{1}$	
Underlaps	1 1	2
		6

<u>Front bar</u>		<u>Total</u>
Loops	$\overbrace{1 - 0}^{2}\quad\overbrace{2 - 4}^{2}$	4
	1 - 0 2 - 4	
Underlaps	$1 - \underbrace{0\quad 2}_{2} - \underbrace{4\quad\;}_{2}$	4
		8

Ratio of front bar to back bar - 8:6 or 4:3 or 1.33 : 1.00

IV. COMPARISON OF RASCHEL AND TRICOT MACHINES

In a definition of Raschel and tricot machines, it is general to describe the difference by stating simply that a tricot machine uses bearded or compound needles while a Raschel machine uses latch needles. There is, however, a more important difference which is the manner in which the fabric is removed from the needles. On a tricot machine, the fabric is taken away at approximately 90 degrees to the axis of the needle movement, while in a Raschel machine the fabric is removed at approximately 180 degrees to the needle movement.

The bearded needle is a one piece needle and, therefore, easier to manufacture in fine gauges than a latch needle, and it is for this reason that the bearded needle machine developed with the warp knitting trade at the introduction of continuous filament yarns, 28 gauge being the common gauge with 32 gauge more popular for finer fabrics. The latch needle was used in 24 and 32 gauge, (12 and 16 needles per inch), at about this time and used mainly for fibrous yarns.

Modern needle manufacturing methods now make it possible to produce much finer latch needles and 36, 40 and 48 gauge machines are now available. At the present time 56 and 64 gauge machines are the ultimate in Raschel gauges but these are used only for elastomeric materials, (power net). The reason for this is that if tricot type fabrics, (locknit, loop raised, queens cord, etc.), were produced on fine gauge Raschel machines, the resultant fabric would be marred by lines running down the length of the fabric which is attributed to malformation of the loop. The cause of these lines is yet to be identified and cured, but it is not possible to produce these fabrics on a commercial basis as is possible on tricot machines. The use of an elastomeric material distorts the ground structure thus disguising the lines which still exist, but at a tolerable commercial level.

Modern needle manufacture has also enabled the bearded needle to be manufactured at finer gauges and 36 and 40 needles per inch are now possible.

(a) Layout of knitting elements

The different layout of knitting elements in the two machines make each suitable for different classes of fabric because the holding down power supplied to the fabric is greater on a Raschel machine than on a tricot machine.

Consider the basic layout of the knitting elements shown in Fig. 24. With the Raschel machine, Fig. 24a, the forces exerted on the fabric when the needles rise tend to lift the fabric. These

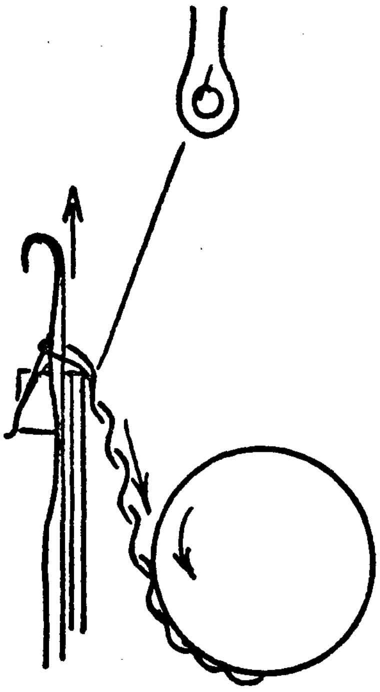


Fig. 24a

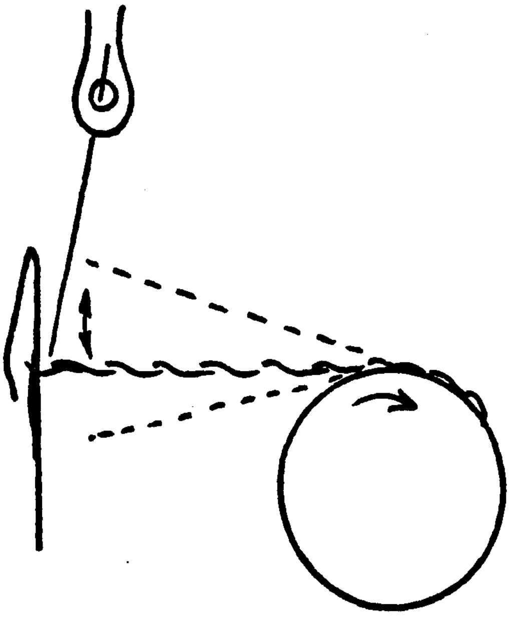


Fig. 24b

forces are the tension in the warp threads, (which is small), and the frictional forces between the needle and the loop. This latter force is the greater as the loop opens the latch and the loop expands over the increased thickness of the needle at the point of the latch pivot. The pull of the fabric supplied by the take-up rollers is, however, almost in a direct opposition to the needle movement, the fabric, therefore, holds down well irrespective of the lapping movement. In fact, the only factor which allows the loop to rise with the needle, is the stretch in the fabric and this is kept to a minimum by placing the take-up rollers as close to the knitting point as practicable.

The Raschel machine will thus work without sinkers, the greater the force supplied by the take-up rollers the better the fabric is held down and it is, therefore, evident that this machine is ideal for fabrics which do not have a regular underlap such as tulle and marquisette nets. While it is possible to knit without sinkers, it is evident that the density or quality of fabrics that could be produced would be limited as they must be made under maximum fabric tension; thus sinkers are used to extend the range of qualities possible.

The tricot machine has, however, no holding down properties at all if the sinkers are omitted. As the needle rises, the loop sticks on the eye of the needle, (thickest part of the needle). The friction between the needle and loop, therefore, causes the fabric to rise and fall with the needle, the fabric "hingeing" on the take-up roller. Any increase in take-up tension provided by

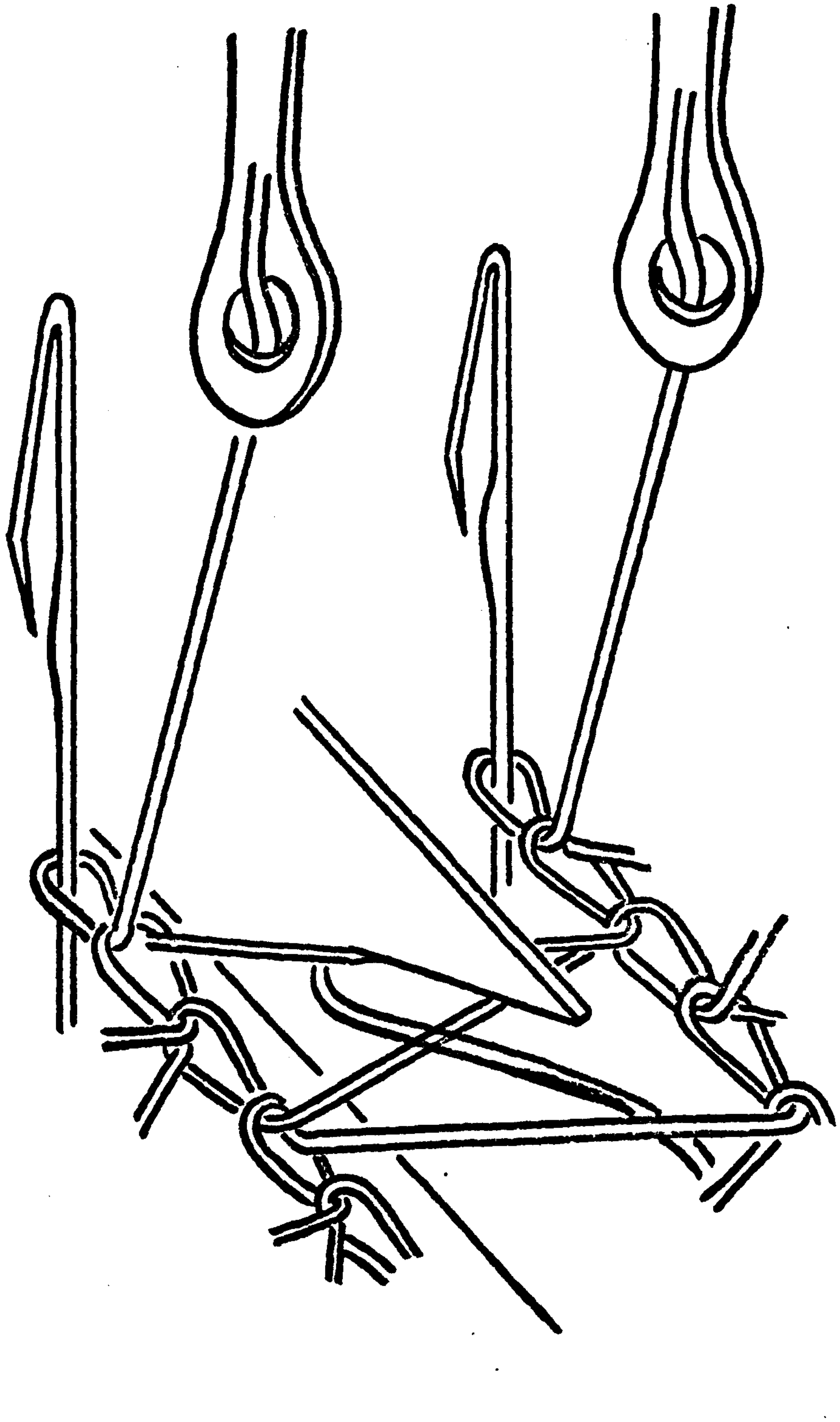


Fig. 25

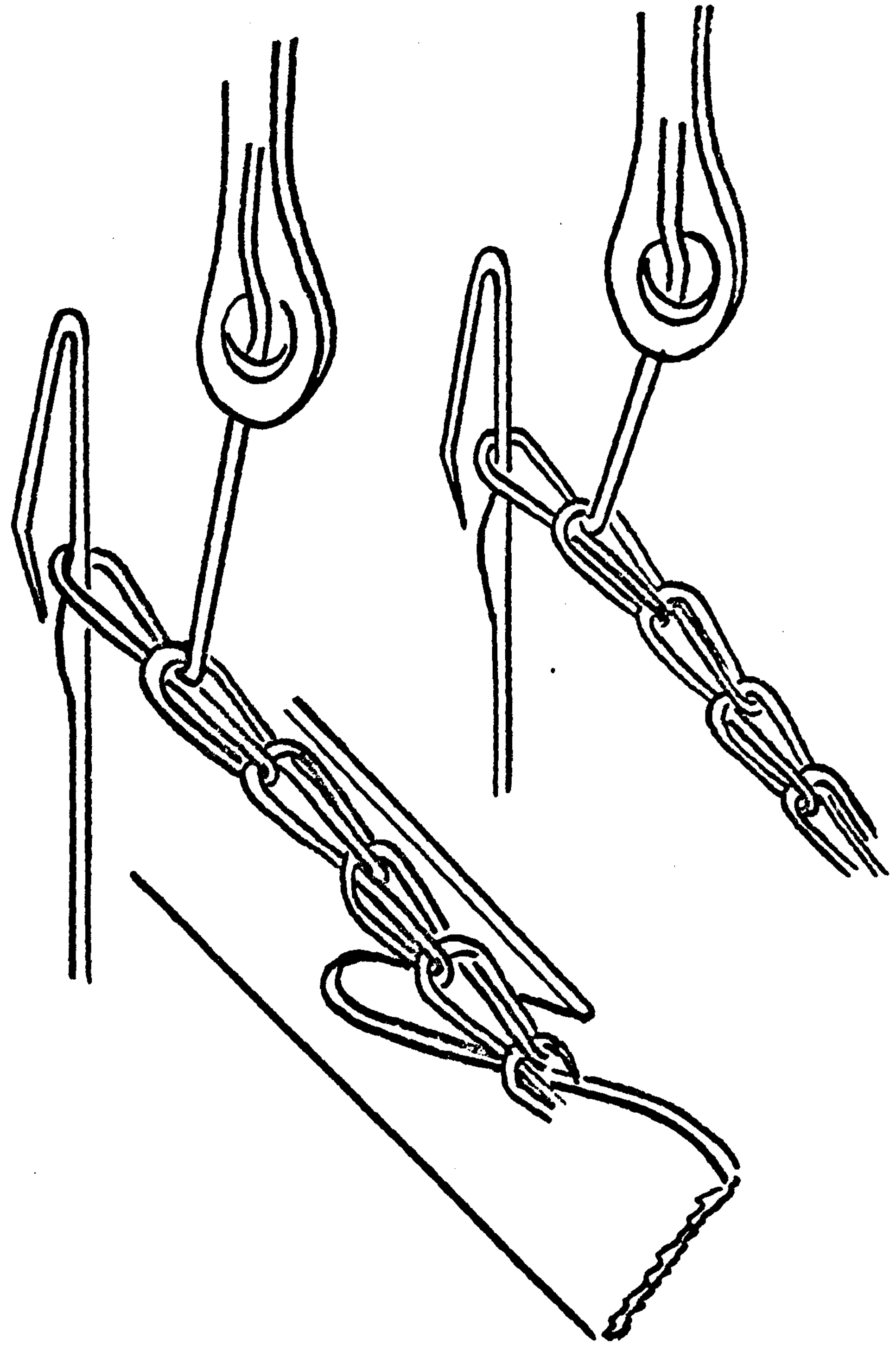


Fig. 26

the take-up rollers only makes the situation worse as the loop is held more firmly on the needle. Thus the old loop remains inside the beard, a condition under which knitting cannot be performed.

The bearded needle must, therefore, be used with sinkers and on constructions which use an underlap on each course. This operation of the sinker is shown in Fig. 25. Chaining constructions, however, would rise with the needle, (see Fig. 26), the loop remaining inside the beard. The bearded needle is not therefore suitable for constructions which miss the underlap for one or more courses, or slack constructions which have no underlap, e.g. open lap atlas movements.

A second difficulty sometimes encountered on tricot machines is failure to knock-over when the loop remains on the head of the needle and passes down between the sinkers. This fault is obviously more acute on structures without an underlap and is not troublesome on a Raschel machine where the trickplate forms "a knocking over edge".

Thus the tricot machine is suitable for fine gauge fabrics which have an underlap on each course. The Raschel machine is suitable for coarser fabrics in which chaining movements are common.

(b). Three links per course on tricot machines

Although two links per course are necessary for fabric formation, it is advantageous to use three or four links per course in certain circumstances.

Three links per course is the standard arrangement on tricot machines in order to obtain two movements for the underlap so that

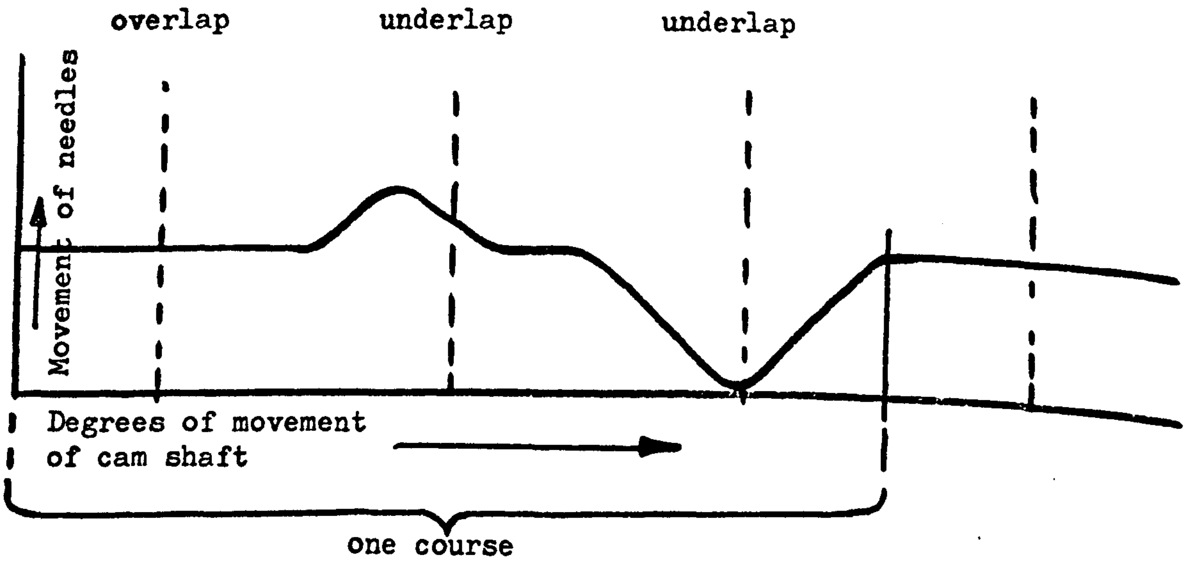


Fig. 27a

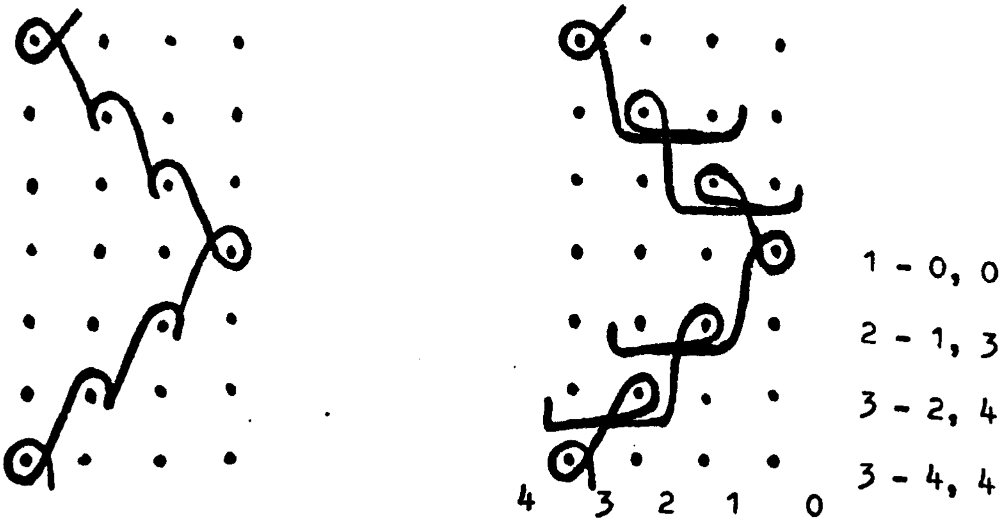


Fig. 27b

large movements may be made in two small steps which is superior from the point of view of high speed knitting.

The timing of the two underlap movements is illustrated in Fig.27a. The first movement takes place during pressing and landing and the second as the sinkers come forward after knocking over.

The method of plotting lapping movements when using three links per course is to plot as if two links were used, i.e. for the overlap and then insert the third link so that it splits the underlap movement -

e.g. 1 - 0 / 2 - 3 would be 1 - 0 - 1 / 2 - 3 - 2
1 - 0 / 4 - 5 would be 1 - 0 - 2 / 4 - 5 - 3

If a machine is equipped to give three links per course and a lapping movement is used in which no underlap is employed, or in which the underlap is only one needle space, the second link is duplicated -

e.g. 1 - 0 / 1 - 2 would be 1 - 0 - 0 / 1 - 2 - 2
1 - 0 / 0 - 1 would be 1 - 0 - 0 / 0 - 1 - 1

Three links per course are also used to obtain the correct time of movement and to ease knitting difficulties. One example of this is the production of the loop raised construction. If two links per course are used, or if three links per course are used where the underlap is split into two separate movements, threads are liable to split on the sinker neb causing vertical lines in the fabric. It is general, therefore, to use a front bar movement

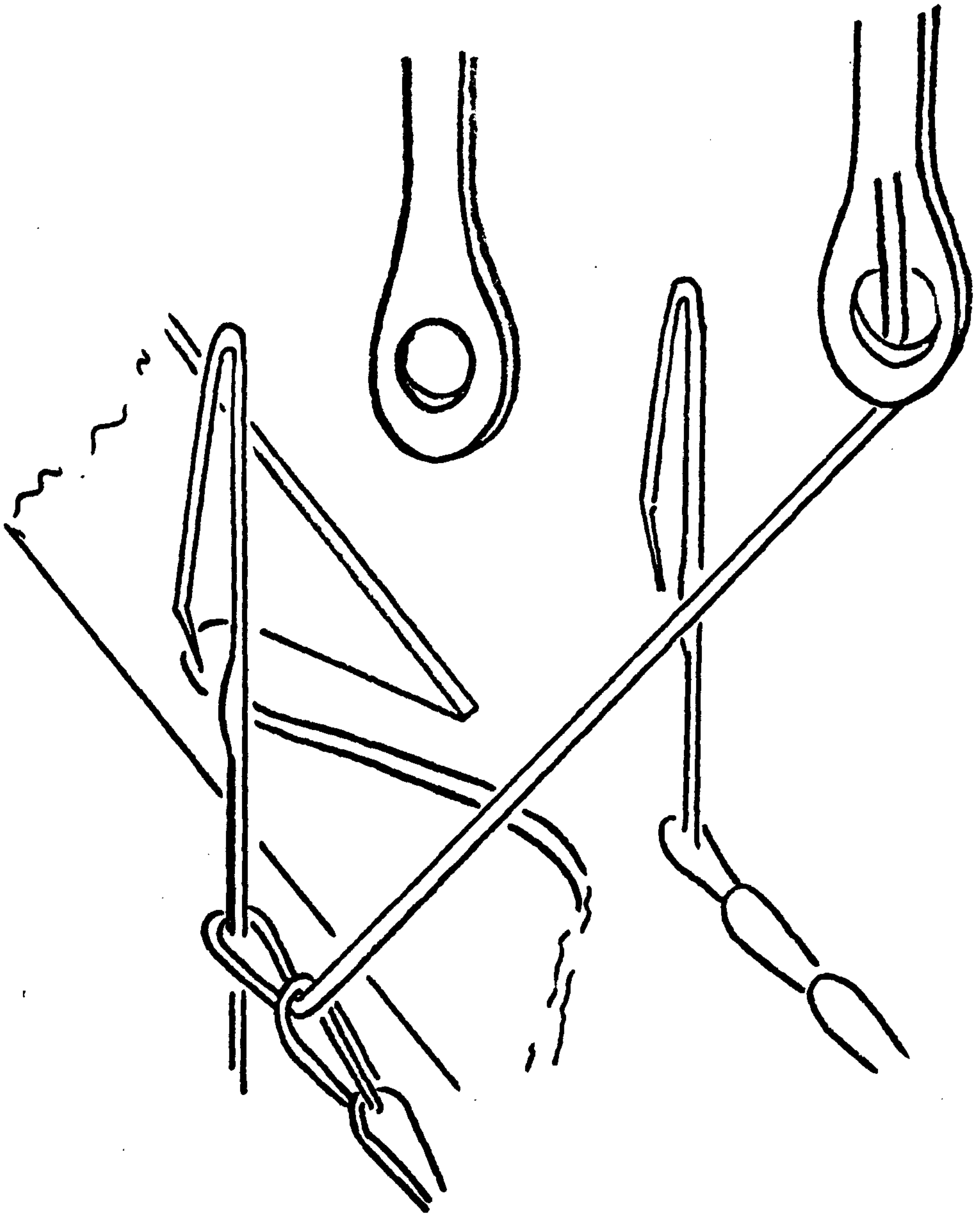


Fig. 28

of 1 - 0 - 0 / 3 - 4 - 4 so that the underlap is delayed until the sinkers have come forward.

A second example of easing knitting difficulties when using three links per course is the blind lap.

(c) Blind Lap ("Putting a cross in")

Blind lapping is a technique used on bearded needle machines to ease knitting difficulties which may be encountered in the production of fabrics such as tulle and marquisette and in some cases open lap atlas which do not have an underlap on each course. It is achieved by the use of three links per course, the timing of which is shown in Fig. 27a.

After the needles have been lapped in the normal manner, they descend to press and land and, at this point, the guides make the first underlap, the blind lap, (see Fig. 28). The needles then descend to knock-over in the usual way, the sinkers coming forward over the underlap, as shown in Fig. 29, to hold the fabric down as the needles rise. During this time the second underlap is made, as illustrated in Fig. 30, to position the guides ready for lapping on the next course. When the sinkers withdraw, the yarn placed round the sinker neb is released and the tension in the yarn supplied by the tension rail pulls the yarn straight so that the blind lap has no effect on the fabric construction.

The blind lap is, therefore, an underlap inserted by using three links per course to ease knitting conditions and does not influence the structure of the fabric being produced.

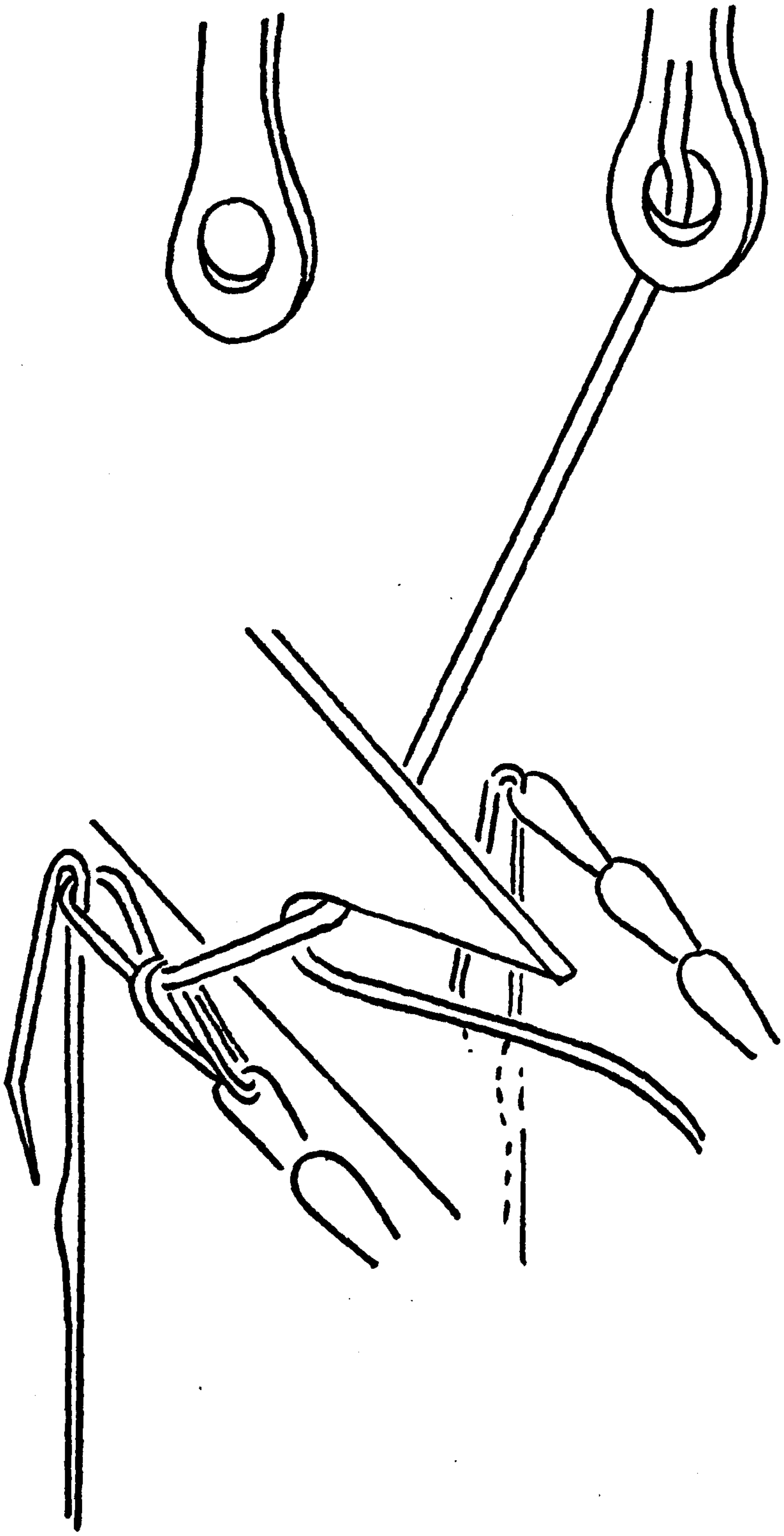


Fig. 29

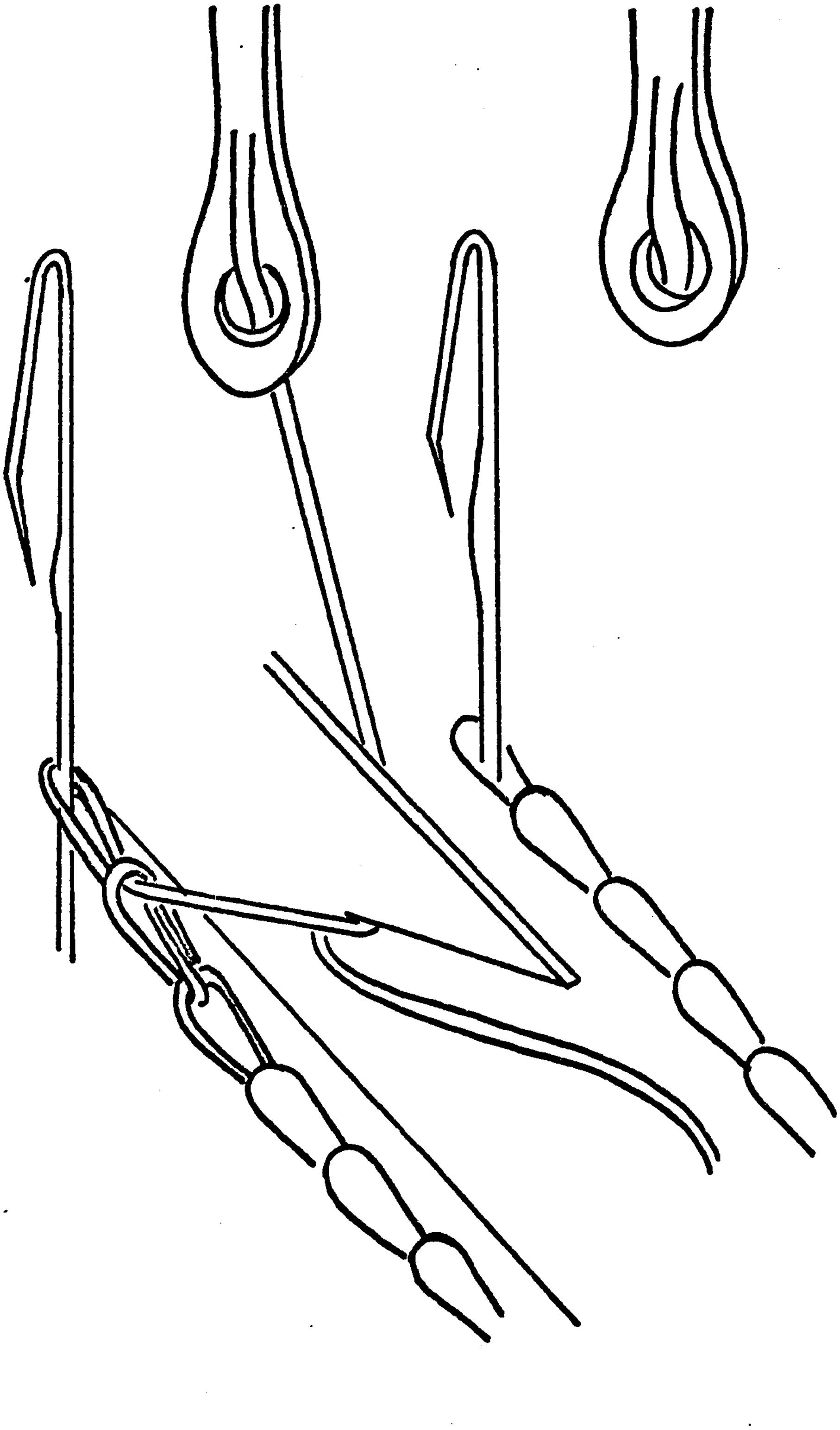


Fig. 30

The method of plotting a blind lap is shown in Fig. 27b. The blind lap is always made in the opposite direction to the following overlap.

(d) Knock-off lap (Blind lap)

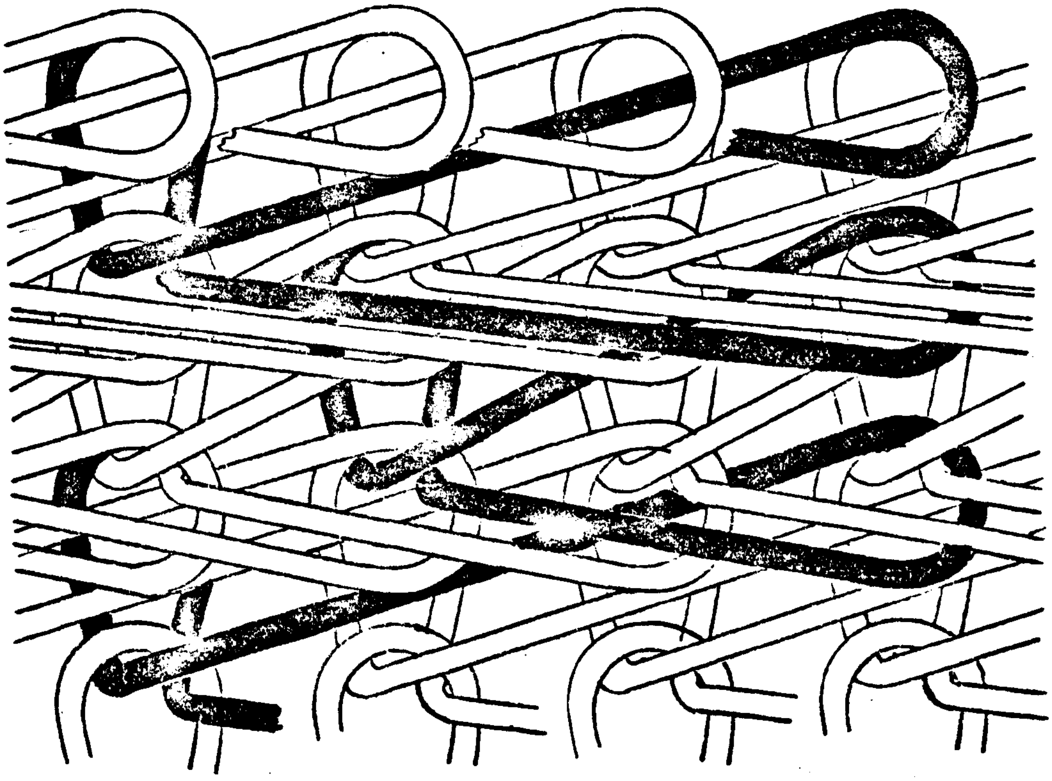
The knock-off lap is a term used to indicate that the presser is not used on certain courses, so leaving the threads lapped on that course under the needle beard when knocking-over. On the next course, the guide bar laps in the normal manner and so the needles will have two sets of loops. Pressing, landing and knocking-over are now performed in the usual way.

The original term was "double looped framework", (as described in the original patent[4]). Unfortunately this operation has also been described as blind lapping which leads to confusion with the more general use of the term previously described.

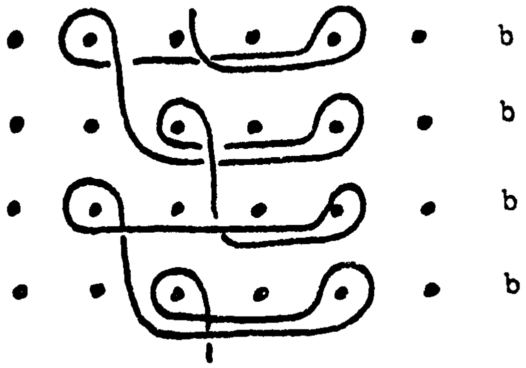
Knock-off laps were extensively used for the production of pile type fabrics in the late 1800s and early 1900s for jackets and trouserings. The loop structure and lapping movement of such a fabric are shown in Fig. 31.

(e) Two needle overlap

It is possible to produce fabrics by lapping two needles on the overlap, but this technique is not very popular as two loops have to draw their yarn from a single warp thread. The yarn, therefore, tends to chop across the sinker between the two needles lapped. Such fabrics have to be made with minimum knock-over, minimum warp tension and yarn with natural elasticity. An openwork fabric produced in this manner is shown in Fig. 32.



Loop Structure



Lapping Movement

b = blind lap (miss-press)

Fig. 31

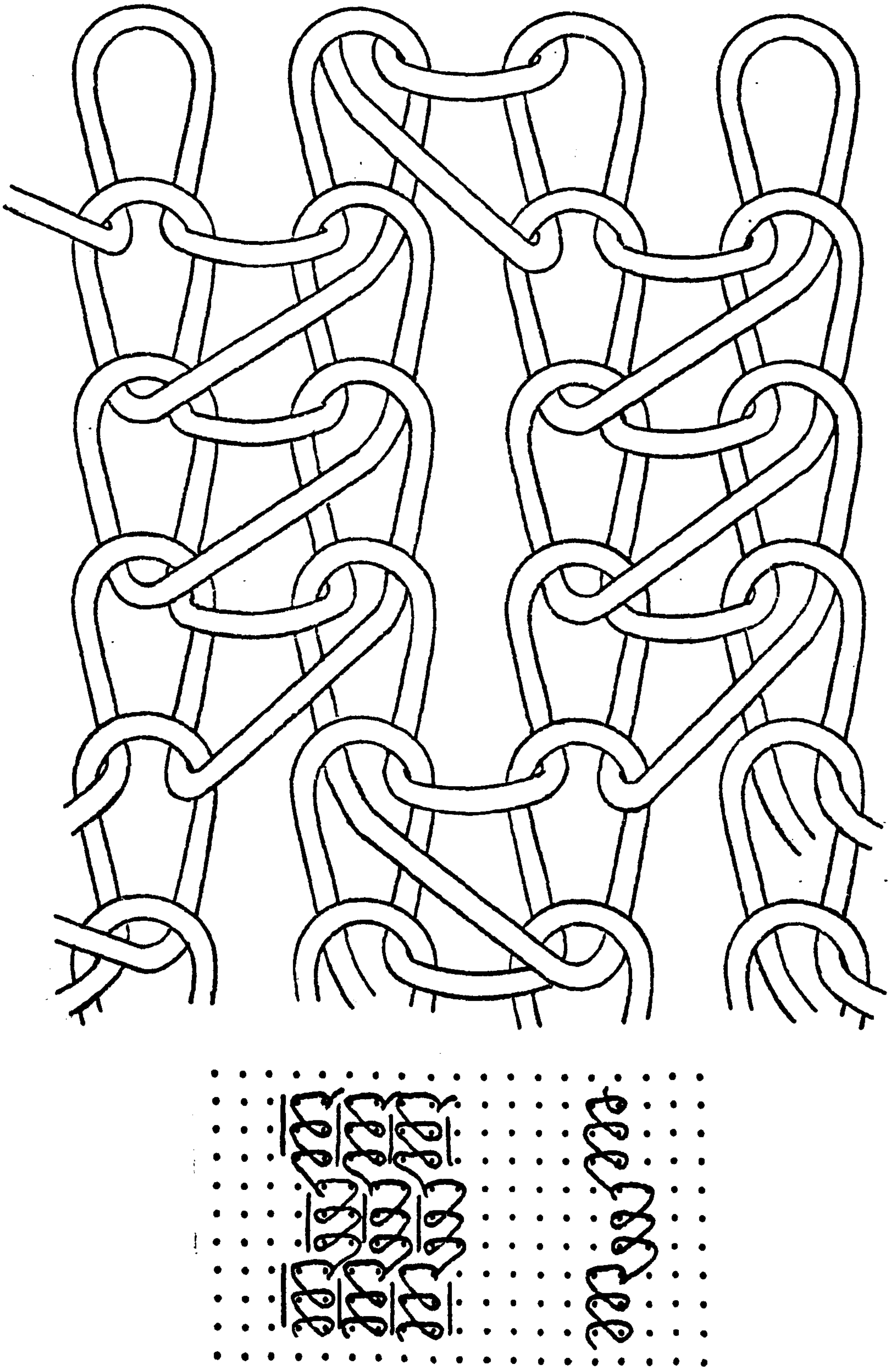


Fig. 32

CHAPTER II

HISTORICAL SURVEY OF WARP KNITTING

As modern weft knitting is a mechanical means of producing hand knitted fabrics, so modern warp knitting is a mechanical means of producing hand crochet work.

The first knitting machine was the hand stocking frame invented by the Rev. William Lee of Calverton in Nottinghamshire in 1589[5]. The machine's primary use was for the production of hose being made as a flat fabric and shaped on the machine thus producing a selvedged piece of material which held well after seaming.

I. THE HAND WARP FRAME

Machine production of warp knitted fabrics commenced somewhat later by the invention of the hand warp frame, generally attributed to Crane in 1775[6], who fitted warp guides to the hand frame. London stockingers apparently had a different account at the time as recorded by Henderson[7], suggesting that it was the invention of a Dutchman, Vandyke. However, it is generally accepted that Crane invented the hand warp frame, but Vandyke was responsible for the production of atlas fabrics for use in stockings, often produced to give blue and white stripes for fashionable hose of the time. Such fabrics, however, did not remain popular for long. Although they were made in silk, an expensive quality material, owing to the inelastic nature of the fabric, they were difficult to pull on and off the leg and this, together with the fact that they were cut from flat pieces of fabric with no selvedge, caused them to burst at the seams. Warp knit hose made in cotton was very popular in Germany where some 300 frames were employed.

Some ten years after the invention, the first significant improvements were made to the hand warp frame by Tarrett of Nottingham[4][8]. These consisted of utilising the pedals, (normally used for operating the sinkers and the jacks), to perform the up and down movement of the guides, and simplifying the sinker head to use one type of sinker only.

It would appear that the hand warp frame was not extensively used for the production of hosiery apart from the initial attempts with the exception of the success in Germany as mentioned above. It was mainly used for the plainer types of fabric and it is fairly certain that the production of the hand warp frame was in excess of either the hand frame or the weaving loom. The hand frame required time to make the "draw", (sink and divide), while the warp frame only required to lap. The weaving loom could only insert a pick at a time, a smaller unit than a course, and although the flying shuttle was invented, the power loom was not in general use before 1805[9]. Also of note, from the point of view of speed of the hand warp frame, was the introduction of a moveable needle bar by Robert Barber of Bilborough, Nottinghamshire[10]. This machine was also used for the first production of double looped framework. (See Chapter I).

In 1797, Barber took out a further patent[11] for the improvement of double looped framework and for the production of pile fabrics made on this principle, being either cut or looped pile. The common term at that time for long loop pile was "shagg". The following is an interesting quotation from page 7 of this patent:-

"There is a known practice in the common warp work of laying a thread across the frame, under the needles, to serve the threads over, which I recommend to be used in making some kinds of my long-looped or shagg manufacture, especially for carpets".

So, in 1797, weft insertion was known and practised as was warp knitted carpet manufacture, two fields of technology in which warp knitters are showing great interest at the present time.

Also in Barber's patent is reference to the introduction of the Derby Rib machine to his frame, the first reference to warp knitted rib work. It is fairly evident that the lay-out of the knitting elements would be such that the guide bars lapped the horizontal needles, which on withdrawing to form the stitch, drew loops round the vertical needles which then descended to knock-over.

The above, and other patents, show that fabrics suitable for a variety of end uses from bedding to wearing apparel were produced, and it is fairly evident that large quantities of these goods were made in wool and heavily fulled. An extract from Felkin indicates the importance of this work - "and larger contracts were entered into from time to time with the government, for the supply of woollen jackets and trousers. Our sailors fought for years clothed in Nottingham manufactures, for the supply of which 500 machines were employed, made from fine frames and good materials; this webbing formed an excellent article for gentlemen's pantaloons"[12].

The trade, thus prosperous and with markets for its productions, stimulated an interest and many developments and inventions were introduced. Worthy of note are the placing of the needles in an upright position by Brown and Pinder in 1796[13], 120 such frames being employed, and the claim to the first two guide bar machine by Brown in 1804[14].

Two major developments around this time which shaped the destiny of the trade were the introduction of Dawson's Wheel for guide bar control in 1791, and the introduction of the first warp lace frame in 1795[15 & 16]. By 1810, some 435 lace frames were in use. It is interesting to note that the virtues of warp knitting were expounded as often and loudly at the turn of the 18th century as they are today. At this point in time, Felkin says[17], "Thus the warp frame was found capable of competing in the woollen and cotton cloth markets with the common loom, and with a variety in its productions beyond its rival at that and even up to the present time (1867). Indeed it is impossible to describe all the methods and uses of this frame; no other machine is so universally applicable. Every kind of thread may be used; silk, cotton, linen and animal wool. Its speed is also unequalled, as it loses no time in passing weft threads; only one gait or thread to the next is required, each thread being looped through a steel guide to its neighbour; all the series thus operating together across the loom. The cloth when made will not tear out, it must be cut. Velvet has been made on warp machines 150 inches wide, without using wires for raising the pile.

The number of warp machines making cloth in the early part of this century was very large in England. Its great usefulness and rapid power of varied production caused it to be used abroad extensively, it having found its way into France, Spain, Italy and Germany."

II. ROTARY WARP FRAME - INTRODUCTION OF POWER

The invention of the pattern wheel by Dawson in 1791 as mentioned above was probably the most significant development of the period as it paved the way for the introduction of power, a feat attributed to Orgil in 1807[18].

The Dawson's wheel was a simple wheel of irregular periphery which pushed the guide bar to the correct position for the overlap and underlap, the same as today's pattern wheel. It is interesting to note that for ten years prior to this, the organ barrel was used for this purpose. The invention of the jacquard and its introduction in Paris and Lyons occurred ten years after the introduction of Dawson's wheel. It was not in fact applied for guide bar control on warp frames until some ten years after its introduction in Paris.

Power was applied to warp frames before it was applied to weft frames owing to their simpler construction and the fact that no fashioning action was required. It allowed frames to be built 72 inches wide and often two frames were coupled together to be operated at 30 c.p.m. by one man. Before this, a hand frame was 44 inches wide and was operated at about 10 courses per minute.

Warp knitting had thus established itself as a major fabric producing section of the trade during and at the end of the Napoleonic Wars. However, keen competition from the power loom caused warp knitters to turn to more lucrative markets, mainly on open-work fabrics, braids, sashes, tattings, galloons, etc., the plainer nets being the largest market using mainly cotton with some silk.

At this stage, the twist lace frame was invented in 1802 by R. Brown to be followed by Heathcoat in 1808 and Leavers in 1813. Both the latter were concerned with developments in twist lace. This led to severe competition between "twist" and "warp" lace, a battle which has raged within the trade right up to the present, each taking its turn as the leader. The first effect of this battle was to cause the plain warp net to be driven out by the twist counterpart forcing the warp knitter to develop fancy effects and in 1831[19] warp knit production under the patronage of the Court became very large and many rotary frames were built, but depressed times again came in 1835 when twist lace producers developed fancy fabrics of similar type.

In 1839, Draper applied the jacquard to the warp lace frame, (individual guide control), for the production of elaborate designs in shawls, scarves, falls, laces, etc. which, together with mitts, gloves and gimps gave a fillip to the warp lace trade, but these in turn were superceded by their twist lace counterpart and the warp lace trade fell on hard times once more.

The severe competition from twist lace once again forced warp knitters to change their products and various patents were taken out around this time for such fabrics as elastic woollen cloth, hat bands, gloves, pile cloths, velvet and combinations of velvet and lace. One of the most interesting patents about this time was that taken out by Messrs. Whiteley & Co.[20] for the production of taffeta, which is today referred to as milanese and was subsequently improved by other patents in 1851 and 1854[21].

Circular milanese was also first produced around this time. Felkin attributes this to Messrs. Ball & Co. of Ilkeston, Notts. at the Paris Exhibition in 1855. It is most probable that latch needles were used in this machine.

Little is said in the literature available around this time of the gauge of warp knitting machines, whether rotary or hand warp frame, although Reisfeld[22] suggests 18 to 20 gauge, but fails to state whether this is needles per inch or per one and a half inches as is used on the hand frame. It is, however, reasonable to assume that fairly coarse gauge machines were used to accommodate the available yarns. Of particular interest from this point of view, is an invention by Dunnicliff and Dexter in 1845[23] for making "velvet pile ornamentation wrought in lace" using a number of guide bars some with individual spring guides controlled from a jacquard, and with independent pressers for each needle also controlled from a jacquard and at 28 needles per inch, which must have been a mechanical feat for that time.

Wilkomm refers to fine gauge machines at 40 gauge[24], but again does not state whether this means needles per inch or needles per one and a half inches.

The production of machinery then was obviously very pedestrian compared with modern standards, but nevertheless showed great advances on the original inventions as illustrated by the following extract from Felkin[25]:

"As a striking example of the progress of this class of machinery, it may be stated, that the average width of warp blonde machines was 54 inches in 1830, and the production 80 racks, or 50 square yards per week. But Messrs. Ball of Ilkeston and Nottingham placed in the Exhibition of 1851 a power warp machine, which if worked twelve hours per day would produce 800 racks, equal to 1200 square yards in a week, or 60,000 square yards in a year. A square yard of silk blonde sold in 1830 for 2s and in 1851 had become reduced to 6d.".

The latch needle was invented by M. Townsend of Leicester in 1847 and was not used in the hand warp frame, but was used in the rotary warp machine, but only to a small extent at first in circular and double rib machines[26 & 27].

Redgate, an Englishman, was the first to attempt the production of rotary rib work in 1855 using bearded needles, but this arrangement was obviously clumsy, requiring the use of two pressers and two sets of sinkers. The horizontal needles were lapped, drawing loops round the vertical needle as they withdrew to knock-over. The vertical needles then descended to knock-over. It is presumed, therefore, that this arrangement was soon superceded by a much simpler construction, the double rib loom, using latch needles, the two sets of needles placed back to back each rising in turn to be lapped. This machine was known as early as 1859[28] by various names, Fang Kettenstuhl Raschel Machine and Polker Machine in Germany, and as the Double Rib Loom in England.

The double needle bar Raschel machine thus described appears to have been little used. The only fabrics which were made were a few fancy constructions suitable for jackets and shawls the most popular of which was the Raschel equivalent of 1 x 1 weft knit, but this had the appearance of the weft knit polka rib and for this reason was named the Polka Rib Machine.

The lack of popularity of the Raschel machine seems to be borne out by the fact that both Willkom[29] and Merrill, Murden & Rowan[30] give a list of common warp knitted fabrics, but neither mention Raschel fabrics.

III. WARP KNITTED FABRICS 1870 - 1925

The common warp knitted fabric over the period 1870 to 1925 would appear to have been as follows:-

1. Single Bar Constructions

a). Plain Tricot (Plain Warp, Denbigh, or One and One)

1 x 1 Closed lap, produced in cotton, woollen and worsted for light linings, shawls and rugs, and for a base fabric for fancy constructions. (Fig.33a).

b). Plain Cord (Warp Cloth)

2 x 1 Closed lap, made in woollen yarn in medium gauges, (about 30), then dressed in the same way as a woven fabric, milled, dyed, stretched, teaseled, sheared, and pressed and used for gloves, gaiters and occasionally for coatings, suitings and trouserings. (Fig.33b).

c). Single Vandyke (Single Lap Loop, Single Guide Satin or Single Atlas)

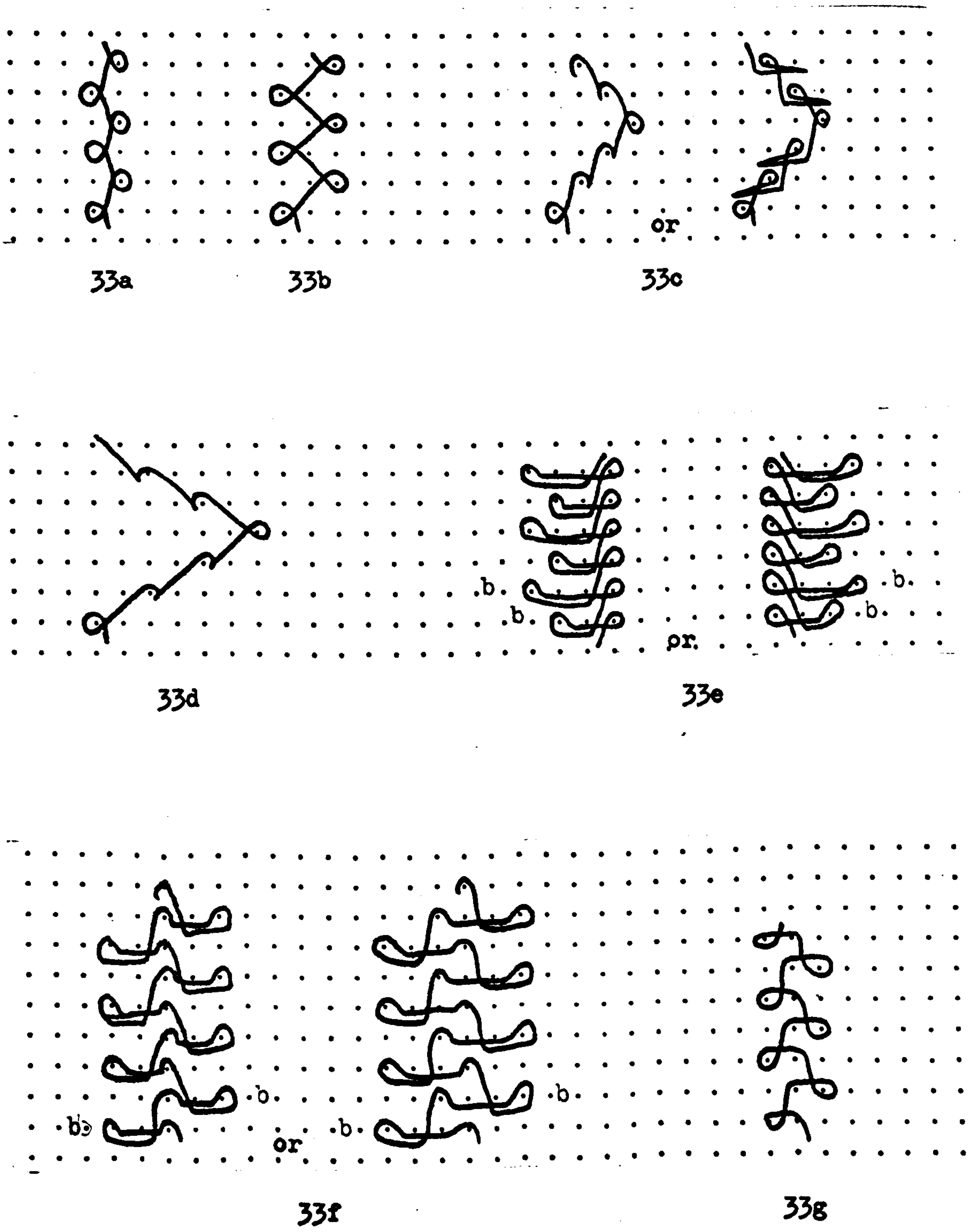
Single bar atlas open lap closed on the turn, generally made in silk or fine cotton for summer gloves. The most common constructions were 4, 8, 20, and 24 courses lapping in one direction before the lap was reversed. It was necessary to "put a cross in" to produce this fabric. The fabric was occasionally made in closed lap in which case "putting a cross in" was unnecessary. (Fig.33c).

d). New Milanese (Back Lap Warp Knit)

Single bar atlas open lap closed on the turn, lapping alternate needles. (Fig. 33d).

e). Diagonal English Leather (Stout Berlin)

Made generally of carded wool, but occasionally of cotton and used for riding breeches, heavy gloves and shoe linings. It



b = miss-press

Fig.33
Single Bar Constructions

was a thick fabric, soft in handle. The lapping movements were as shown with knock-off laps on alternate courses, (Fig. 33e). The fabric had a diagonal appearance as the knock-off lap was always made in the same direction, the direction of the diagonal depending on the position of the knock-off lap.

f). Straight English Leather (Stout Berlin)

This was the same as the previous fabric except that the knock-off laps were made alternately to the right and the left so that the fabric appeared straight and the knock-off laps were raised and stood erect in the fabric thus forming a pile surface. (Fig. 33f).

g). Double Cloth

A solid fabric made from soft yarns using a double needle overlap to obtain a thick material. The fabric was produced with minimum knock-over. It could also be manufactured with a half set threading, in which case the fabric was thinner and of an open nature. (Fig. 33g).

2. Two Bar Constructions

In the fabrics listed below the guide bars are called 'front bar' and 'back bar' as with a conventional machine using a vertically positioned needle bar. These fabrics were, however, generally made with a horizontally positioned needle bar in which case the front bar would be equivalent to the bottom guide bar and the back bar would be equivalent to the top guide bar.

a). Double Denbigh (Plain Tricot, Single Rib or Single Tricot)

Produced in silk or cotton and used for summer gloves.

Front bar 1 - 2 / 1 - 0

Back bar 1 - 0 / 1 - 2 (Fig. 34a).

b). Double Bar Cord (Doppel Tricot, Double Tricot)

Same yarns and use as double denbigh.

Front bar 1 - 0 / 2 - 3

Back bar 2 - 3 / 1 - 0 (Fig. 34b).

c). Back Lap Tricot

Front bar 1 - 0 / 2 - 3

Back bar 1 - 2 / 1 - 0 (Fig. 34c).

d). Woollen Velvet (Plush, Woollen Plush)

Front bar 4 - 5 / 1 - 0

Back bar 1 - 0 / 1 - 2 / 2 - 3 / 2 - 1

The front bar threads were made of wool and the back bar of cotton. The long wool underlaps of the bottom bar were cut with special knives in the finishing process and subsequently brushed to give a pile fabric and used for linings. The atlas movement was used on the back bar as it required the least "run-in", but the denbigh stitch was sometimes used. The fabric was made in all wool when used as the main material in a garment and could be ornamented by different coloured warps or part set threadings to give stripe effects. (Fig. 34d.)

e). Double Vandyke (Diamond Fabric)

This fabric was made from silk or cotton and used as a glove

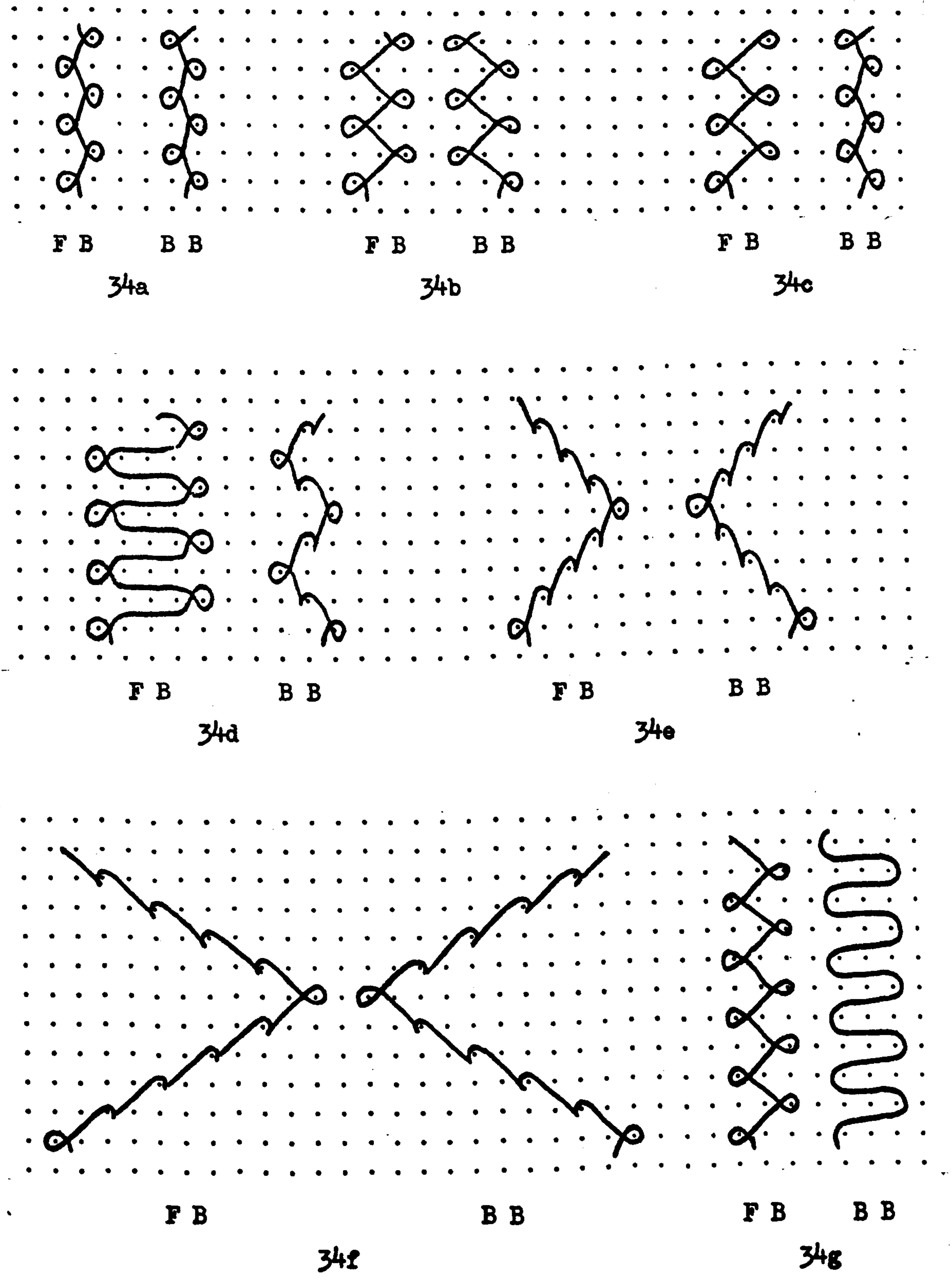


Fig. 34
Two bar constructions

cloth. It was made with two guide bars full set threaded producing normal atlas movements. If the traverse of the bars was only for a small number of courses before the return, it was often referred to as Satin Tricot. Willkom[24] refers to the use of fine gauge machines for this fabric, and states that 24 courses is the maximum traverse used, i.e. 48 courses per complete repeat. (Fig.34e).

f). Double Milanese

MADE FROM two bars which produced atlas movements working in opposition lapping on alternate needles often for 24 courses and then returning. (Fig.34f).

g). Lined Cloth (Cloth with Lining or Lining Cloth)

This was produced with two guide bars, one making a 2 x 1 closed lap and the other laying-in over three needles moving with the knitting bar.

The laid-in threads lay on the technical back of the fabric and were subsequently brushed in finishing to give a soft fibrous pile; the fabric was sometimes used to produce garments but more often for a lining, particularly for gloves. A number of variations of the structures were made as follows:-

Name	Front Bar (Ground Yarn)	Back Bar (Pile Yarn)
Cotton Lining (Cotton with lining)	Hard cotton	Soft cotton
Double Cloth (Camlet)	Wool	Wool
Lined Cloth	Wool	Cotton
Plush Lining	Cotton	Wool

(Fig.34g).

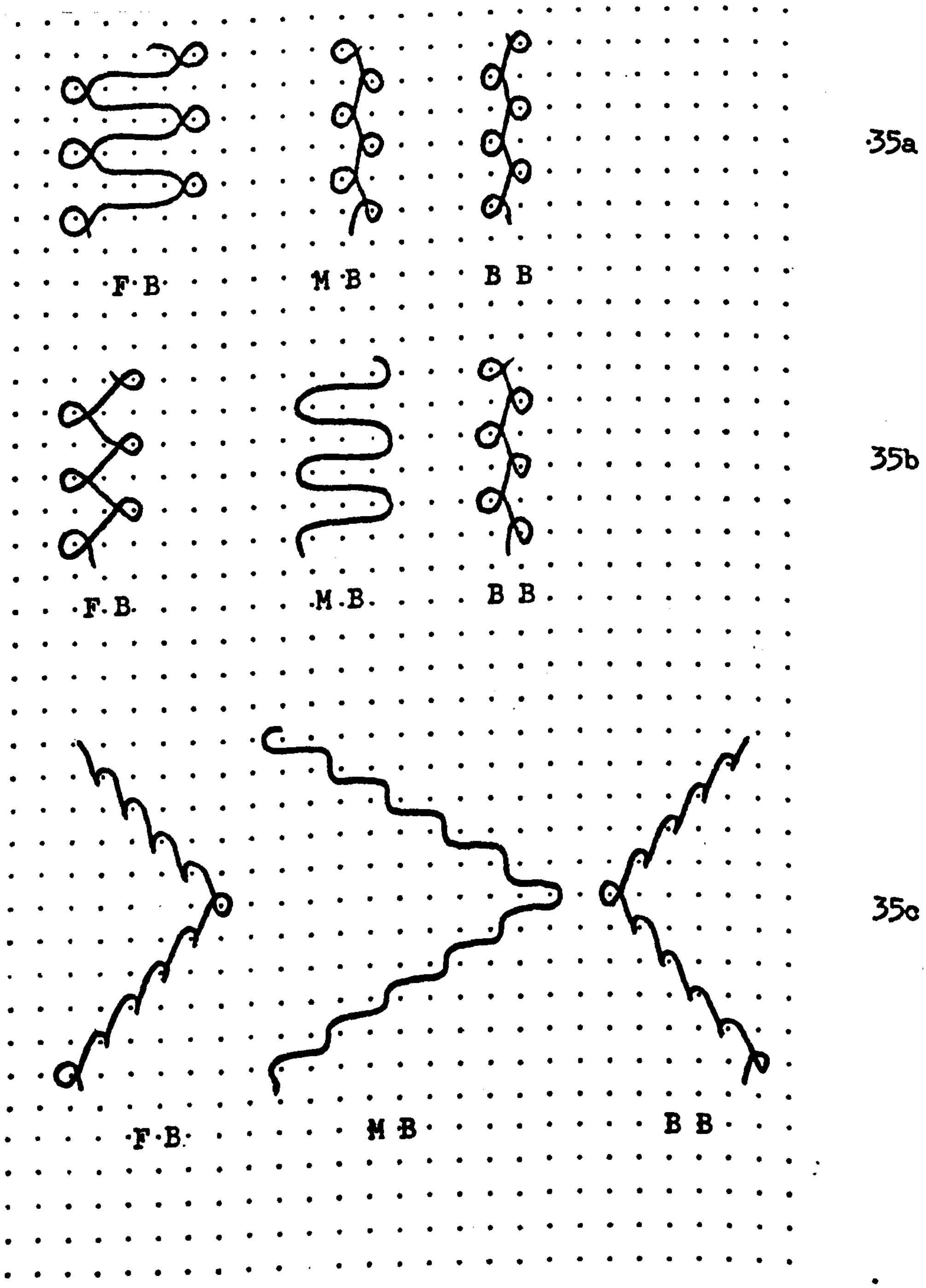


Fig. 35

Three bar constructions

3. Three Bar Constructions

a). Plush

Woollen three bar construction produced by the front bar making a 4 x 1 closed lap and the remaining two bars making 1 x 1 in opposition. The wool pile was cut and brushed and the ground, in general, was cotton. (Fig.35a).

Silk Velvet (Silk Plush) was a variation using the same lapping movements as plush, but the front bar used silk yarn. It was not generally used as a fabric but in strips for trimmings.

b). Lined Single Rib (Lined Tricot)

Front bar 2 x 1

Middle bar laying-in over three needles moving with front bar.

Back bar 1 x 1 in opposition to the front bar.

Generally made of cotton, silk or a combination of both materials and raised during finishing. The fabric was used for the production of garments, the pile normally being used inside. The back bar sometimes made an atlas movement. (Fig.35b).

c). Lined Satin (Lined Atlas)

The front and back bars moved in an atlas manner, the middle bar laying-in and moving with the front bar over two needles. (Fig.35c).

Willkom continues to list other fabrics produced on warp knitting machines. These are fancy fabrics and jacquard constructions produced by guide deflection. The only group of fabrics in these of interest from the point of view of wool is cut presser work[31,32,33].

A presser with a serated pressing edge is used in conjunction with a part set threaded guide bar and only those needles which are lapped are pressed giving characteristic work referred to in the latter part of the nineteenth century as imitation crochet. On early machines, the presser was traversed by a direct connection with the guide bar, a connecting lever having one needle play to allow for the overlap. It is not known at what time this type of fabric was introduced, but it was an established type at the time Willkom wrote his book and was produced mainly in wool and cotton as an ornate fabric being used for dresses, jumpers, shawls, baby blankets, etc.

From the period of about 1870 to the outbreak of the First World War (1914), the warp knitting trade appeared to be small but viable, wool being one of the main fibres used and the constructions were as outlined above. However, possibly the main section of the trade was that of glove manufacture for which cotton and silk were extensively used. Various constructions were made from plain denbigh, atlas and milanese to thick 'duplex' constructions made by pasting two atlas cotton fabrics together with their technical faces outermost and then finishing the fabric to give an imitation chamois leather or suede appearance. Also very fancy jacquard constructions were made including elbow length dance gloves.

IV. WARP KNIT & RASCHEL MACHINERY 1914 - 1925

During this time, steady development was made in the warp knitting field both in machine construction and in fabric development. Worthy of note is the invention of the Simplex machine in 1915 by E. E. Preston of Leicester[34]. This was a fine gauge double needle bar machine using bearded needles with two guide bars. It produced a double faced fabric for glove manufacture causing the duplex construction to become obsolete. The machine's mechanical construction was the bearded needle equivalent of the Raschel machine in that each needle bar rose, lapped and fell, to knit alternately, thus having a different knitting action to earlier bearded needle rib machines. Machines of this type are still in use for the manufacture of glove fabrics.

It is difficult to trace the development of the Raschel machine around this time, but the omission of reference to it in publications of the period indicates that it was used only to a small extent and it would appear that this was for fancy coarse gauge work which could not be done on bearded needle machines, for example such fabrics as fall-plate, crepe, double needle bar and speciality work on jacquards. The machine was often fitted with a fringing motion[35].

After the First World War, the warp knitting trade continued in its steady state of development. Great effort was placed in the production of glove fabrics[36 & 37]. The production of other fabrics remained much as described previously. The most common machine gauges were 12 to 18 needles per inch[38]. The use of bearded needles mounted vertically in a moveable needle bar was now becoming common and these were known as Atlas looms or fast warp frames. Sinkers were fitted to Raschel machines when producing single needle bar work[39].

Quilter and Chamberlain[40] give the following as a list of machinery available at this time -

Bearded Needle Machines

Flat looms - plain type machines with provision for knock-off laps, horizontal fixed needle bar and sometimes referred to as the chain loom.

Fast looms - vertically mounted moving needle bar

Milanese

Double warp machines - for the production of warp lace fabrics.

Double bar warp machines - Simplex

Latch Needle Machines

Sinker looms - single vertical needle bar with sinkers.

Double rib loom or Raschel loom - two needle bars, creping mechanism, fringing apparatus.

Special machines - jacquard looms, picker looms, (presumably weft insertion), plush looms, and small diameter circular machines for the production of gas mantles and neck ties.

V. INTRODUCTION OF CONTINUOUS FILAMENT YARN

In 1921 the first commercial batch of continuous filament acetate was produced[41] for the warp knitting trade and was an immediate success. This was to be the most significant development of the decade. Continuous filament materials and the warp knit structures' inherent resistance to laddering gave an excellent combination for the greater expansion of this means of fabric production. Continuous filament materials are smooth and will, therefore, run on warp knitting machines without the accumulation of lint and at a low fault rate. The material can be spun fine yet sufficiently strong to withstand knitting strains and moreover, at economical prices, thus enabling the production of a new range of light-weight fabrics, and allowing two, three and four bar fabrics to develop which otherwise would be too heavy and expensive for general use. Fine yarns and lighter fabrics soon led to the use of finer gauges and 28 needles per inch became standard. The widths of machines also became established at 84 inches and wide width machines were introduced. Various widths were used but the standard wider machine was 168 inches.

Under these new conditions, the warp knitting tricot trade developed at a considerable rate, locknit being the main fabric produced. The majority of the machines were two bar machines and speeds of production developed from 200 c.p.m. in 1924 to 510 c.p.m. in 1939. A number of 3 and 4 bar machines were also used, but these were small in comparison to the number of 2 bar machines. (Considerable mechanical development was made in machine construction[42] but mainly in the interests of speed and efficiency rather than in new fabric structures[43].)

The use of fine gauges and higher speeds had a disastrous effect on the use of wool and fibrous yarns in general as they were unsuitable for fine gauge work in that they could not be spun fine enough or at an economical price, and the fault rate when using such yarns was high. Wool, therefore, assumed a minority role and was used for speciality fabrics both in coarse gauge Raschel and tricot, mainly in ladies wearing apparel for outerwear, dresses, blouses, jumpers, etc.

The Second World War caused a temporary halt in warp knitting development, but afterwards manufacturers tackled the future with renewed vigour. Two significant developments were introduced; first the increase in knitting speeds to twice that of the pre-war level and second, the use of thermo plastic yarns, nylon and Terylene[44 & 45].

VI. HIGH SPEED KNITTING

In 1945 F.N.F. Ltd. of Burton-on-Trent, England[46] introduced to the trade a new machine which doubled the speed of knitting maintaining a cruising speed of 1,000 c.p.m. This machine embodied a number of new features and paved the way for the development of tricot and Raschel machines to the high speed precision instruments as we know them today. The new features were -

(i) The use of a compound needle

(ii) The use of eccentrics as a means of driving the knitting elements.

(iii) The use of a positive warp let-off motion

(iv) Improved machine design to achieve static and dynamic balance

(v) The use of better engineering techniques to achieve more accurate movement at higher speeds with less wear, etc.

The compound needle was not new, but represented an improvement on existing types. The true origin of the compound needle is somewhat obscure. Some attribute it to Lembeke and Gottlebe[47], but Willkom[48] states that an attempt was made in Germany in 1858 to use a pipe needle, (the drawings of which show this to be virtually the same as a compound needle), and he comments - "This needle is exactly the same as one formerly made in Leicester by Jeacock, and known as Jeacock's needle".

However, the use of the compound needle in the F.N.F. machine was the first practical industrial use of this type of needle.

VII. MODERN MACHINES AND FABRICS

Around 1950, nylon and later polyester, became available to the warp knitting trade for commercial use and this gave the trade its final boost to enter markets which had not been previously available to the warp knitter. This set off a chain re-action with machine builders to develop machines suitable for these new end markets.

The main property which makes nylon so suitable is its thermoplasticity enabling structures to be made which would not be stable in themselves but which can be set to the required dimensions by passage through a stenter during the finishing operations, sometimes with the addition of a resin, (Raschel laces). A second important property of nylon is that it is a strong yarn so that finer yarns and fabrics may be produced. The spinning limit of acetate for example in yarns intended for warp knitting is 55 denier while 20 and 30 denier nylon are used in considerable quantities.

The main use of warp knitted fabrics is in lingerie followed by shirting fabrics. Other large markets are dress materials, linings, glove fabrics, blouses, working smocks, bed sheets, etc.

Raschel fabrics show their biggest potential in laces and nets for curtaining, dress nets and edgings, and for the production of elastomeric constructions for foundation garments and swimwear. Other uses are fishnet stockings, vegetable bags, shoe linings, wearing apparel, dress fabric, costumes, etc. References to modern fabrics and machine mechanisms may be found in Paling[49].

Although the use of nylon and polyester have without doubt been responsible for the growth of the warp knitting trade, this expansion could not have taken place without a parallel development of warp knitting machinery and, although the F.N.F. machine set the standards and made the initial move, the majority of growth subsequently has come from German machine builders.

In the early 1950s, two bar bearded needle machines were introduced with a commercial knitting speed of 1,000 c.p.m. by K. Mayer of Germany and from this firm followed a formidable development in warp knitting equipment; high speed 3 and 4 bar tricot machines soon followed with special mechanisms for tulle nets[50]. In 1956 the first true Raschel lace machine was made using twelve guide bars. In 1963 warp knitting machines were introduced with 12 bars and Raschel lace machines with 30, the latter being increased to 42 by 1968. Other significant machinery developments include high speed Raschel machines for power net[51], plain nets and outerwear, general purpose Raschel for outerwear and industrial fabrics, fish-net Raschel, carpet Raschel, double needle bar Raschels and machines for pile fabric production. This is not a complete list, but it may be summarised by saying that tricot machinery has developed into a high speed unit, generally of 28 gauge and of varying widths up to 260 inches. Two bar machines are the most common, but large numbers of three and four bar machines are used. The majority of machines in industry today are bearded needle machines and although the initial development OF THE COMPOUND NEEDLE MACHINE was by F.N.F. Ltd., the Company went out of business in 1965. A new compound needle machine was introduced at the Basle Textile Machinery Exhibition in 1967 and a number of these have been installed within the industry. It is too early at this time to judge how this machine will compare with its bearded needle counterpart, but it looks most promising.

Since the early 1950s, the Raschel machine has shown the greatest development in its history. The main reason for this is that instead of building multi-purpose machines as was the early tendency with this type of equipment, machine builders have concentrated on building a Raschel machine for a specific purpose to develop fabrics for a particular end use.

From the point of view of wool, the development of this machinery is of little consequence as 95% is concerned with continuous filament materials for reasons outlined above.

Wool is still used to a small extent for ladies' apparel, dresses, skirts, costumes, etc. and can be knitted on a commercial basis at relatively low speeds[52], (up to 200 to 300 c.p.m.), and on relatively coarse gauge machines, (up to 16 needles per inch). Although production would appear to be low in terms of courses, production in terms of linear yards per hour is commercially acceptable as the courses per inch used in the fabric are relatively low.

From the foregoing, therefore, it may be concluded that at the beginning of the warp knitting trade, wool was in great demand as a raw material for this type of knitting. It is obvious that the quantities used rose and fell with fluctuation in trade and fashion requirements. However, it held its place as a major fibre used until the introduction of continuous filament materials when, as with all natural fibres, its consumption fell. Today, in general, only fabrics having a special effect or aesthetic appeal which cannot be obtained in another manner, are produced. These then stand in their own right as a fabric and have little competition from other fabrics produced. They have, however, only a small market as they tend to be speciality fabrics fluctuating with fashion demands and made in relatively small quantities. Examples are knop and shell fabrics made on cut presser machines, various forms of laid-in fabrics produced on Raschel machines, Raschel fall-plate fabrics and some carpets[53 & 54].

CHAPTER III

PREVIOUS WORK ON THE PHYSICAL AND GEOMETRICAL PROPERTIES OF KNITTED FABRICS

I. INTRODUCTION

All knitted fabrics change in dimensions on leaving the knitting machine. In the past, it has generally been considered that the factors affecting the change in dimensions are many and include the following -

Yarn:	Yarn count, type, single or twofold, twist and fibre content.
Machine:	Type of machine, type of needle, stitch length, setting of sinkers, needles and other knitting elements and the timing of the various motions.
Type of fabric:	Weft knitted, warp knitted, plain, rib, interlock, double jersey, etc.
Relaxation:	The way in which the fabric has been relaxed after knitting.
Finishing:	The various dyeing, finishing and drying treatments given during the finishing operation.

It is evident that some of the above factors have a major influence on fabric shrinkage and others have a very marginal effect. It is only by systematic study that the importance of the various parameters can be ascertained.

Types of Shrinkage

The actual shrinkage which takes place in a fabric can be divided into three categories, -

a). Relaxation Shrinkage - that shrinkage which takes place after knitting and during subsequent processing, either dry or wet and is caused by the fabric recovering from the strains imposed during knitting.

b). Consolidation shrinkage - that shrinkage which takes place after relaxation shrinkage, often during further wet processing, particularly in fabrics other than wool.

c). Felting shrinkage - that shrinkage which is peculiar to wool fabrics and caused by the special properties of the wool fibres.

Generally, relaxation shrinkage is large, consolidation shrinkage is small and both shrinkages take place up to the finished fabric stage. In the case of a fabric which is being fulled, the fabric is made to felt, when some additional felting shrinkage will occur.

If a fabric is produced in which a large amount of relaxation shrinkage is still dormant, and the garment is made from the fabric, then on the first wash the fabric will shrink, rendering the garment useless. Similarly, if a fabric is set to dimensions greater than its truly relaxed dimensions and that set is temporary, then the fabric will again shrink if this set is released on washing, also giving an unserviceable garment. It is, therefore, essential that if a fabric with satisfactory stable dimensions is to be produced, it should be finished to conditions close to its fully relaxed dimensions or it must be effectively set in its distorted state. The object of fabric geometry is to predict accurately the dimensions of a piece of fabric in its fully relaxed condition.

II. GEOMETRY OF PLAIN STITCH WEFT KNITTED FABRICS

1. Experimental Findings

Work on fabric geometry was first undertaken on weft knitted structures and more work has been done in this field than in warp knitting.

Possibly the first account of the systematic study of the dimensions of a knitted fabric were recorded by Tompkins[55] in 1914 in his book "The Science of Knitting". He states that the product of w.p.i. and c.p.i. is a constant irrespective of the distortion of the fabric. He also found that for a plain fabric and a rib fabric the linear dimensions were dependent on yarn diameter.

At that time, the trade apparently controlled fabric production in one of two ways, either by controlling the number of courses per inch on the machine or, by controlling stitches per foot of yarn. Chamberlain[56] states that "the former was more popular in Britain, but the latter method is a more accurate means of quality control." Thus, at this point in time, the concept of stitch length as a parameter of the fabric structure was appreciated, but the effect of this parameter on the fabric dimensions was not understood. It is also of interest to note that the Nottingham & District Technical College taught as basic knitting technology that an important factor in the reproduction of fabrics was stitches per foot of yarn and all students unroved fabrics for this purpose and made the corresponding stitch cam settings during practical classes.

In 1944, Dutton[57] published his results from a large amount of experimental data in which an attempt was made to relate the dimensional changes observed in knitted fabrics with the knitting and production conditions. He concluded that the regularity and quality of plain weft knitted fabrics were dependent upon many factors, e.g. machine type and speed, temperature and humidity of storage and knitting room, type of yarn, type of yarn package, etc. This work also showed that relaxation shrinkage and felting shrinkage were critically dependent on knitting conditions.

The first significant step which was taken in the concept of modern fabric geometry was that by Doyle[58] who was the first to observe that the area dimensions of knitted fabrics were solely dependent on the length of yarn knitted into the stitch, (ℓ), in a relationship of the form -

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

where S is the number of loops per square inch or stitch density.

He proposed, therefore, that stitch length was the most accurate means of controlling knitting quality since, unlike measurements of a linear nature, i.e. c.p.i. and w.p.i., it is not affected by fabric strains, (~~stretch~~).

Although it was known that the stitch length was a major parameter controlling fabric quality, this work can still be considered a major step forward as it gave a relationship between ℓ

and S and formed a scientific foundation for the study of knitted geometry and a more fundamental understanding of the structure. It was also a major step forward in that it made possible the wider appreciation of the importance of ℓ within the trade.

In 1959 Munden[59] emphasised the points made by Doyle and further he showed, that when the fabric was relaxed and was free from the strains imposed during its construction, the loop took up a unique shape independent of the yarn, count, knitting conditions or knitting construction (stitch length), such that the dimensional properties were related in the following manner -

$$S \times \ell^2 = \text{constant } (k_s)$$
$$\text{c.p.i.} \times \ell = \text{constant } (k_c)$$
$$\text{w.p.i.} \times \ell = \text{constant } (k_w)$$
$$\frac{\text{c.p.i.}}{\text{w.p.i.}} = \frac{k_c}{k_w} = \text{constant } (k_r)$$

Munden pointed out that the value of the constants varies according to the relaxation state of the fabrics and increases as the fabric becomes more relaxed. He investigated two relaxed states as follows -

Dry relaxed - fabrics measured after standing for several weeks in a dry state.

Wet relaxed - fabrics immersed in water for at least two/three hours, often overnight, and then laid flat on a suitable surface and allowed to dry, all measurements being taken when the fabric is dry.

It was considered at this time that the wet relaxed condition represented the completely relaxed state. The k values obtained were as follows -

	Dry relaxed	Wet relaxed
k_s	19.0	21.6
k_c	5.0	5.3
k_w	3.8	4.1
k_r	1.3	1.3

In a further paper[60], Munden went on to show that the shrinkage which did take place was not associated with yarn shrinkage, but solely with a change in the configuration of the yarn in the loop. In fact, it was shown that with light washing procedures fabric shrinkage of up to 30% could be obtained where the yarn shrinkage was less than 2%.

To summarise at this stage, it is convenient to quote Natkanski[61] who, on talking of the constants, (k_s, k_c, k_w, k_r), states, "These formulae can be considered as the basic laws of knitted structures in that they indicate the dimensions which any plain knitted structure tends to 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 which governs the dimensions of the knitted fabric and that is the length of yarn knitted in the stitch.

These experimental relationships have been accepted by subsequent researchers in this field and used as basic principles for further investigations."

In 1968 Knapton, Ahrens, Ingenthron and Fong[62] produced a significant piece of work which stated that the wet relaxed condition does not give the fully relaxed state of the fabric, and it is necessary to tumble dry the material after wet relaxation in order to achieve a fully relaxed state. This in itself is important, but a more interesting statement claimed that the product of loop length and c.p.i. or w.p.i., and ℓ^2 and stitch density, are not a constant in the dry relaxed state or the wet relaxed state, but only when the fabric is truly relaxed, i.e. after tumble drying.

2. Loop Models

Many attempts have been made in recent years to construct loop models in order to explain the practical results already outlined above in order to obtain a more thorough understanding of the factors affecting fabric dimensions.

The first of these attempts was made by Chamberlain[63] who proposed a loop model to give maximum cover by suggesting that the needle loops touch at the sides and the sinker loops touch the needle loops at the top and the bottom to give maximum cover. From this model, Chamberlain was able to show that the following relationships should apply -

$$\frac{1}{\text{w.p.i.}} = 4d \qquad \text{(where d = yarn diameter)}$$

$$\frac{1}{\text{c.p.i.}} = \frac{\sqrt{3}}{2\ \text{w.p.i.}}$$

$$\ell = \frac{3w + 2\sqrt{13}}{4.\text{w.p.i.}}$$

$$\frac{\text{c.p.i.}}{\text{w.p.i.}} = \frac{2}{\sqrt{3}} = 1.15$$

Remarking on the accuracy of his model, Chamberlain concluded - "In practice, however, there are so many other factors involved that the results obtained theoretically do not agree with those obtained practically......."

One limitation of Chamberlain's model was that he considered a two dimensional model only. Pierce[64] made a generalisation of Chamberlain's model and extended this to a three dimensional arrangement by bending the loops over a cylinder running in a course-wise direction and by suggesting alterations in the loop length due to yarn diameter by adding straight sections in the loop. As a result of this analysis, he showed that a formula linking courses, wales and loop length on the plain knitted stitch could be derived as follows -

$$\ell = \frac{2}{\text{c.p.i.}} + \frac{1}{\text{w.p.i.}} + 5.94d$$

In 1955 Shinn[65] considered a two dimensional model basically similar to that of Chamberlain's. Also in that year, Leaf and Glaskin[66] criticised Pierce's model on the ground that it was physically unrealistic suggesting discontinuities in curvature at points in the structure where no external forces were acting. They proposed a model which did not include these physical limitations, but the model was found to give results which did not agree accurately with the practical results already established.

Further models of the plain loop of varying degrees of complexity have been proposed at various times by Leaf[67], Munden[68], Munden and Postle[69], etc.

III. GEOMETRY OF WEFT KNITTED CONSTRUCTIONS OTHER THAN PLAIN

Similar work on the dimensional and geometrical properties of other constructions has been attempted, although these other structures have not been investigated to the same degree. This work has concentrated on dry relaxed, wet relaxed and, more recently, tumble dry conditions obtaining various k values and investigating the effects of stitch length ratio and yarn count. This work includes 1 x 1 ribbed studies by Smirfitt[70] and Natkanski[61], interlock by Hurt[71] and various double jersey constructions by Knapton[72].

Very limited work has been done on the models of the loop configuration of these more complicated structures.

IV. FELTING

Untreated wool fabrics felt when washed and many workers have investigated the felting properties of weft knitted structures[73,74,75]. The important feature which determines the felting rate of the fabric is the tightness of the structure which may be conveniently described algebraically by the formula $\frac{\sqrt{\text{Tex}}}{\ell}$ or $\frac{1}{\ell\sqrt{N}}$ (where N equals the indirect count).

It has been shown that for an extreme range of tightness of any knitted construction, the k_s values after dry, wet and tumble dry relaxation, are independent of the fabric tightness. However, if felting of the fabric occurs, the k_s value of the fabric after any washing treatment is critically affected by the tightness[73]. (To obtain this value for k_s, the c.p.i. and w.p.i. of the fabric are as measured after the washing treatment, the value of ℓ is as measured when knitted into the stitch.)

It has been suggested[74] that the k_s value measured in this way is an accurate manner of expressing the degree of felting of any piece of fabric knitted from wool, as it has been established that shrinkage which takes place to bring the fabric to its fully relaxed condition is attributed to loop configuration changes until a k_s value of 23.6 is obtained. True felting shrinkage is, however, associated with actual yarn shrinkage. Thus if the k_s value is calculated using a value corrected for yarn shrinkage, the k_s value will remain constant, (somewhere between 23 and 24), at its fully relaxed value giving no indication of the magnitude of the felting.

V. WARP KNITTED CONSTRUCTIONS

Although a considerable amount of work has been undertaken in the investigation of the geometry of warp knitted structures, it is by no means as large as that in the weft knitting sector of the industry. The reasons for this may be attributed to the fact that warp knitted fabrics are not as extendible as weft knitted constructions and therefore do not suffer from variations in dimensions to the same extent. In addition, the following features of warp knitting and warp knitted fabrics reduce the magnitude of fabric dimensional changes.

1. Fabrics are generally constructed from thermoplastic yarns and heat set during the finishing process.
2. Continuous filament yarns are generally used which suffer less from relaxation shrinkage than fibrous yarns.
3. Stitch length has always been the controlling parameter of fabric properties.

4. Positive feed has been used for many years.

The first written research appears to be that by Stimmel[76,77] who investigated the effect of structural variables, run-in, run-in ratio and courses per inch on fabric dimensions in order to predict the properties of locknit fabric.

He produced a range of locknit fabrics from 55/14 denier acetate yarns knitted at various run-ins, run-in ratios and courses per inch on the machine. He then measured the c.p.i. and w.p.i. off the machine in the grey state together with the bursting strength and yield, plotting this data graphically and drawing a number of conclusions which were not related to any theory and which were, generally speaking, accepted knowledge within the trade. However, his work was a valuable contribution as it drew conclusions from experimental data rather than repeating trade know-how and it drew attention to the importance of runner ratio, as Stimmel pointed out that there is an optimum distribution between back and front bar run-in when each underlap will take equal strain and so give maximum bursting strength.

The next published work was that by Fletcher and Roberts[78] who also investigated the locknit structure by producing 97 fabrics of various deniers of acetate and viscose. These fabrics were studied in the grey state and also scoured, being set on a pin stenter. In an attempt to discover the relationship between stitch length and fabric parameters, they found that an equation similar to that derived by Pierce[64] for weft knitted fabrics could be used by varying it according to yarn type. The expressions obtained were -

$$\ell = 4c + 3.5w + 11.75d \text{ for acetate}$$

$$\ell = 4c + 3.5w + 13.52d \text{ for viscose}$$

where ℓ is the total stitch length (back bar plus front bar) c = course spacing, w = wale spacing and d = diameter of the yarn.

They pointed out that in addition, the numerical factor by which d is multiplied, (namely, 11.75d for acetate and 13.52d for viscose), increased with increase in runner ratio if the front bar stitch length was considered separately and decreased with increase in runner ratio if the back bar stitch length was considered separately. However, if the sum of the stitch length of both bars was considered, then the coefficient of d was a constant. They also demonstrated that the fabric changed considerably in dimensions during laundering unless previously relaxed to remove knitting strains. They noted too that the changes which did occur were a geometrical re-arrangement of the yarn within the loop and that yarn shrinkage was no more than 2%. They also established that the average $\frac{c}{w}$ values were 0.854 for viscose and 0.7555 for acetate. The data for relaxed and laundered fabrics was not given in the paper.

The next published work was that by Allison[79] who constructed a loop model by splitting the loop configuration into four basic parts, an underlap, two arms and a semi-circle and showed that the stitch length was the addition of the components as follows -

$$\ell = \sqrt{c^2 + n^2w^2} + d \quad + \quad 2(1.025\sqrt{d^2 + c^2}) \quad + \pi 2d$$

underlap arms of loop head of loop

where ℓ = stitch length, c = course spacing, w = wale spacing, d = yarn diameter and n = needles traversed on the underlap.

This model did not take into consideration the three dimensional shape of the loop, nor did it make any attempt to differentiate between the length of yarn in the back bar and the front bar. It applied only to the machine state fabric.

Grosberg[80] was next to publish a loop model and in this case, he pointed out that the front bar yarn is more prominent on the front and on the back of the fabric so would use more yarn than the back bar. Secondly, he considered the underlap and loop separately, classifying the underlap as a straight line in the dry state, but as an arc of a circle after relaxation, and the loop as an elastica, (constant relationship between the length of yarn in the loop and the loop height, L = 2.543b where b = the loop height). The formulae given are -

Machine state fabric

Front bar $\ell_f = \sqrt{c^2 + n_f^2 w^2} + 2.543c + 7.12d$

Back bar $\ell_b = \sqrt{c^2 + n_b^2 w^2} + 2.543c + 4.683d$

underlap loop factor for plating yarn thickness etc.

Relaxed fabric

Front bar $\ell_f = 1.29\sqrt{c^2 + n_f^2 w^2} + 2.543c + 7.12d$

Back bar $\ell_b = 1.29\sqrt{c^2 + n_b^2 w^2} + 2.543c + 4.683d$

where ℓ_f is the loop length of the front bar, ℓ_b = loop length of the back bar, c = course spacing, w = wale spacing and n =

number of needle spaces moved on the underlap.

Grosberg found that his formulae held true for the total run-in, i.e. back bar plus front bar, but the individual values of back bar and front bar stitch length were often inaccurate. Also, if the calculation was reversed to obtain values of c.p.i. and w.p.i., these were also inaccurate.

In their second paper, Fletcher and Roberts[81], in 1961 extended their work to include cotton and to investigate the effect of twist. They used Allison's formula for the finished fabric and Grosberg's formula for the relaxed fabrics and reported good correlation between the experimental and calculated values of stitch length in each case. They also applied Munden's equation for the stitch density of weft knitted fabrics, viz :

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

where S = stitch density, ℓ = stitch length and k = a constant dependent on the actual configuration of the loop and applicable to a wide range of fabrics with constant runner ratio.

They also found that $\frac{c}{w} = 0.91$ for a wide range of fabrics which is at variance with their previous work.

Smirfitt's work[82] performed the detailed study of the effect of run-in ratio of the back and front bars on fabric dimensional properties and undertook emperical corrections to Grosberg's formula stating that corrections were required for -

1. Variation in plating
2. Inclination of loops to the vertical
3. Curvature of the underlap.

Later work by Grosberg[83] divided two bar full set warp knit structures into two classes -

(a) Semi stable - e.g. locknit, three needle satin, etc.
Those structures which are relatively elastic and change in dimensional properties on relaxation.

(b) Stable constructions - e.g. sharkskin, queenscord, etc.
Those fabrics which are rigid and exhibit little change in dimensions on relaxation.

He improved his original study by taking into consideration loop inclination, the curved underlap and the three dimensional form of the loop. Grosberg's final formula was as follows -

$$\frac{\ell}{w} = K\frac{d}{w}\left\{-3.057 + 2.857\sqrt{1.145 + 2.856\left[1 + \left(\frac{c}{w}\right)^2\left(\frac{w}{d}\right)^2\right]}\right\} +$$

$$A\left\{\left(\left(n + \frac{d}{w}(2.802 - 0.749)\sqrt{1.145 + 2.856\left(1 + \left(\frac{c}{w}\right)^2\left(\frac{w}{d}\right)^2\right)}\right)\right)^2 + \left(\frac{c}{w}\right)^2\right\}^{\frac{1}{2}}$$

where c = course spacing, w = wale spacing, ℓ = loop length, d = diameter of yarn, n = number of needle spaces moved on the underlap, k = a factor for the bending of the loops out of fabric plane and interlacing with other loops, a = constant for curvature of underlap having a value of 1 for the machine state fabric in which the underlap is straight and varies in relaxed fabrics with $\frac{c}{w}$.

Grosberg c~~alculated~~ PROVIDED FOR the values of $\frac{\ell}{w}$ ~~coul~~d to be ~~found~~ DETERMINED graphically. This proved useful for machine state fabrics where the value of w is given by the needle spacing. To use these graphs to predict the dimensions of the fabric in the relaxed state, a number of assumptions are necessary, the validity of which are of considerable doubt.

Tiryaki[84] progressed on Grosberg's work by investigating the dimensions of two bar full set fabrics in their relaxed states deriving a method of determining the relationship between loop length and the physical dimensions, in which he assumed that a fabric was relaxed when the loops touched. This gave a further condition to Grosberg's work and resulted in the following equation -

$$\ell = 4.08kc \sec \theta + A \left\{ \left((n + 2)d + (n - 1)\ 1.07c \sec \theta \right)^2 + c^2 \right\}^{\frac{1}{2}}$$

$$\frac{\ell}{c} = 4.08k \sec \theta + A \left\{ \left((n + 2)\frac{d}{c} + (n - 1)\ 1.07c \sec \theta \right)^2 + 1 \right\}^{\frac{1}{2}}$$

On plotting graphs $\frac{\ell}{c}$, $\frac{\ell}{w}$ and $\frac{\ell^2}{cw}$ against $\frac{\ell}{d}$, Tiryaki observed that for a wide range of $\frac{\ell}{d}$ values, constants were obtained as follows -

(a) $\frac{\ell}{c}$ was a constant kc and equal to 5.7

(b) $\frac{\ell}{w}$ was a constant kw and equal to 4.3

(c) $\frac{\ell^2}{cw}$ was a constant ks and equal to 24.6

These values were checked with a large range of stable and semi-stable constructions made from 40 denier nylon on a 28 gauge machine. He found that for the semi-stable structures good agreement was obtained with the theoretical values if the ℓ value used was that of the bar which made the shortest movement.

Further work showed that the best run-in ratio to obtain maximum stability and strength when yarns from both bars took equal strain was locknit 1.24 and 3 needle satin 1.57.

Tiryaki further investigated stable constructions and found that the linear dimensions of the fabric were not in agreement with the theory due to the inability of the cloths to relax fully under any normal relaxation treatment. However, the area dimensions were found to be predictable from the stitch length but the following relationships obtained experimentally.

Machine state

Full tricot $S = \frac{18.7}{\ell^2_f}$ or $\frac{18.7}{\ell^2_b}$ (using whichever value is the shortest)

Reverse locknit $S = \frac{19.3}{\ell^2_f}$

Locknit $S = \frac{19.1}{\ell^2_b}$

3 needle satin $S = \frac{18.7}{\ell^2_b}$

After relaxation

Full tricot $S = \frac{24.6}{\ell^2_f}$ or $\frac{24.6}{\ell^2_b}$ (using whichever value is the shortest)

Reverse locknit $S = \frac{24.3}{\ell^2_f}$

Locknit $S = \frac{26.8}{\ell^2_b}$

3 needle satin $S = \frac{24.2}{\ell^2_b}$

Shinn and El-Aref[85] investigated a series of two bar full set fabrics including tricot, locknit and satin in order to derive a formula to predict the run-in of two bar fabrics for a given c.p.i. and w.p.i. The suggested formula for lapping movements with an underlap is -

$$\ell = \sqrt{10d^2 + c^2} + \sqrt{18d^2 + c^2} + \sqrt{c^2 + (nw - 2d)^2} + 2.5\pi d$$

and that for the chain stitch is -

$$\ell = \sqrt{10d^2 + c^2} + \sqrt{18d^2 + c^2} + \sqrt{4d^2 + c^2} + 2.5\pi d$$

Good correlation between the experimental results and those predicted by the formulae was reported.

Darlington[86] investigated the validity of Tiryaki's work when extended to a wide range of fabrics produced from wool using a larger range of run-in ratios and a number of different structures, namely, tricot, locknit, reverse locknit, sharkskin and queenscord. He gave a formula for the length of yarn in the chain stitch as follows -

$$\ell = 4.08k_{\ell} \sec \theta + Ac$$

He also investigated different states of relaxation and found difficulty in obtaining stable constructions in a fully relaxed condition.

This work showed that good correlation with Tiryaki's results existed only when the run-in ratio values were similar to those investigated by Tiryaki.

Darlington also showed that -

(i) The run-in ratio varied with courses per inch in the fabric, thus giving a direct relationship between k_s value and the runner ratio.

(ii) The dimensions of the fabric were not determined by the shortest lapping movement, but by the lapping movement which had been run-in tighter than that required for both yarns to take equal strain to give maximum bursting strength.

(iii) The value obtained for yarn diameter varies according to the method of measurement and the actual diameter of yarn varies according to the space available in the fabric. He concludes, "These results suggest that no fixed value can be given to the diameter of a wool yarn; the actual diameter of the yarn in the fabric being critically dependent upon the fabric structure and also upon the relaxed condition of the fabric. This fact has not been taken into account in previous work on the geometry of warp knitted fabrics, all of which have assumed a fixed value for yarn diameter."

CHAPTER IV

DETAILS OF MACHINE USED FOR EXPERIMENTAL WORK AND INITIAL INVESTIGATION INTO EFFECTS OF MACHINE VARIABLES ON THE DIMENSIONAL PROPERTIES OF THE FABRIC

I. CHOICE OF MACHINE

It is generally accepted in the warp knitting industry that a Raschel machine is more versatile than a tricot machine for the knitting of fibrous yarns and since this thesis is concerned with the knitting of wool, a Raschel machine was chosen for the production of the samples.

The type of Raschel machine used was the Karl Mayer RML.6, (Photograph 2). This is a bench top model, ideal for research and sample work as it operates from small warps produced by hand. The warps are made on 6 inch diameter by 6 inch wide spools on a special hand warper, (Photograph 1), the spools being mounted onto a common spindle or beam for placing in the machine.

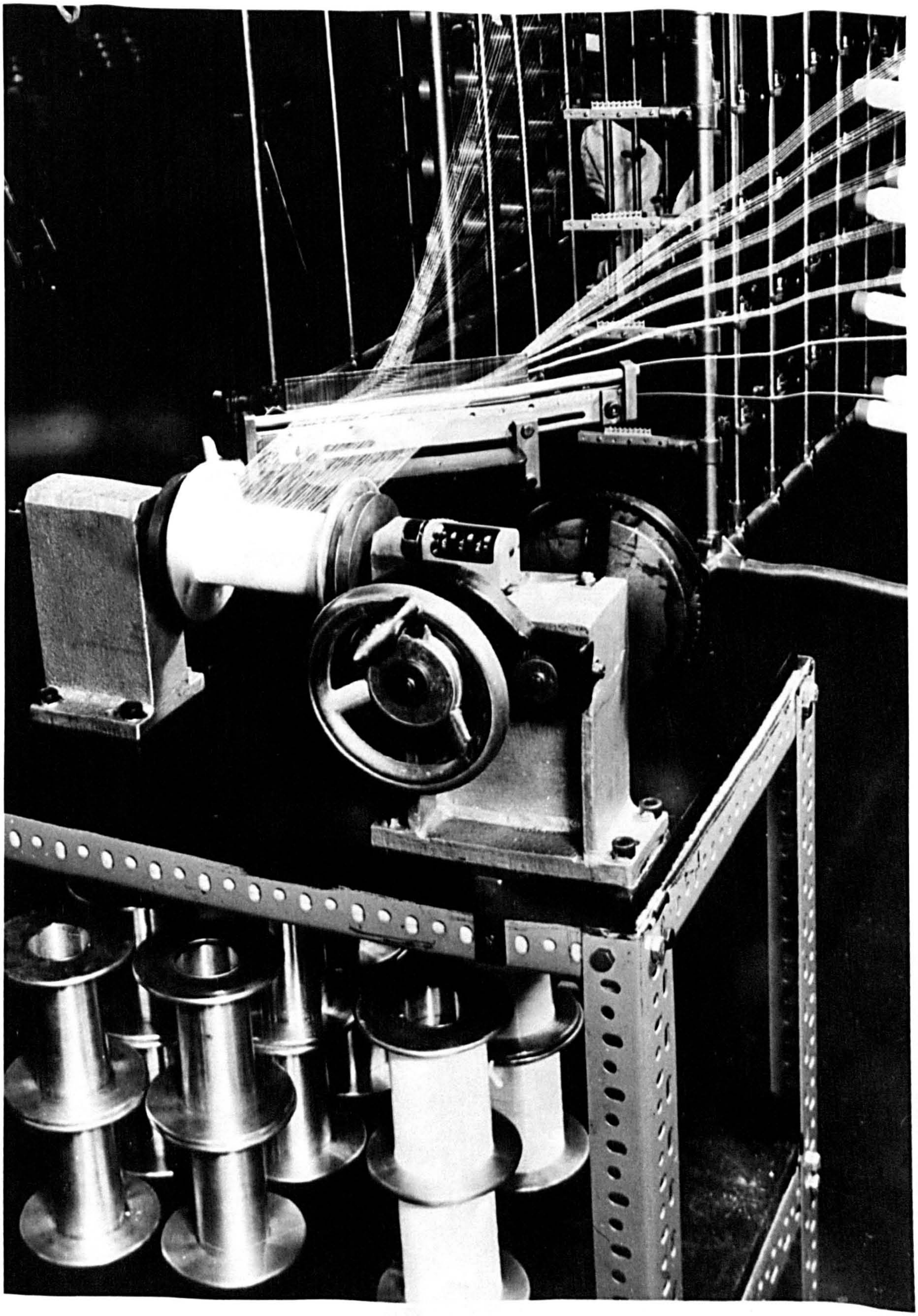
Thus the experiment can be decided upon, the warps made and placed on the machine in a matter of hours rather than weeks as would be experienced on a full sized machine. Furthermore, small samples can be produced from small lots of yarn which would be impracticable on full size equipment.

II. MACHINE DETAILS

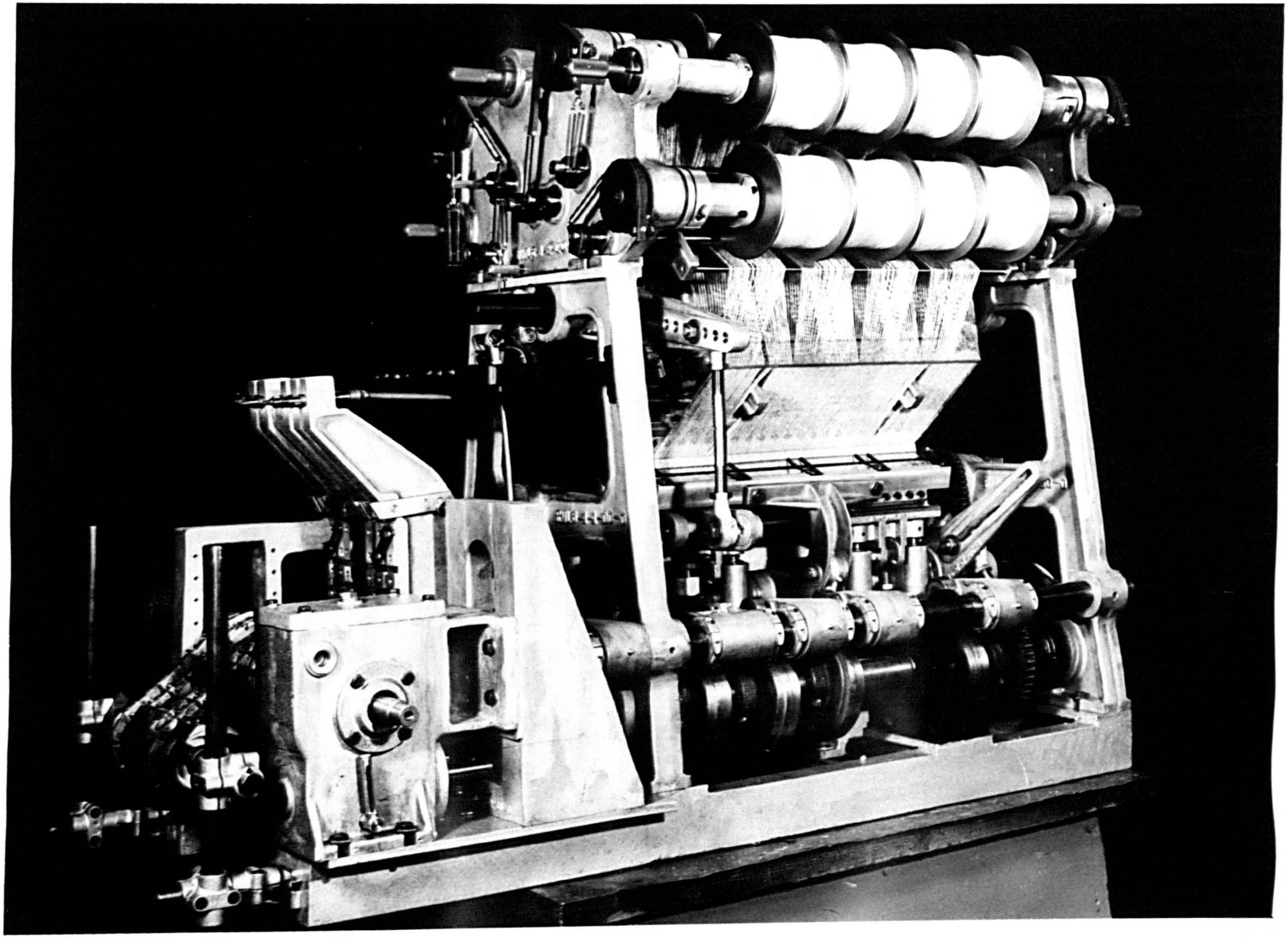
1. Gauge

32 gauge (16 needles per inch)

2. Number of Guide Bars ... six



Photograph 1



Photograph 2

3. Knitting Action

This is basically similar to that described in the introduction, the timing diagrams being illustrated in Fig.36. The only difference is that on the RML 6 machine, the needle bar is given a horizontal movement in exact opposition to the guide bars, (derived from the guide bar cam), to reduce guide bar swing, so diminishing machine vibration and easing tension control.

4. Cams

This machine is intended for the production of a variety of fancy fabrics and is, therefore, equipped to take one of three different sets of cams -

(i) To knit on two bars

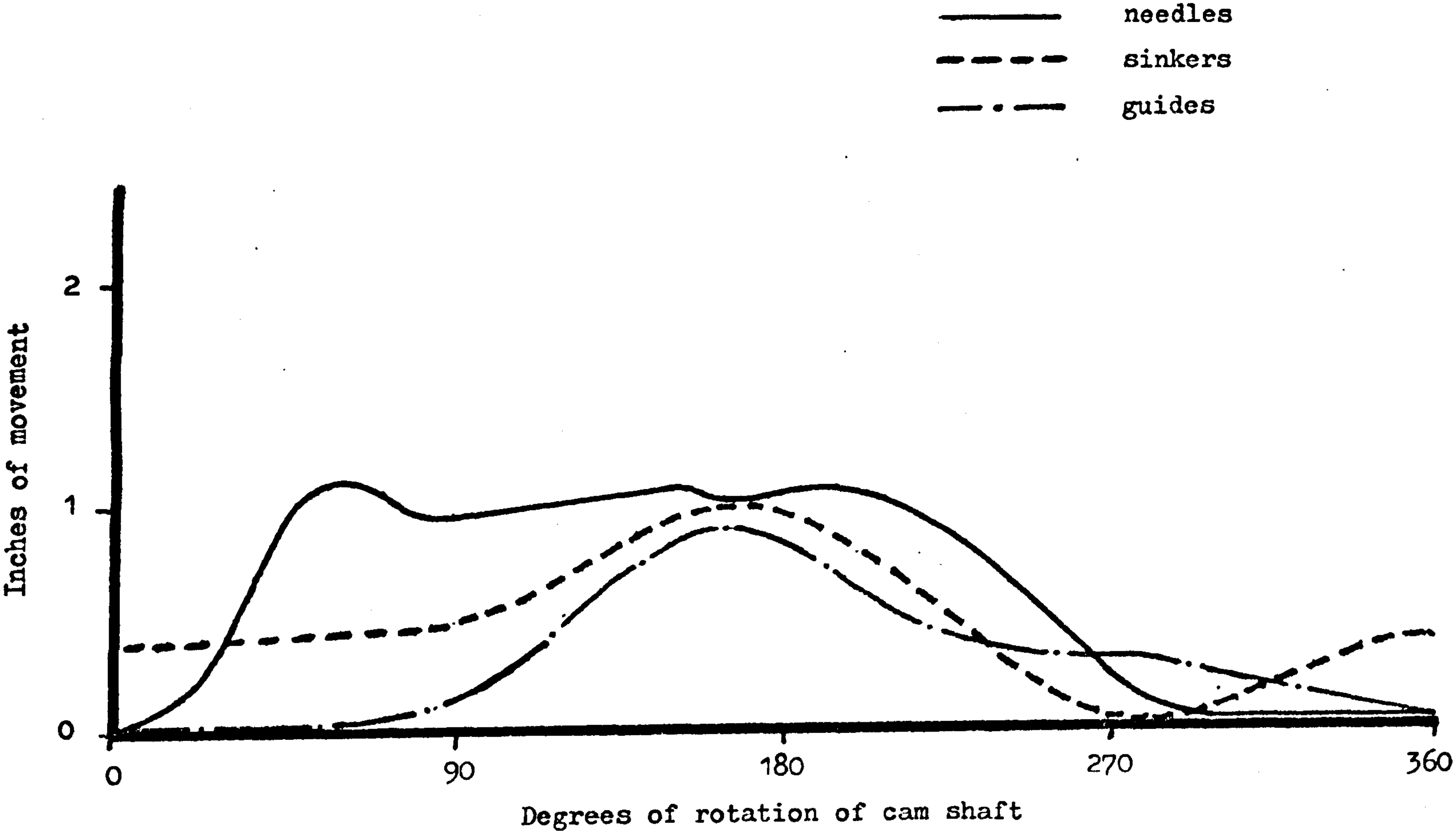
(ii) To knit on four bars

(iii) For use when using the fall-plate mechanism.

The difference between these cams is concerned with the needle bar vertical movement and the relative movement with the guide bars in a horizontal direction, (swing), the latter is the same for cams (i) and (ii) above, the difference being concerned solely with descent of needles. In the first instance (i), the needles descend as the second guide bar is level with the needles on the return swing so that it is only possible to knit on the first two guide bars, the remainder being used to lay-in. The second set of cams (ii), allows the needle to descend when the fourth guide bar is level on the return swing and it is, therefore, possible to knit on the first four guide bars. As it is also possible to lay-in on

Fig. 36

Displacement Graph of Knitting Elements - Raschel Machine Type RML 6



these bars, this arrangement is the more versatile. The third set of cams (iii) allows all bars to perform the return swing before the needles descend, but also the guide bars dwell on returning to the front of the machine while the fall-plate is lowered. These cams are, in the main, suitable for fall-plate work only.

The cams chosen were, therefore, those which enable knitting on four bars, as they offer greatest scope should the work require it, or should the machine be needed for more complex work at a later date. Furthermore, this type of camming is the easiest to set for knitting as the tolerances between guide bar and needle bar movement are greatest.

5. Pattern Drum Mechanism

The pattern drum mechanism used on this machine is of the lever type illustrated in Fig.37. The principle involved is that the pattern drum itself operates on a lever fulcrummed at its lower end to the top of which is attached the guide bar push rod. The point at which the pattern drum links bear upon the lever is dependent on the gauge of the machine.

The advantages of this kind of mechanism are that the same type and gauge of link can be used on all gauge machines, and the gauge of the machine may be changed if required for the cost of a new inside, (needles, guides and sinkers), a nominal cost compared to that of a completely new machine.

6. The Fabric Take Up Motion

The fabric is removed from the needles by a set of three take-up

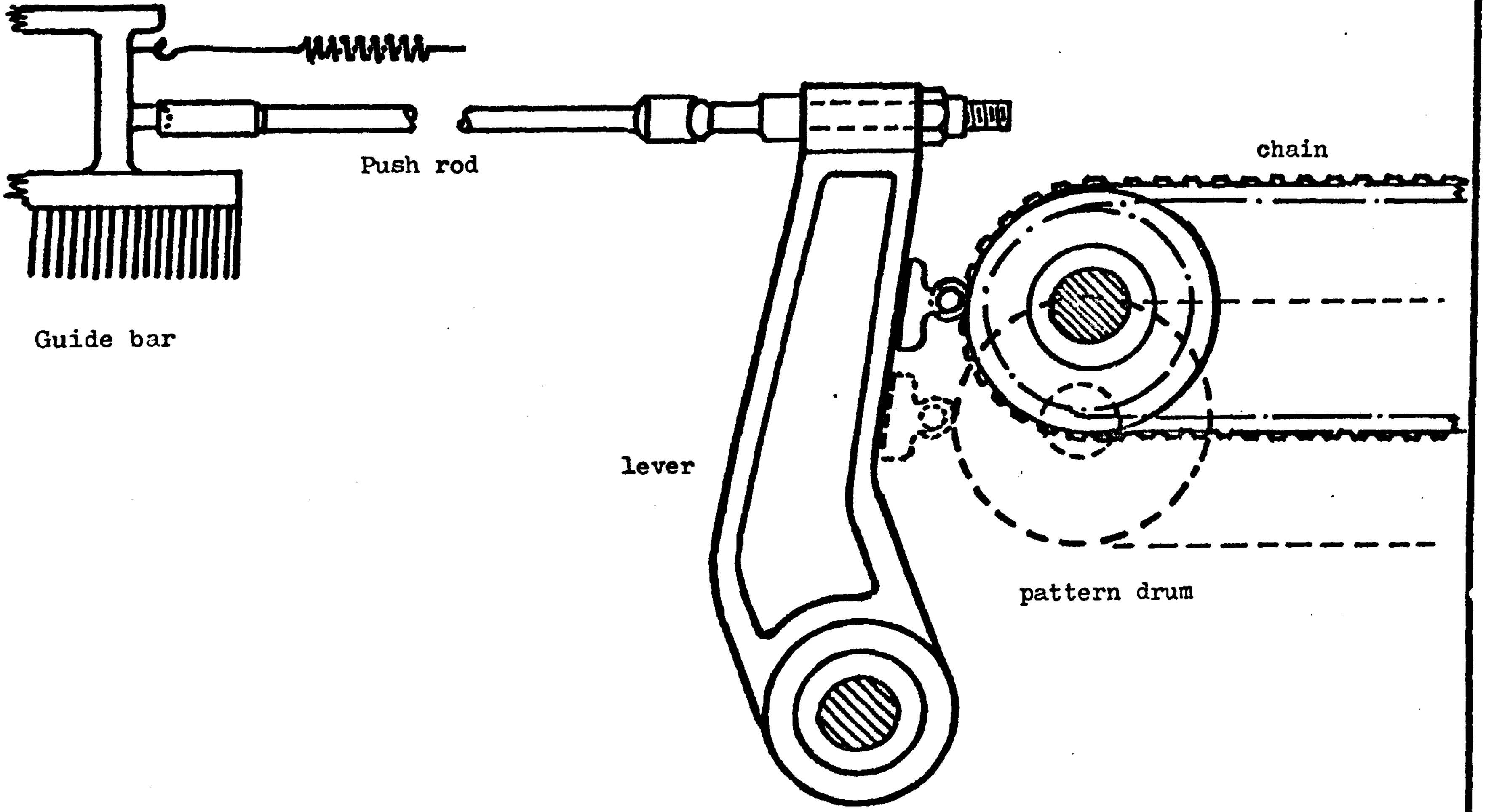


Fig. 37 Pattern Drum Mechanism

rollers situated as close to the knitting point as practicable, Fig.38. One roller (a) is driven by means of a ratchet from the main cam shaft of the machine via an eccentric. The second roller (b) is driven from (a) at the same surface speed by means of a chain connecting the two rollers. The third roller (c) is driven by frictional contact with the fabric, the tighter the fabric is pulled, the tighter the grip provided by this roller.

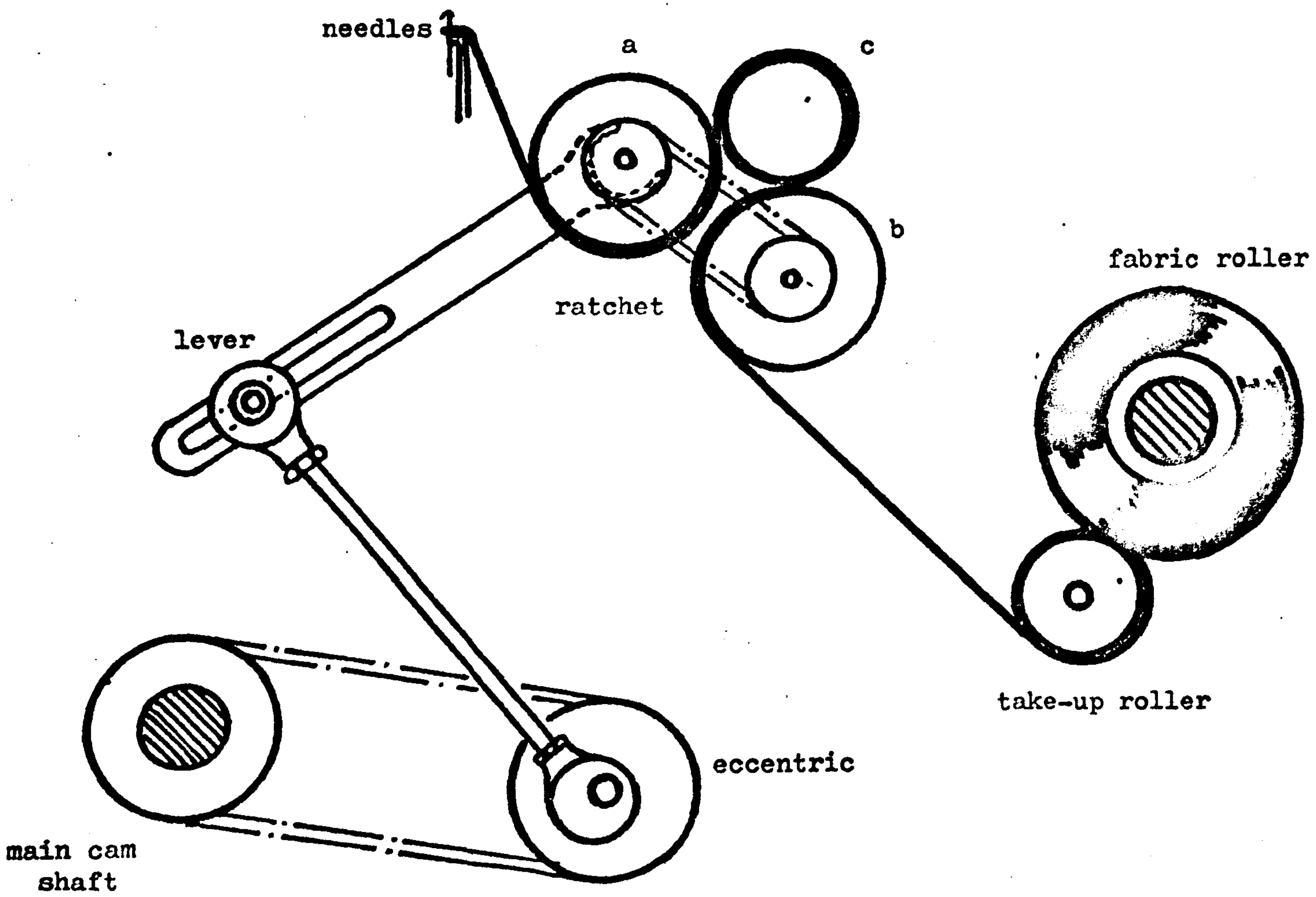
The take-up motion on a warp knitting machine governs the courses per inch in the fabric on the machine. The method of changing the c.p.i. on the machine under discussion is by means of the stroke of the ratchet lever driven from the eccentric. Two eccentrics were used which, in conjunction with the leverage available, gave a range of 10 to 40 courses per inch.

The take-up motion thus described does differ somewhat from that employed on a full size machine in that the take-up rollers are driven direct from the main cam shaft via a gear box, this gearing being changed to alter the courses per inch in the fabric when on the machine.

7. Warp Let-off Mechanism

This consists of two essential parts, (a) the yarn take-up section which was a spring loaded bar oscillating up and down against the spring tension to take up cyclic variations in yarn length during the formation of each course due to the swing of the guide bars and the rise and fall of the needles, and (b) the warp control mechanism which holds the warp firm until yarn is required

Fig. 38 Fabric Take-up Mechanism



when it allows the needles to pull the required amount of yarn forward.

This latter part consists simply of a brake constructed of a "v" belt mounted in the groove of a "v" pulley positioned on the end of the beam bearing. This "v" belt is anchored at one end and tensioned by means of a spring at the other. (Fig. 39).

The mode of operation is as follows:- As the machine runs, the tension bar moves up and down accommodating cyclic variations in warp tension until the tension reaches a peak at which point the tension rail is depressed further than usual and a casting mounted on the end of the tension rail raises the "v" belt, thus releasing the braking force on the beam and allowing the yarn to be pulled forward by the knitting elements. As soon as yarn is delivered, the tension is obviously reduced, allowing the tension rail to rise, so re-applying the brake. Generally speaking, if correctly set, this type of let-off motion will allow yarn to be taken once per course when tension is at its highest, i.e. at the overlap.

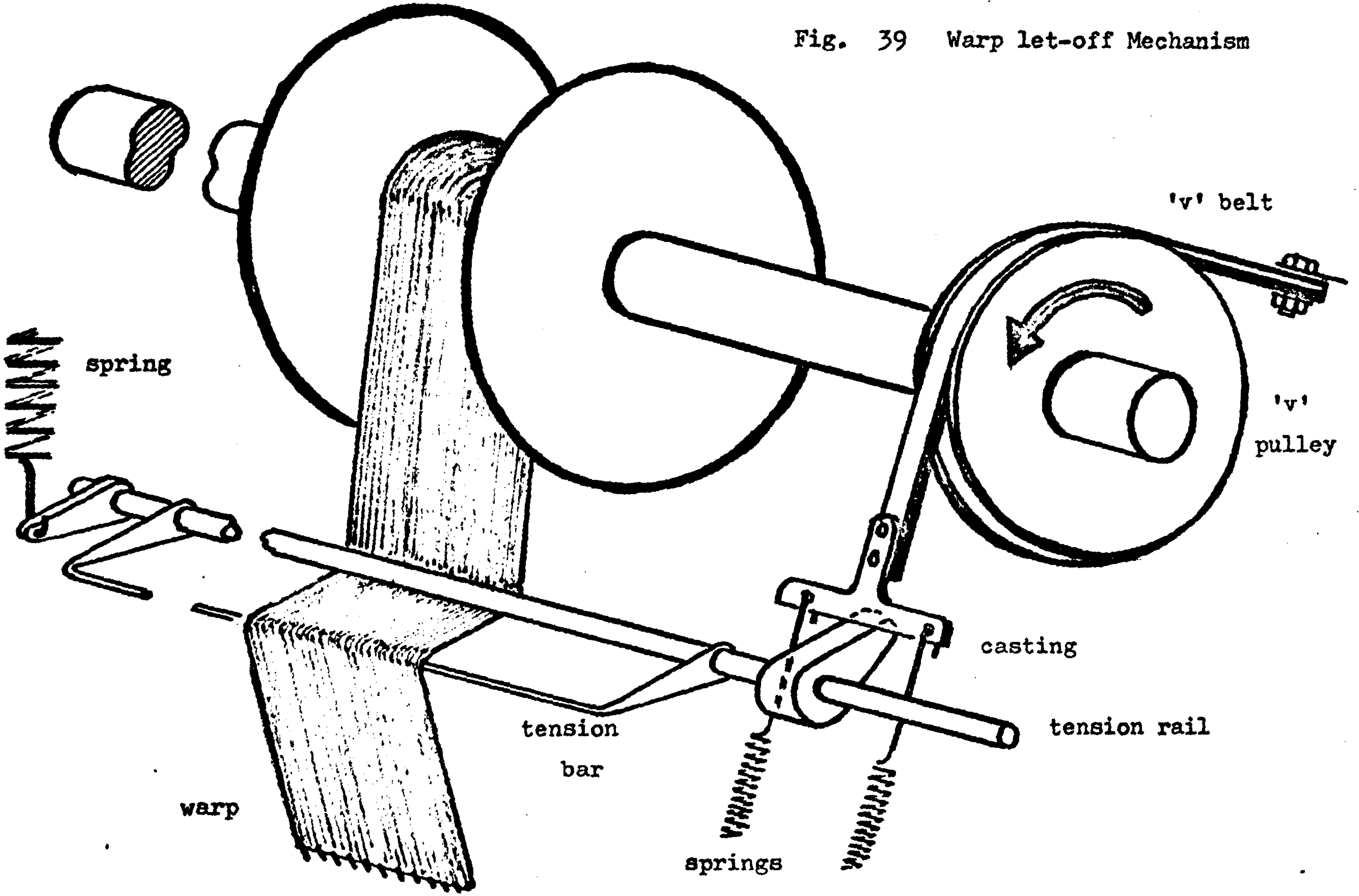
III. STITCH LENGTH CONTROL

A preliminary glance at the knitting action will suggest that only three things can affect the stitch length on a Raschel machine. (1) the fabric tension, (2) the knock over setting, (3) the warp tension.

1. The Fabric Tension

The fabric take-up mechanism on a Raschel machine is generally a positive direct drive from the main cam shaft with change gears

Fig. 39 Warp let-off Mechanism



to alter the courses per inch. The fabric is taken away at $\frac{1}{\text{c.p.i.}}$ inches per course.

N.B. There must be no slippage between fabric and roller otherwise uniformity of fabric cannot be guaranteed.

The fabric will be under constant tension and stretch so that this movement, although continually occurring in the fabric, will take place at the knitting point as each loop is formed as the needles rise from knocking over.

2. The Knock Over Setting

It may be considered that the depth to which the needle descends below the top of the trick plate, (knock over setting), will influence the length of the stitch. This, however, is not so because the yarn is "live" during loop formation, one end of yarn passing direct to the tension rail. As the needles rise from the knocking over position, yarn is pulled back out of the loop by the tension rail until equilibrium is reached with the take-up tension.

3. The Warp Tension

For any given setting of the take-up rollers, it is possible to produce fabrics under a variety of warp tensions. If the warp tension, however, is set "too slack" there will be a tendency for the fabric to rise with the needles and for the ascending needle to rise through the old fabric loop. If the warp tension is set too high, yarn breakage will occur. Also, the fabric loop will be too tight, sticking on the latch as the needles rise. Under these two extreme conditions, it is impossible to knit, but between these two points a limited variety of stitch lengths may be produced.

IV. QUALITY CONTROL

It is generally accepted within the warp knitting trade that the ultimate dimensions of the fabric are determined by the stitch length, the courses per inch on the machine being of secondary importance. The stitch length is controlled by keeping the machine knitting at a constant "run-in". This run-in is defined as the amount of yarn knitted in one rack, i.e. 480 courses. The length of fabric is measured on the machine in the grey state in racks.

Thus, if a piece of fabric requires 48 c.p.i. finished, the length of fabric to be knitted on the machine for 100 yards is $\frac{48 \times 36 \times 100}{480} = 360$ racks. The courses per inch in the grey state is not considered, and the stitch length required to obtain these finished courses is obtained from past records, or in the case of a new fabric, industrial "know how", or trial and error. Some firms consider, that owing to the fabric's distorted condition, a grey fabric has no physical dimensions other than weight.

V. PRELIMINARY EXPERIMENT TO DETERMINE EFFECT OF MACHINE VARIABLES ON FABRIC DIMENSIONS

During preliminary running of the machine, it was noticed that if excessive tension was placed on the warp let-off motion, it appeared to hold the take-up rollers back, and it was thought that this may adversely affect the results unless its effect was completely understood. Consequently, it was decided to run a preliminary experiment to ascertain if in fact the rollers were being held back and if so, what effect this had on the resultant fabrics.

In order to determine the effect of the various mechanisms on the fabric properties, it was decided to produce fabrics at five settings of the take-up rollers, (nominally five c.p.i. on the machine), and at each setting to use three different warp tensions, slack, medium and tight.

To ascertain if the take-up roller was in fact being held back by the warp, the machine was set so that it was knitting with the minimum tension which when tested with the M.A.N.R.A. tensometer proved to be 9 grams per end. The c.p.i. on the machine was 24. The run-in per rack was 94.6 inches.

A free piece of yarn was then placed round the rollers and the surface speed of the rollers obtained by measuring the length of yarn moved by the rollers. This was found to be 20" per rack.

The tension was then increased to its maximum, (25 grams), without altering the setting of the take-up roller and it was found that the run-in was reduced to 84.5 inches per rack, the surface speed of the take-up rollers was reduced to 17 inches per rack and the c.p.i. measured on the machine was 28.

The c.p.i. on the machine was dependent on the let-off motion. The ratchet drive on the take-up rollers proved to be negative if the warp tension was high, its effectiveness as a drive being subject to the balance between warp tension and fabric tension.

Thus it is not possible to perform experiments isolating the effect of either warp tension or fabric take-up.
TO PERFORM THIS EXPERIMENT 1x1 CLOSED LAP FABRICS WERE FROM WOOL YARNS

The fabrics were now relaxed by wet relaxation and tumble drying, the dry relaxed state being ignored as it is known that fabrics in this condition are distorted.

The results obtained in the tumble dry state are shown in Table 1 and graphs in Figs. 40 and 41.

It will be observed that for all practical purposes the results fall on a straight line according to stitch length and do not group themselves according to warp tension or take-up roller setting.

These results indicate that :-

(a) The fabric properties and dimensions are only determined by the stitch length, as has been established for weft knitting.

(b) The fabric take-up setting does not affect the final fabric dimensions, only the ease of knitting.

(c) Warp tension does not affect the final fabric dimensions unless it changes the stitch length.

(d) The RML 6 table top model machine is perfectly adequate to perform scientific investigations. Although the ratchet take-up motion is not truly positive, it does not affect the fabric dimensional properties in the relaxed state.

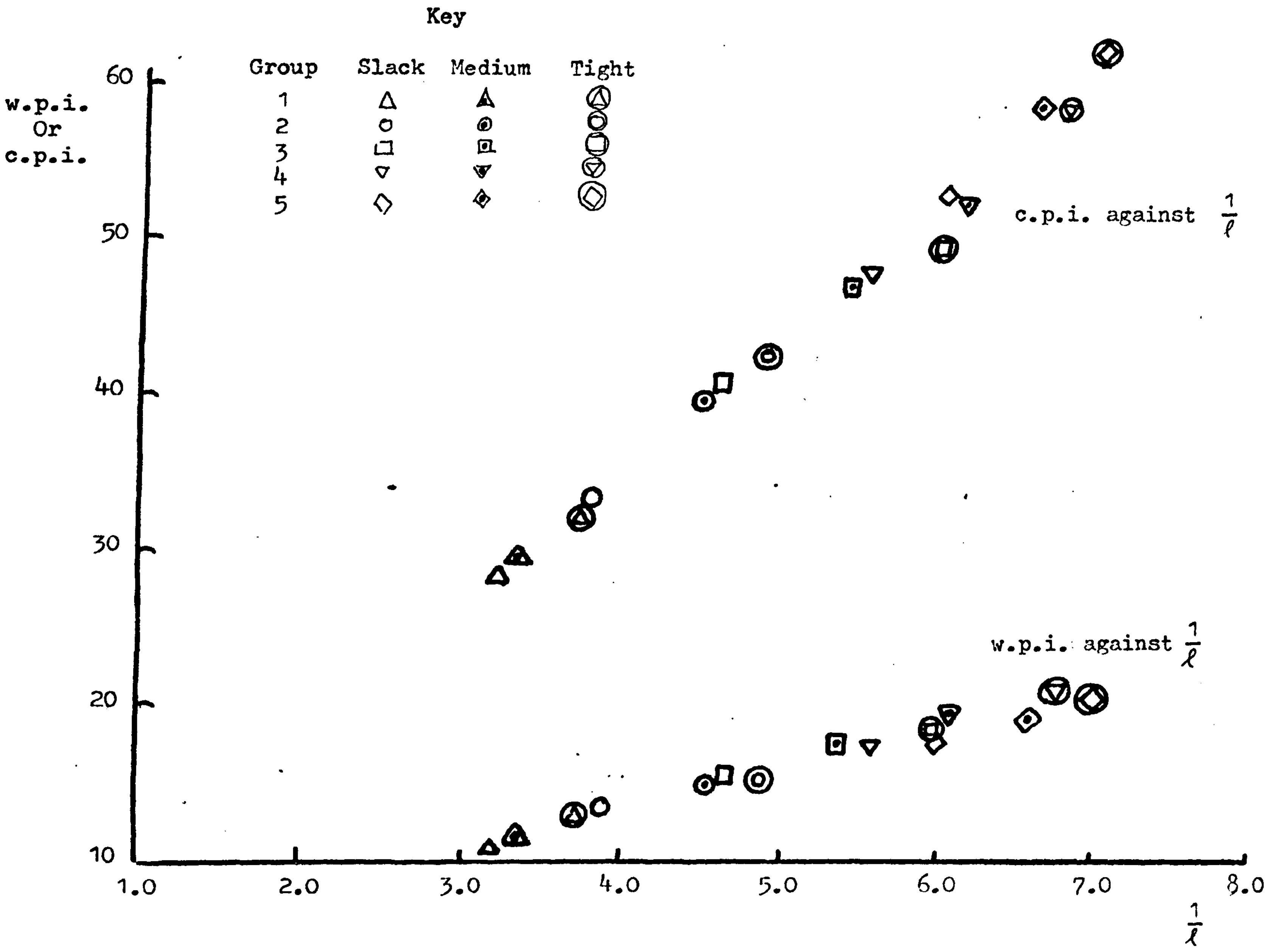


Fig. 40 Effect of Warp Tension on Fabric Dimensions

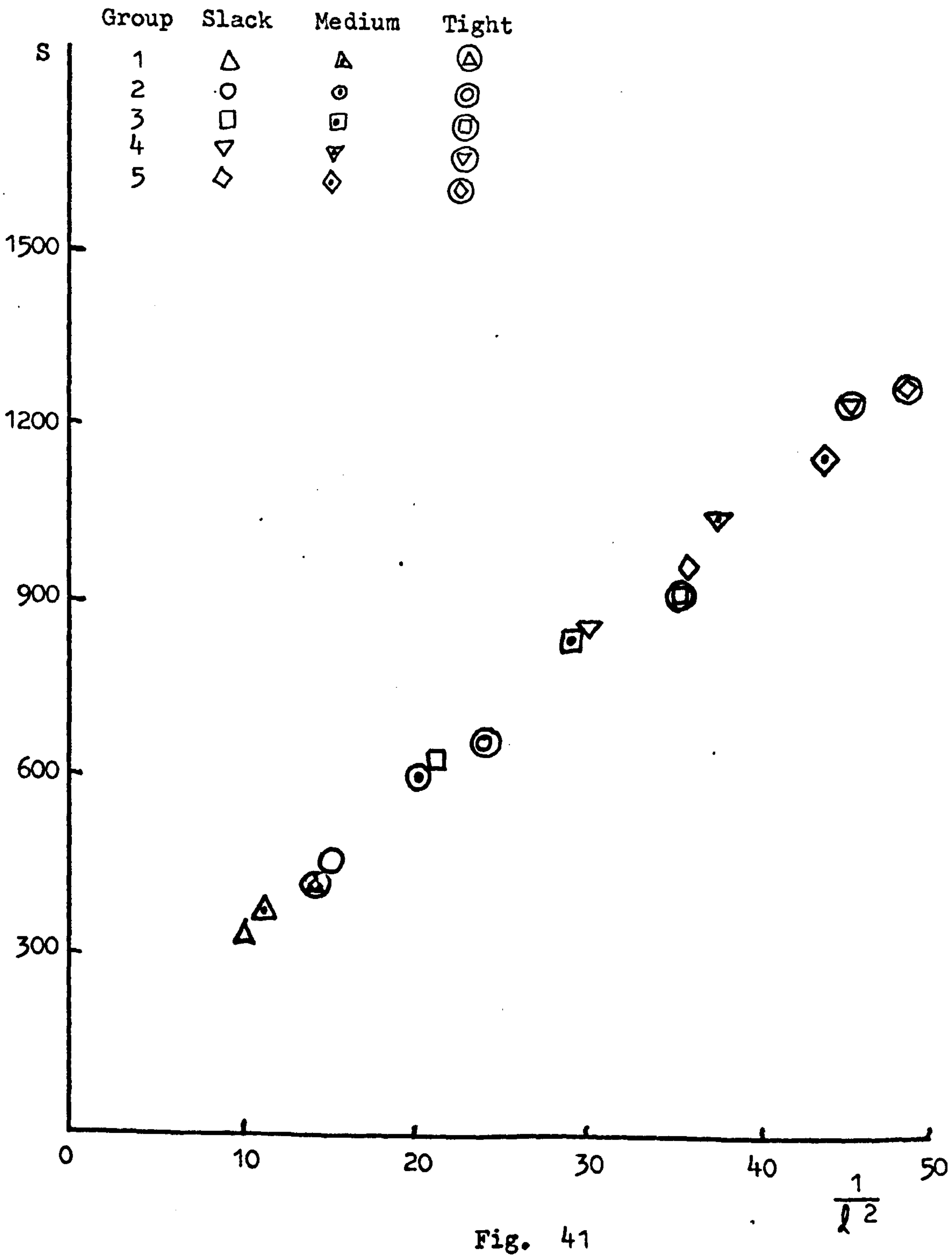


Fig. 41

Effect of Warp Tension on Stitch Density

TABLE 1

Relationship between stitch length and fabric dimensions after relaxing by tumble drying for fabrics knitted at different tensions

Fabric group	l	c.p.i. on machine	Tension	Relaxed c.p.i.	Relaxed w.p.i.	Relaxed stitch density
1	0.267	15	T	32.73	13.24	433.21
	0.300	13	M	30.00	12.00	360.00
	0.312	12	S	28.80	11.71	337.16
2	0.203	21	T	42.86	15.74	674.47
	0.219	19	M	40.00	15.24	609.52
	0.257	16	S	33.49	13.74	459.27
3	0.167	25	T	49.66	18.46	916.71
	0.183	23	M	48.00	17.78	853.33
	0.215	20	S	41.43	15.48	637.05
4	0.148	36	T	59.02	20.87	1231.64
	0.162	31	M	53.33	19.59	1044.90
	0.181	26	S	48.00	17.46	837.82
5	0.143	44	T	62.61	20.43	1278.81
	0.153	41	M	59.02	19.59	1156.24
	0.165	37	S	53.33	18.46	984.61

T = Tight (25 gm.)
M = Medium (16 gm.)
S = Slack (9 gm.)

CHAPTER V

PRELIMINARY EXPERIMENT TO INVESTIGATE THE EFFECT OF DIFFERENT RELAXATION CONDITIONS ON THE DIMENSIONAL PROPERTIES OF 1 X 1 CLOSED LAP FABRICS

I. INTRODUCTION

Numerous relaxation procedures have been adopted by various research workers in order to relax fabrics and it is evident that each procedure gives a different relaxed condition. The object of these relaxation treatments is to remove all relaxation shrinkage so that the fabric assumes a stable state and no further shrinkage occurs on subsequent washing or treatment. This is then considered to be the "fully relaxed condition".

The "fully relaxed condition" is difficult to establish, particularly in fabrics which felt, (i.e. wool fabrics), and different fabrics such as rib, plain, tuck, double jersey, etc. require different treatments to obtain the fully relaxed state. There is, therefore, no certainty that a relaxation procedure used to fully relax weft knitted or other warp knitted constructions would be suitable for the warp knitted fabrics under investigation.

The following experiment was conducted, therefore, to investigate the effect of various relaxation treatments on the dimensional properties of the 1 x 1 closed lap warp knitted construction and to investigate whether relationships between the fabric dimensions and the knitted stitch length, similar to those observed in weft knitted structures, exist and are constant in the various relaxed conditions.

II. EXPERIMENTAL DETAILS

For this work, 16 wool samples were produced consisting of four different stitch lengths of 4 yarn counts. Each fabric was made 240 wales wide and approximately 500 courses deep.

For measurement purposes in the length direction, two coloured yarns were laid across the needle bed, (laid-in), 360 courses apart. Similarly, for measurement in a width direction, marker threads were introduced into the warp 180 wales apart.

1. Machine Control

The c.p.i. were measured on the machine with a piece glass at a point between the trick plate and the take-up rollers when the needles had reached their highest position and before the guide bars commenced their swing movement. The amount of yarn required to produce 360 courses was measured by marking a spare end from the warp at the commencement and the completion of knitting the 360 courses. The distance between these two marks was measured on a H.A.T.R.A. Course Length Tester.

2. Measurement of Samples

The width and length of each sample was ascertained at each stage of relaxation by measuring between the marker threads. Both width and length were determined in three different places and the average taken. The use of marker threads in this manner reduces the problems of measuring due to edge curling and is more accurate and quicker than the use of a piece glass.

3. Relaxation Treatments

The following relaxation treatments were used in the experimental work -

a). Dry relaxation

The fabrics were allowed to stand on a flat surface for 48 hours and then measured.

b). Wet relaxation

Overnight soaking in water with wetting-out agent; fabrics allowed to dry on flat smooth surface and then measured dry.

c). Dry tumble

The fabrics, after wet relaxing as (b) above, were tumbled in a dry state for a total of 60 minutes and were removed and measured on a flat surface at intervals of 5, 10, 15, 20 and 60 minutes tumbling.

d). Tumble dry

The fabrics previously wet relaxed as (b) above were re-wetted out with wetting agent for 15 minutes, hydro extracted for 15 minutes and tumble dried at 70°C for one hour in a Kamsin hot air tumble dryer. The fabrics were then laid flat and measured.

4. Measurement of Fabric Parameters

a). Courses per inch and Wales per inch

From the two measurements of width and length, the average w.p.i. and c.p.i. were calculated as follows:-

$$\text{w.p.i.} = \frac{180}{\text{measured width}}$$

$$\text{c.p.i.} = \frac{360}{\text{measured length}}$$

b) Stitch density

The stitch density (S) was calculated as the product of w.p.i. and c.p.i.

$$\text{i.e.} \quad S = \text{w.p.i.} \times \text{c.p.i.}$$

c) Course/Wale ratio (k_r)

This is the ratio of the course spacing to wale spacing and is calculated from the formula -

$$k_r = \frac{\text{c.p.i.}}{\text{w.p.i.}}$$

d) Stitch length (ℓ)

The total length of yarn required to form one stitch was calculated, the stitch being defined as a loop and an underlap and was calculated from the total length of yarn required to produce the sample between the two coloured markers using the following formula -

$$\ell = \frac{\text{Yarn length}}{360}$$

e) k_c, k_w and k_s values

These values were calculated for each of the samples at all stages of relaxation using the following formulae:-

$$k_c = \text{c.p.i.} \times \ell$$

$$k_w = \text{w.p.i.} \times \ell$$

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

f) Cover factor

This was intended as a means of measuring cover in a knitted fabric as in a woven fabric and is proportional to $\frac{1}{\ell\sqrt{N}}$.

This means of measuring cover factor takes into consideration only the yarn count and stitch length and is, therefore, only a measure of knitting tightness, since, in addition to these variables, the cover will be determined by the degree of relaxation of the knitted construction.

For the 16 samples mentioned above, the details of yarn count, stitch length, w.p.i., c.p.i., k values, etc. for each relaxation treatment are shown in tables given in Appendix I.

III. EXPERIMENTAL RESULTS AND DISCUSSION

1. Preliminary Investigation

As a preliminary investigation, it was decided to plot k_c and k_w values for each fabric against the relaxation state, (time), to ascertain the effect of each relaxation condition and to verify if a full analysis of each relaxation state was justified.

Each yarn count was plotted separately in this manner and as a similar set of graphs was obtained for each count, only that for 1/20s is illustrated, (Fig.42). From this information, it was possible to ascertain the following facts -

(i) As measured on the machine, a considerable difference in k_c and k_w values is observed from the measurements of the individual fabrics. The k_c value decreases with increase in stitch length and the k_w value increases with increase in stitch length.

(ii) After dry relaxation the k_c values show less spread, but there is still a significant decrease with increase in stitch length. However, the k_w values are now similar and are not

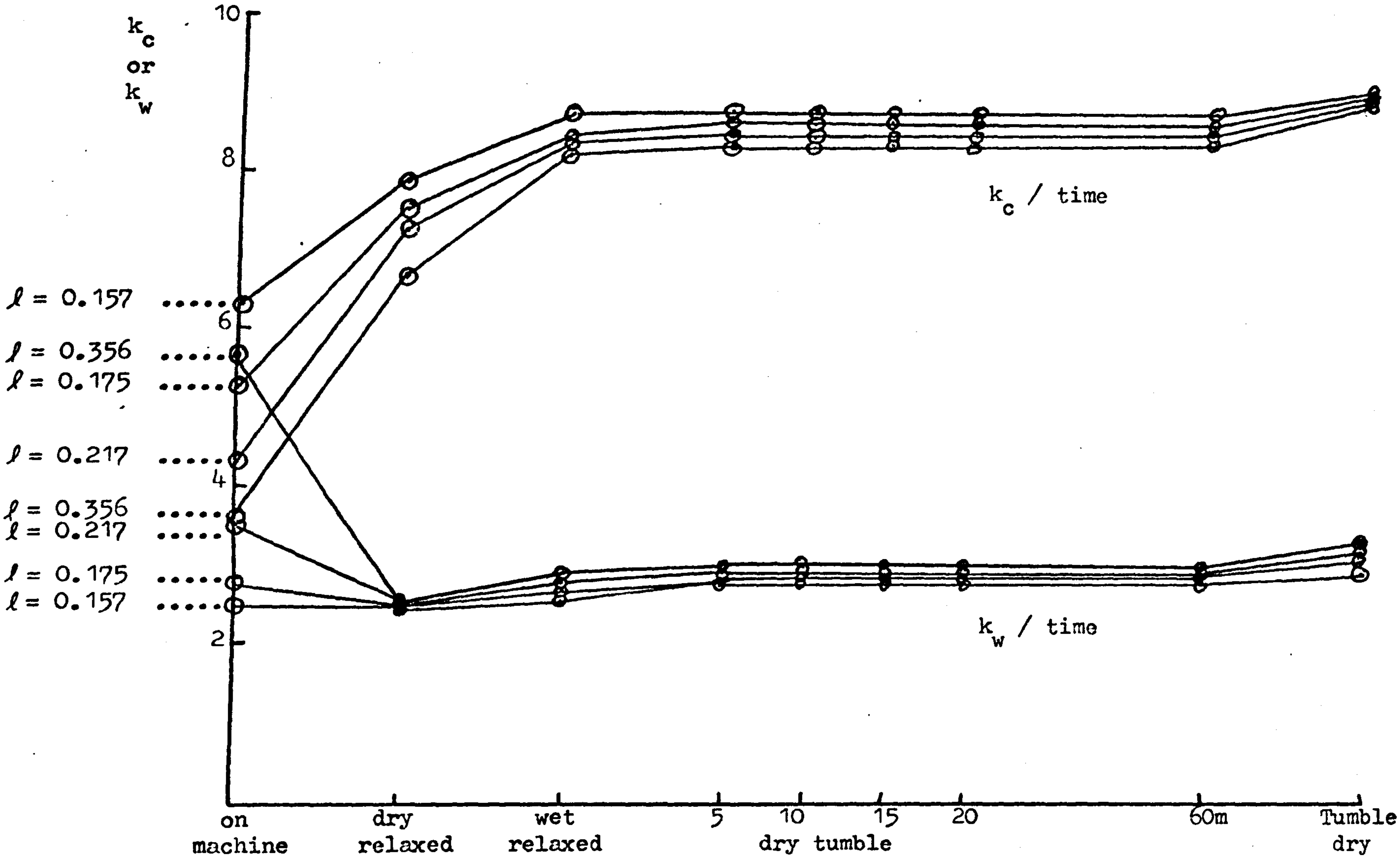


Fig. 42 Effect of Relaxation Treatment on k_c and k_w values

affected by difference in stitch length.

(iii) After wet relaxation, the k_c values are brought even closer together, but the k_w values exhibit a slightly increased spread compared with the dry relaxed state, the k_w value increasing with increase in stitch length.

(iv) Subsequent relaxation has little effect on the spread of either the k_c or k_w values, except in the case of the tumble dry condition when a reduction in the spread of the k_c values may be observed.

(v) There is a much greater change in k values for slack stitch lengths than tight stitch lengths during dry and wet relaxation. This is probably due to the fact that the slack fabrics are much more distorted on the machine than the tight fabrics.

(vi) Tumbling the fabrics in the dry condition shows little change in the k value.

The general relationships between the dimensional parameters and the stitch length are observed by plotting c.p.i. and w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$ for each relaxation condition. These graphs for the dry relaxed, wet relaxed, and tumble dry conditions are shown in Figs. 43 - 48. From these graphs the following general conclusions can be drawn:-

(a) The points show little spread with no apparent relationship with yarn count. It may be concluded, therefore, that yarn count has no effect on the dimensional parameters of the fabric. This fact is discussed in more detail in Chapter VI.

Key to Graphs 43 - 51

△ = 2/48 worsted

○ = 1/20 "

□ = 2/32 "

◇ = 1/12 "

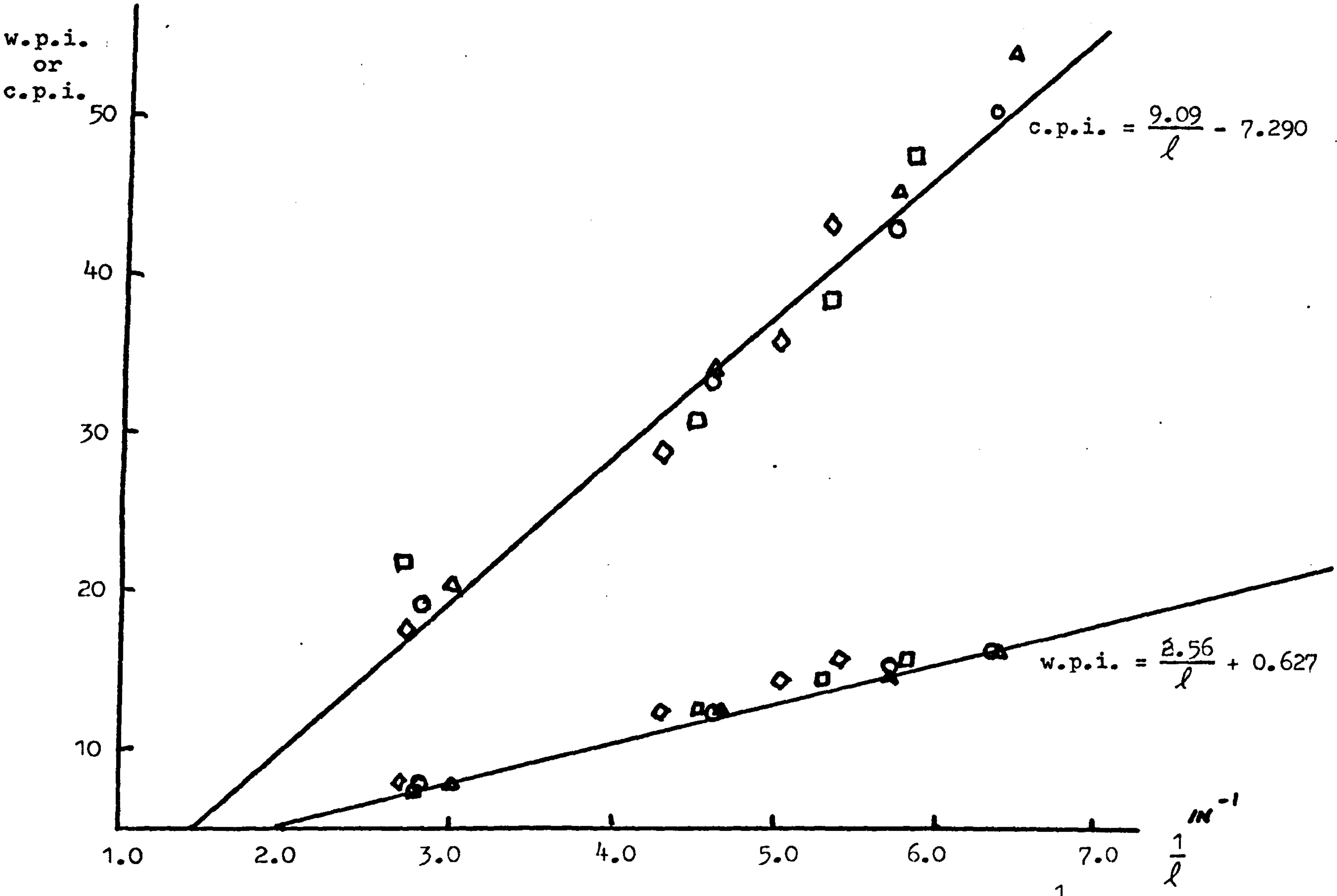


Fig. 43 Dry Relaxed Relationship between w.p.i. and c.p.i. and $\frac{1}{\ell}$

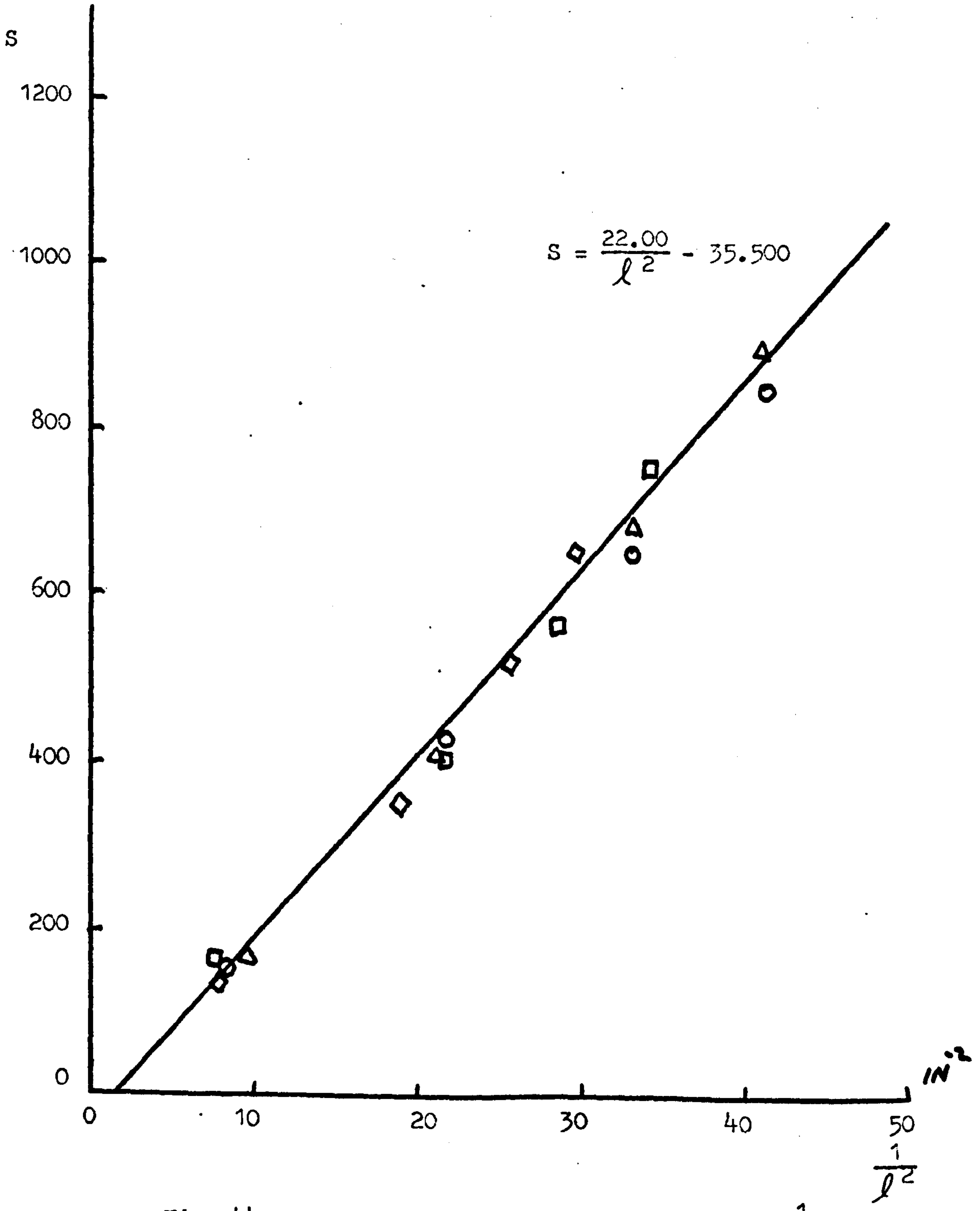


Fig. 44 Dry Relaxed Relationship of S with $\frac{1}{\ell^2}$

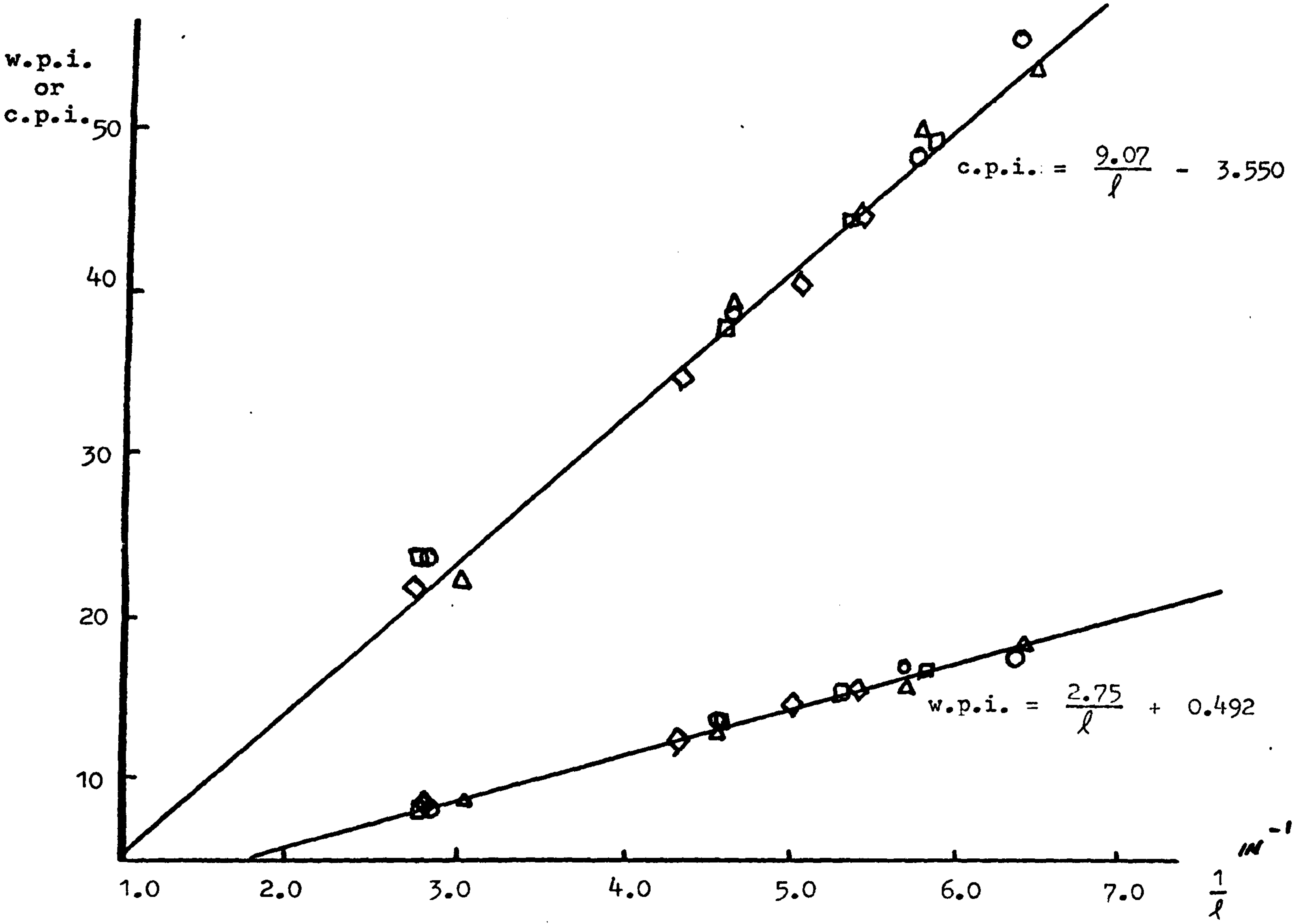


Fig. 45 Wet Relaxed Relationship between c.p.i. and w.p.i. and $\frac{1}{\ell}$

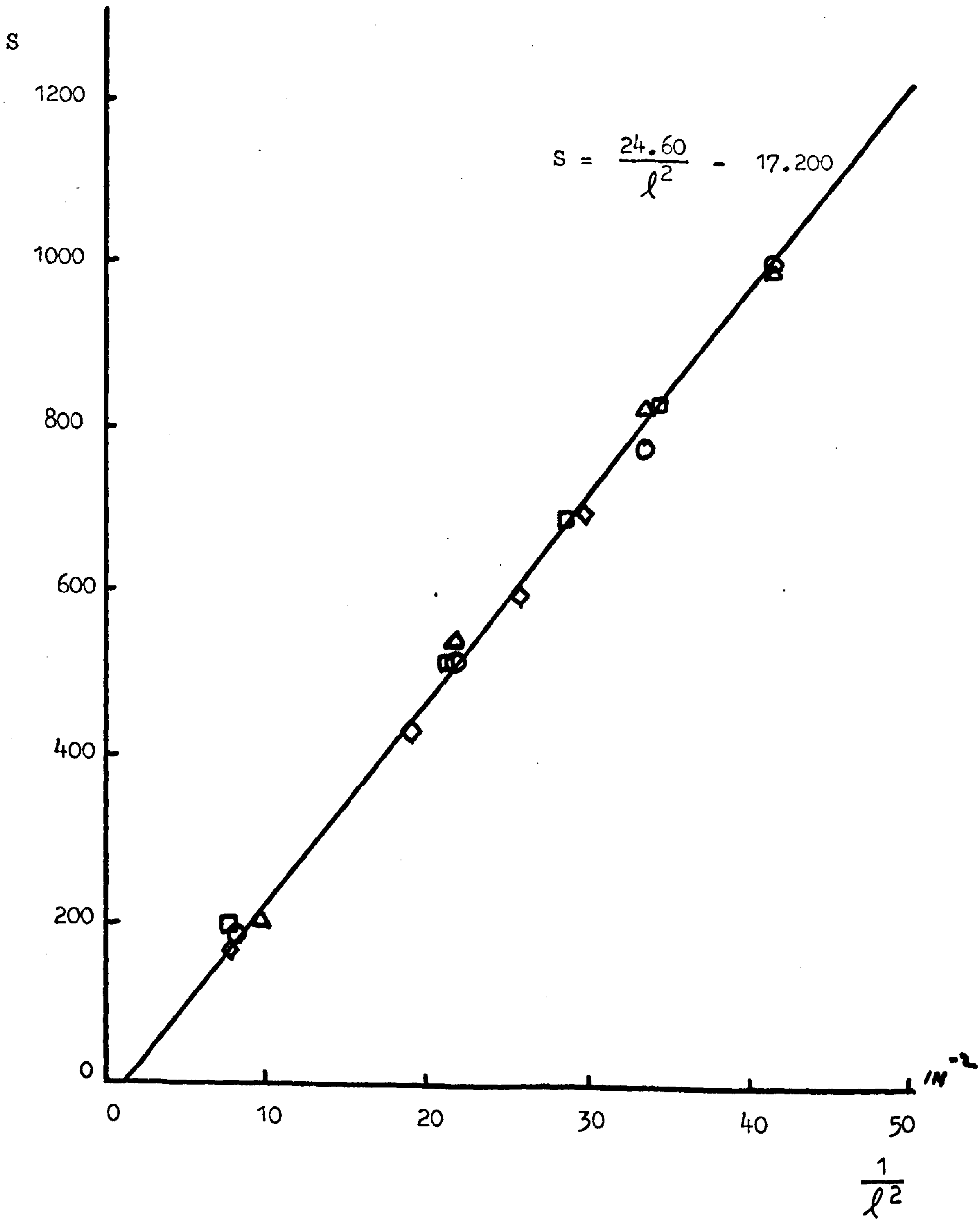


Fig. 46 Wet Relaxed Relationship of S with $\frac{1}{\ell^2}$

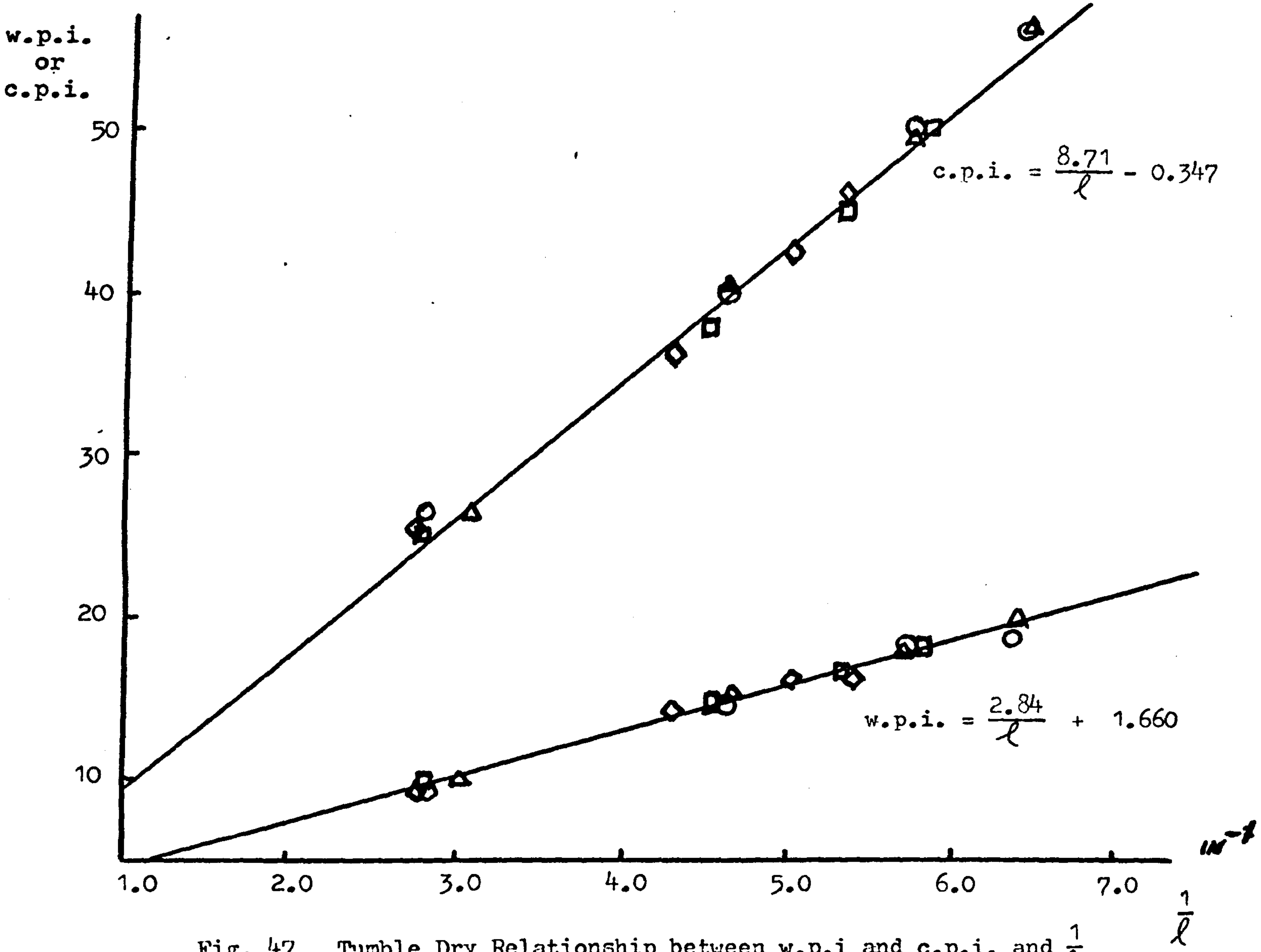


Fig. 47 Tumble Dry Relationship between w.p.i and c.p.i. and $\frac{1}{\ell}$

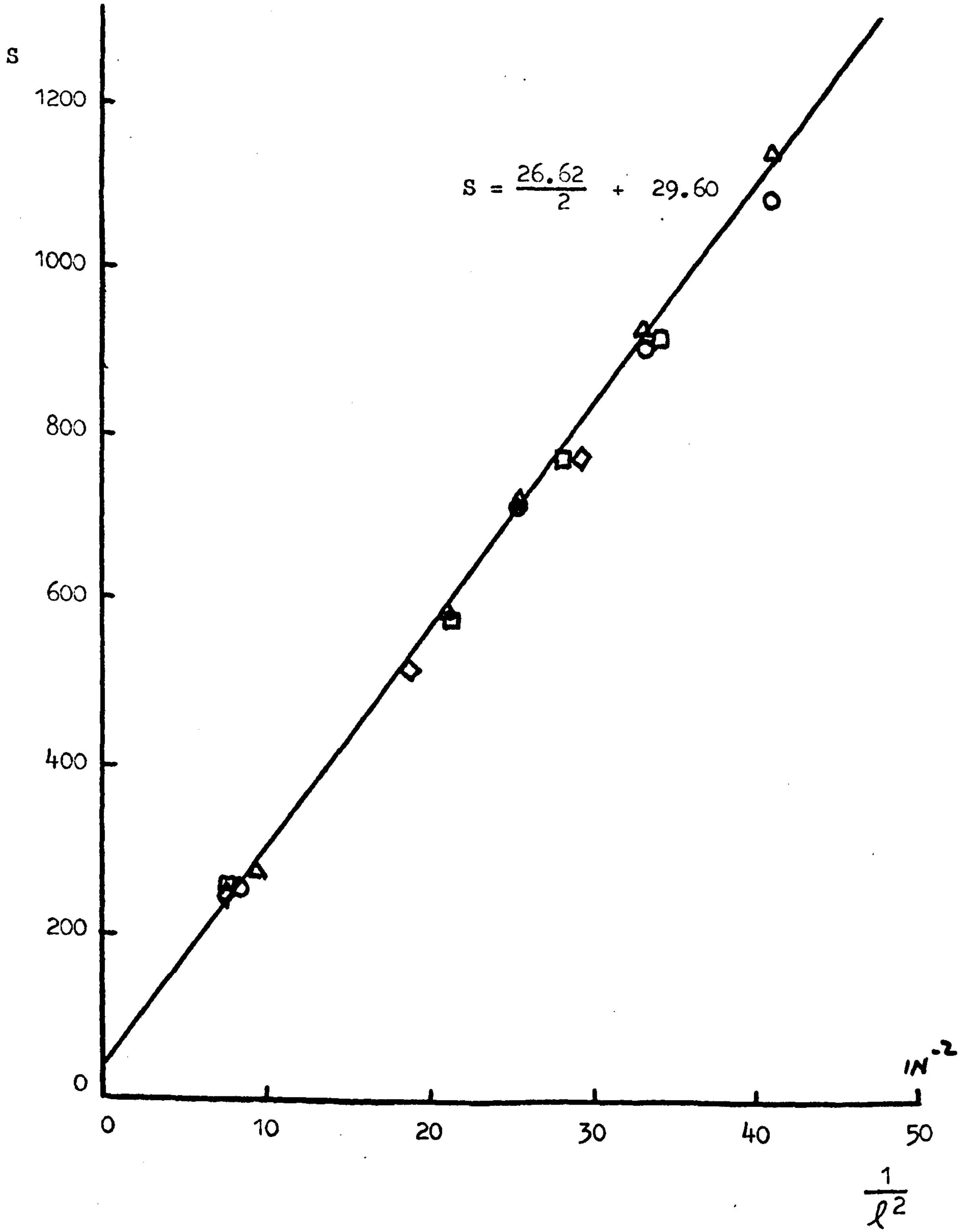


Fig. 48 Tumble Dry Relationship between S and $\frac{1}{\ell^2}$

(b) There is a straight line in relationship between the measured fabric parameters of c.p.i. and w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$.

(c) The best fit line through the points gives an intercept the magnitude and sign of which varies with different parameters and different relaxation conditions.

It must be realised that if an intercept is present, it means that the k value, (relationship between the two plotted parameters), is NOT a constant, but will vary with ℓ.

An alternative way of showing these results is to plot the k values (determined by k_c = c.p.i. x ℓ, k_w = w.p.i. x ℓ and $k_s = S \times \ell^2$), against stitch length for each relaxation condition. The appropriate graphs for the dry relaxed, wet relaxed and tumble dry conditions are shown in Figs. 49 - 51. Visual observation confirms that the k values are not apparently constant, but vary with ℓ.

2. Statistical Analysis of Results

It is general to analyse experimental results of this type by regression analysis, each relaxation state being considered separately. Owing to the little change in dimensions obtained during tumbling in the dry condition, it was decided to omit the 10 minutes and 20 minutes dry tumble tests from regression analysis.

This form of analysis can be used to test if the intercept obtained is real or if it is one which could be attributed to experimental and sampling error. If it is ascertained that it is

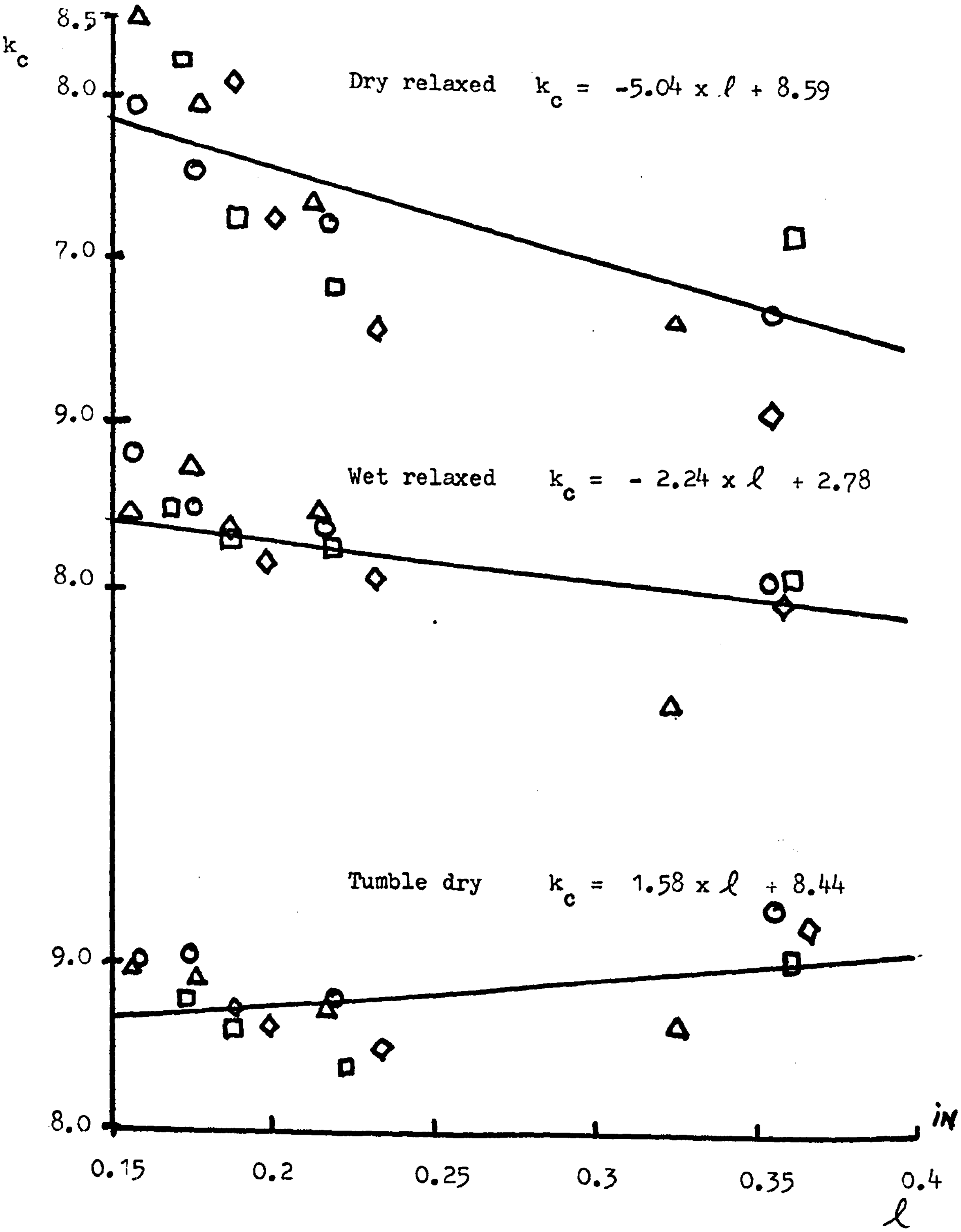


Fig. 49

Relationship between k_c and ℓ in the Dry Relaxed, Wet Relaxed and Tumble Dry Conditions.

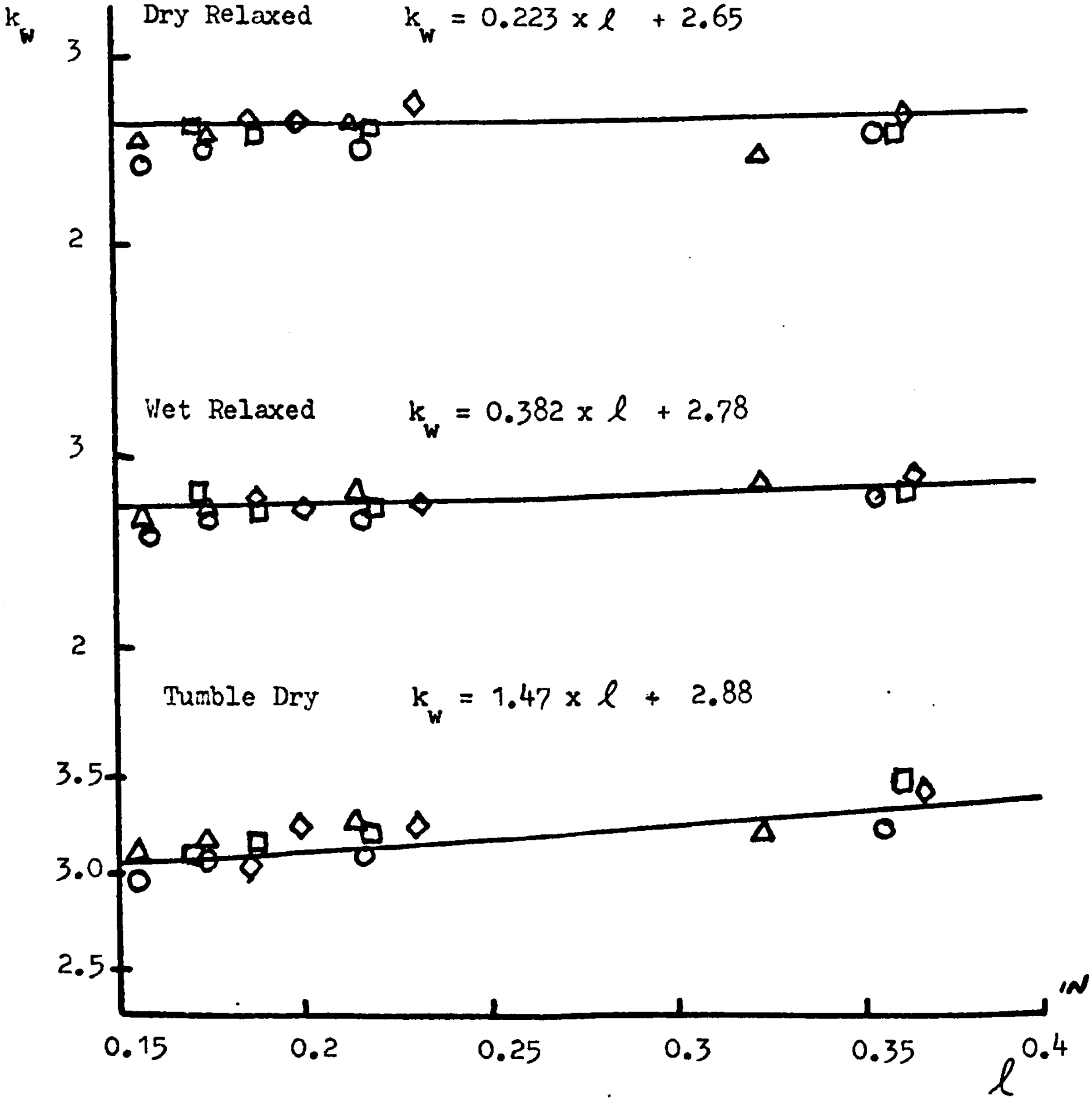


Fig. 50
Relationship between k_w and ℓ in the Dry Relaxed, Wet Relaxed and Tumble Dry Conditions

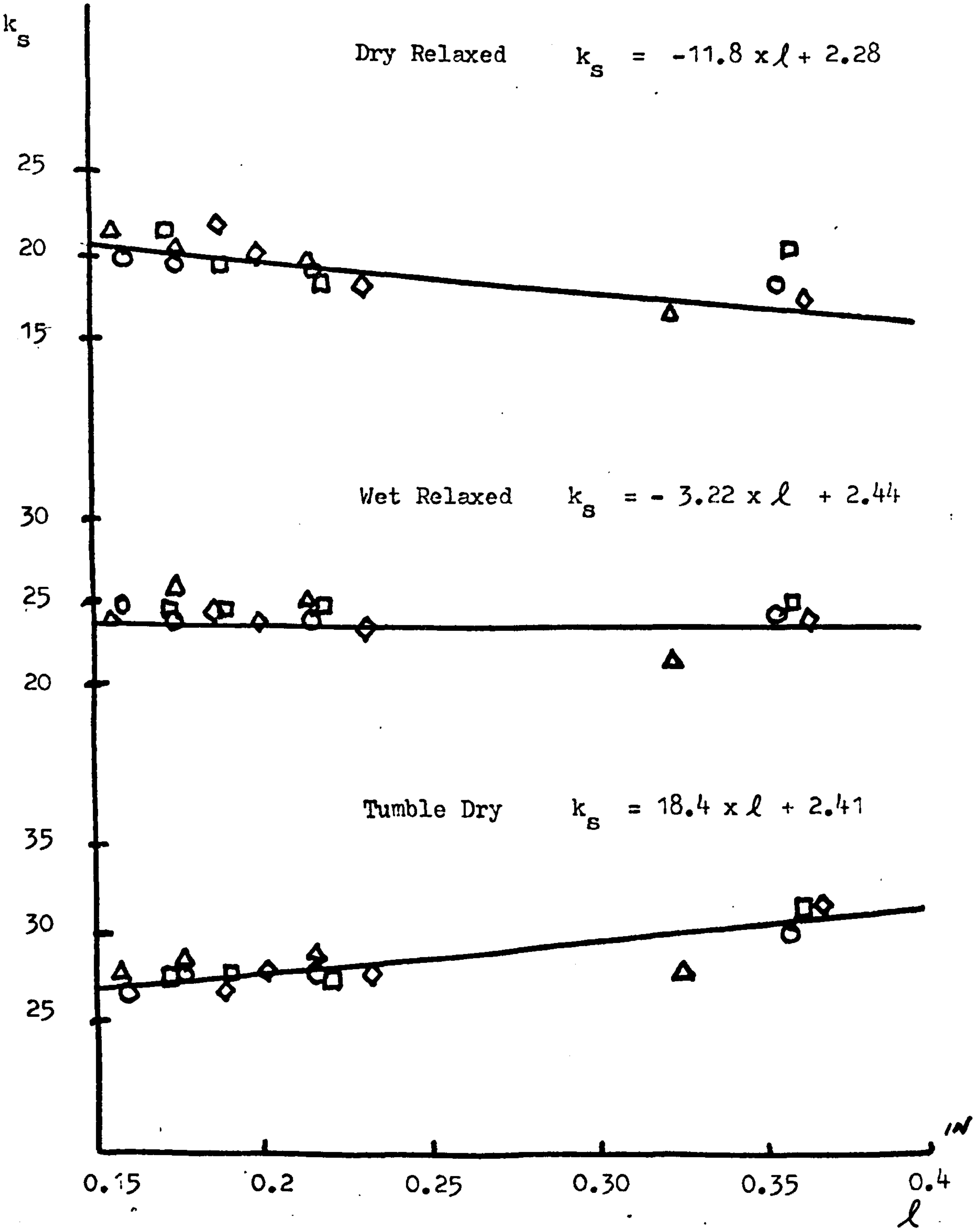


Fig. 51

Relationship between k_s and ℓ in the Dry Relaxed, Wet Relaxed and Tumble Dry Conditions attributable to experimental and sampling errors, the regression line is recalculated to pass through zero, the slope of this line being the k value.

The method used is to test the significance of the intercept by the Student's t-test, assuming the correct intercept to be zero, (null hypothesis), the resultant figures being converted by probability tables to give the percentage probability. It is generally accepted that for values above 5%, the null hypothesis has not been disproved and that in the statistical sense the intercept is not significantly different from zero. If the value is below 5% the null hypothesis has not been proved and the intercept may be truly different from zero.

Care must be exercised in using this test for the following reasons -

1. If a true intercept is present, this shows that the k value obtained from the regression line is NOT a constant. If the regression line is then recalculated to pass through zero, an error will be introduced, the magnitude of which depends on the size of the intercept.

2. The value of 5%, generally accepted as the dividing line between an intercept which is statistically different from zero and one which is not, is not a fixed value but one which can be adjusted in the light of the circumstances under consideration, as Blackhouse[87] states,

"Here it is worth adding that the statistician never has the last word in a statistical investigation - in any field such as medicine, economics, psychology, etc., it is up to the expert in the field to interpret the results in the light of his special knowledge".

The results of the statistical analysis of c.p.i. and w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$, are given in Table 2. It will be observed from these results -

(i) A high correlation exists between c.p.i. and w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$.

(ii) The values for k_c, k_w and k_s are not all constant in any one condition, but vary as itemised below -

(a) <u>k_c values</u>

The regression line for c.p.i. against $\frac{1}{\ell}$ has a negative intercept in all cases except the tumble dry condition. The k_c value cannot be considered a constant in the dry state, and after tumble drying, the intercept becomes such that the k_c value may be considered a constant. In general, the intercept decreases with increase in relaxation condition.

(b) <u>k_w values</u>

The k_w value shows a reverse trend, in that the intercept is positive and there is a general trend for it to increase with increased relaxation, so that the k value can only be considered a

TABLE 2

Relation between stitch length and fabric dimensions - Statistical Analysis

Relaxation treatment	Regression equation	Standard error of		Standard deviation about regression line	Correlation coefficient	t-test of c % probability
		m	c			
Dry Relaxation	c.p.i. = $\frac{9.09}{\ell} - 7.290$	0.4802	2.3360	2.3480	0.981	0.7
	w.p.i. = $\frac{2.56}{\ell} + 0.627$	0.0975	0.4732	0.4779	0.990	20.0
	S = $\frac{22.00}{\ell^2} - 35.500$	0.6455	16.8310	28.2831	0.994	7.0
Wet Relaxation	c.p.i. = $\frac{9.07}{\ell} - 3.550$	0.3458	1.6811	1.6904	0.990	6.0
	w.p.i. = $\frac{2.75}{\ell} + 0.492$	0.0571	0.2774	0.2794	0.997	10.0
	S = $\frac{24.60}{\ell^2} - 17.200$	0.4153	10.8178	18.1965	0.998	15.0
Dry Tumble 5 min.	c.p.i. = $\frac{8.75}{\ell} - 1.250$	0.2100	1.0222	1.0273	0.996	26.0
	w.p.i. = $\frac{2.83}{\ell} + 0.819$	0.0681	0.3298	0.3326	0.996	3.0
	S = $\frac{25.30}{\ell^2} + 4.440$	0.4276	11.0118	18.7384	0.998	60.0

TABLE 2 (Continued)

Relaxation treatment	Regression equation	Standard error of		Standard deviation about regression line	Correlation coefficient	t-test of c % probability
		m	c			
Dry Tumble 15 mins.	c.p.i. = $\frac{8.75}{\ell} - 1.050$	0.2100	1.0222	1.0276	0.996	35.0
	w.p.i. = $\frac{2.77}{\ell} + 1.240$	0.0666	0.3237	0.3257	0.996	0.4
	S = $\frac{25.20}{\ell^2} + 15.000$	0.3595	11.0943	18.667	0.998	20.0
Dry Tumble 60 mins.	c.p.i.m= $\frac{8.72}{\ell} - 0.788$	0.2093	1.0172	1.0226	0.996	40.0
	w.p.i. = $\frac{2.79}{\ell} + 1.180$	0.0581	0.2821	0.2839	0.997	0.1
	S = $\frac{25.30}{\ell^2} + 15.100$	0.4276	11.1391	18.7373	0.998	20.0
Tumble Dry	c.p.i. = $\frac{8.71}{\ell} - 0.347$	0.2335	1.1367	1.1419	0.995	70.0
	w.p.i. = $\frac{2.84}{\ell} + 1.660$	0.0764	0.4064	0.3734	0.994	0.1
	S = $\frac{26.62}{\ell^2} + 29.600$	0.4496	11.7128	19.7542	0.998	2.5

constant in the dry and wet relaxed condition. On subsequent dry tumbling and on re-wetting and tumble drying, the intercept becomes increasingly large so that the k value is not a constant.

(c) k_s values

The k_s value is a constant in all cases except the tumble dry condition. The dry relaxed and wet relaxed conditions show a negative intercept, and other conditions a positive intercept. This is only to be expected as the k_c value shows a negative intercept and the k_w a positive intercept, the k_s value being a combination of the two.

3. Summary

The results obtained from these experiments, (see Fig. 42), suggest that the dry relaxed and wet relaxed conditions do not represent the fully relaxed condition of the fabrics and that tumbling in the dry state has little effect on the fabric dimensions. The condition investigated representing the most completely relaxed state is the tumble dry condition in which the fabrics were wet out for a second time and then tumbled until dry.

It is interesting to compare the k values obtained from these fabrics in the various stages of relaxation with those obtained by previous workers in weft knitting[62] where it has been reported that the constancy of all k values is increased with increase in relaxation of the fabric.

In the case of the 1 x 1 closed lap warp knit construction, whilst the k_c value is constant, k_w varies with ℓ to an increased extent as the relaxation becomes more complete.

The k_s value which, it has been suggested, is of value since it is less affected by fabric strains, exhibits its greatest constancy after 5 minutes dry tumbling. With greater relaxation than this, the intercept increases to such a magnitude in the tumble dry condition that the k_s value cannot be considered to be a constant, but varies with stitch length.

CHAPTER VI

MORE DETAILED INVESTIGATION INTO THE DIMENSIONAL PROPERTIES AND FELTING BEHAVIOUR OF 1 x 1 CLOSED LAP FABRICS

INTRODUCTION

In Chapter V, the effect of relaxation treatments on the dimensional properties of the 1 x 1 closed lap structure has been described. One of the major objects of the present investigation was to establish the felting characteristics of wool warp knit fabrics under standard washing conditions and to do this a further larger set of samples was produced from a greater range of yarn counts.

The opportunity was taken to verify the surprising results obtained in Chapter V, namely, that with complete relaxation, the k values did not acquire a constant value and also to verify that yarn count had no effect on the fabric parameters.

The results in Chapter V had indicated that to obtain a fabric in its relaxed state, wetting of the fabric was essential and, therefore, the relaxation treatments studied on this wider range of fabrics were confined to the wet relaxed and tumble dry conditions.

PART I RELAXATION RESULTS

I. EXPERIMENTAL DETAILS

For this work a total of 57 samples was produced from 12 different yarn counts.

The experimental details of sample size, marking and measuring of samples, machine control, etc. were all as used in Chapter V.

1. Yarn Counts

A range of yarn counts was used from 1/28's to 1/4's in steps of 4 counts with their equivalent two fold yarns. It was found that 1/4's and 2/8's gave considerable trouble in knitting due to limitation of gauge and, therefore, they were omitted from the experiments. The following yarn counts were used -

2/56's	and	1/28's	(31 Tex)
2/48's	and	1/24's	(37 Tex)
2/40's	and	1/20's	(44 Tex)
2/32's	and	1/16's	(55 Tex)
2/24's	and	1/12's	(74 Tex)
2/16's	and	1/8's	(95 Tex)

2. Relaxation Treatments

a) Wet Relaxed
b) Tumble Dry

Details of the wet relaxation and tumble dried treatments were as described in Chapter V.

3. Measurement of Fabric Parameters

All fabric parameters were measured in the manner described II (4), Chapter V.

For the 57 samples produced, the details of yarn count, stitch length, w.p.i., c.p.i., k values, etc. for each relaxation and felting treatment are shown in Appendix II.

II. DISCUSSION OF RESULTS - RELAXATION

1. Effect of Relaxation on k Values

The results for the wet relaxed and tumble dry conditions were analysed by regression analysis. The graphs for w.p.i. and c.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$ for the tumble dry condition are shown in Figs. 52 to 55.

The regression equation, slope (m), standard error of slope and intercept (c), standard deviation about the regression line, correlation coefficient and Students' t-test of the intercept for all graphs relating to all yarns are given in Table 3.

From these graphs and this analysis, it will be observed that the conclusions drawn in Chapter V are endorsed by this information. In neither the wet relaxed nor the tumble dry conditions are all parameters, k_c, k_w, and k_s constant. The two conditions may be considered as follows -

a) Wet relaxed

In the wet relaxed condition, the k_c and k_w values are not constant but the k_s value has a probability of 23% by the Students' t-test and, therefore, may be considered to be a constant. This is not surprising as the k_c value has a negative intercept and the k_w value a positive intercept.

b) Tumble dry

In the tumble dry condition, the k_c value can be considered to be a constant. A small intercept is obtained, but the Students' t-test gives a probability of 80%. The k_w value, however, is not

Key to Graphs 51 - 68

▼ = 2/56 worsted

▲ = 2/48 worsted

● = 2/40 worsted

■ = 2/32 worsted

◆ = 2/24 worsted

\+ = 2/16 worsted

⊙ = Calculated values for
Graph 52a

▽ = 1/28 worsted

△ = 1/24 worsted

○ = 1/20 worsted

□ = 1/16 worsted

◇ = 1/12 worsted

X = 1/8 worsted

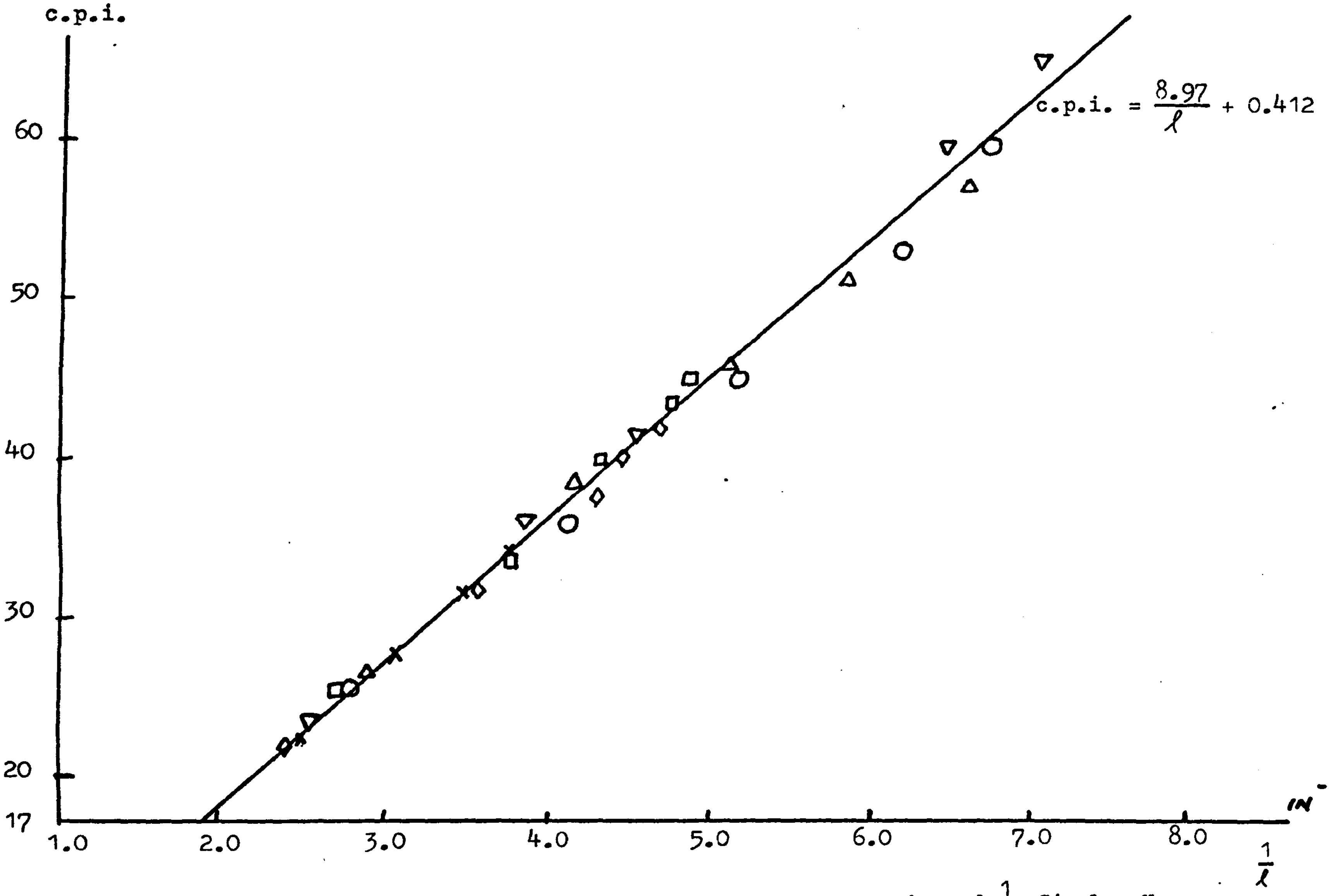


Fig. 52 Tumble Dry Relationship between c.p.i. and $\frac{1}{\ell}$ Singles Yarns

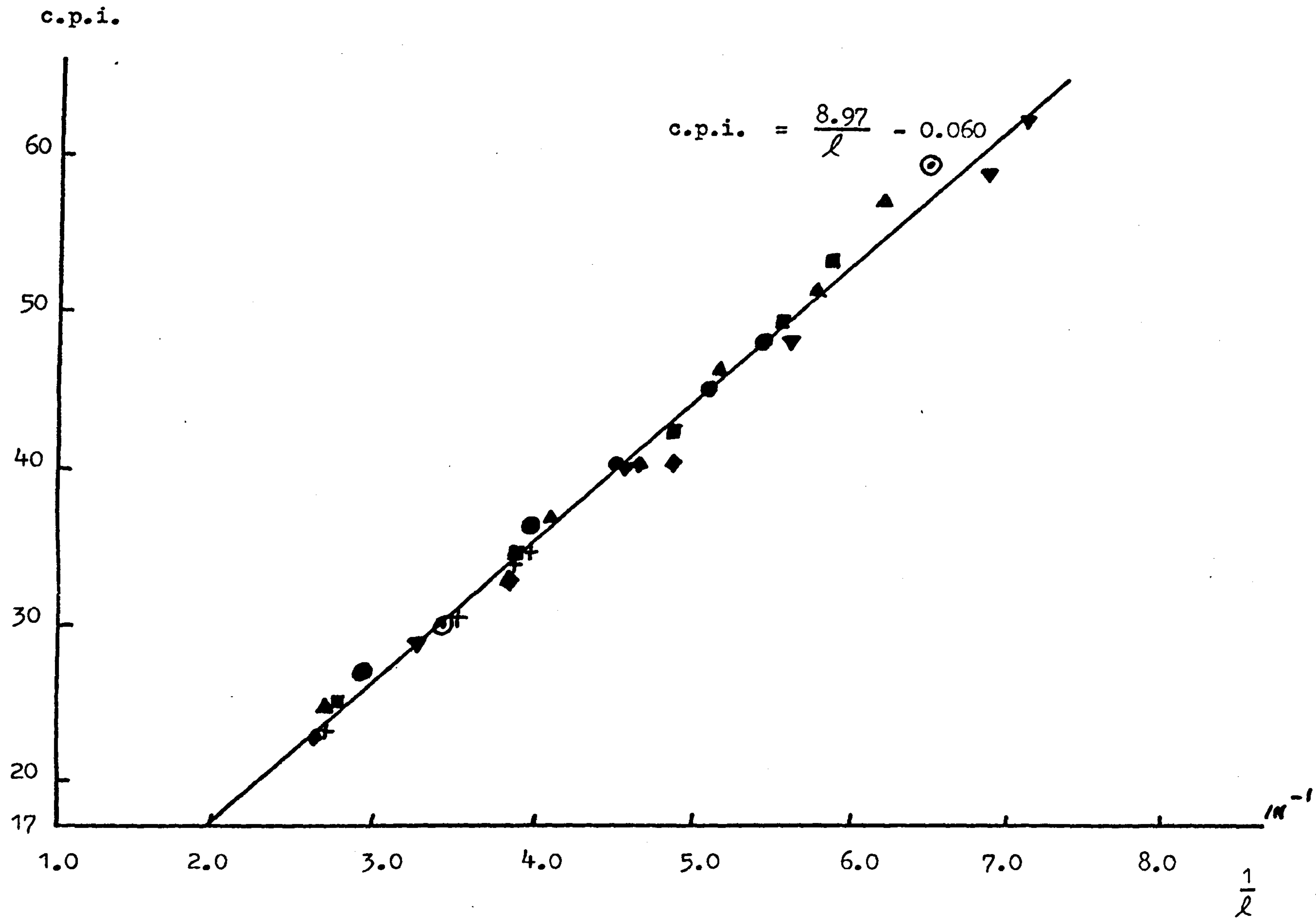


Fig. 52a Tumble Dry Relationship between c.p.i. and $\frac{1}{\ell}$ Two Fold Yarns

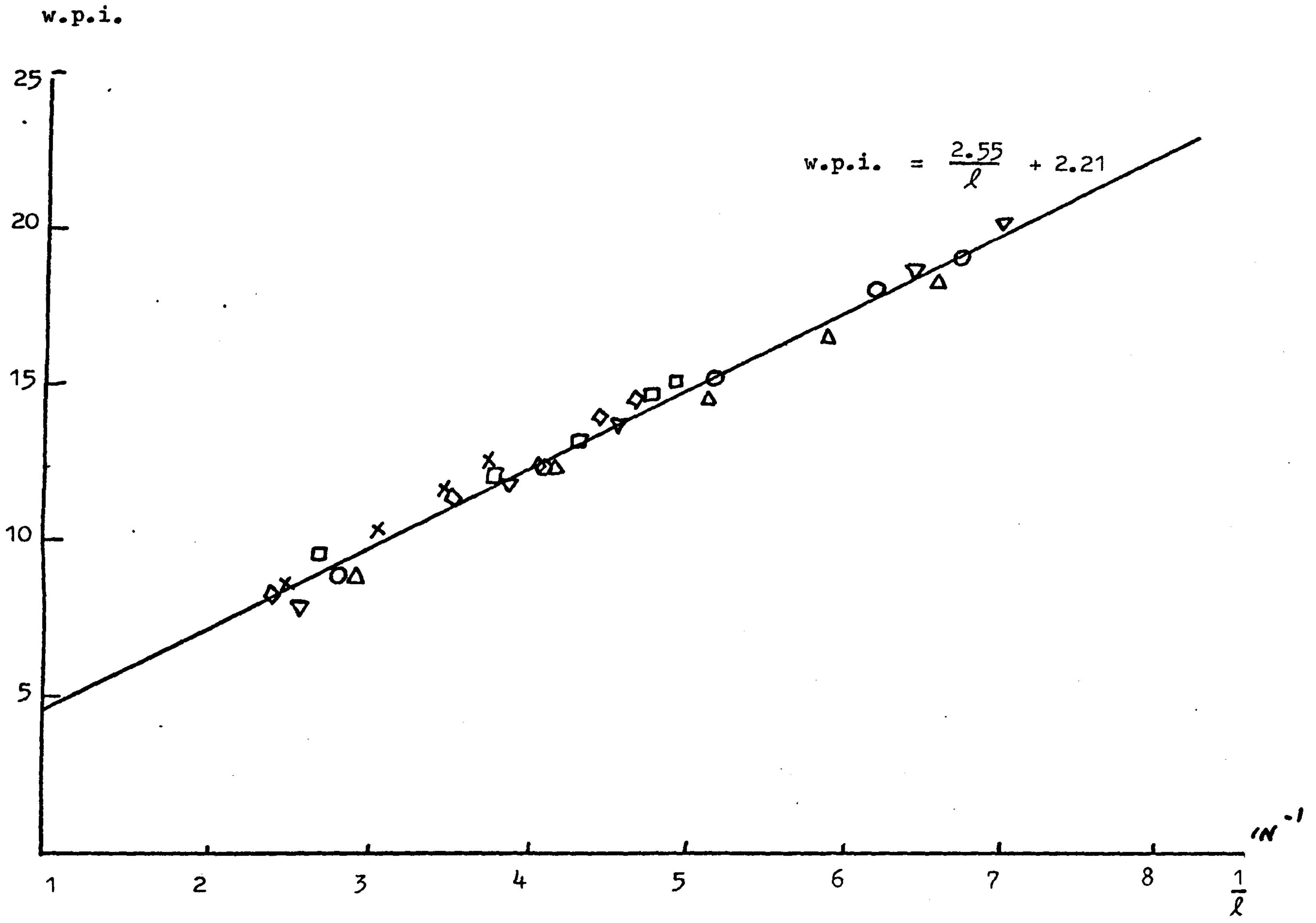


Fig. 53 Tumble Dry Relationship between w.p.i. and $\frac{1}{\ell}$ Singles Yarns

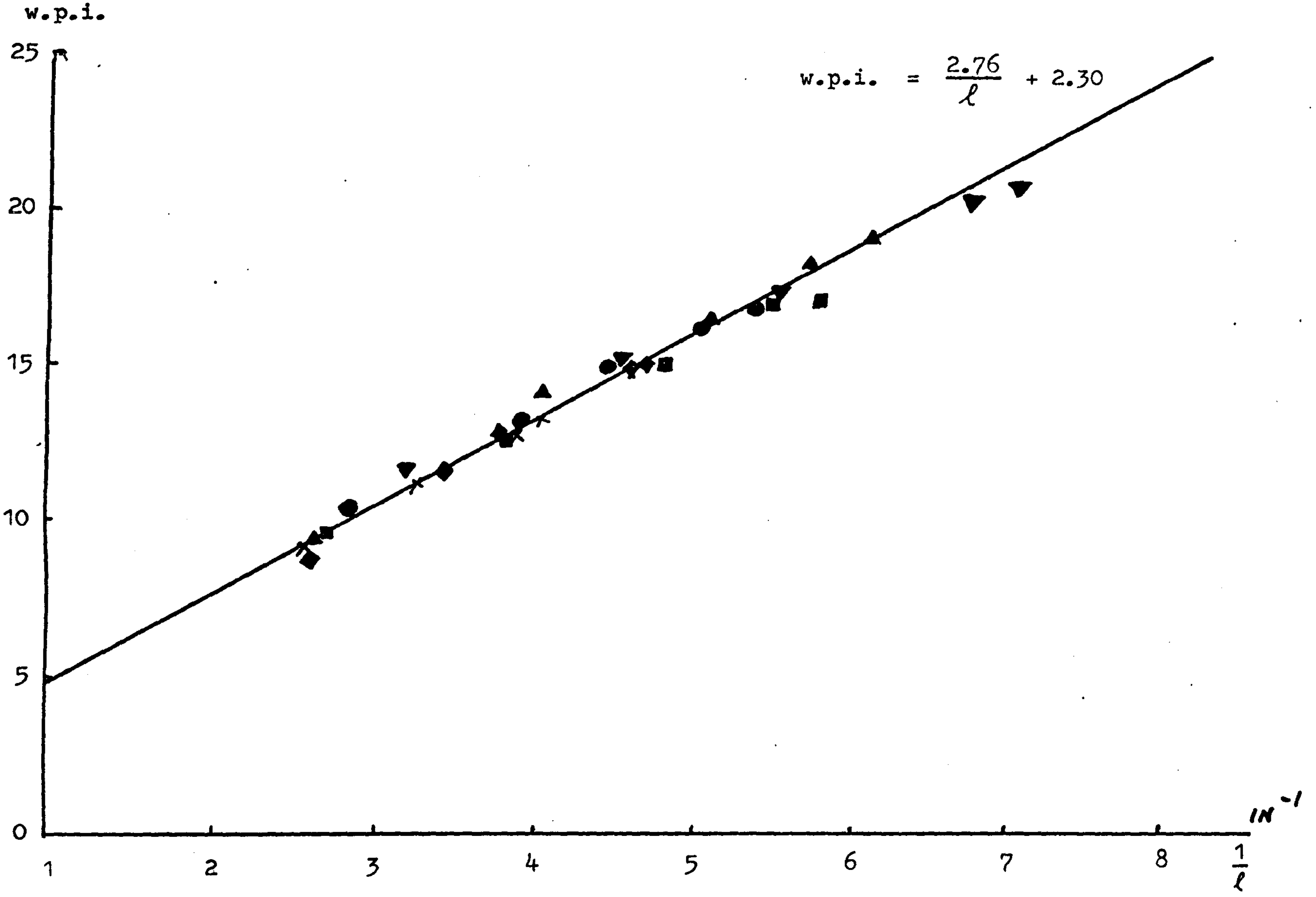


Fig. 53a Tumble Dry Relationship between W.P.I. and $\frac{1}{\ell}$ Two Fold Yarns

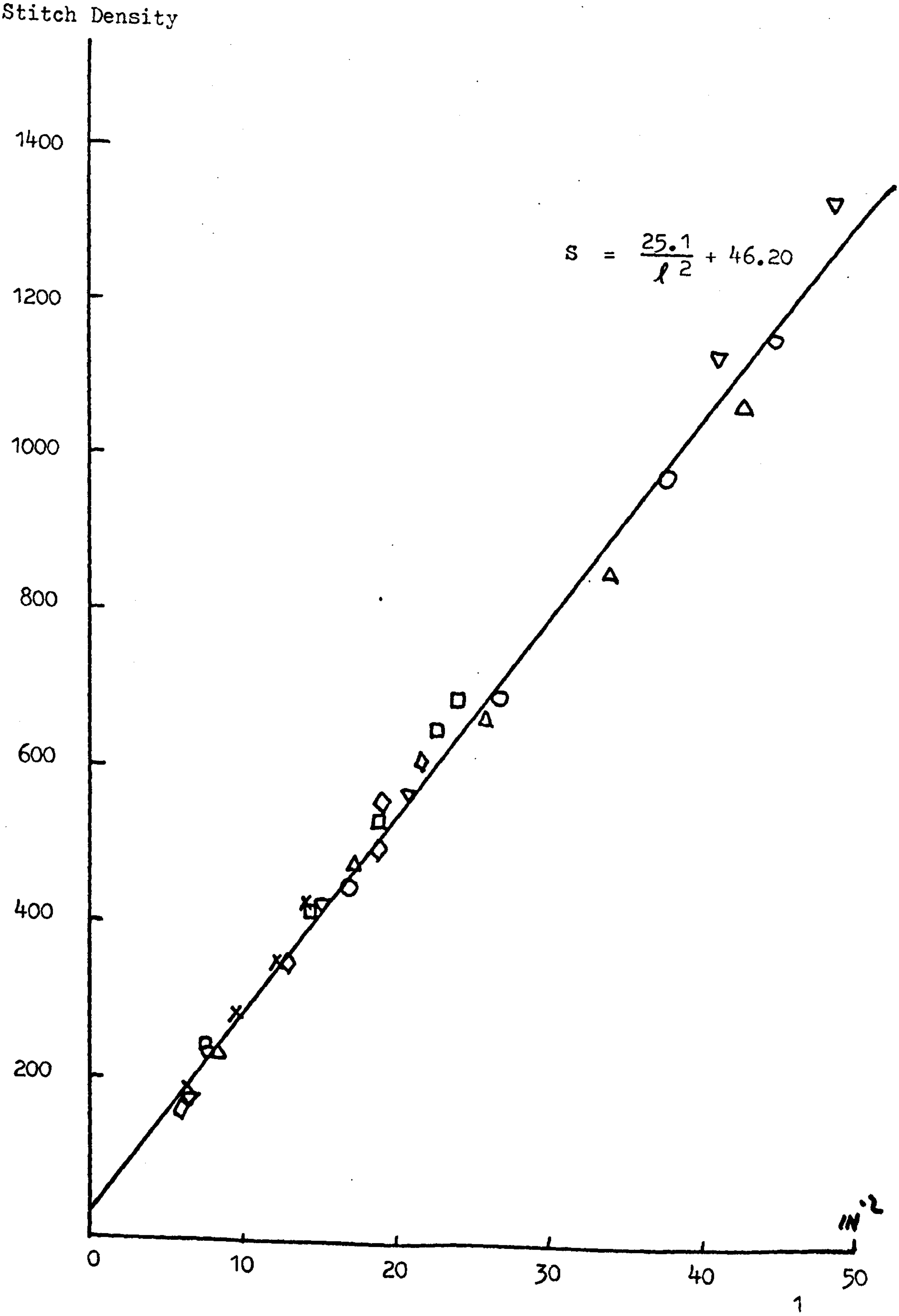


Fig. 54

Tumble Dry Relationship between S and $\frac{1}{\ell^2}$ Singles Yarns

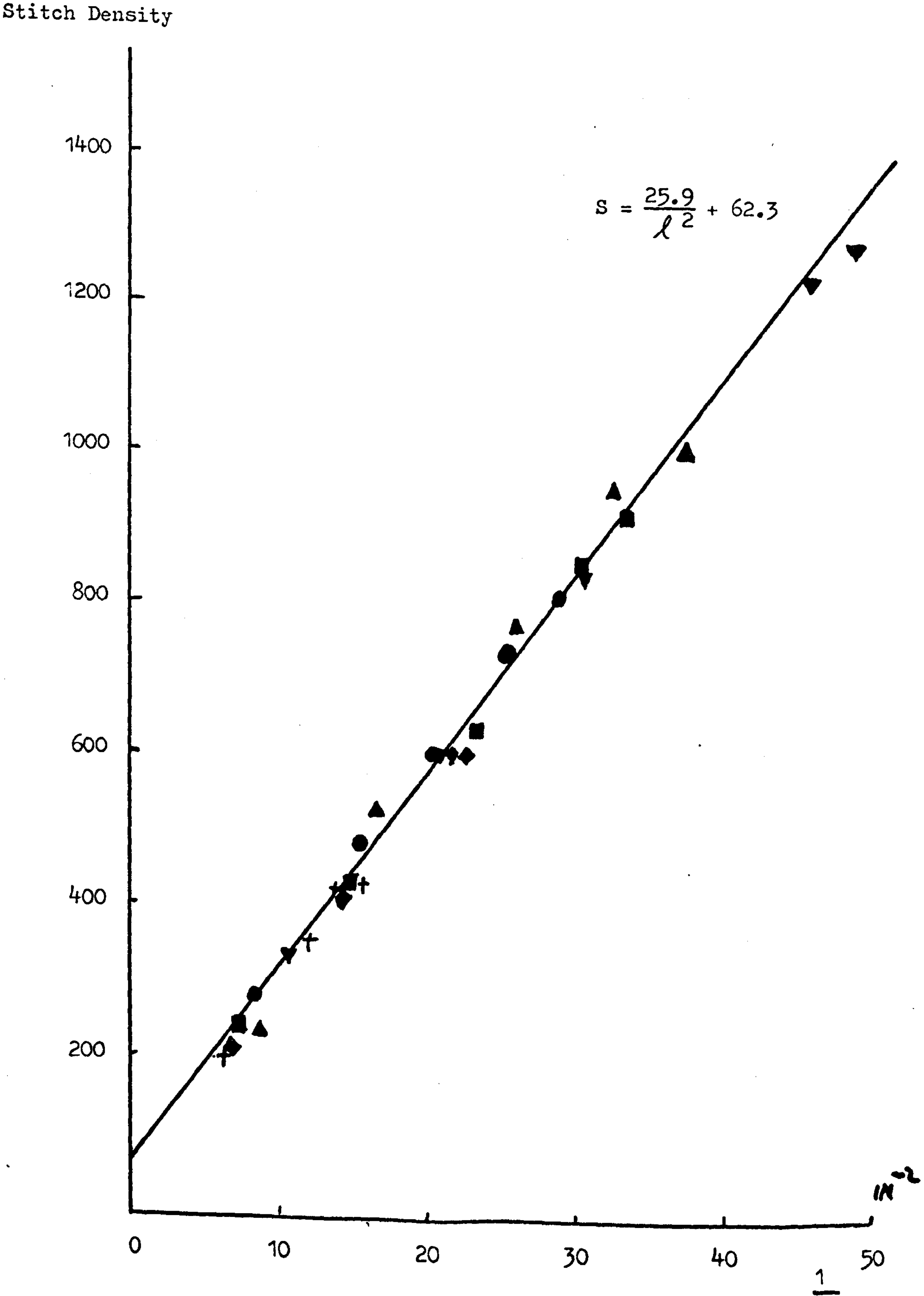


Fig. 55

Tumble Dry Relationship between S and $\frac{1}{l^2}$ two fold Yarns

TABLE 3

Relation between stitch length and fabric dimensions - Statistical Analysis

Relaxation treatment	Regression equation	Standard error of		Standard deviation about regression line	Correlation coefficient	t-test of c % probability
		m slope	c intercept			
Wet Relaxation	c.p.i. = $\frac{10.2}{\ell} - 6.390$	0.1380	0.6332	1.3370	0.995	0.05
	w.p.i. = $\frac{2.66}{\ell} + 1.520$	0.0518	0.2340	0.4949	0.990	0.07
	S = $\frac{26.80}{\ell^2} - 10.500$	0.3632	8.7760	32.5450	0.995	23.00
Tumble Dry	c.p.i. = $\frac{8.96}{\ell} + 0.210$	0.1080	0.4220	1.0510	0.996	80.00
	w.p.i. = $\frac{2.66}{\ell} + 2.240$	0.0883	0.4051	0.8560	0.971	0.03
	S = $\frac{25.50}{\ell^2} + 54.200$	0.3778	9.1290	33.8580	0.994	0.07

a constant, the intercept being of a higher value than that obtained in the wet relaxed condition. As would be expected, therefore, the k_s value is not a constant in this case.

As the k values are not generally constants, their dependence upon ℓ may be observed by plotting graphs of k value, (where k_c = c.p.i. x ℓ , k_w = w.p.i. x ℓ , $k_s = S \times \ell^2$), against stitch length. The graphs confirm the results from the statistical analysis and show as follows -

(i) The k_c value decreases with increase in ℓ in the wet relaxed condition, but is constant in the tumble dry state.

(ii) The k_w value increases with ℓ in both relaxation conditions, the tumble dry condition showing the greater increase.

(iii) The k_s value is constant in the wet relaxed condition, but increases with increase in value of ℓ in the tumble dry condition.

The graphs for the tumble dry condition are shown in Fig. 56.

c) k_r values

The k_r value $(\frac{\text{c.p.i.}}{\text{w.p.i.}})$ in the tumble dry condition is shown plotted against ℓ in Fig. 57. Statistical examination shows that the ratio of courses to wales per unit area is not a constant in the wet relaxed or tumble dry condition, (Table 4). In the wet relaxed condition the value varies from 3.2 to 2.4 decreasing with increase in stitch length. In the tumble dry condition, the variation is less, being from 3.0 to 2.6 decreasing with increase in stitch length.

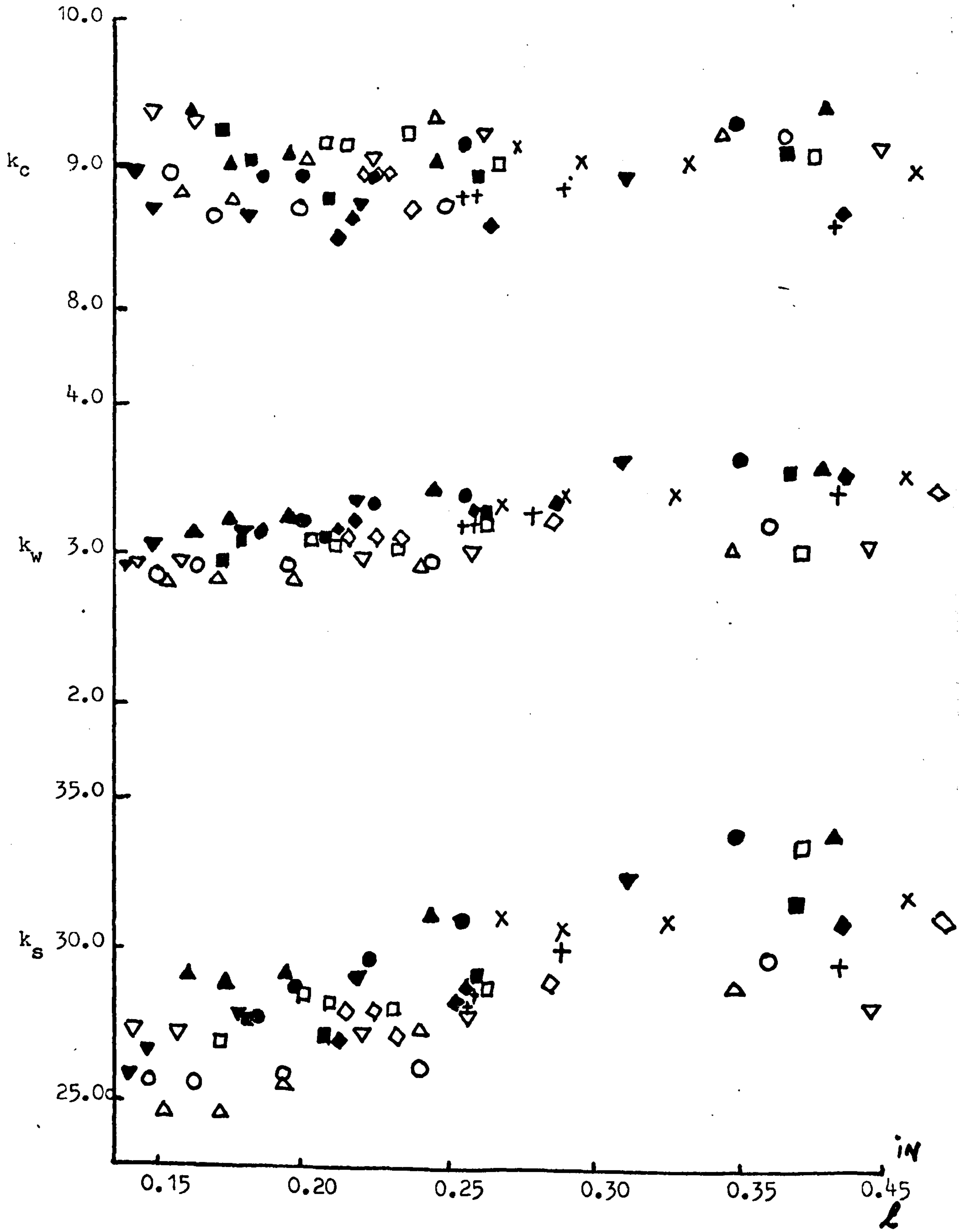


Fig. 56 Tumble Dry Relationship between k_c, k_w and k_s and ℓ

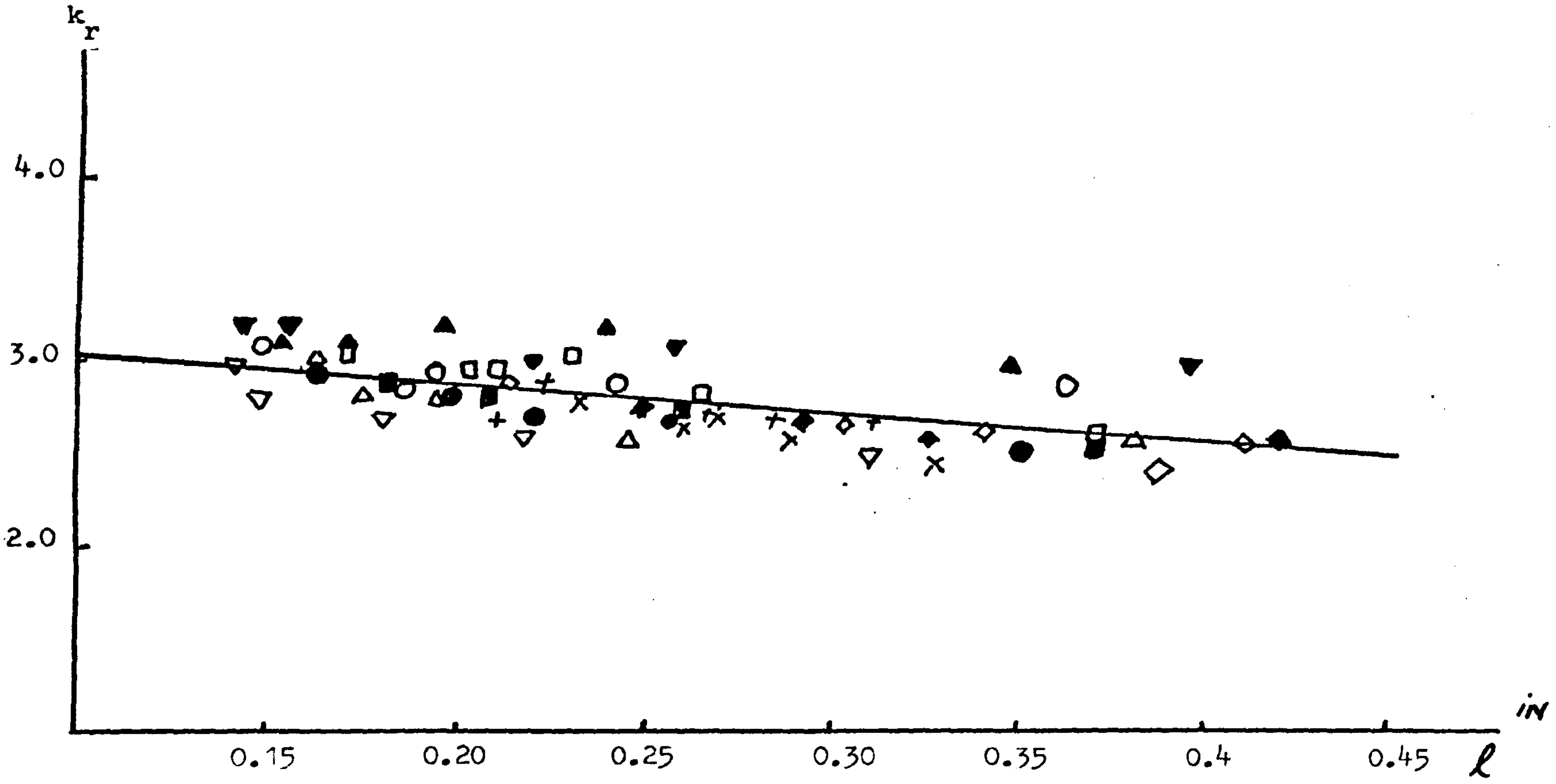


Fig. 57 Tumble Dry Relationship between k_r and ℓ

TABLE 4

Regression Analysis - k_r against ℓ

Relaxation Condition	Regression Equation	Standard error of		Standard deviation about regression line	Correlation coefficient	% probability of correlation coefficient
		m	c			
Wet Relaxed	$k_r = -3.22 \quad + 3.65$	0.3213	0.1117	0.1873	-0.804	***
Tumble Dry	$k_r = -1.61 \quad + 3.22$	0.2808	0.0343	0.1634	-0.611	***

*** - Significantly different from a horizontal line at the 0.1% level

TABLE 5

Count Analysis - Wet Relaxed Condition

All yarns separately

Yarn Count	c.p.i. / $\frac{1}{\ell}$			w.p.i. / $\frac{1}{\ell}$			S / $\frac{1}{\ell^2}$		
	Slope	Intercept	Corr. Coeff.	Slope	Intercept	Corr. Coeff.	Slope	Intercept	Corr. Coeff.
1/8	10.60	-7.91	0.982	3.12	0.461	0.996	30.1	-37.60	0.995
1/12	9.67	-4.18	0.997	2.87	0.383	0.998	26.4	-13.12	0.999
1/16	11.01	-9.48	0.997	2.59	1.910	0.993	28.2	-27.50	0.999
1/20	10.10	-7.38	0.999	2.71	0.628	0.999	25.9	-36.71	1.000
1/24	9.86	-4.21	0.999	2.72	0.467	0.999	26.1	-20.44	0.999
1/28	10.70	-7.44	0.995	2.81	0.433	0.997	28.3	-44.50	0.999
2/16	10.50	-7.75	0.997	2.87	1.020	0.996	28.5	-26.91	0.999
2/24	9.41	-3.88	0.999	2.68	1.682	0.999	25.9	3.97	0.999
2/32	10.50	-8.09	0.999	2.75	1.260	0.999	28.2	-35.33	0.999
2/40	9.60	-2.73	0.997	2.59	2.01	0.998	26.2	20.22	0.999
2/48	10.54	-6.22	0.998	2.81	1.47	0.998	28.8	-2.30	0.998
2/56	10.00	-7.38	0.998	2.55	2.40	0.998	26.5	-8.23	0.998

TABLE 5 (Continued)

Resultant counts

Yarn Count	c.p.i. $/\frac{1}{\ell}$			w.p.i. $/\frac{1}{\ell}$			S $/\frac{1}{\ell^2}$		
	Slope	Intercept	Corr. Coeff.	Slope	Intercept	Corr. Coeff.	Slope	Intercept	Corr. Coeff.
1/8 + 2/16	10.50	-7.73	0.991	2.92	0.969	0.992	28.9	-28.50	0.997
1/12 + 2/24	9.54	-3.98	0.997	2.80	0.910	0.991	26.2	- 5.97	0.998
1/16 + 2/32	10.60	-8.21	0.997	2.70	1.471	0.997	28.1	- 2.96	0.999
1/20 + 2/40	9.69	-4.24	0.993	2.58	1.64	0.991	25.1	12.90	0.994
1/24 + 2/48	10.10	-5.04	0.997	2.73	1:15	0.999	27.0	- 2.81	0.989
1/28 + 2/56	10.33	-6.63	0.994	2.73	1.10	0.994	27.4	-28.70	0.998

Single Yarns

Singles	10.30	-6.60	0.995	2.61	1.42	0.991	26.5	-16.22	0.996

Folded yarns

Two-fold	10.20	-6.11	0.995	2.69	1.66	0.997	27.2	- 5.01	0.996

Allyarns

All yarns	10.2	-6.39	0.995	2.66	1.52	0.990	26.8	-10.50	0.995

TABLE 6

Count Analysis - Tumble Dry Condition

All yarns separately

Yarn Count	c.p.i. / $\frac{1}{\ell}$			w.p.i. / $\frac{1}{\ell}$			S / $\frac{1}{\ell^2}$		
	Slope	Intercept	Corr. Coeff.	Slope	Inter-cept	Corr. Coeff.	Slope	Inter-cept	Corr. Coeff.
1/8	9.41	-0.984	1.000	3.06	1.13	1.000	30.4	7.95	1.000
1/12	8.97	-0.113	0.998	2.70	1.89	0.999	26.6	26.64	0.999
1/16	8.96	0.995	0.999	2.51	2.73	0.994	26.3	45.84	0.999
1/20	8.64	1.123	0.998	2.68	1.43	0.999	24.7	31.43	1.000
1/24	8.31	3.531	0.999	2.60	1.41	1.000	23.5	55.02	0.999
1/28	9.58	-1.442	0.999	2.83	0.66	1.000	27.3	3.98	1.000
2/16	9.12	-1.083	0.999	3.01	1.10	0.995	28.1	13.90	0.998
2/24	8.44	0.761	0.999	2.76	2.20	0.999	21.7	124.00	0.996
2/32	9.17	-0.510	0.997	2.54	2.81	0.996	26.2	44.32	0.999
2/40	8.40	2.870	0.999	2.61	3.08	0.997	25.5	81.71	0.999
2/48	9.11	0.474	0.997	2.79	2.35	0.997	27.8	48.60	1.000
2/56	8.82	-0.024	0.998	2.45	4.59	0.914	24.7	87.30	1.000

TABLE 6 (Continued)

Resultant counts

Yarn Count	c.p.i. $/\frac{1}{\ell}$			w.p.i. $/\frac{1}{\ell}$			S $/\frac{1}{\ell^2}$		
	Slope	Intercept	Corr. Coeff.	Slope	Intercept	Corr. Coeff.	Slope	Intercept	Corr. Coeff.
1/8 + 2/16	8.99	-0.119	0.994	2.99	1.27	0.996	28.3	20.50	0.994
1/12 + 2/24	8.70	0.385	0.995	2.74	1.98	0.992	24.4	70.11	0.990
1/16 + 2/32	9.03	0.411	0.997	2.55	2.64	0.995	26.2	46.02	0.999
1/20 + 2/40	8.50	2.114	0.998	2.51	2.87	0.977	24.0	81.30	0.993
1/24 + 2/48	8.68	2.113	0.996	2.64	2.12	0.962	25.1	62.91	0.982
1/28 + 2/56	9.12	-0.402	0.994	2.78	1.86	0.946	26.2	38.02	0.999

Singles yarns

Singles	8.97	0.412	0.996	2.55	2.21	0.991	25.1	46.20	0.996

Two-fold yarns

Two-fold	8.97	-0.060	0.995	2.76	2.30	0.973	25.9	62.30	0.996

All yarns

All yarns	8.96	0.210	0.996	2.66	2.24	0.971	25.5	54.20	0.994

2. Yarn Count

Although there was no apparent effect of yarn count on the knitted parameters, some workers in the weft knitting field[62] have suggested from time to time that count may have an effect. To ~~thoroughly~~ investigate thoroughly this fact, regression analysis of c.p.i. and w.p.i. against ℓ and S against ℓ^2 was performed as follows -

a) On each yarn separately.

b) On resultant counts, i.e. on each singles yarn with its equivalent two-fold yarn.

c) On all singles yarns

d) On all two-fold yarns.

This analysis was performed in both the wet relaxed and tumble dry conditions and is shown in Tables 5 and 6 from which the following conclusions can be drawn: -

a) Each yarn separately

A high correlation coefficient was obtained for each yarn showing that a definite relationship existed with c.p.i. and w.p.i. with $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$. Observation of both the slope of the regression line and the intercept revealed that a variation in their individual values existed, but this variation was very scattered and showed no relationship with count.

b) Resultant counts

These results also gave high correlation coefficients, showing again a good relationship between the two parameters for each regression equation.

The values of both slope and intercept contained a variation in value, but this variation was again scattered and showed no relationship with count.

c) & d) Singles and Two-fold yarns

A high correlation coefficient was obtained both for the singles and the two-fold yarns.

A small difference exists between the slopes and intercepts of the two regression lines and, since Knapton[62] drew his conclusions from a singles and two-fold yarn, it was decided to analyse if, in fact, any difference did exist between these two.

This was performed by analysing the slope and the intercept of each parameter in each relaxation condition. This analysis is shown in Tables 7 and 8. It will be noted that in all cases the Students' t-test gives a value well in excess of 5% for both slope and intercept.

From this analysis, it can be concluded that count and ply of yarn have no effect on the k values as calculated in the wet relaxed and tumble dry conditions, i.e. for a given value of ℓ the fabric parameters, c.p.i., w.p.i. and stitch density are not affected by yarn count or ply.

3. Comparison of Results with those given in Chapter V

The values obtained for the slope and the intercept of the regression equation for c.p.i. and w.p.i. against $\frac{1}{\ell}$ and S against

TABLE 7

Slope Analysis - Difference between Singles and Two Fold

Relaxation Condition	Regression Equation	Standard error of slope		"Average" variance about regression line	Variance of difference between slopes	Students 'T' Test % probability that slopes are same
		Singles	Folded			
Wet Relaxation	c.p.i. / $\frac{1}{\ell}$	0.0627	0.0634	0.4319	0.0896	30
	w.p.i. / $\frac{1}{\ell}$	0.0679	0.0410	0.3950	0.0818	99
	S / $\frac{1}{\ell^2}$	0.4580	0.4790	29.6000	0.6648	35
Tumble Dry	c.p.i. / $\frac{1}{\ell}$	0.1550	0.1690	1.2206	0.2292	100
	w.p.i. / $\frac{1}{\ell}$	0.0664	0.1290	0.6775	0.1406	12
	S / $\frac{1}{\ell^2}$	0.4328	0.4560	28.0900	0.6307	24

TABLE 8

Intercept Analysis - Difference between Singles and Folded

Relaxation Condition	Regression Equation	Standard error of Intercept		Variance of the difference between Intercepts	Students 'T' Test % probability that intercepts are same
		Singles	Folded		
Wet Relaxation	c.p.i. / $\frac{1}{\ell}$	0.2840	0.2910	0.5086	26%
	w.p.i. / $\frac{1}{\ell}$	0.3084	0.1883	0.2494	60%
	s / $\frac{1}{\ell^2}$	11.0240	11.4920	1.8134	90%
Tumble Dry	c.p.i. / $\frac{1}{\ell}$	0.7037	0.7757	0.8155	30%
	w.p.i. / $\frac{1}{\ell}$	0.3015	0.5908	0.6317	90%
	s / $\frac{1}{\ell^2}$	10.4260	10.9452	1.7622	80%

$\frac{1}{\ell^2}$ for the set of 57 samples are different from those obtained for the set of 16 samples in Chapter V. This comparison is shown in Table 9.

a) Wet relaxed condition

These two sets of results can be shown to be statistically different, so that they must be treated separately. It will be noted from Table 9 that the significance of the intercept for the c.p.i. and w.p.i. against $\frac{1}{\ell}$ was very much less in the case of 57 samples than for the 16. Whereas in the case of the 16 samples the level of significance was in the 5% to 10% range which suggests a 1 in 20 chance of being different from zero, the level for the 57 samples is such as to indicate that the intercept is not significantly different from zero. This illustrates the point that a probability in the 5% to 10% range should be treated with caution. Since the second set is obtained from 57 samples, as opposed to 16, these have been accepted as the more accurate.

The intercept obtained from S against $\frac{1}{\ell^2}$ is not significantly different from zero and therefore may be recalculated to pass through zero.

The final relationships between the knitted parameters and the stitch length in the wet relaxed condition are -

$$\text{c.p.i.} = \frac{10.2}{\ell} - 6.39$$

$$\text{w.p.i.} = \frac{2.66}{\ell} + 1.52$$

$$S = \frac{26.25}{\ell^2}$$

$$\frac{\text{c.p.i.}}{\text{w.p.i.}} = -3.22\ell + 3.65$$

TABLE 9

Comparison of Results of the two Experiments - 16 samples and 57 samples

Relaxation Condition		Slope		Intercept		Student 'T' Test	
		16	57	16	57	16	57
Wet Relaxation	c.p.i. / $\frac{1}{\ell}$	9.07	10.20	-3.550	-6.39	6.0%	00.05%
	w.p.i. / $\frac{1}{\ell}$	2.75	2.66	0.492	1.52	10.0%	00.07%
	S / $\frac{1}{\ell^2}$	24.60	26.80	-17.200	-10.50	15.0%	23.00%
Tumble Dry	c.p.i. / $\frac{1}{\ell}$	8.71	8.96	0.347	0.21	70.0%	80.00%
	w.p.i. / $\frac{1}{\ell}$	2.84	2.66	1.660	2.24	0.1%	0.03%
	S / $\frac{1}{\ell^2}$	26.60	25.50	29.600	54.20	2.5%	0.07%

Some small differences are to be expected due to the different number of samples used in the experiments. Also it was shown in Chapter V that the wet relaxed condition, consisting only of a static soak, is not the completely relaxed condition which accounts for the discrepancy between the two sets of results in the wet relaxed state.

b) Tumble dry condition

Observation of Table 9 shows that the slope and intercept obtained in the regression analysis of the set of 57 samples is very similar to those obtained for the set of 16 samples. Analysis of the two sets of results, (Table 10), shows that statistically they are the same, therefore, they may be added together to give a final result from 72 samples. The results obtained from this addition are -

$$\text{c.p.i.} = \frac{8.88}{\ell} + 0.33$$

$$\text{w.p.i.} = \frac{2.70}{\ell} + 2.13$$

$$S = \frac{25.64}{\ell^2} + 52.46$$

$$\frac{\text{c.p.i.}}{\text{w.p.i.}} = -1.61\ell + 3.22$$

It can be shown that the intercept of c.p.i. against $\frac{1}{\ell}$ is not significantly different from zero and, therefore, the slope may be recalculated to pass through zero. The intercepts for w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$ are, however, statistically different from zero. Therefore, the final relationships between

TABLE 10

Intercept and Slope Analysis - 16 and 57 samples

		Intercept Analysis				Slope Analysis				
Relaxation Condition	Regression equation	New Slope	New Intercepts		Students 'T' test probability that intercepts are same	Standard error of slope		"Average" variance about regression	Variance of difference between slopes	Students 'T' test probability that slopes are same
			16 samples	56 samples		16 samples	56 samples			
Tumble Dry	c.p.i. / $\frac{1}{\ell}$	8.909	0.59	0.42	38%	0.2336	0.1090	0.790	0.1820	40%
	w.p.i. / $\frac{1}{\ell}$	2.690	2.35	2.13	80%	0.0836	0.0890	1.075	0.2476	30%
	s / $\frac{1}{\ell^2}$	25.710	49.50	49.10	90%	0.4498	0.0120	31.700	0.8030	15%

the knitted parameters and the stitch length in the tumble dry state are -

$$\text{c.p.i.} = \frac{8.95}{\ell}$$

$$\text{w.p.i.} = \frac{2.70}{\ell} + 2.13$$

$$S = \frac{25.60}{\ell^2} + 52.50$$

$$\frac{\text{c.p.i.}}{\text{w.p.i.}} = -1.61\ell + 3.22$$

PART II FELTING RESULTS

I. EXPERIMENTAL DETAILS

For this work, the same 57 samples were used as in Part I of this chapter and the experimental details of sample size, marking and measuring of samples, machine control, etc. were as used in Chapter V.

1. Yarn Counts

These were as in Part I of this chapter.

2. Felting Treatments

a) Half hour Cubex

The fabrics were washed in a Cubex Washer in order to assess the felting characteristics of the fabrics. The test consisted of treating a 1 kilogram load, (500 gram. samples plus 500 gram. make-weight), in a 25 litre solution of 4.5 grams/litre Sodium di-hydrogen phosphate and 9 grams/litre of Di-sodium phosphate at 40°C.

b) One hour Cubex

This treatment involved a further half hour Cubex as (a) above.

c) One and a half hours Cubex

This treatment involved a further half hour Cubex as (b) above.

d) Two hours Cubex

This treatment involved a further half hour Cubex as (c) above.

The samples were hydro-extracted for 15 minutes and then tumble dried after each Cubex operation at 70°C for half an hour and the fabrics measured dry on a flat surface.

3. Measurement of Fabric Parameters

All fabric parameters were measured in the manner described in II (4) Chapter V.

For the 57 samples produced, the details of yarn count, stitch length, w.p.i., c.p.i., k values for the various felting treatments are given in Appendix 2.

II. DISCUSSION OF RESULTS

1. k_c, k_w and k_s Values

By plotting the graphs of w.p.i. and c.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$ in the same manner as for the unfelted fabrics, it is possible to see the effect of stitch length on the fabric dimensions after felting. Similar relationships were obtained for each of the washing treatments and as an example graphs are shown in Figs. 58 to 60 for the one hour Cubex treatment only. It may be seen from these graphs that the results separate themselves according to count. This separation increases with increase in washing time. It is also apparent that the k_c, k_w and k_s values vary greatly with ℓ because very large intercepts are obtained and that these values, (k_c, k_w and k_s), will themselves be count dependent as each count has a different intercept. This is illustrated in graphs of k_c, k_w and k_s plotted against ℓ, Figs. 61 to 63, showing that the k values vary vastly with ℓ and

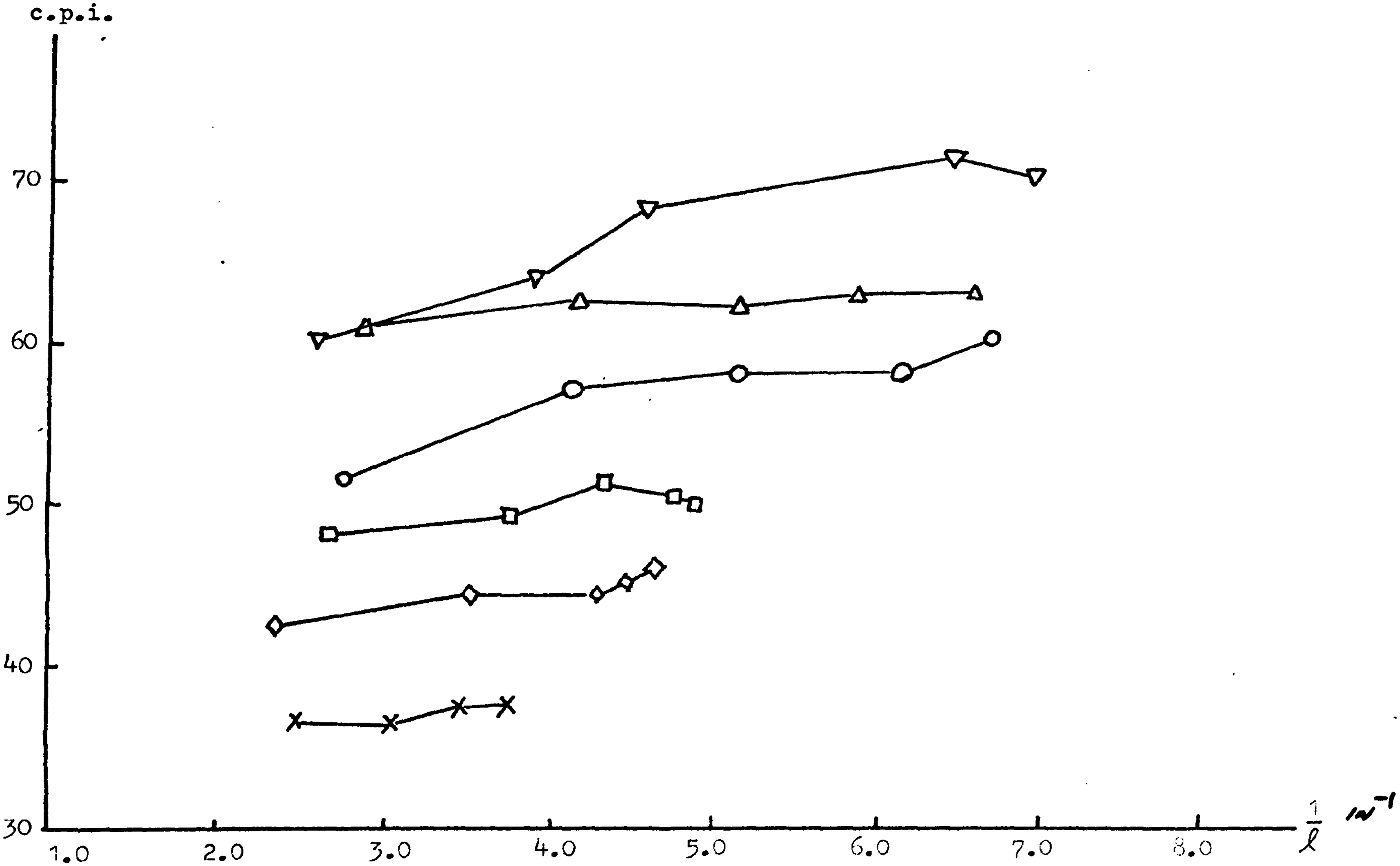


FIG. 58

Relationship between c.p.i. and $\frac{1}{\ell}$ ~~and~~ in the one hour Cubex condition

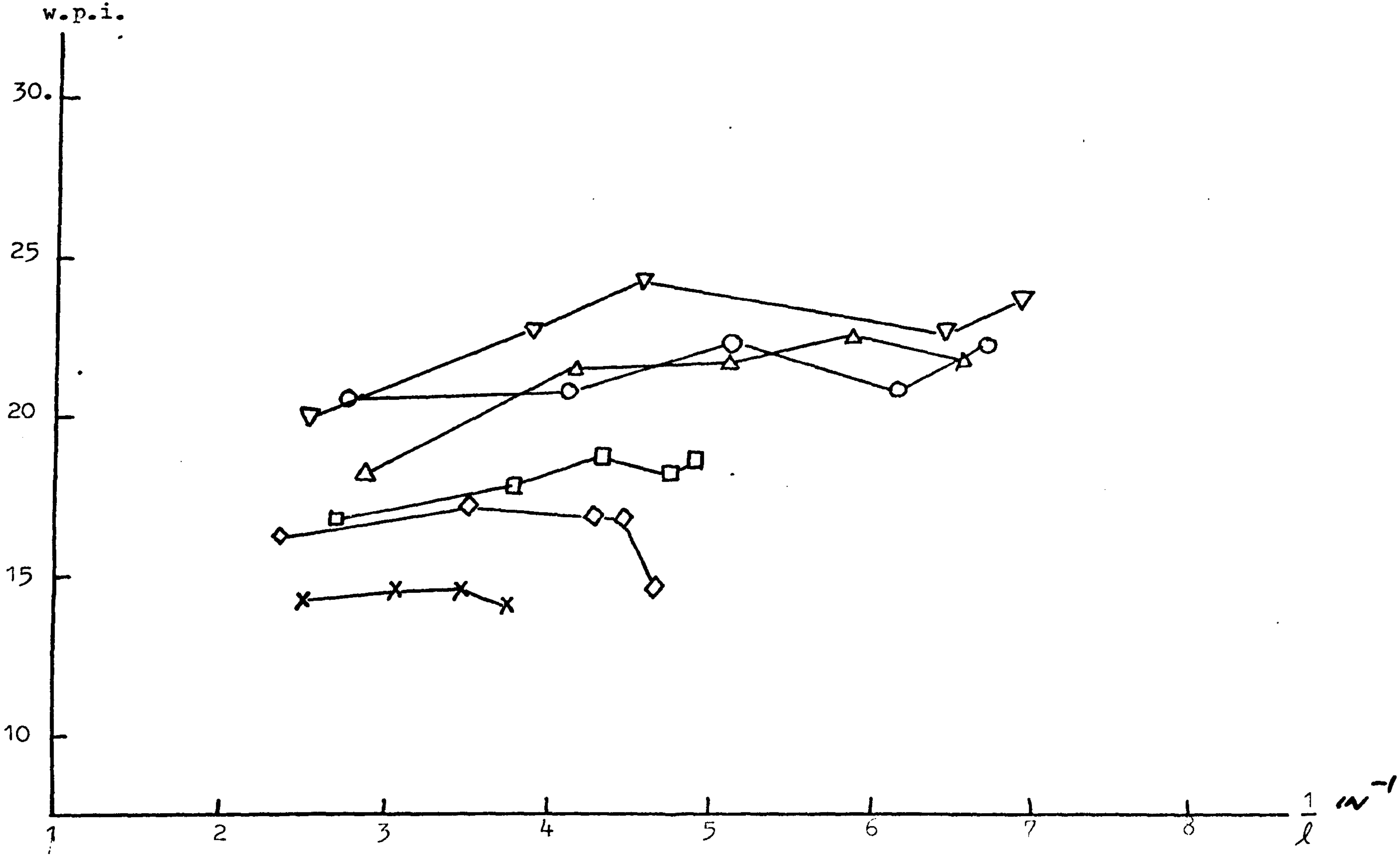


FIG. 59

Relationship between c.p.i. and $\frac{1}{\ell}$ in the one hour Cubex condition

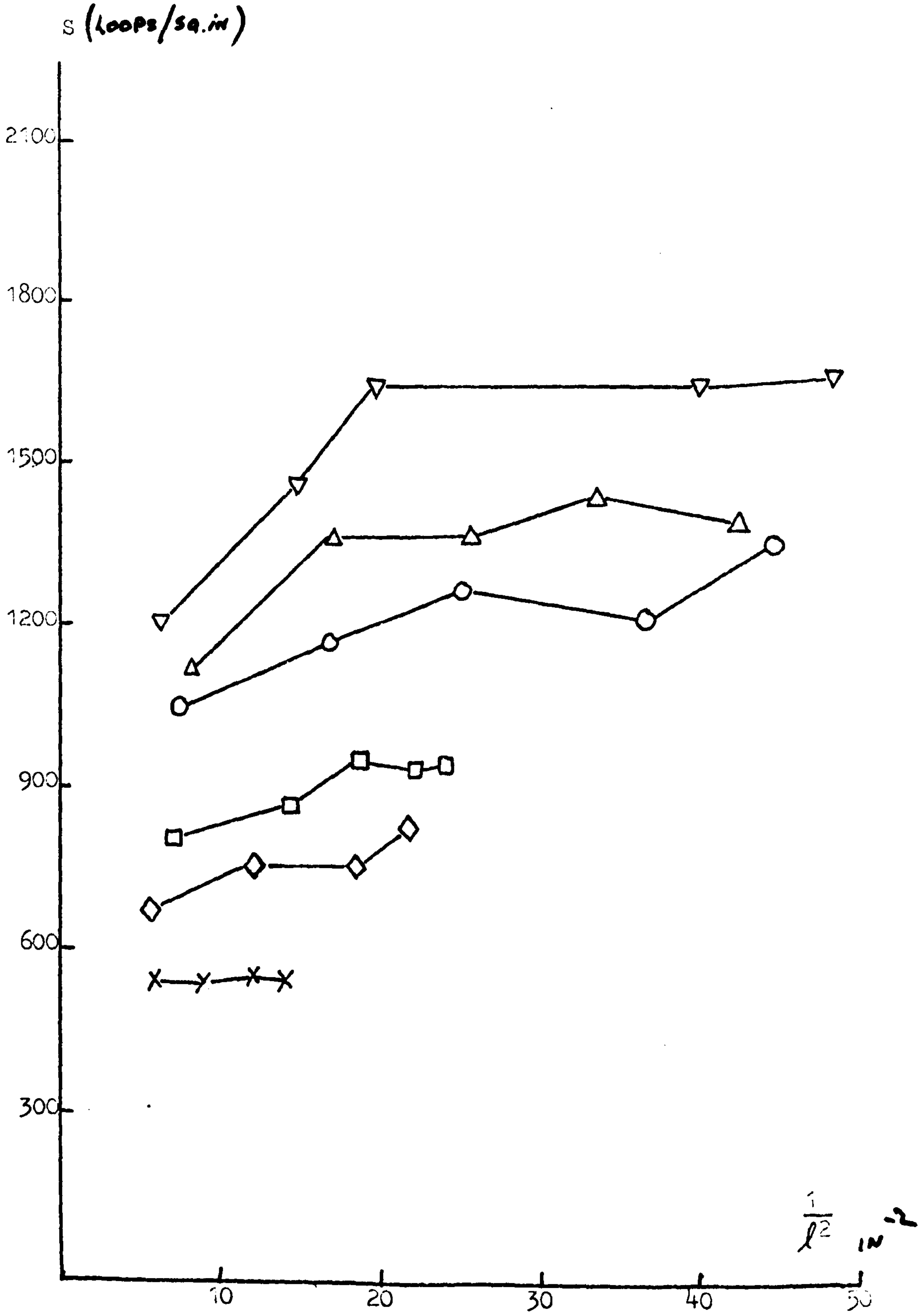


FIG. 60

Relationship between stitch density and

$\frac{1}{l^2}$ in the one hour Cubex condition

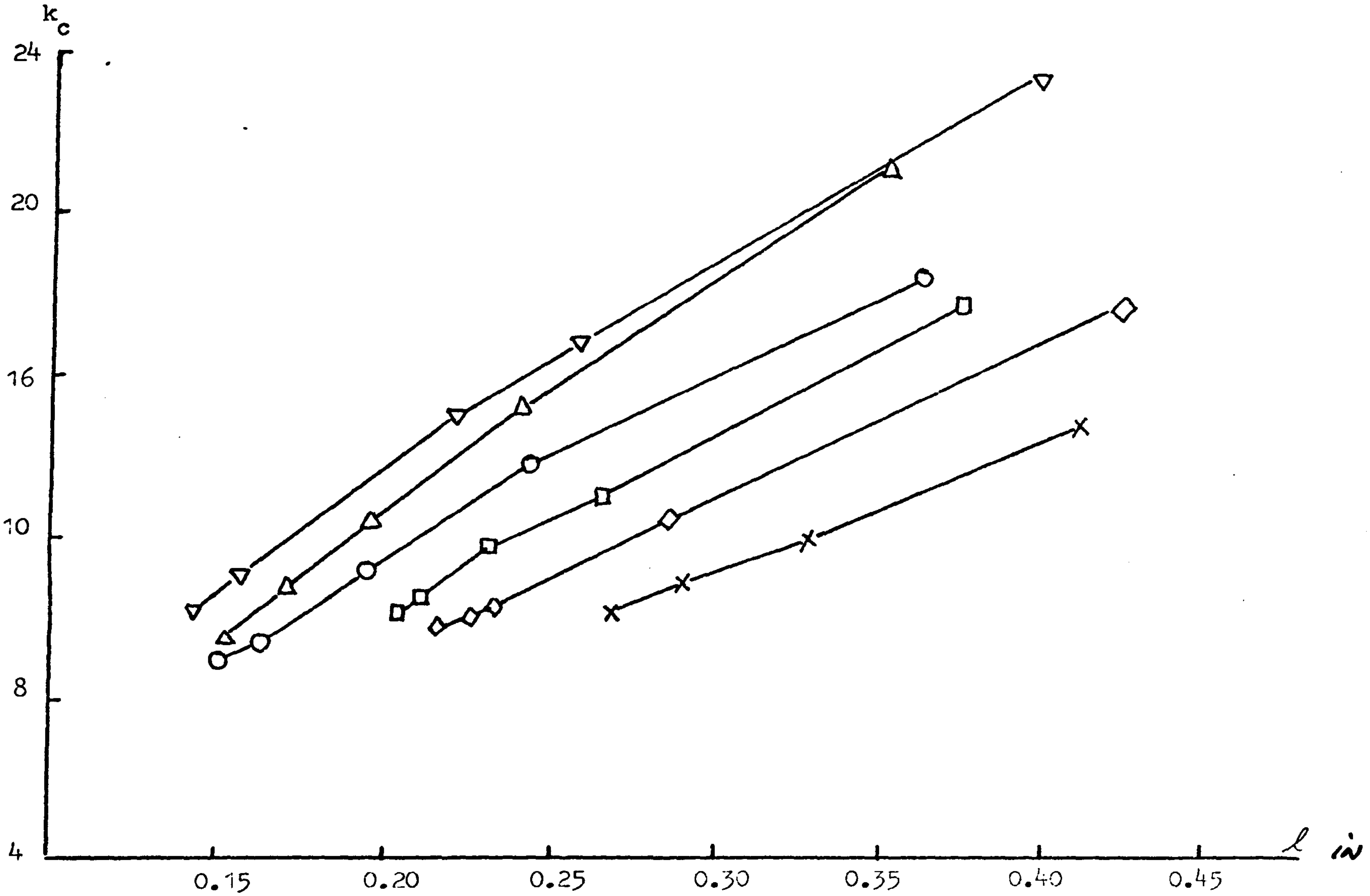


FIG. 61

Relationship between k_c and stitch length in the one hour Cubex condition

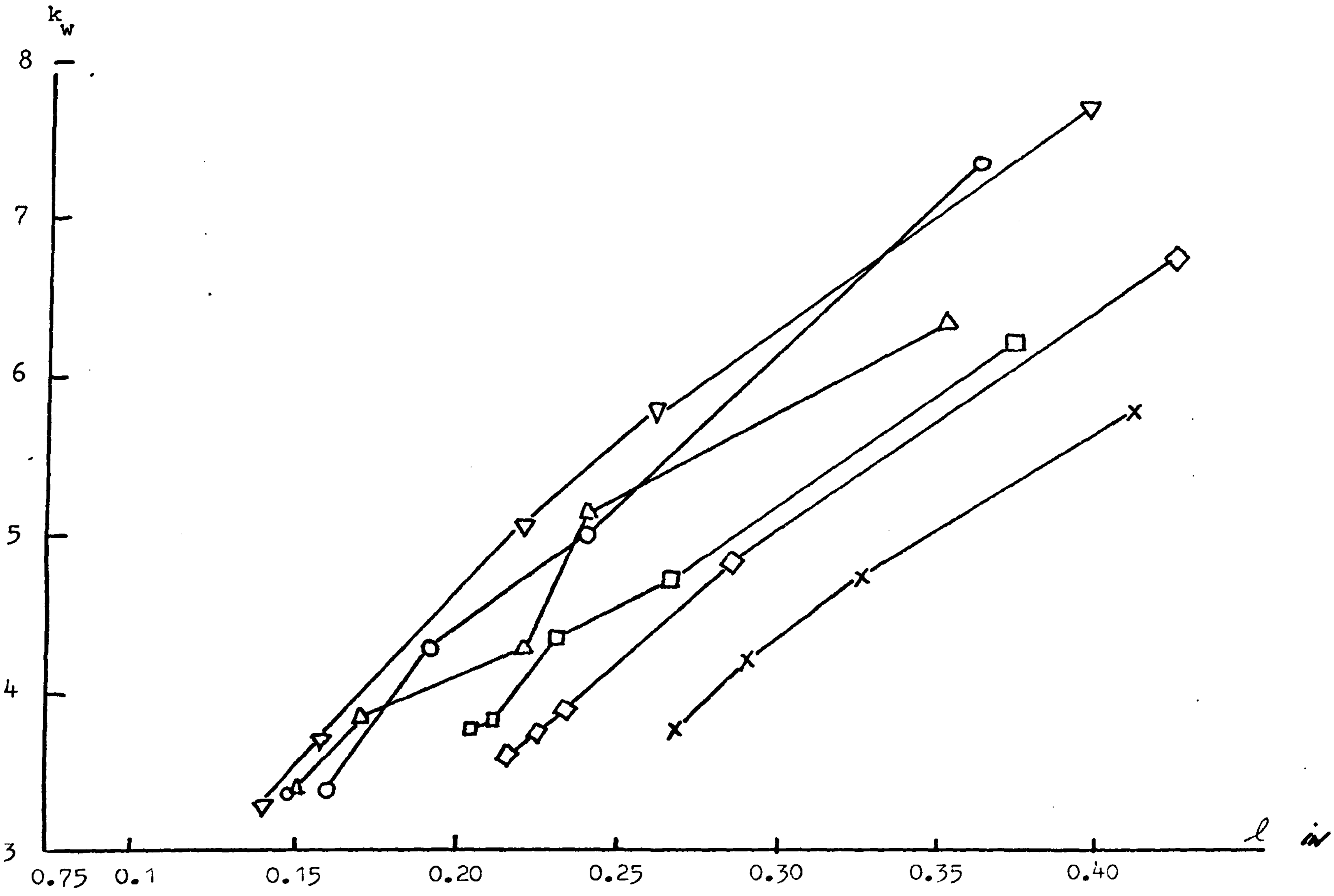


FIG. 62

Relationship between k_w and the stitch length in the one hour Cubex condition

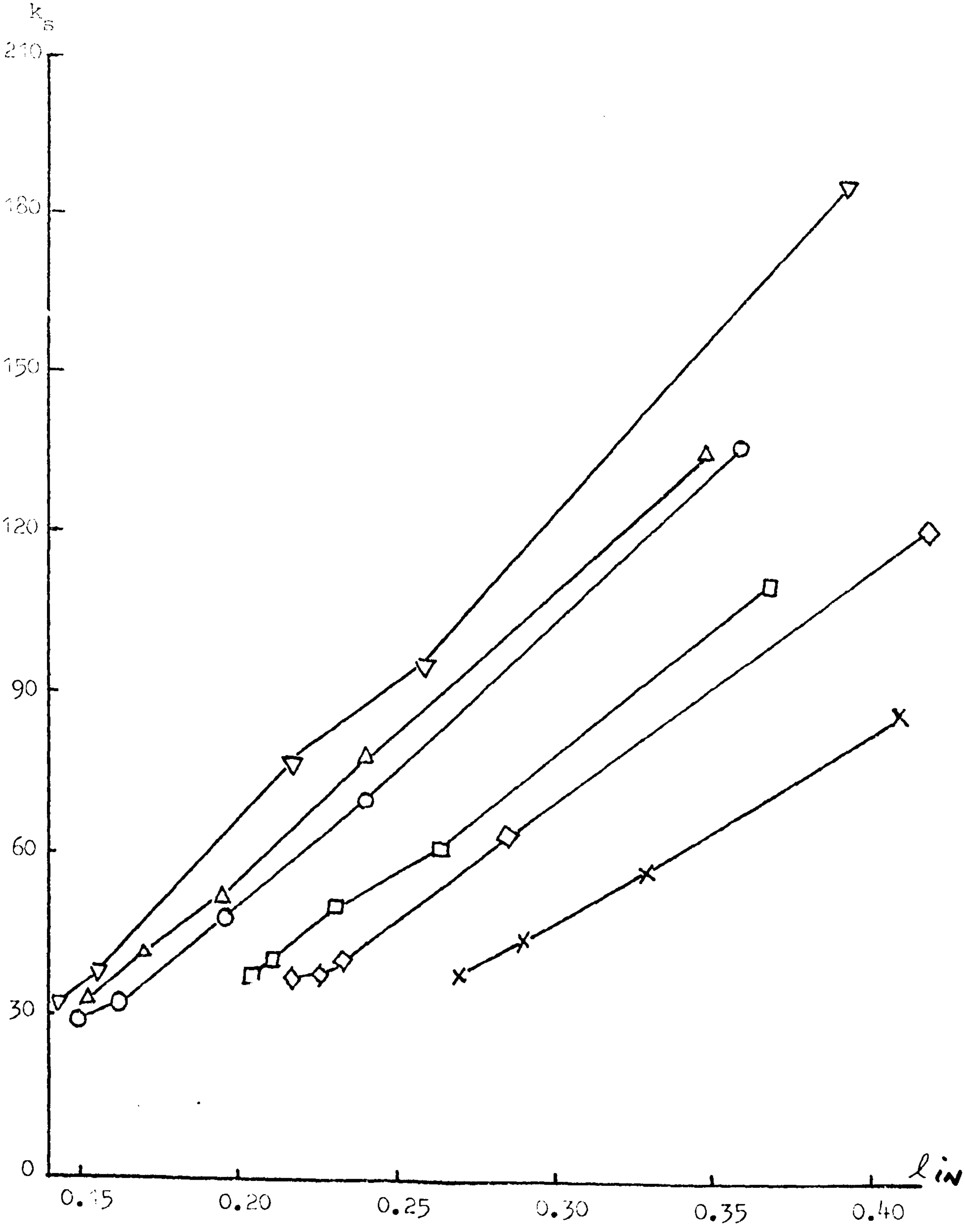


FIG. 63

Relationship between k_s and stitch length in the one hour Cubex condition

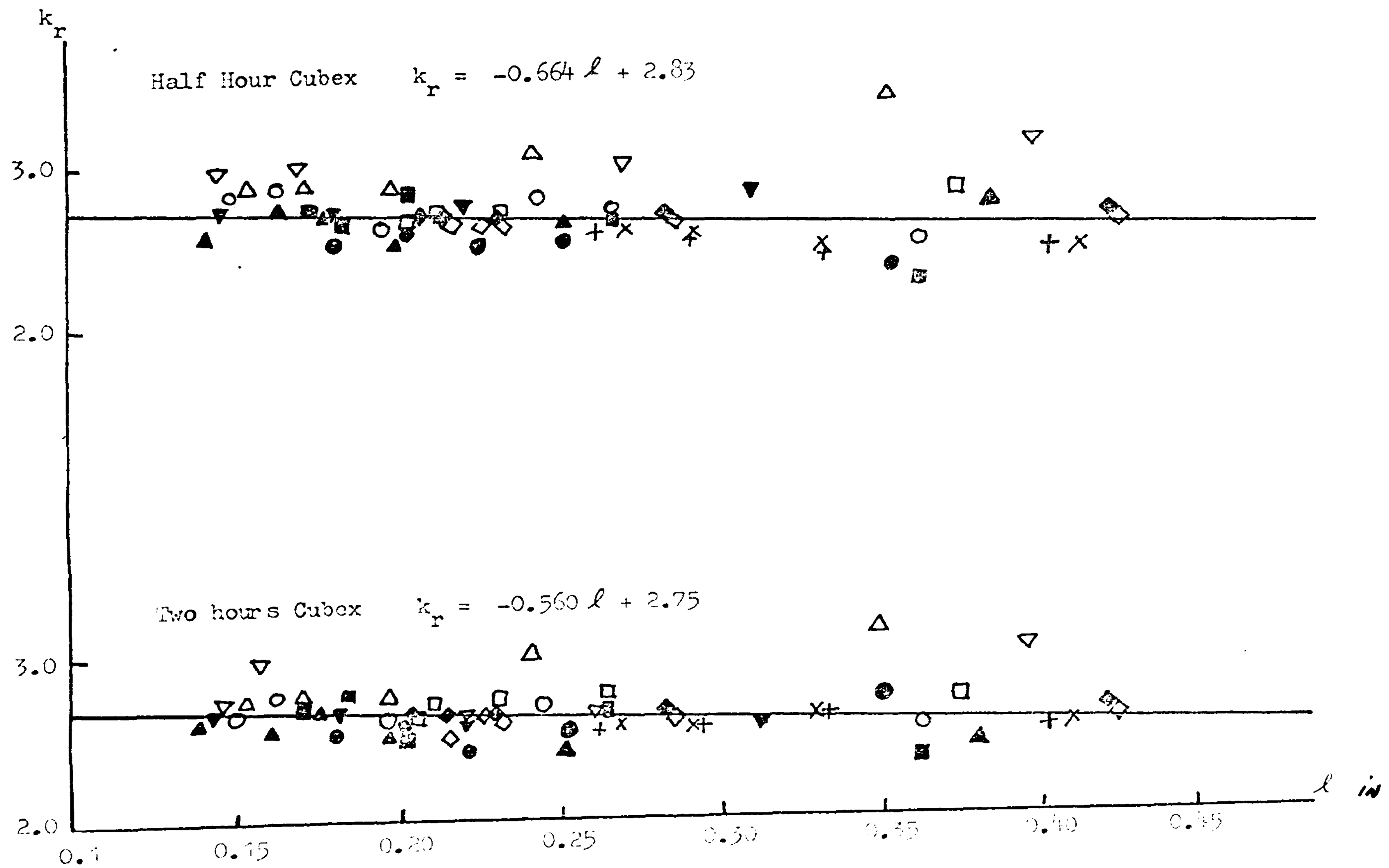


FIG. 64

Relationship between k_r and ℓ in the half hour and two hour Cubex condition that they are, in fact, count dependent.

These results are in general accord with similar investigations conducted on weft knitted wool fabrics.

2. k_r Values

Once the fabrics have become felted, the k_r value becomes constant. This is shown in Fig. 64 which illustrates the relationship between k_r and ℓ in the half hour Cubex and the two hour Cubex conditions. Table 11 shows the regression analysis for these parameters in all felting conditions and it will be seen that in fact there is no correlation between the two parameters in any of the felting states. Thus, the average k_r value may be taken as the operative value.

Further analysis of the k_r values shows that there is no statistical difference between the largest and smallest average value. Thus, it may be concluded that once the fabric has become felted, its k_r value is constant and that value is 2.69.

3. Cover Factor

Marfatia[73] states in his study of the plain weft knitted construction that the felting properties are dependent on the cover factor rather than an individual effect of stitch length or count. To investigate this, the k values were plotted against $\ell\sqrt{n},$ (i.e. the reciprocal of cover factor). The resulting graphs for the two hour Cubex are shown in Figs. 65 to 67. It will be observed that the points now fall in a single line for all the yarn counts showing that after each felting treatment the

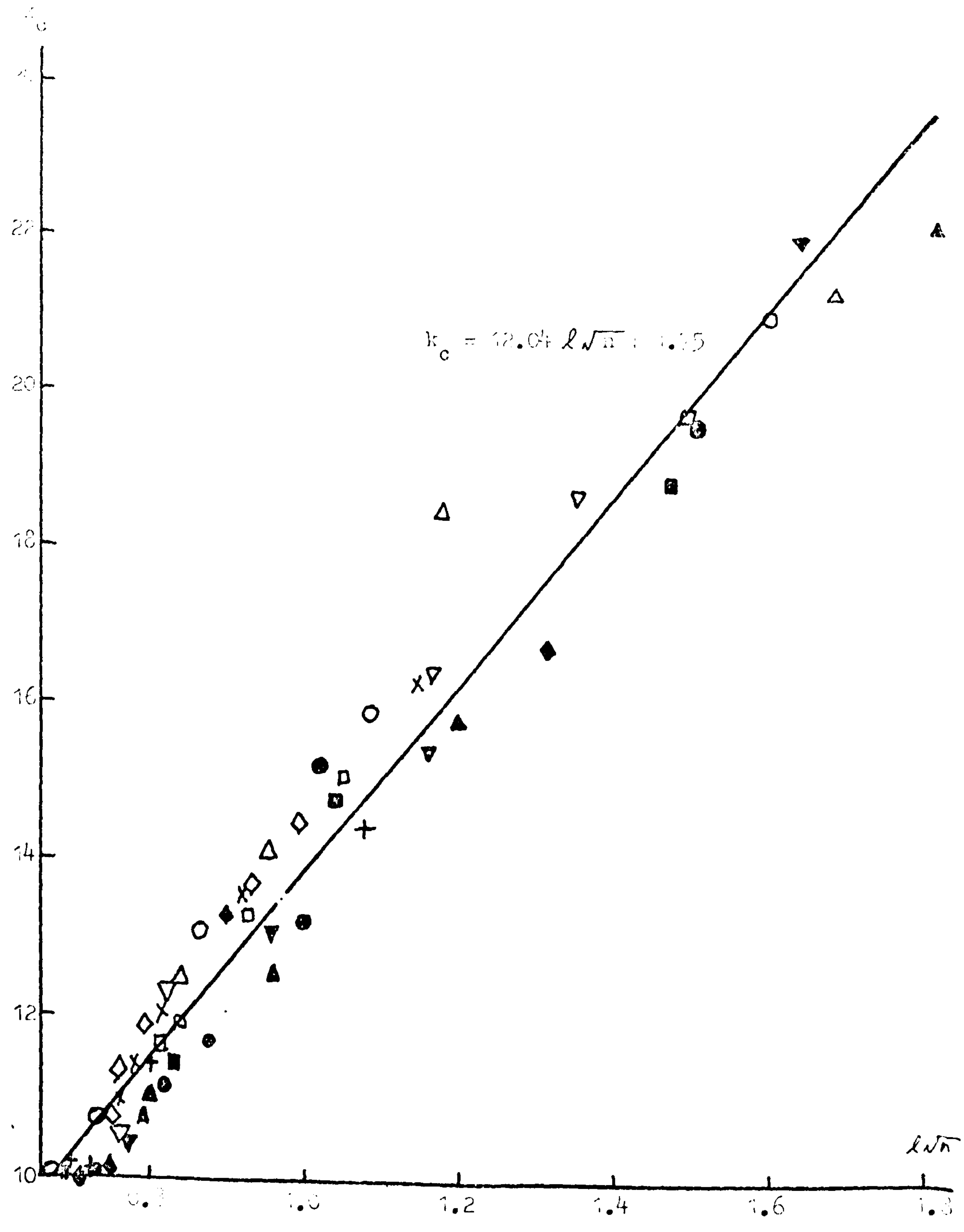


FIG. 65

Relationship between k_c and $\ell\sqrt{n}$ in the two hours Cubex condition

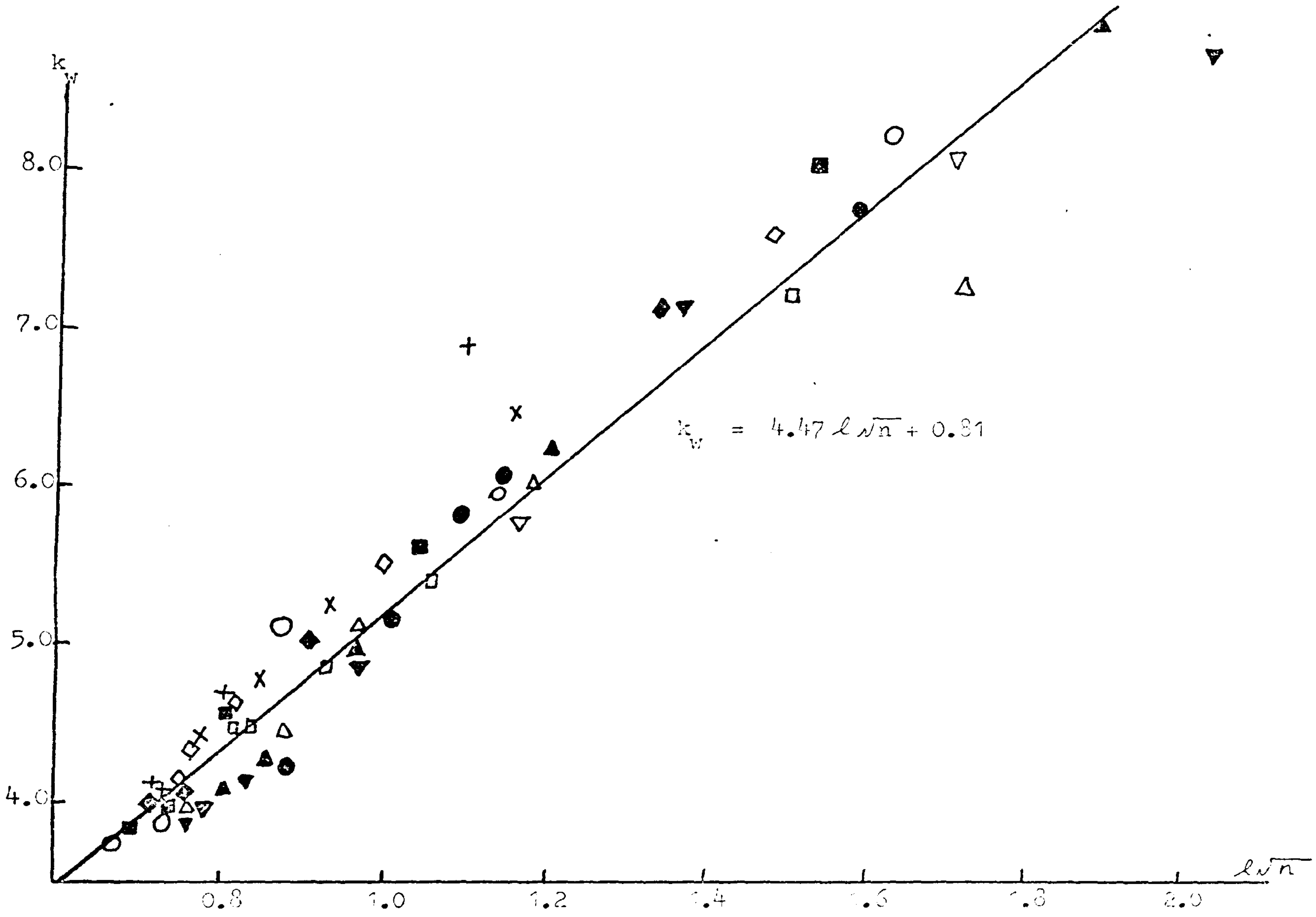


FIG. 66

Relationship between k_w and $\ell\sqrt{n}$ in the two hour Cubex condition

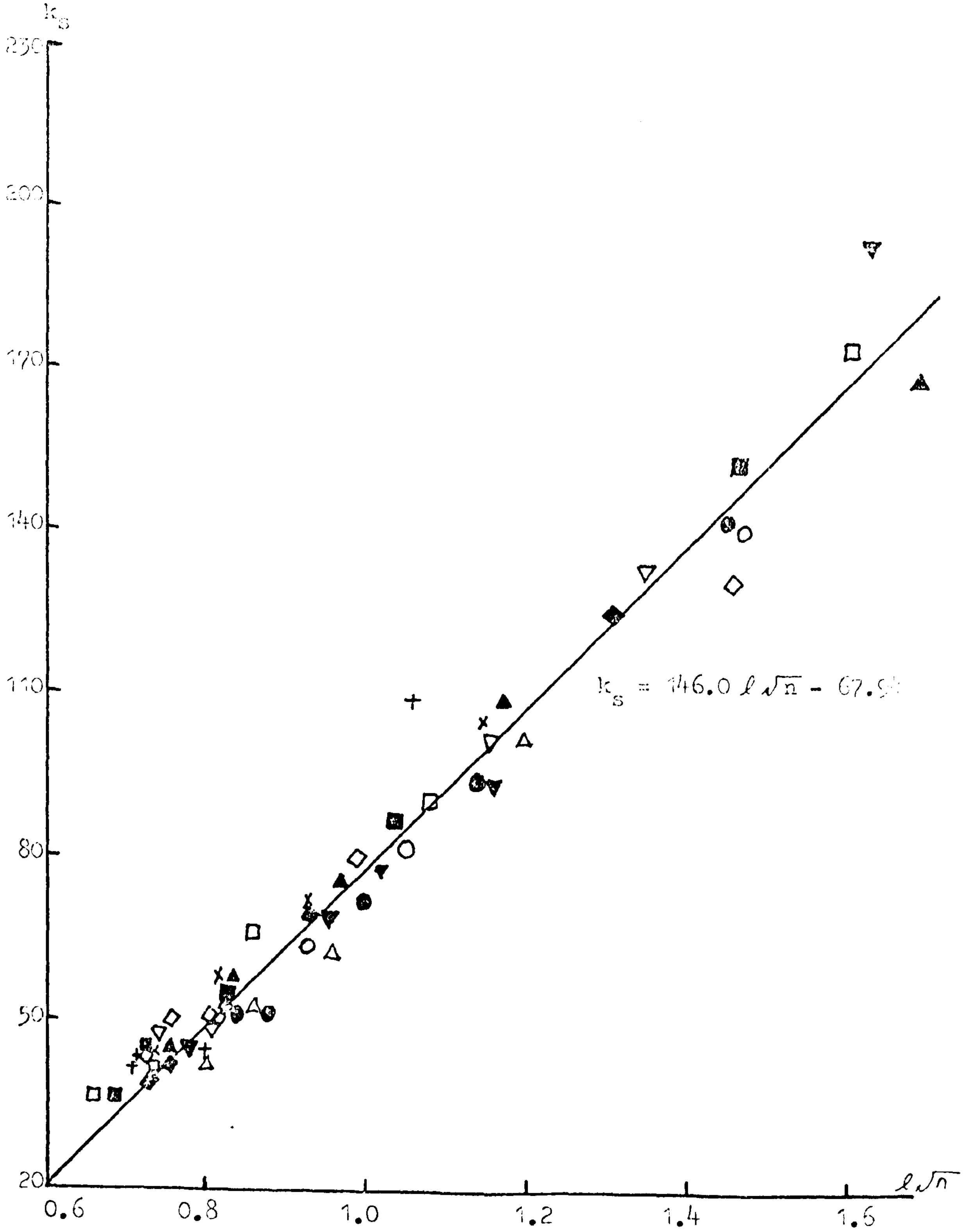


FIG. 67

Relationship between k_s and $\ell\sqrt{n}$ in the two hours Cubex condition

TABLE 11

Regression Analysis - k_r against

Relaxation Condition	Regression equation	Standard Error of		Standard deviation about regression line	Corr. Coeff.	% probability of corr. coeff.	Average kr value
		m	c				
½ hr. Cubex	$k_r = -0.664\ell + 2.83$	0.577	0.068	0.337	-0.241	n.s.	2.706
1 hr. Cubex	$k_r = -0.607\ell + 2.81$	0.942	0.099	0.549	-0.174	n.s.	2.711
1½ hr. Cubex	$k_r = -0.640\ell + 2.81$	0.775	0.085	0.452	-0.202	n.s.	2.699
2 hr. Cubex	$k_r = -0.560\ell + 2.75$	0.578	0.069	0.337	-0.204	n.s.	2.658

n.s. = Not significantly different from a horizontal line k values are independent of the individual count and are related only to the cover factor of the fabric. Table 12 gives the regression equation of the k values against $\ell\sqrt{n}$, and from this, it will be noted that the positive slope of the graph indicates the k value increases with decrease in cover factor; (k increases with increase of reciprocal of cover factor, see graphs). It will be noted that the slope of the line increases with increase in felting treatment. The angle of this slope, therefore, will give an indication of the amount of felting treatment a particular set of samples have received, but it will not indicate the degree of felting of any particular fabric. As Marfatia suggests, it is the k_s value which gives the best indication of the degree of felting of any particular fabric. It will be observed from the graphs that after each treatment, the slack fabrics have a high k_s value, while the tight fabrics have a low k_s value, indicating the increased felting of the slack fabric in comparison with the tight one. This effect may also be observed in Fig. 68 where the change of k_s with time of washing is plotted for a selection of the fabric samples. It will be noted that the individual curves separate on washing according to the reciprocal of cover factor, (i.e. $\ell\sqrt{n}$ value).

TABLE 12

Regression Equation of k_c, k_w and k_s against $\ell \sqrt{n}$

Condition	Parameter	Slope	Intercept	Corr. Coeff.
½ hr. Cubex	$k_c / \ell \sqrt{n}$	7.653	3.399	0.968
	$k_w / \ell \sqrt{n}$	2.641	1.522	0.916
	$k_s / \ell \sqrt{n}$	65.430	-16.900	0.899
1 hr. Cubex	$k_c / \ell \sqrt{n}$	10.433	1.834	0.974
	$k_w / \ell \sqrt{n}$	3.719	0.894	0.955
	$k_s / \ell \sqrt{n}$	105.100	-44.828	0.931
1½ hr. Cubex	$k_c / \ell \sqrt{n}$	11.460	1.621	0.977
	$k_w / \ell \sqrt{n}$	3.950	1.014	0.934
	$k_s / \ell \sqrt{n}$	128.740	-59.817	0.980
2 hr. Cubex	$k_c / \ell \sqrt{n}$	12.038	1.747	0.985
	$k_w / \ell \sqrt{n}$	4.467	0.814	0.977
	$k_s / \ell \sqrt{n}$	146.050	-67.940	0.991

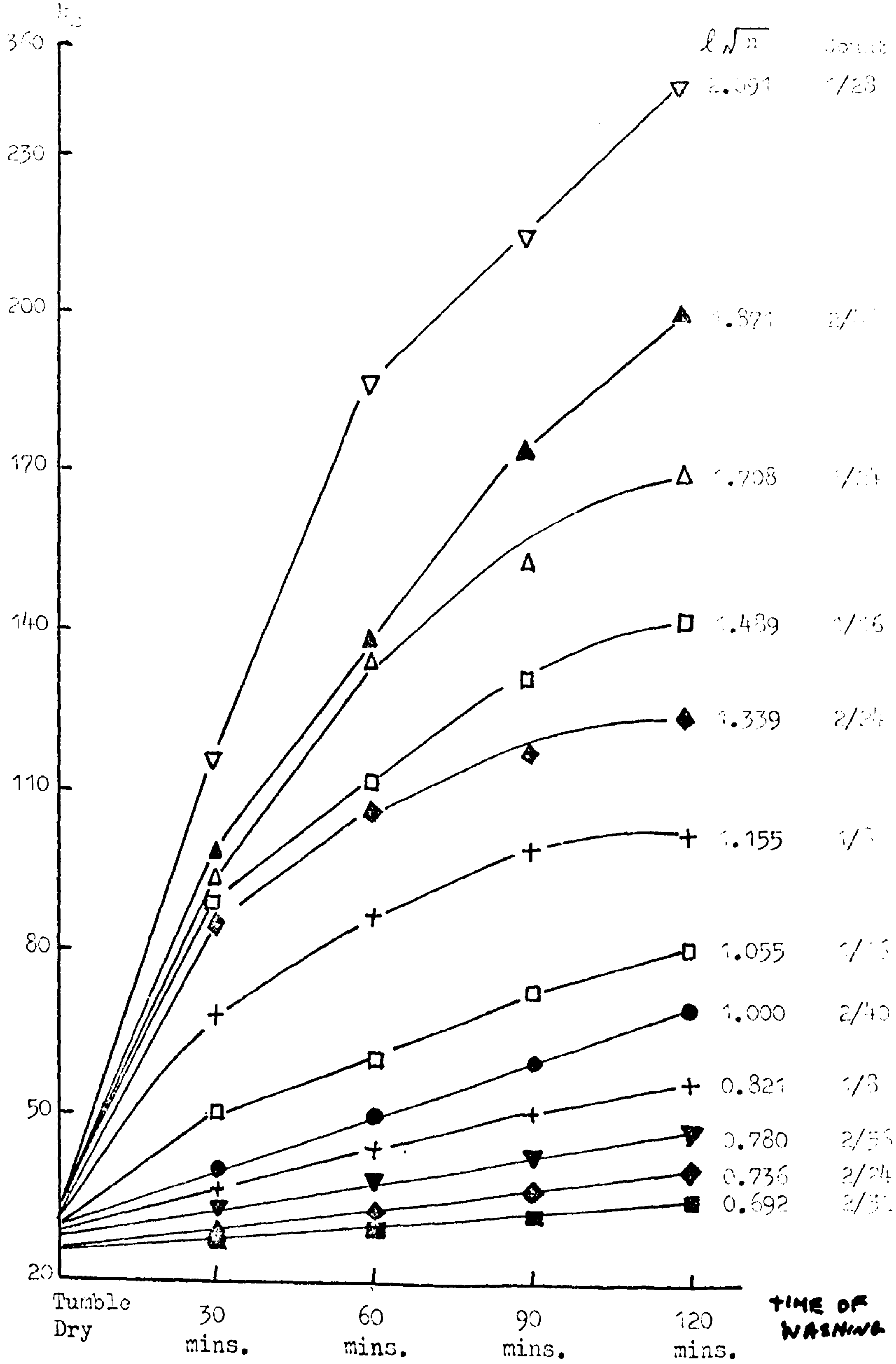


FIG. 68. Relationship between k_s and felting time. A selection of results showing the distribution of k_s according to reciprocal of cover factor ($\ell\sqrt{n}$)

CHAPTER VII

INVESTIGATION INTO DIMENSIONAL PROPERTIES OF 2 x 1, 3 x 1 AND 4 x 1 CLOSED LAP AND 1 x 1, 2 x 1, 3 x 1 AND 4 x 1 OPEN LAP CONSTRUCTIONS

I. INTRODUCTION

The basic constructions used in the production of warp knitted fabrics are simple regular lapping movements repeating on two courses in a manner similar to the 1 x 1 construction previously discussed except that the length of the underlap is changed to be 2, 3 or 4 needles. Such fabrics are known as 2 x 1, 3 x 1 and 4 x 1. A further means by which the basic construction is varied is to make the underlap in the same direction as the preceding overlap so that open lap constructions are formed. It is the object of the work in this chapter to investigate the dimensional properties of 2 x 1, 3 x 1 and 4 x 1 closed lap and 1 x 1, 2 x 1, 3 x 1 and 4 x 1 open lap constructions.

II. EXPERIMENTAL DETAILS

For this work, a total of 84 samples was produced, 12 fabrics of each construction. Each set of 12 samples consisted of three stitch lengths of four yarn counts.

The experimental details of sample size, marking and measuring of samples, machine control, etc. were all as described in Chapter V.

1. Yarn Count

The yarn counts used for the 2 x 1, 3 x 1, 4 x 1 closed lap constructions were 1/12's, 2/32's, 1/20's and 2/48's worsted. (100% WOOL)

The yarn counts used for the 1 x 1, 2 x 1, 3 x 1 and 4 x 1 open lap constructions were 2/16's, 1/16's, 2/48's and 1/28's. (100% WOOL)

It was imperitive that all fabrics were produced from the same batch of yarns as those used for the 1 x 1 closed lap constructions so that all results would be comparable.

As there was insufficient yarn to produce the open lap and closed lap samples required for the work in this chapter from the same counts, different counts were used, it being anticipated that this would have no effect on the results to be investigated as shown in the case of the 1 x 1 closed lap construction, (Chapter VI). It was necessary to use different counts however to verify this.

2. Relaxation Treatment

Three relaxation treatments were investigated as follows -

a) Dry relaxed

b) Wet relaxed

c) Tumble dry relaxed

Details of these relaxation treatments were as described in Chapter V.

3. Measurement of Fabric Parameters

All fabric parameters were measured in the manner described in II. 2 Chapter V.

For the 84 samples produced, the details of yarn count, stitch length, w.p.i. and c.p.i., k values, etc. for each relaxation treatment are shown in Appendix 3.

III. DISCUSSION OF THE RESULTS FOR 2 x 1, 3 x 1 AND 4 x 1 CLOSED LAP CONSTRUCTIONS

The results of c.p.i. and w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$ for the dry relaxed, wet relaxed and tumble dry conditions for each separate fabric were analysed by regression analysis and the results for the slope and intercept are shown in Table 13.

The graphs for each construction in the tumble dry condition are shown in Figs. 76 to 80.

1. General Discussion

From the graphs and Table 13 it will be observed that the behaviour of the 2 x 1, 3 x 1 and 4 x 1 closed lap constructions is, in general terms, the same as that for the 1 x 1 closed lap construction, the following points being of note:-

Each graph consists of 12 points which represent three stitch lengths of four yarn counts. It will be observed that in all cases for a single construction all the points fall in a single line and there is no separation of the results in terms of yarn count. Thus it may be concluded that yarn count has no effect on the dimensional properties of these constructions, nor on the resulting parameters of c.p.i. and w.p.i.

The scatter of the points about the regression line decreases with each subsequent relaxation process showing that the fabrics

TABLE 13

Slope and Intercept for 2 x 1, 3 x 1 and 4 x 1 Closed Lap Structures in each Condition of Relaxation

	Relaxation Condition	c.p.i. against $\frac{1}{\ell}$			w.p.i. against $\frac{1}{\ell}$			S against $\frac{1}{\ell^2}$		
		2 x 1	3 x 1	4 x 1	2x 1	3x 1	4x 1	2 x 1	3x 1	4 x 1
Slope	Dry Relaxed	7.64	7.64	9.37	4.48	4.97	6.73	32.8	39.3	60.8
	Wet Relaxed	7.41	7.24	8.21	4.54	5.59	7.78	35.1	44.2	65.4
	Tumble Dry	7.15	7.49	8.77	5.14	6.11	8.29	40.4	52.1	78.8
Intercept	Dry Relaxed	-3.06	-1.76	-5.57	0.44	3.23	2.93	-19.8	29.3	-27.4
	Wet Relaxed	-2.61	-1.60	-3.73	3.01	5.15	4.41	10.6	42.7	- 9.0
	Tumble Dry	0.97	0.45	-2.24	2.72	5.50	5.27	41.3	75.3	19.0

Key to Figs. 76 - 86

▽ = 1/28's Worsted
○ = 1/20's Worsted
□ = 1/16's Worsted
◇ = 1/12's Worsted
▲ = 2/48's Worsted
■ = 2/32's Worsted
✚ = 2/16's Worsted
⊙ = Calculated Values

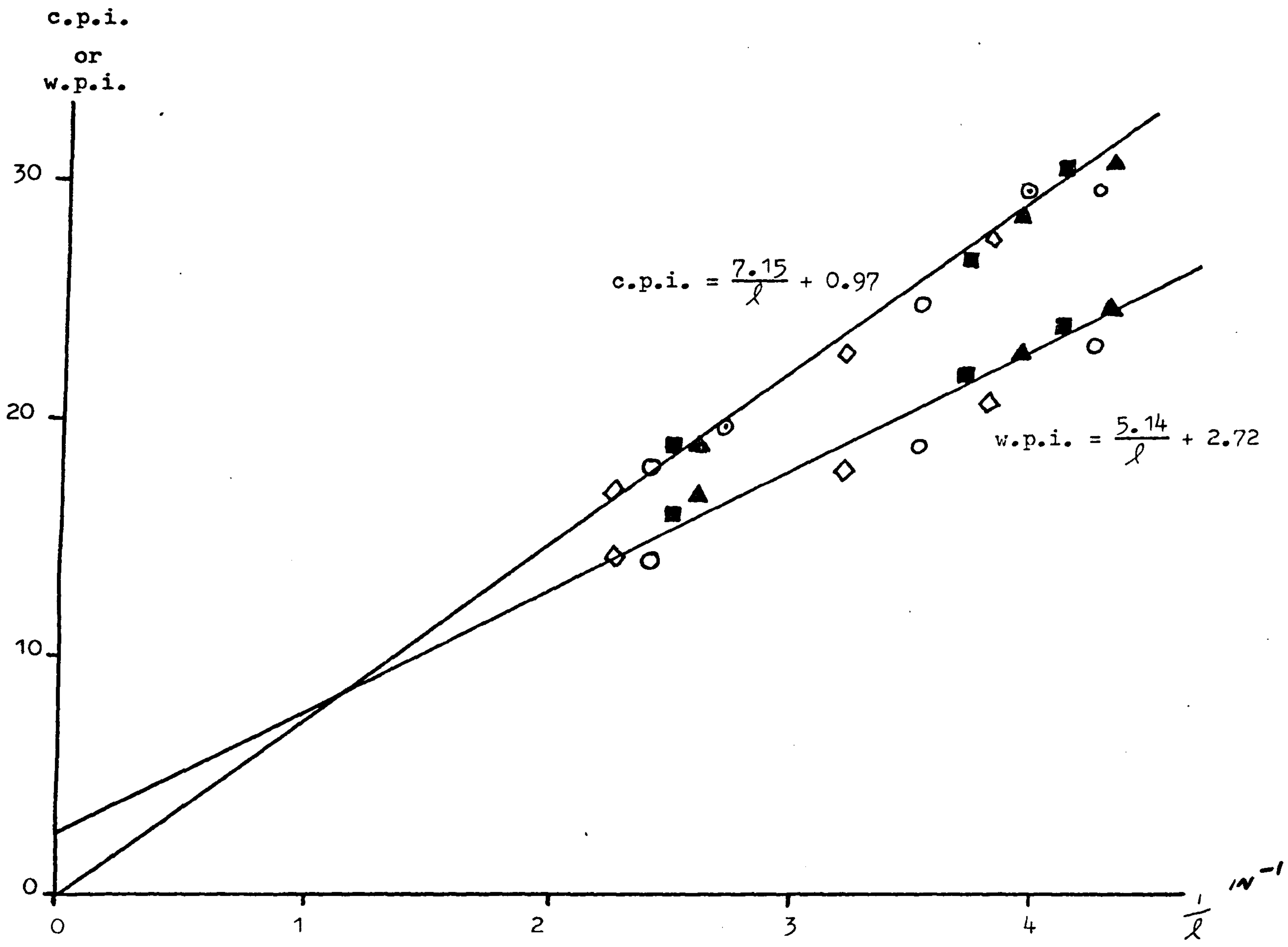


FIG. 76

Relationship between c.p.i. and w.p.i. against $\frac{1}{\ell}$ for 2 x 1 closed lap in tumble dry condition

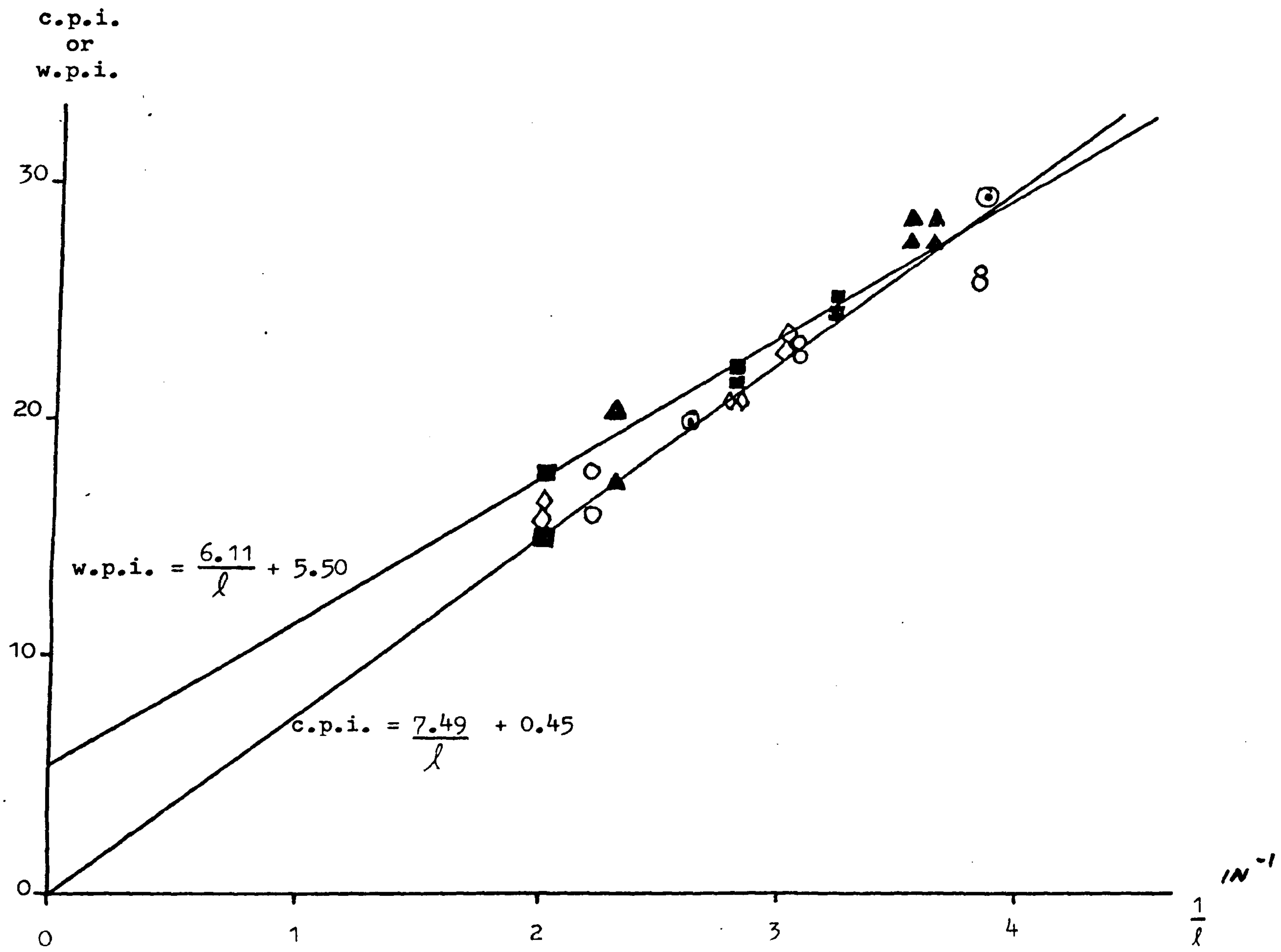


FIG. 77

Relationship between c.p.i. and w.p.i. against $\frac{1}{\ell}$ for 3 x 1 closed lap in tumble dry condition

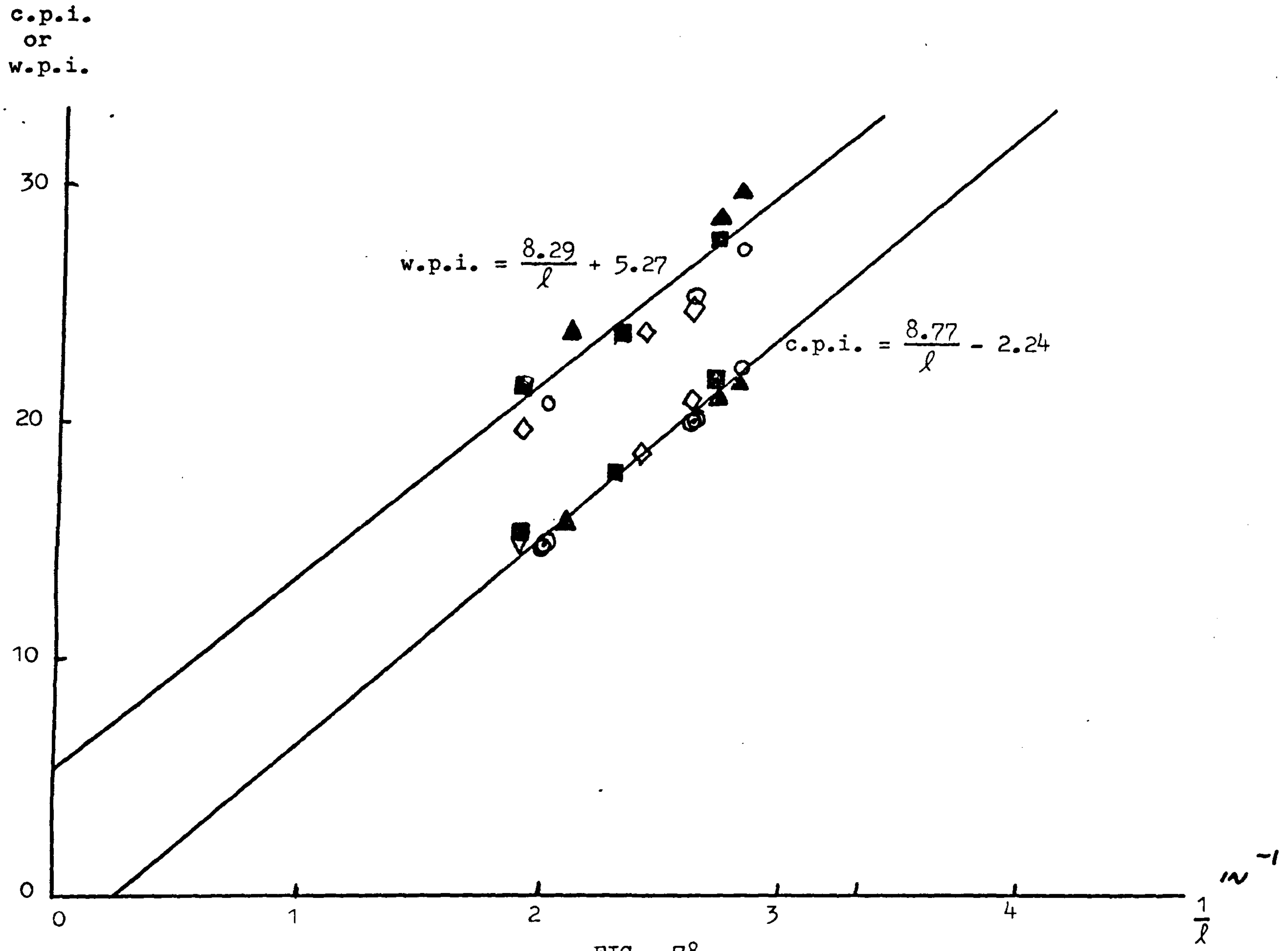


FIG. 78

Relationship between c.p.i. and w.p.i. against $\frac{1}{\ell}$ for 4 x 1 closed lap in tumble dry condition

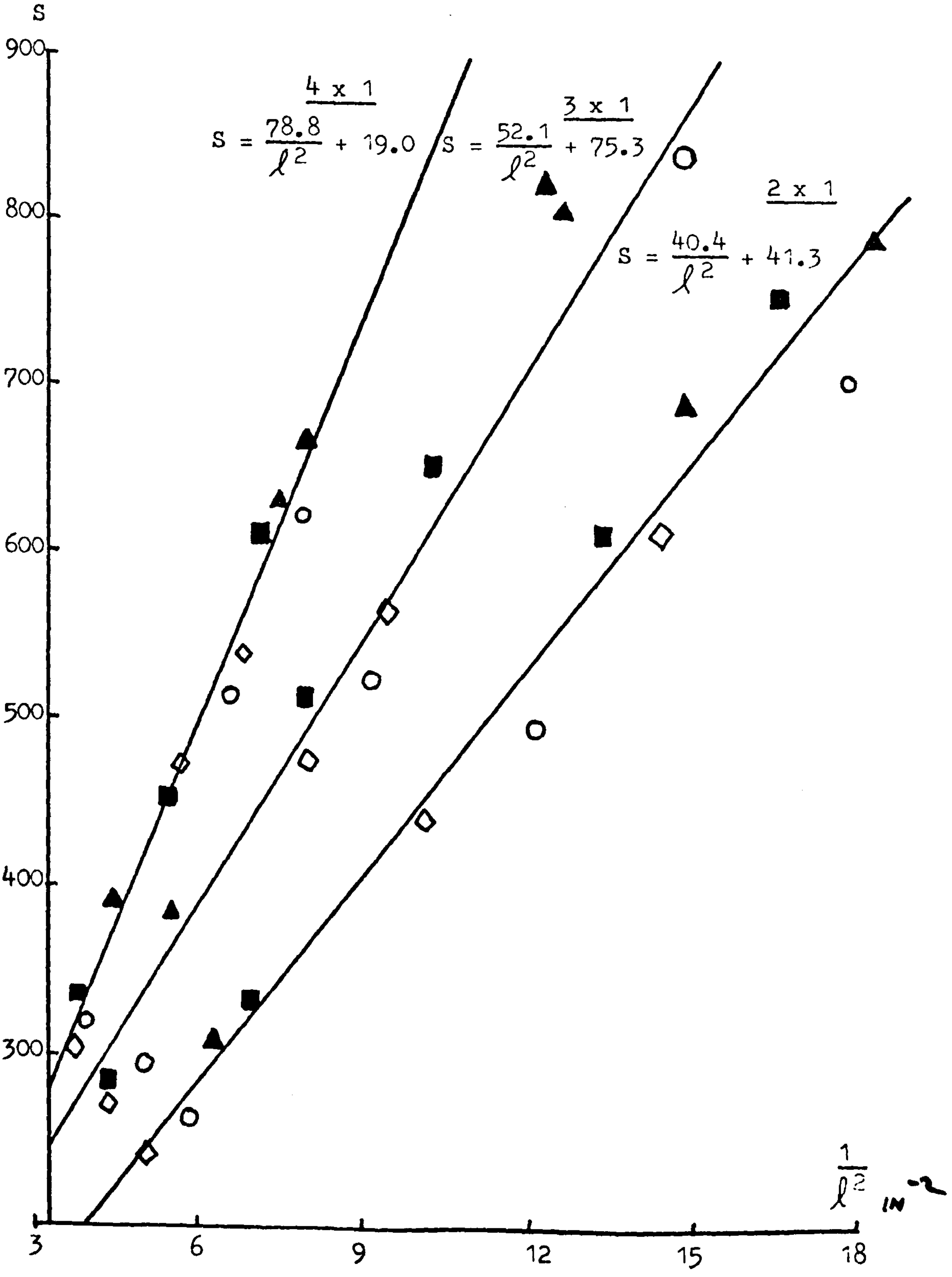


FIG. 79

Relationship between S and $\frac{1}{\ell^2}$ for 2 x 1, 3 x 1 and 4 x 1 closed laps in the tumble dry condition

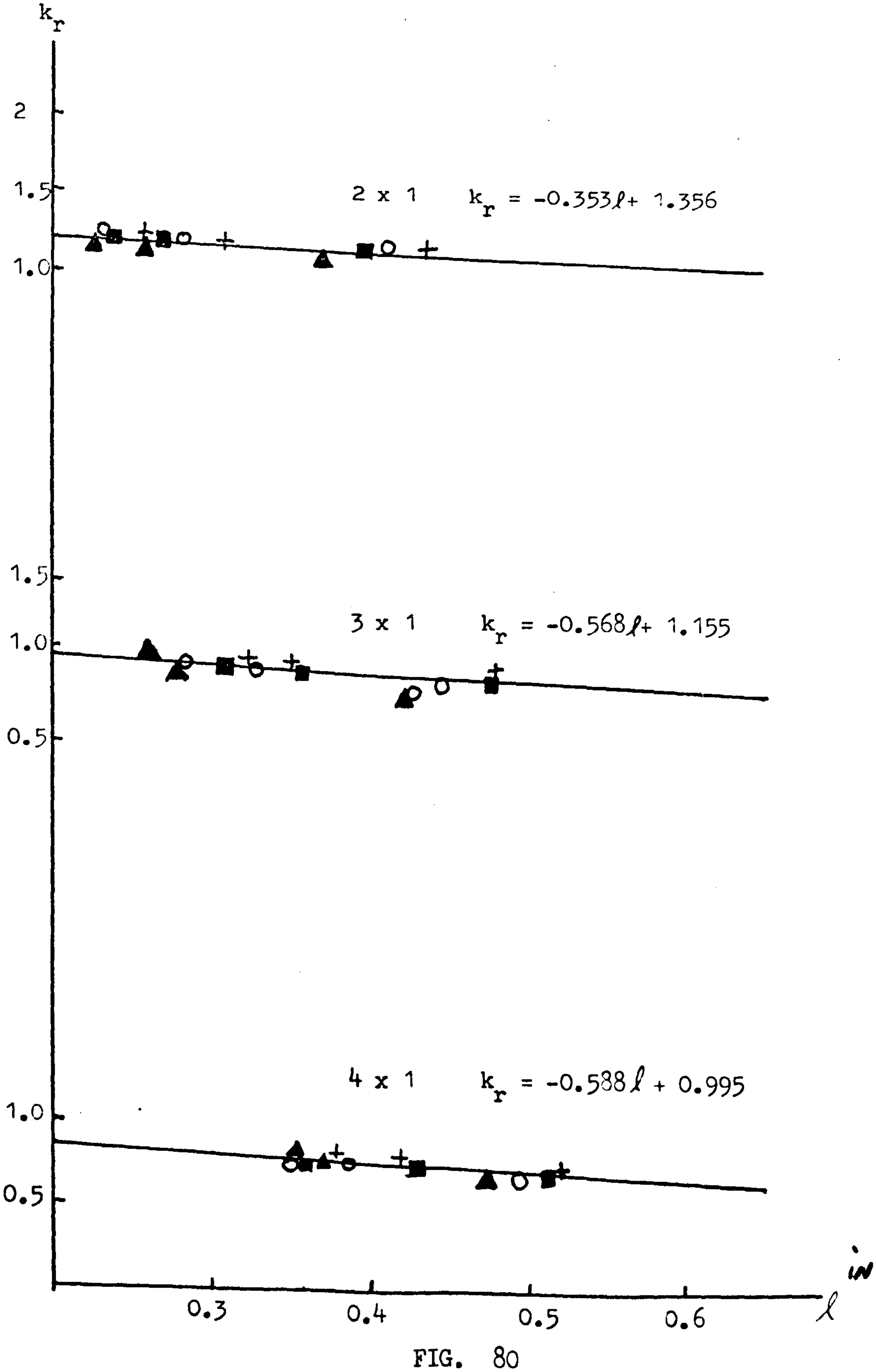


FIG. 80

Relationship between k_r and ℓ for 2 x 1, 3 x 1 and 4 x 1 closed lap in the tumble dry condition are becoming more relaxed and reaching their state of equilibrium.

Examination of the slope and intercept relating to the graphs of c.p.i. against $\frac{1}{\ell}$ reveals three facts -

i) As the relaxation of the fabric increases, the slope of the line decreases.

ii) A negative intercept is obtained in the dry relaxed and wet relaxed condition.

iii) The magnitude of the intercept decreases with each relaxation treatment.

The graphs of w.p.i. against $\frac{1}{\ell}$ show that, as the relaxation increases, the slope of the line increases and a positive intercept is obtained which increases with the relaxation treatment.

Observation of the regression analysis of S against $\frac{1}{\ell^2}$ reveals that both the intercept and the slope of the line increases with increase in relaxation. This is not surprising as the S value is the product of c.p.i. and w.p.i.

The graphs of k_r against ℓ show that the k_r value decreases with increase in the value of ℓ.

Thus it can be concluded that in general behaviour the 2 x 1, 3 x 1 and 4 x 1 closed lap constructions are the same as the 1 x 1 closed lap. Differences do exist, however, in the actual value of the slopes of all graphs and the intercept for w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$. These differences are discussed below.

Examination of the specific values of the slope, and the intercept for each parameter and in each relaxation condition reveals two interesting facts -

i) That the value of the slope of c.p.i. against $\frac{1}{\ell}$ is similar irrespective of the structure and the intercept is almost zero in the tumble dry condition.

ii) The value of the slope w.p.i. against $\frac{1}{\ell}$ varies according to the structure, the slope increasing as the length of the underlap increases in the structure.

2. Detailed discussion of c.p.i. Values

Table 14 shows the results of a complete regression analysis of c.p.i. against $\frac{1}{\ell}$, listing the regression equation, the standard error of the slope, standard deviation about the regression line, the correlation coefficient and the percentage probability obtained from the Students' t-test of the intercept for all structures at each stage of relaxation.

From these results, it will be observed that in the tumble dry condition the intercept is not significantly different from zero except in the case of the 4 x 1 closed lap. Examination of the 4 x 1 results, (see graph, Fig. 78), indicates that the results for this structure are confined to a very narrow range of stitch lengths. There is no physical reason why this structure should be exceptional. It is reasonable to assume, therefore, that if samples could have been made over a wider range of stitch lengths, results similar to those obtained for the other structures would have been established.

The regression line for this construction was recalculated to

TABLE 14

Regression Analysis of c.p.i. Against 1/ℓ For 2x1, 3x1 & 4x1 Closed Lap

Relaxation Condition	Structure	Regression Equation	Standard Error		Standard Deviation About Regression Line	Correlation Coefficient	t-test of Intercept % Probability
			m (slope)	c (inter)			
Dry Relaxed	2x1	$\text{c.p.i.} = \underline{7.64} - 3.06$	0.617	2.121	1.528	0.969	n.s.
	3x1	$\text{c.p.i.} = \underline{7.64} - 1.76$	0.536	1.581	1.075	0.976	n.s.
	4x1	$\text{c.p.i.} = \underline{9.37} - 5.57$	0.843	2.055	0.972	0.962	n.s.
Wet Relaxed	2x1	$\text{c.p.i.} = \underline{7.41} - 2.61$	0.317	1.090	0.785	0.991	*
	3x1	$\text{c.p.i.} = \underline{7.24} - 1.60$	0.584	1.720	1.166	0.969	n.s.
	4x1	$\text{c.p.i.} = \underline{8.21} - 3.73$	0.738	1.801	0.851	0.962	n.s.
Tumble Dry	2x1	$\text{c.p.i.} = \underline{7.15} + 0.97$	0.269	0.926	0.667	0.993	n.s.
	3x1	$\text{c.p.i.} = \underline{7.49} + 0.45$	0.572	2.843	1.147	0.972	n.s.
	4x1	$\text{c.p.i.} = \underline{8.77} - 2.24$	0.395	0.962	0.455	0.990	*

n.s. - not significantly different from zero

* - significant at the 5-1% level

pass through zero in the same manner as that for the 2 x 1 and 3 x 1 closed lap fabrics. The values thus calculated in the tumble dry condition are as follows -

2 x 1 closed lap $\quad$ c.p.i. = $\frac{7.44}{\ell}$

3 x 1 closed lap $\quad$ c.p.i. = $\frac{7.62}{\ell}$

4 x 1 closed lap $\quad$ c.p.i. = $\frac{7.88}{\ell}$

3. Detailed Discussion of w.p.i. Values

Examination of the dimensional properties in a wale direction is made by observing the graphs of w.p.i. against $\frac{1}{\ell}$, (Figs. 76 to 78), and the regression analysis in Table 15. This gives the regression equation, standard error of the slope, standard deviation about the regression line, correlation coefficient, and Students' t-test of the intercept.

These show that in the majority of cases, the intercept is significantly different from zero; thus the product of w.p.i. and ℓ is not a constant. In each case, the intercept tends to increase with relaxation treatment but there appears to be no relationship between intercept and fabric construction. The slope increases with increase in relaxation treatment.

The appropriate equations relating w.p.i. with stitch length are therefore as given in Table 15, the relationship for the tumble dry condition being as follows :-

2 x 1 closed lap $\quad$ w.p.i. = $\frac{5.14}{\ell} + 2.72$

3 x 1 closed lap $\quad$ w.p.i. = $\frac{6.11}{\ell} + 5.50$

4 x 1 closed lap $\quad$ w.p.i. = $\frac{8.29}{\ell} + 5.27$

TABLE 15

Regression Analysis of w.p.i. Against $1/\ell$ For 2x1, 3x1 & 4x1 Closed Lap

Relaxation Condition	Structure	Regression Equation	Standard Error		Standard Deviation About Regression Line	Correlation Coefficient	t-test of Intercept % Probability
			m (slope)	c (inter)			
Dry Relaxed	2x1	$\text{w.p.i.} = \frac{4.48}{\ell} + 0.44$	0.213	0.731	0.527	0.989	n.s.
	3x1	$\text{w.p.i.} = \frac{4.97}{\ell} + 3.23$	0.440	1.298	0.883	0.963	*
	4x1	$\text{w.p.i.} = \frac{6.73}{\ell} + 2.93$	0.752	1.832	0.867	0.943	n.s.
Wet Relaxed	2x1	$\text{w.p.i.} = \frac{4.54}{\ell} + 3.01$	0.334	1.148	0.827	0.974	*
	3x1	$\text{w.p.i.} = \frac{5.59}{\ell} + 5.15$	0.605	1.784	1.213	0.946	*
	4x1	$\text{w.p.i.} = \frac{7.78}{\ell} + 4.41$	1.033	2.519	1.191	0.922	n.s.
Tumble Dry	2x1	$\text{w.p.i.} = \frac{5.14}{\ell} + 2.72$	0.330	1.136	0.818	0.980	*
	3x1	$\text{w.p.i.} = \frac{6.11}{\ell} + 5.50$	0.770	2.270	1.544	0.929	*
	4x1	$\text{w.p.i.} = \frac{8.29}{\ell} + 5.27$	0.906	2.209	1.044	0.945	*

n.s. - not significantly different from zero

* - significant at the 5-1% level

4. Detailed Discussion of Stitch Density Values

Examination of this data, (Table 16) reveals that the intercepts are not significantly different from zero in the wet relaxed and tumble dry conditions, but the intercepts for the 3 x 1 and 4 x 1 closed lap constructions are significantly different from zero in the dry relaxed state.

The actual value of the slope increases both with the relaxation treatment and the length of the underlap.

The values of the slopes which have intercepts which are not significantly different from zero may be recalculated to pass through zero and the appropriate values thus found give the relationships between stitch density and stitch length in the tumble dry condition as -

2 x 1 closed lap $S = \frac{43.5}{\ell^2}$

3 x 1 closed lap $S = \frac{59.8}{\ell^2}$

4 x 1 closed lap $S = \frac{81.7}{\ell^2}$

5. Detailed Discussion of the Course/Wale Ratio Values

Examination of the data in Table 17 indicates that with the exception of the 2 x 1 construction in the tumble dry condition, the relationship between k_r and ℓ is not a constant but varies with ℓ, the k_r value decreasing with increase in the value of ℓ.

The appropriate relationships between the k_r value and the stitch length are given in Table 17. The relationships in the tumble dry condition being as follows -

TABLE 16

Regression Analysis of s Against $1/\ell^2$ For 2x1, 3x1 & 4x1 Closed Lap

Relaxation Condition	Structure	Regression Equation	Standard Error		Standard Deviation About Regression Line	Correlation Coefficient	t-test of Intercept % Probability
			m (slope)	c (inter)			
Dry Relaxed	2x1	$s = \frac{32.8}{\ell^2} - 19.8$	1.406	17.89	22.81	0.991	n.s.
	3x1	$s = \frac{39.3}{\ell^2} + 29.3$	3.435	7.47	40.05	0.964	**
	4x1	$s = \frac{60.8}{\ell^2} - 27.4$	1.720	10.60	9.42	0.996	*
Wet Relaxed	2x1	$s = \frac{35.1}{\ell^2} + 10.6$	1.666	21.19	27.02	0.989	n.s.
	3x1	$s = \frac{44.2}{\ell^2} + 42.7$	4.591	42.65	53.53	0.950	n.s.
	4x1	$s = \frac{65.4}{\ell^2} - 8.9$	2.463	15.18	13.49	0.993	n.s.
Tumble Dry	2x1	$s = \frac{40.4}{\ell^2} + 41.3$	2.005	25.52	32.53	0.988	n.s.
	3x1	$s = \frac{52.1}{\ell^2} + 75.3$	5.699	52.97	66.46	0.945	n.s.
	4x1	$s = \frac{78.8}{\ell^2} + 19.0$	3.733	23.01	20.45	0.989	n.s.

n.s. - not significantly different from zero
* - significant at the 5-1% level
** - significant at the 1-0.1% level
*** - significant at the 0.1% level & lower

KEY TO TABLE 17

n.s. = not significantly different from a horizontal line

* = significantly different at the 5 - 1% level

** = " " " " 1 - 0.1% level

*** = " " " " 0.1% level and lower

TABLE 17

Regression Analysis of k_r against for 2 x 1, 3 x 1 and 4 x 1

Closed Lap Constructions

Structure	Relaxation Condition	Regression Equation	Standard error of		Standard deviation about regression line	Corr. Coeff.	% probability of correlation coefficient
			m	c			
2 x 1	Dry Relaxed	$k_r = -0.558\ell + 1.628$	0.354	0.103	0.142	-0.296	*
	Wet Relaxed	$k_r = -1.902\ell + 1.802$	0.684	0.193	0.076	-1.408	***
	Tumble Dry	$k_r = -0.353\ell + 1.356$	0.122	0.193	0.050	-0.240	n.s.
3 x 1	Dry Relaxed	$k_r = -0.853\ell + 1.456$	0.132	0.298	0.048	-0.808	**
	Wet Relaxed	$k_r = -0.850\ell + 1.203$	0.194	0.061	0.078	-0.870	***
	Tumble Dry	$k_r = -0.568\ell + 1.155$	0.119	0.085	0.048	-0.676	**
4 x 1	Dry Relaxed	$k_r = -1.030\ell + 1.321$	0.392	0.103	0.077	-0.655	**
	Wet Relaxed	$k_r = -0.694\ell + 0.985$	0.325	0.111	0.064	-0.571	**
	Tumble Dry	$k_r = -0.588\ell + 0.995$	0.188	0.096	0.037	-0.698	**

2 x 1 closed lap $k_r = -0.353\ell + 1.356$

3 x 1 closed lap $k_r = -0.568\ell + 1.155$

4 x 1 closed lap $k_r = -0.588\ell + 0.995$

Note: The value for the 2 x 1 closed lap construction is not significantly different from zero and could, therefore, be substituted with the average value of k_r. This, however, has not been done because the significance level is almost 5% and the point is given more consideration in Chapter VIII.

IV. DISCUSSION OF RESULTS FOR 1 x 1, 2 x 1, 3 x 1 AND 4 x 1 OPEN LAP CONSTRUCTIONS

The results for the dry relaxed, wet relaxed and tumble dry conditions were analysed by regression analysis in the usual way and the results for the slope and intercept for each construction and at each stage of relaxation are shown in Table 18 and the graphs for these structures in the tumble dry condition are shown in Figs. 81 to 86.

1. General Discussion

In general terms, the behaviour of this set of fabrics is similar to that of the previously considered closed lap constructions as follows -

i) The slope of the regression line for c.p.i. against $\frac{1}{\ell}$ is less after tumble drying than after dry relaxation for the 1 x 1 and 2 x 1 open lap constructions.

ii) The intercept of the regression line for c.p.i. against $\frac{1}{\ell}$ in general decreases with increase in relaxation.

TABLE 18

Slope and Intercept for 1 x 1, 2 x 1, 3 x 1 and 4 x 1 Open Lap Structures in each Condition of Relaxation

	Relaxation Condition	c.p.i. against $\frac{1}{\ell}$				w.p.i. against $\frac{1}{\ell}$				S against $\frac{1}{\ell^2}$			
		1 x 1 open	2 x 1 open	3 x 1 open	4 x 1 open	1 x 1 open	2x 1 open	3x 1 open	4x 1 open	1 x 1 open	2 x 1 open	3 x1 open	4x 1 open
Slope	Dry Relaxed	8.52	8.20	7.93	8.13	3.23	4.51	4.91	6.63	25.8	35.0	43.3	58.3
	Wet Relaxed	7.89	7.65	6.61	6.32	4.03	5.13	6.88	10.1	30.2	39.8	50.3	68.3
	Tumble Dry	7.26	7.71	8.29	8.18	4.13	4.88	6.02	9.45	31.3	41.9	55.8	80.7
Intercept	Dry Relaxed	-3.10	-5.85	-4.03	-4.00	-0.67	2.24	6.33	6.03	-31.5	-16.2	24.5	1.9
	Wet Relaxed	0.30	-1.81	1.64	1.69	-1.49	2.20	3.31	1.27	-13.9	16.3	59.9	36.0
	Tumble Dry	4.05	-0.08	-1.45	-0.72	-0.29	4.28	6.02	3.07	36.7	60.4	60.5	21.0

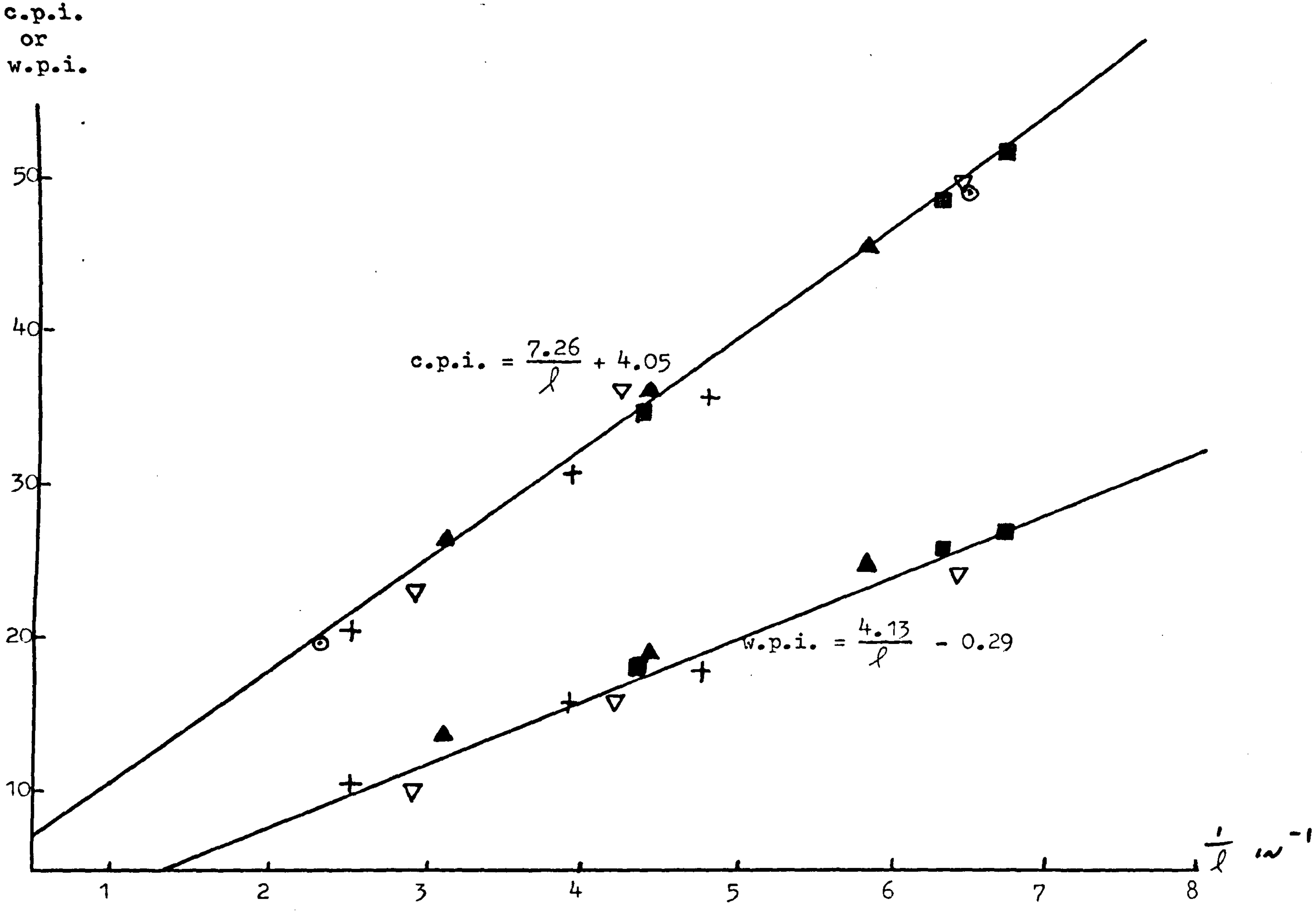


FIG. 81

Relationship between c.p.i. and w.p.i. against $\frac{1}{\ell}$ for 1 x 1 open lap in tumble dry condition

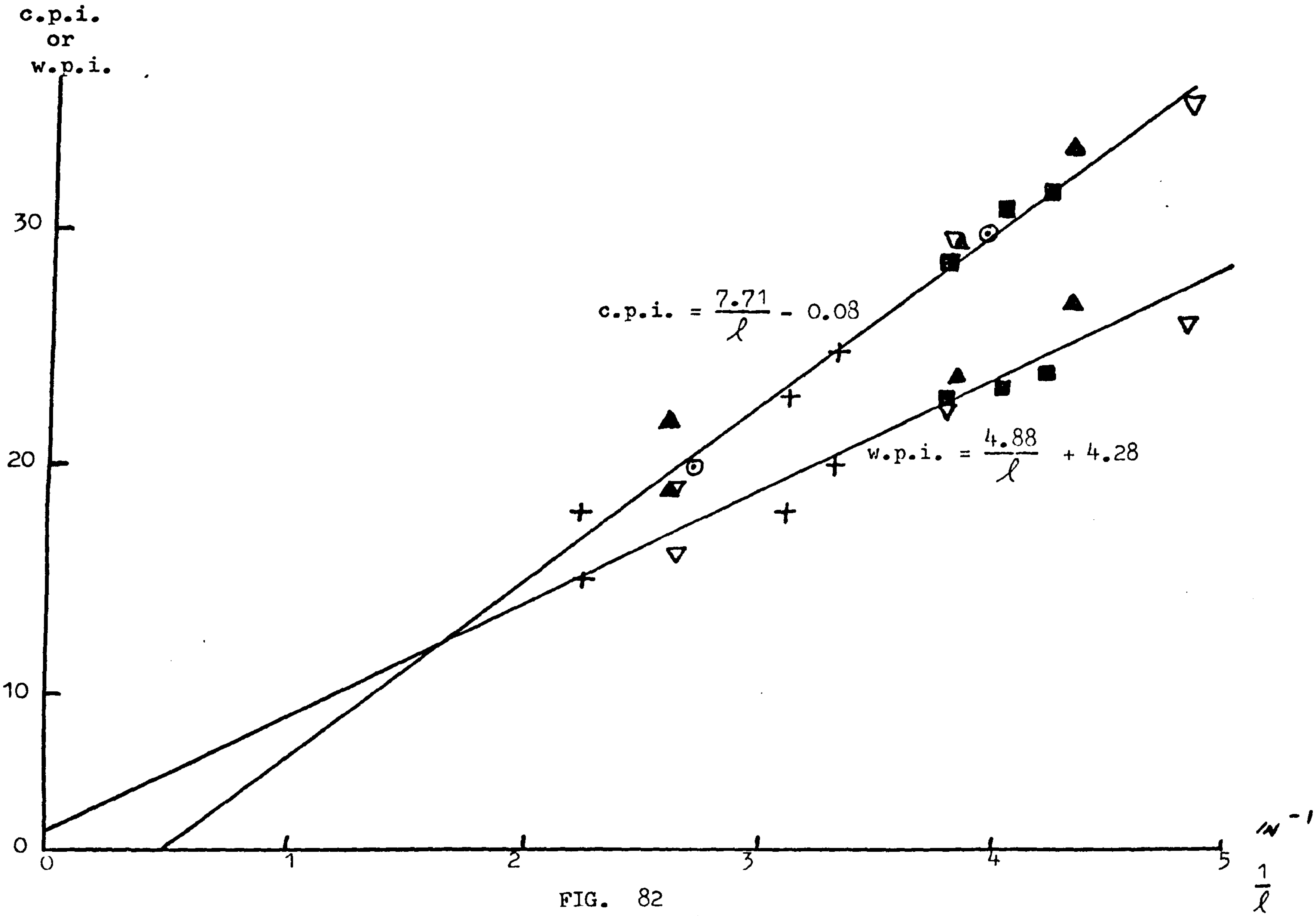


FIG. 82

Relationship between c.p.i. and w.p.i. against $\frac{1}{\ell}$ for 2 x 1 open lap in tumble dry condition

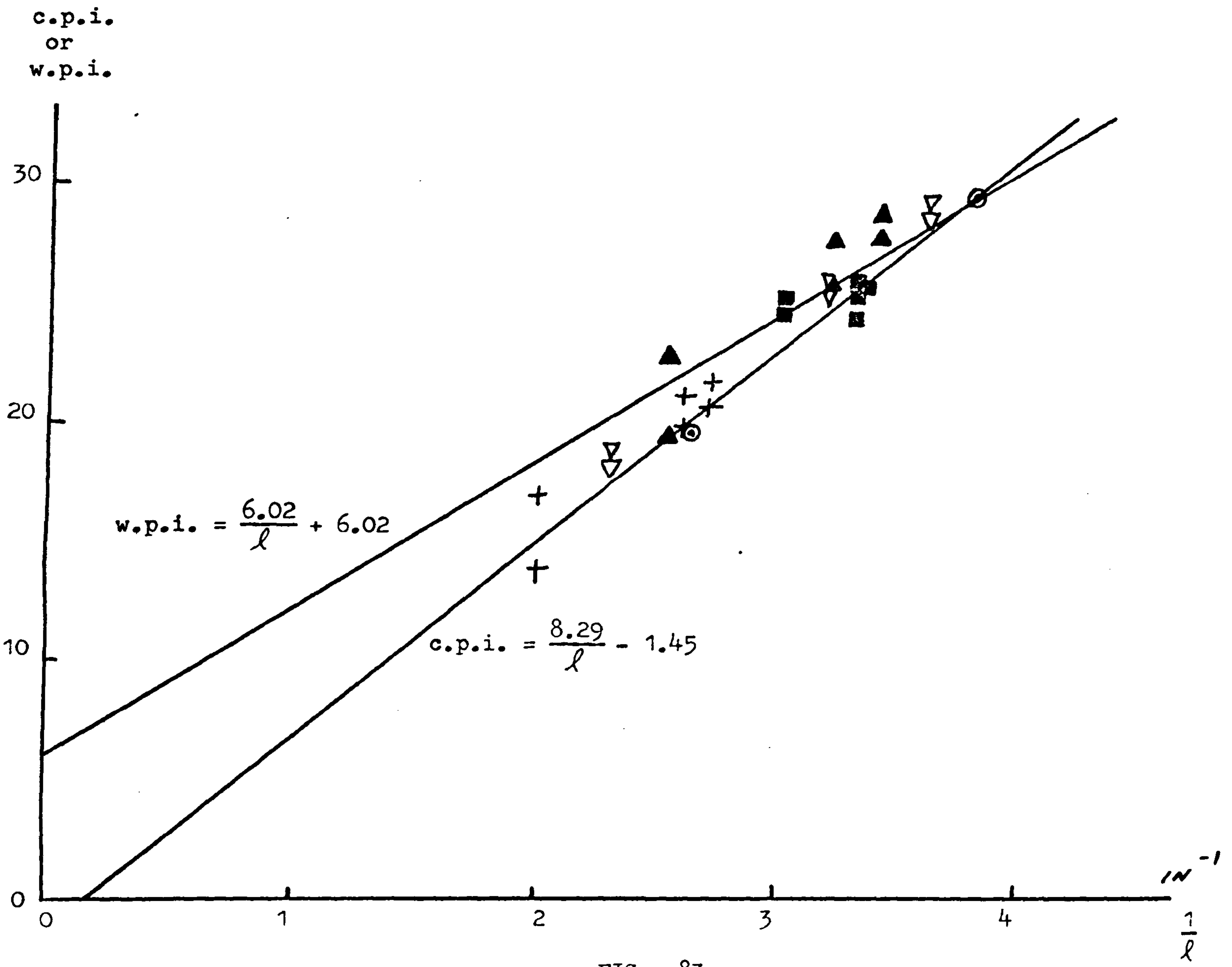


FIG. 83

Relationship between c.p.i. and w.p.i. against $\frac{1}{\ell}$ 3 x 1 open lap in tumble dry condition

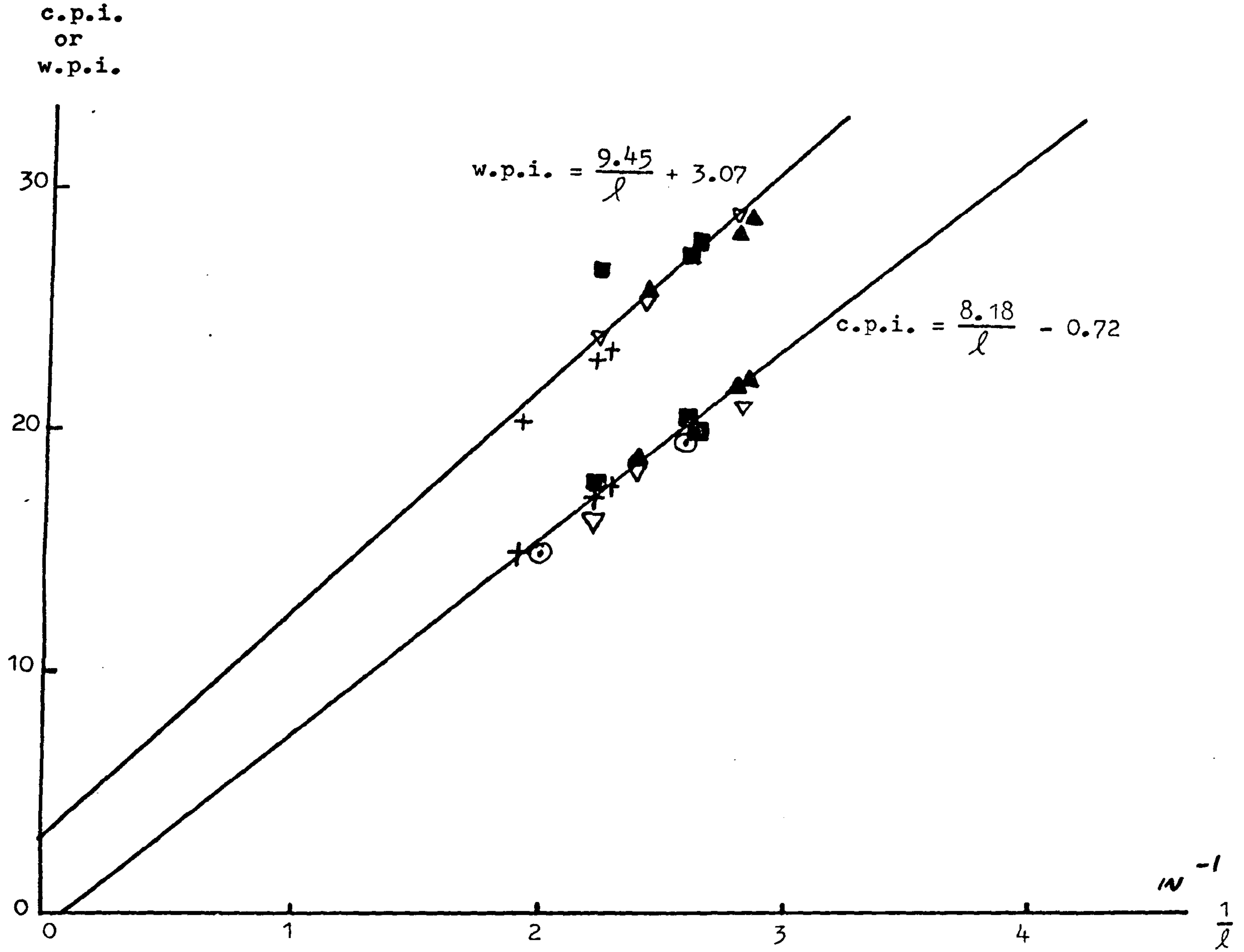


FIG. 84

Relationship between c.p.i. and w.p.i. against $\frac{1}{\ell}$ for 4 x 1 open lap in tumble dry condition

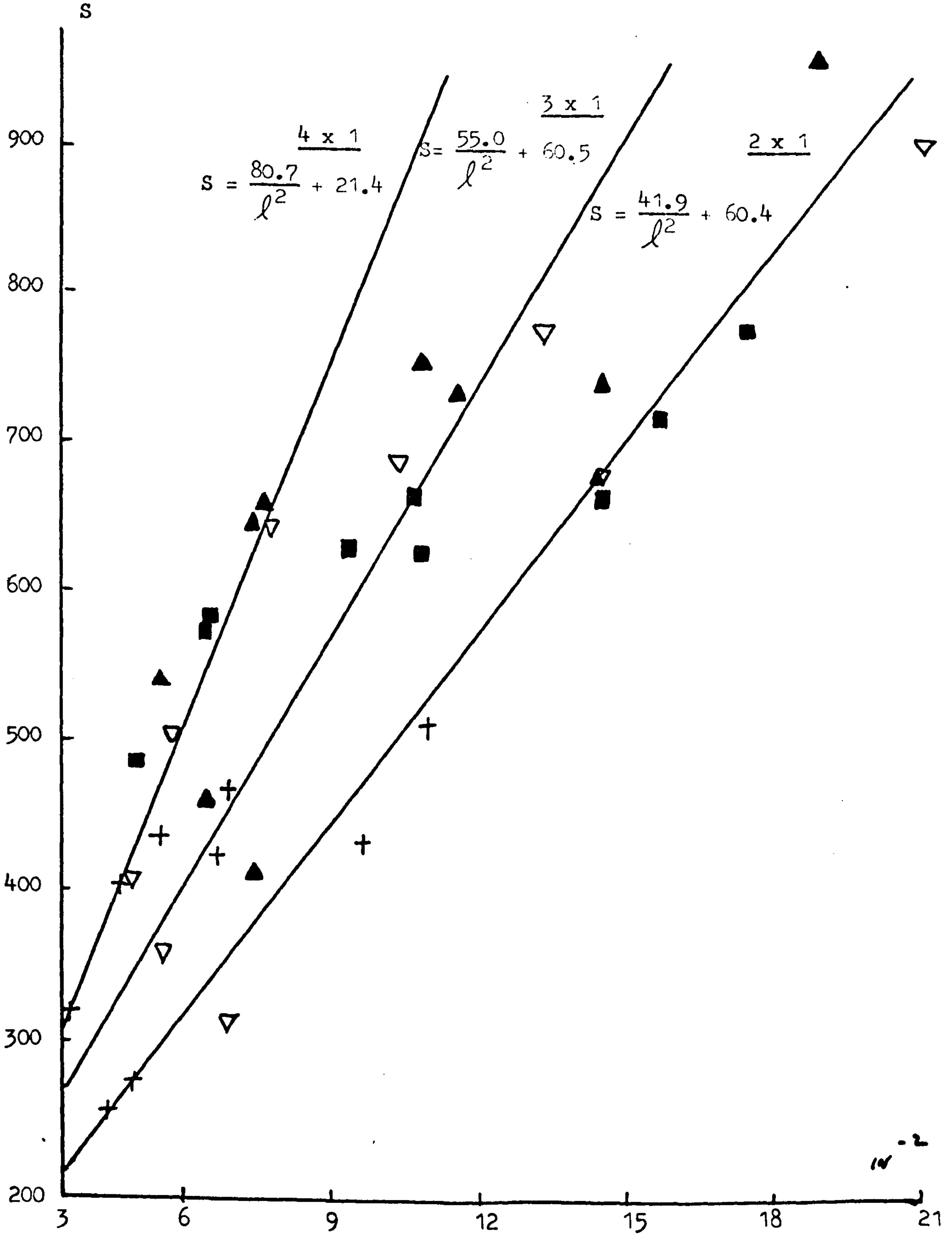


FIG. 85

Relationship between S and $\frac{1}{\ell^2}$ for 2 x 1, 3 x 1 and 4 x 1 open laps in the tumble dry condition

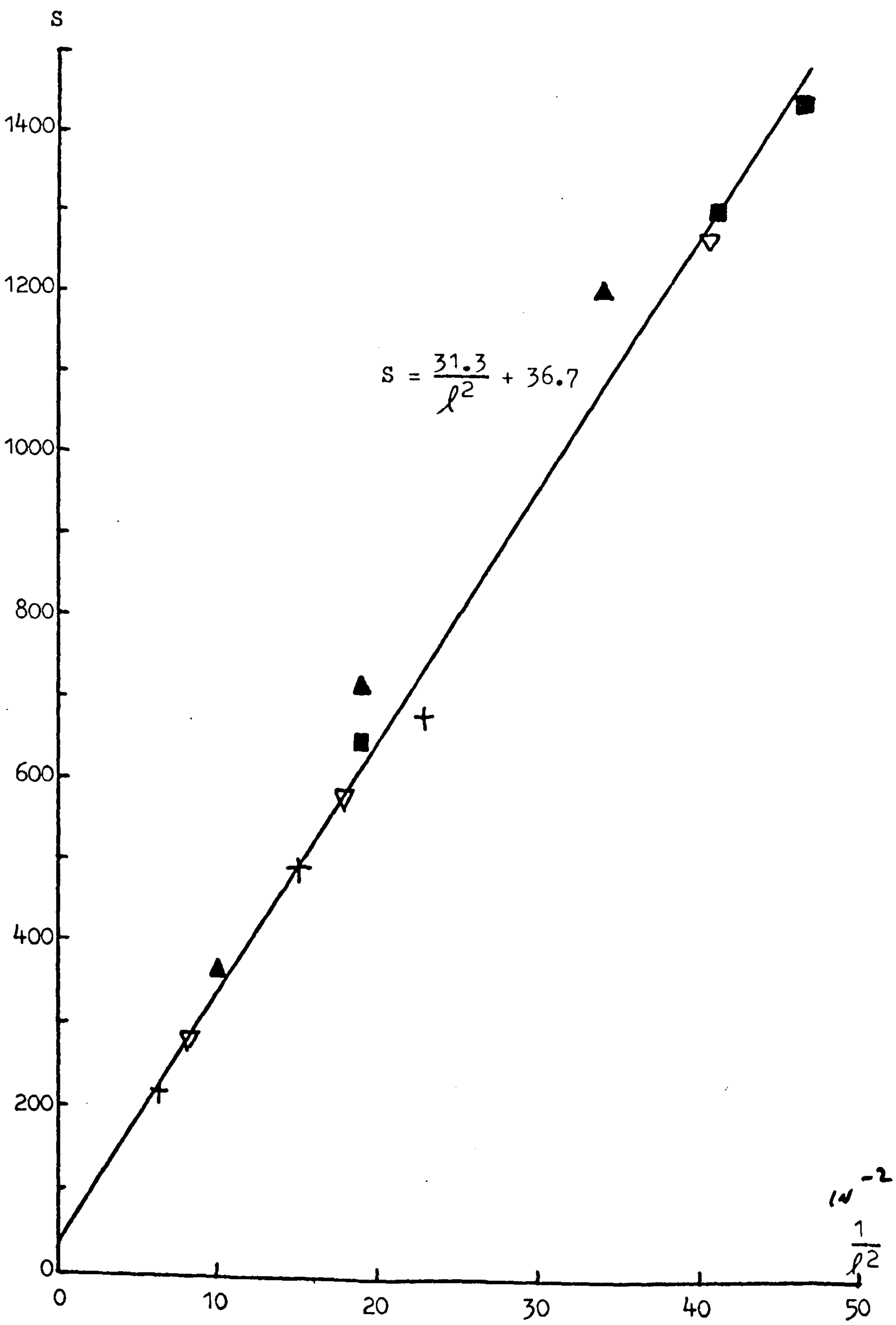


FIG. 85 continued

Relationship between stitch density and $\frac{1}{\ell^2}$ for the 1 x 1 open lap in the tumble dry condition

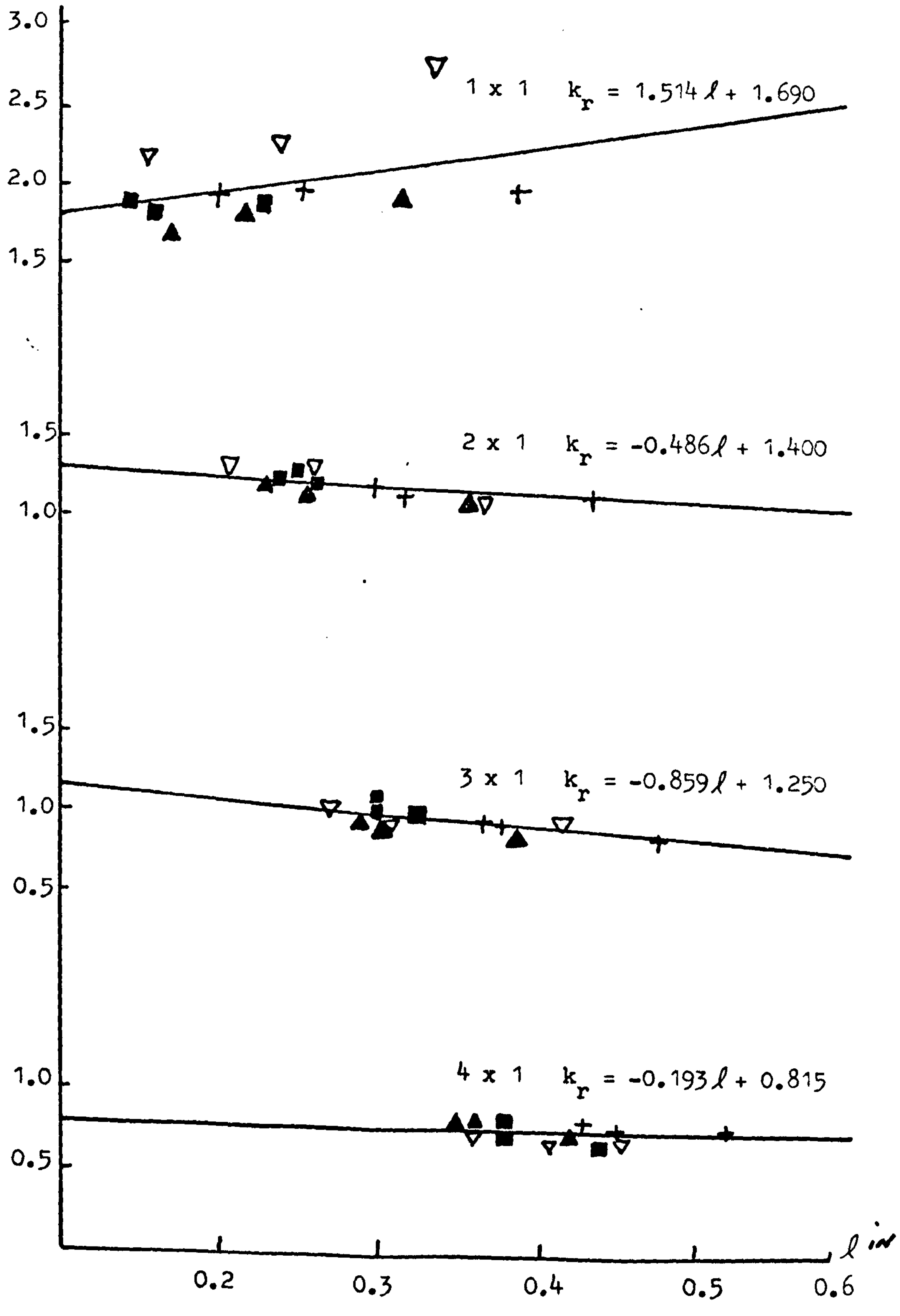


FIG. 86

Relationship between k_r and ℓ for 1 x 1, 2 x 1, 3 x 1 and 4 x 1 open lap in the tumble dry condition

iii) The slope of the regression line of w.p.i. against $\frac{1}{\ell}$ and that for S against $\frac{1}{\ell^2}$ has an overall increase from the dry relaxed condition to the tumble dry condition.

iv) The intercept of the regression line of w.p.i. against $\frac{1}{\ell}$ and that for S against $\frac{1}{\ell^2}$ increases in the tumble dry condition compared to the dry relaxed condition.

v) The results obtained are independent of yarn count because the individual points show no separation according to yarn count. Figs. 81 to 86 show the tumble dry graphs for c.p.i. against $\frac{1}{\ell}$, w.p.i. against $\frac{1}{\ell}$, S against $\frac{1}{\ell^2}$ and k_r against ℓ with each count marked differently. No separation according to count is visible.

vi) The regression equations of k_r against ℓ show that the relationship between these two parameters is not generally a constant, the k_r value varying with ℓ.

A more detailed consideration is given in the following notes pointing out the differences which do exist.

2. Detailed Discussion of c.p.i. Values

Table 19 shows a complete regression analysis of the results for c.p.i. against $\frac{1}{\ell}$ giving the regression equation, standard error of slope, standard deviation about the regression line, correlation coefficient and percentage probability calculated from Students' t-test of the intercept.

Examination of this analysis in conjunction with an

TABLE 19

Regression Analysis of c.p.i. Against 1/ℓ For 1xl, 2xl, 3xl & 4xl Open Lap

Relaxation Condition	Structure	Regression Equation	Standard Error		Standard Deviation About Regression Line	Correlation Coefficient	t-test of Intercept % Probability
			m (slope)	c (inter)			
Dry Relaxed	1xl	$\text{c.p.i.} = \frac{8.52}{\ell} - 3.10$	0.506	1.037	2.404	0.983	n.s.
	2xl	$\text{c.p.i.} = \frac{8.20}{\ell} - 5.85$	0.649	2.375	1.645	0.970	*
	3xl	$\text{c.p.i.} = \frac{7.93}{\ell} - 4.03$	1.071	3.210	1.772	0.920	n.s.
	4xl	$\text{c.p.i.} = \frac{8.13}{\ell} - 4.00$	1.914	4.699	1.727	0.801	n.s.
Wet Relaxed	1xl	$\text{c.p.i.} = \frac{7.89}{\ell} + 0.30$	0.374	3.283	1.780	0.989	n.s.
	2xl	$\text{c.p.i.} = \frac{7.65}{\ell} - 1.81$	0.288	1.054	0.730	0.993	n.s.
	3xl	$\text{c.p.i.} = \frac{6.61}{\ell} + 1.61$	0.514	1.541	0.851	0.971	n.s.
	4xl	$\text{c.p.i.} = \frac{6.32}{\ell} + 1.69$	1.139	2.797	1.028	0.869	n.s.

Continued ...

TABLE 19 (Continued)

Relaxation Condition	Structure	Regression Equation	Standard Error		Standard Deviation About Regression Line	Correlation Coefficient	t-test of Intercept % Probability
			m (slope)	c (inter)			
Tumble Dry	1x1	$\text{c.p.i.} = \frac{7.26}{\ell} + 4.05$	0.390	1.890	1.856	0.986	n.s.
	2x1	$\text{c.p.i.} = \frac{7.71}{\ell} - 0.08$	0.366	1.337	0.926	0.989	n.s.
	3x1	$\text{c.p.i.} = \frac{8.29}{\ell} - 1.45$	0.411	1.233	0.681	0.988	n.s.
	4x1	$\text{c.p.i.} = \frac{8.18}{\ell} - 0.72$	0.450	1.692	0.605	0.968	n.s.

n.s. - not significantly different from zero

* - significant at the 5-1% level

examination of the graphs in Figs. 81 to 84 shows that for the 1 x 1 open lap construction the slope of the line decreases gradually as the relaxation increases, but with the remaining structures, 2 x 1, 3 x 1 and 4 x 1 open laps, the slope decreases in the wet relaxed condition, but then increases again in the tumble dry state, the amount of decrease and subsequent increase increasing with the length of the underlap. It is suggested that this may be due to the fact that the long lap constructions are less stable in a single bar fabric than the short lap constructions.

A similar phenomenon is present in the intercepts for these constructions, being more marked in the 3 x 1 and 4 x 1 open lap constructions. However, the Students' t-test shows that in the tumble dry condition the intercepts for all constructions are not significantly different from zero, thus the regression lines may be recalculated to pass through zero. In this respect, therefore, these structures react in the relaxation process in the same manner as all other structures investigated. The final values in the tumble dry condition are -

1 x 1 open lap c.p.i. = $\frac{8.062}{\ell}$

2 x 1 open lap c.p.i. = $\frac{7.576}{\ell}$

3 x 1 open lap c. p.i.= $\frac{7.794}{\ell}$

4 x 1 open lap c.p.i. = $\frac{7.887}{\ell}$

3. Detailed Discussion of w.p.i. Values

Table 20 shows the complete regression analysis for w.p.i. against $\frac{1}{\ell}$ in all stages of relaxation for all the open lap constructions investigated. Observation of this table, together with the graphs, Figs. 81 to 84, shows that for all structures except the 1 x 1 open lap, the slope of the regression line increases from the dry relaxed to the wet relaxed conditions and then decreases from the wet relaxed state to the tumble dry condition. However, the overall effect is to show an increase from the dry relaxed state. In the tumble dry condition the intercept for 2 x 1 and 3 x 1 constructions are statistically different from zero.

The 1 x 1 open lap construction must be treated separately as the slope shows a gradual increase and the intercept is not significantly different from zero in any relaxation state.

In the tumble dry condition, the relationship between w.p.i. and stitch length for each structure is as follows -

1 x 1 open lap $\quad \text{w.p.i.} = \frac{4.13}{\ell} - 0.29$

2 x 1 open lap $\quad \text{w.p.i.} = \frac{4.88}{\ell} + 4.28$

3 x 1 open lap $\quad \text{w.p.i.} = \frac{6.02}{\ell} + 6.02$

4 x 1 open lap $\quad \text{w.p.i.} = \frac{9.45}{\ell} + 3.07$

4. Detailed Discussion of Stitch Density Values

Table 21 shows a complete regression analysis of S against $\frac{1}{\ell^2}$ for all open lap structures and for each state of relaxation.

TABLE 20

Regression Analysis of w.p.i. Against $1/\ell$ For 1x1, 2x1, 3x1 & 4x1 Open Lap

Relaxation Condition	Structure	Regression Equation	Standard Error		Standard Deviation About Regression Line	Correlation Coefficient	t-test of Intercept % Probability
			m (slope)	c (inter)			
Dry Relaxed	1x1	$\text{w.p.i.} = \frac{3.23}{\ell} - 0.67$	0.186	0.900	0.884	0.984	n.s.
	2x1	$\text{w.p.i.} = \frac{4.51}{\ell} + 2.24$	0.426	1.557	1.079	0.958	n.s.
	3x1	$\text{w.p.i.} = \frac{4.91}{\ell} + 6.33$	0.757	2.271	1.253	0.920	*
	4x1	$\text{w.p.i.} = \frac{6.63}{\ell} + 6.03$	1.764	4.331	1.592	0.765	n.s.
Wet Relaxed	1x1	$\text{w.p.i.} = \frac{4.03}{\ell} - 1.49$	0.388	1.879	1.845	0.975	n.s.
	2x1	$\text{w.p.i.} = \frac{5.13}{\ell} + 2.20$	0.472	1.724	1.195	0.960	n.s.
	3x1	$\text{w.p.i.} = \frac{6.88}{\ell} + 3.31$	0.853	2.559	1.413	0.971	n.s.
	4x1	$\text{w.p.i.} = \frac{10.10}{\ell} + 1.27$	1.261	3.094	1.137	0.930	n.s.

Continued ...

TABLE 20 (Continued)

Relaxation Condition	Structure	Regression Equation	Standard Error		Standard Deviation About Regression Line	Correlation Coefficient	t-test of Intercept % Probability
			m (slope)	c (inter)			
Tumble Dry	1x1	$\text{w.p.i.} = \frac{4.13}{\ell} - 0.29$	0.309	1.497	1.470	0.973	n.s.
	2x1	$\text{w.p.i.} = \frac{4.88}{\ell} + 4.28$	0.480	1.755	1.215	0.955	*
	3x1	$\text{w.p.i.} = \frac{6.02}{\ell} + 6.02$	0.614	1.842	1.016	0.988	**
	4x1	$\text{w.p.i.} = \frac{9.45}{\ell} + 3.07$	1.429	3.510	1.289	0.902	n.s.

n.s. - not significantly different from zero
* - significant at the 5-1% level
** - significant at the 1-0.1% level
*** - significant at the 0.1% level & lower

TABLE 21

Regression Analysis of s Against $1/\ell^2$ For 1x1, 2x1, 3x1 & 4x1 Open Lap

Relaxation Condition	Structure	Regression Equation	Standard Error		Standard Deviation About Regression Line	Correlation Coefficient	t-test of Intercept % Probability
			m (slope)	c (inter)			
Dry Relaxed	1x1	$s = \frac{25.8}{\ell^2} - 31.5$	1.227	32.93	55.69	0.989	n.s.
	2x1	$s = \frac{35.0}{\ell^2} - 16.2$	1.410	20.15	25.11	0.992	n.s.
	3x1	$s = \frac{43.3}{\ell^2} + 24.5$	3.421	32.15	32.41	0.970	n.s.
	4x1	$s = \frac{58.3}{\ell^2} + 1.9$	3.903	24.08	17.06	0.978	n.s.
Wet Relaxed	1x1	$s = \frac{30.2}{\ell^2} - 13.9$	0.960	25.77	43.59	0.995	n.s.
	2x1	$s = \frac{39.8}{\ell^2} + 16.3$	2.053	29.33	36.56	0.987	n.s.
	3x1	$s = \frac{50.3}{\ell^2} + 59.9$	3.611	33.95	34.22	0.975	n.s.
	4x1	$s = \frac{68.3}{\ell^2} + 36.0$	4.792	29.56	20.94	0.976	n.s.

Continued ...

TABLE 21 (Continued)

Relaxation Condition	Structure	Regression Equation	Standard Error		Standard Deviation About Regression Line	Correlation Coefficient	t-test of Intercept % Probability
			m (slope)	c (inter)			
Tumble Dry	1x1	$s = \frac{31.3}{\ell^2} + 36.7$	1.339	35.91	60.74	0.991	n.s.
	2x1	$s = \frac{41.9}{\ell^2} + 60.4$	3.073	43.89	54.70	0.974	n.s.
	3x1	$s = \frac{55.8}{} + 60.5$	3.509	33.10	33.25	0.981	n.s.
	4x1	$s = \frac{80.7}{\ell^2} + 21.4$	5.198	32.07	22.72	0.980	n.s.

n.s. - not significantly different from zero

From this and the graphs in Fig. 85, it will be observed that the slope increases for all structures throughout the relaxation process.

In the case of the intercept, it will be noted that in general the value of the intercept becomes more positive with increase in relaxation and with increase in length of underlap. Again, it is to be observed that the 4 x 1 open lap structure does not conform to the general relationships, presumably largely due to the narrow range of stitch lengths produced for this structure.

However, in the tumble dry condition, the intercepts of all regression lines are not significantly different from zero, the Students' t-test value being greater than 5%, therefore the values may be recalculated to pass through zero, the results for the tumble dry condition being as follows -

1 x 1 open lap $S = \frac{32.4}{\ell^2}$

2 x 1 open lap $S = \frac{45.9}{\ell^2}$

3 x 1 open lap $S = \frac{62.0}{\ell^2}$

4 x 1 open lap $S = \frac{84.1}{\ell^2}$.

5. Detailed Discussion of the Course/Wale Ratio Values

Table 22 shows the complete regression analysis of k_r against ℓ for all open lap constructions in each relaxation state and it will be observed that each structure behaves differently.

The 1 x 1 open lap construction shows a decrease of k_r with

TABLE 22

Regression Analysis of k_r against ℓ - 1 x 1, 2 x 1, 3 x 1 and 4 x 1 Open Lap

Structure	Relaxation Condition	Regression Equation	Standard error of		Standard deviation about regression line	Corr. Coeff.	% probability of correlation coefficient
			m	c			
1 x 1	Dry Relaxed	$k_r = -0.527\ell + 2.669$	1.023	0.106	0.263	-0.163	n.s.
	Wet Relaxed	$k_r = 2.016\ell + 1.694$	1.088	0.106	0.280	0.380	**
	Tumble Dry	$k_r = 1.514\ell + 1.690$	1.039	0.103	0.267	0.425	**
2 x 1	Dry Relaxed	$k_r = -1.405\ell + 1.681$	0.597	0.082	0.134	-0.624	**
	Wet Relaxed	$k_r = -0.619\ell + 1.417$	0.504	0.263	0.113	-0.563	**
	Tumble Dry	$k_r = -0.486\ell + 1.400$	0.744	0.208	0.166	-0.723	**
3 x 1	Dry Relaxed	$k_r = -1.386\ell + 1.412$	0.661	0.096	0.124	-0.584	**
	Wet Relaxed	$k_r = -0.068\ell + 0.928$	0.369	0.111	0.069	-0.077	n.s.
	Tumble Dry	$k_r = -0.859\ell + 1.250$	0.199	0.064	0.037	-0.819	**

TABLE 22 (continued)

Structure	Relaxation Condition	Regression Equation	Standard error of		Standard deviation about regression line	Corr. Coeff.	% probability of correlation coefficient
			m	c			
4 x 1	Dry Relaxed	$k_r = -0.521\ell + 0.959$	0.924	0.134	0.134	0.191	n.s.
	Wet Relaxed	$k_r = 0.165\ell + 0.595$	0.416	0.131	0.060	0.127	n.s.
	Tumble Dry	$k_r = -0.193\ell + 0.815$	0.315	0.131	0.046	0.076	n.s.

n.s. = not significantly different from a horizontal line
* = significantly different at the 5 - 1% level
** = " " " " 1 - 0.1% level
*** = " " " " 0.1% level and lower

an increase in ℓ in the dry relaxed condition, but on wet relaxation and tumble drying the reverse is true, i.e. the k_r value increases with increase in the value of ℓ. This is the only structure which behaves in this manner in these conditions of relaxation.

Of the remaining structures, 2 x 1, 3 x 1 and 4 x 1, the 2 x 1 and 3 x 1 constructions show a relationship between k_r and ℓ in which the k_r value decreases with increase in value of ℓ.

The 4 x 1 construction is also an exception to the general rule in that, from a statistical point of view, the k_r value is a constant in all conditions of relaxation.

The final relationships in the tumble dry condition between the k_r value and the stitch length are given by the following equations -

1 x 1 open lap $\quad k_r = 1.514\ell + 1.690$

2 x 1 open lap $\quad k_r = -0.486\ell + 1.400$

3 x 1 open lap $\quad k_r = -0.859\ell + 1.250$

4 x 1 open lap $\quad k_r = -0.193\ell + 0.815$

Note: As the value for the 4 x 1 construction in the tumble dry condition is not significantly different from zero, it could be replaced by the average value for k_r. This has not been done as the point is given more consideration in Chapter VIII.

CHAPTER VIII

SUMMARY OF THE EXPERIMENTAL EVIDENCE CONCERNING THE DIMENSIONAL PROPERTIES OF SINGLE BAR OPEN AND CLOSED LAP STRUCTURES IN THE TUMBLE DRY CONDITION

I. INTRODUCTION

The dimensional characteristics of single bar constructions in the tumble dry condition, (given in Chapters VI and VII), indicate the following general relationships applicable to all constructions.

i) The dimensional properties of all structures are independent of yarn count.

ii) The product of c.p.i. and ℓ is a constant for any given construction.

iii) The product of w.p.i. and ℓ is not generally a constant and varies considerably according to the construction.

iv) The product of S and ℓ^2 is generally a constant, its value depending on the structure.

v) The k_r value is not generally a constant but varies with ℓ.

II. SUMMARY OF RELATIONSHIPS BETWEEN THE DIMENSIONAL PROPERTIES AND THE STITCH LENGTH

The relationships between the various parameters of c.p.i., w.p.i., stitch density and course/wale ratio with the stitch length are shown in Table 23 for comparison purposes. From this table it is evident that similarities exist between various structures. The object of this chapter is to draw together those relationships which are similar and thus simplify the results. As detailed in Chapter VII, eight different constructions have been investigated which form the base structures used in the formation of warp knitted constructions. It is more convenient to consider these relationships in groups rather than to consider each construction in isolation if at all possible.

From Table 23, it will be observed that the relationships of c.p.i. against $\frac{1}{\ell}$, w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$ are similar for the open and closed lap construction for the 2 x 1, 3 x 1 and 4 x 1 constructions, but the 1 x 1 closed lap and 1 x 1 open lap are completely different from each other and from all other constructions. It was decided therefore to statistically analyse if, in fact, there was any difference between the open and closed constructions in the 2 x 1, 3 x 1 and 4 x 1 lapping movements. The following results were obtained.

III. ANALYSIS OF OPEN AND CLOSED LAP STRUCTURES FOR 2 x 1, 3 x 1 AND 4 x 1 CONSTRUCTIONS

1. Course Values

It has been shown in the regression equation of c.p.i. against $\frac{1}{\ell}$ that in the tumble dry condition the 2 x 1, 3 x 1 and 4 x 1 open and closed lap constructions have intercepts which are not significantly different from zero and, therefore, may be

TABLE 23

Structure	c.p.i. against $\frac{1}{\ell}$	w.p.i. against $\frac{1}{\ell}$	S against $\frac{1}{\ell^2}$	k_r against ℓ
1 x 1 Closed	$\frac{8.95}{\ell}$	$\frac{2.70}{\ell} + 2.13$	$\frac{25.60}{\ell^2} + 52.5$	$-1.610\ell + 3.220$
1 x 1 Open	$\frac{8.06}{\ell}$	$\frac{4.08}{\ell}$	$\frac{32.4}{\ell^2}$	$1.514\ell + 1.690$
2 x 1 Closed	$\frac{7.44}{\ell}$	$\frac{5.14}{\ell} + 2.72$	$\frac{43.5}{\ell^2}$	$-0.353\ell + 1.356$
2 x 1 Open	$\frac{7.58}{\ell}$	$\frac{4.88}{\ell} + 4.28$	$\frac{45.9}{\ell^2}$	$-0.486\ell + 1.400$
3 x 1 Closed	$\frac{7.62}{\ell}$	$\frac{6.11}{\ell} + 5.50$	$\frac{59.8}{\ell^2}$	$-0.568\ell + 1.155$
3 x 1 Open	$\frac{7.79}{\ell}$	$\frac{6.02}{\ell} + 6.02$	$\frac{62.0}{\ell^2}$	$-0.859\ell + 1.250$
4 x 1 Closed	$\frac{7.88}{\ell}$	$\frac{8.29}{\ell} + 5.27$	$\frac{81.74}{\ell^2}$	$-0.588\ell + 0.995$
4 x 1 Open	$\frac{7.89}{\ell}$	$\frac{9.45}{\ell} + 3.07$	$\frac{84.1}{\ell^2}$	$-0.193\ell + 0.815$

Relationships between c.p.i., w.p.i., stitch density and course/wale ratio with stitch length as discussed in Chapters VI and VII considered to be zero, the following values were obtained.

	Closed lap	Open lap
2 x 1	$\frac{7.442}{\ell}$	$\frac{7.576}{\ell}$
3 x 1	$\frac{7.618}{\ell}$	$\frac{7.794}{\ell}$
4 x 1	$\frac{7.878}{\ell}$	$\frac{7.887}{\ell}$

It will be observed that for each construction the value of k_c is similar for the closed and open laps. Comparison of the two sets of results, (Table 24), shows that the Students' t-test indicates that there is no statistical difference between the slopes. It follows, therefore, that these values may be combined giving the following results -

2 x 1 open and closed laps

$$\text{c.p.i.} = \frac{7.509}{\ell}$$

3 x 1 open and closed laps

$$\text{c.p.i.} = \frac{7.699}{\ell}$$

4 x 1 open and closed laps

$$\text{c.p.i.} = \frac{7.883}{\ell}$$

2. Wale Values

It has been shown that the intercepts for these open and closed lap constructions are significantly different from zero and that the regression slope is different for each construction. The relationships between w.p.i. and stitch length for each construction are as follows -

TABLE 24

Students' t-test for c.p.i. against $\frac{1}{\ell}$ for difference between slopes for open and closed lap 2 x 1, 3 x 1 and 4 x 1 constructions.

Structure	Regression Equation	Variance about regression line	Students' t-test % probability that slopes are same
2 x 1 Closed	$\frac{7.442}{\ell}$	0.0025	n.s.
2 x 1 Open	$\frac{7.576}{\ell}$	0.0042	
3 x 1 Closed	$\frac{7.618}{\ell}$	0.0297	n.s.
3x 1 Open	$\frac{7.794}{\ell}$	0.0041	
4 x 1 Closed	$\frac{7.878}{\ell}$	0.0046	n.s.
4 x 1 Open	$\frac{7.887}{\ell}$	0.0035	

n.s. = Slopes not significantly different

		Closed lap	Open lap
2 x 1	w.p.i. =	$\frac{5.14}{\ell} + 2.72$	$\frac{4.88}{\ell} + 4.28$
3 x 1	w.p.i. =	$\frac{6.11}{\ell} + 5.50$	$\frac{6.02}{\ell} + 6.02$
4 x 1	w.p.i. =	$\frac{8.29}{\ell} + 5.27$	$\frac{9.45}{\ell} + 3.07$

It will be observed that for each construction, the value of k_w is similar for the closed lap fabric and for the open lap construction. Comparison of the two sets of results, (Table 25), shows that the Students' t-test indicates that there is no statistical difference between the slopes or the intercepts in the tumble dry condition. It follows, therefore, that the experimental values may be combined giving the following results -

2 x 1 open and closed lap

$$\text{w.p.i.} = \frac{5.07}{\ell} + 3.24$$

3 x 1 open and closed lap

$$\text{w.p.i.} = \frac{6.07}{\ell} + 5.80$$

4 x 1 open and closed lap

$$\text{w.p.i.} = \frac{8.32}{\ell} + 5.54$$

3. Stitch Density Values

It has been shown that the intercepts for the regression slopes in the tumble dry condition of relaxation for each construction ~~is~~ are not significantly different from zero and the slopes, therefore, were recalculated to pass through zero.

TABLE 25

Students' t-test ucl./½ of difference between slope and intercept of open lap and closed lap constructions for 2 x 1, 3 x 1 and 4 x 1 movements in the tumble dry condition

Slope Analysis

Construction	Slope	Standard error of m	Variance of diff. between slopes	Students' t-test % probability that slopes are same
2 x 1 Closed	5.14	0.3302	1.036	n.s.
2 x 1 Open	4.88	0.4798		
3 x 1 Closed	6.11	0.7700	1.307	n.s.
3 x 1 Open	6.02	0.6140		
4 x 1 Closed	8.29	0.9057	1.174	n.s.
4 x 1 Open	9.45	1.4293		

Intercept Analysis

Construction	Intercept	Standard error of Intercept	Variance of diff. between Intercepts	Students' t-test % probability that intercepts are same
2 x 1 Closed	2.72	1.1361	2.073	n.s.
2 x 1 Open	4.28	1.7548		
3 x 1 Closed	5.50	2.2325	3.053	n.s.
3 x 1 Open	6.02	1.8458		
4 x 1 Closed	5.27	2.2095	4.044	n.s.
4 x 1 Open	3.07	3.5097		

n.s. = Slopes not significantly different

The value of the regression line through zero is similar for the open lap and closed lap of each construction. The Students' t-test reveals that in a statistical sense each pair is not significantly different, (Table 26), therefore they may be combined. The final values are as follows -

2 x 1 closed and open lap

$$S = \frac{44.94}{\ell^2}$$

3 x 1 closed and open lap

$$S = \frac{60.95}{\ell^2}$$

4 x 1 closed and open lap

$$S = \frac{82.93}{\ell^2}$$

4. Course/Wale Ratio Values

The k_r against ℓ relationship for the open and closed lap constructions was analysed in the same way as that for the c.p.i. and w.p.i. against $\frac{1}{\ell}$ and stitch density and $\frac{1}{\ell^2}$. It was found that there was no difference between the open and closed lap fabrics in a statistical sense as shown in Table 27. Therefore, the regression equation was calculated for the total 24 samples for the fabrics in the tumble dry condition. The following results were obtained.

TABLE 26

Students' t-test of S against $\frac{1}{\ell^2}$ for the difference between open and closed laps for 2 x 1, 3 x 1 and 4 x 1 constructions in the Tumble Dry Condition

Constructions	Regression Equation	Variance about Regression line	Students' t-test % probability that slopes are same
2 x 1 Closed	$S = \frac{43.51}{\ell^2}$	8.39	n.s.
2 x 1 Open	$S = \frac{45.91}{\ell^2}$	13.87	
3 x 1 Closed	$S = \frac{59.80}{\ell^2}$	29.53	n.s.
3 x 1 Open	$S = \frac{62.01}{\ell^2}$	15.12	
4 x 1 Closed	$S = \frac{81.74}{\ell^2}$	10.40	n.s.
4 x 1 Open	$S = \frac{84.12}{\ell^2}$	9.08	

n.s. = Slopes not significantly different

TABLE 27

Slope and Intercept Analysis of k_r against ℓ - 2 x 1, 3 x 1 and 4 x 1 Open and Closed Laps

Slope Analysis

Construction	Slope	Standard error of m	Variance of diff. between slopes	Students' t-test % probability that slopes are same
2 x 1 Closed	-0.353	0.122	2.727	n.s.
2 x 1 Open	-0.486	0.744		
3 x 1 Closed	-0.568	0.085	1.064	n.s.
3 x 1 Open	-0.859	0.199		
4 x 1 Closed	-0.588	0.188	2.222	n.s.
4 x 1 Open	-0.193	0.315		

Intercept Analysis

Construction	Intercept	Standard error of Intercept	Variance of Diff. between Intercept	Students' t-test % probability that intercepts are same
2 x 1 Closed	1.356	0.193	0.313	n.s.
2 x 1 Open	1.400	0.208		
3 x 1 Closed	1.155	0.085	0.142	n.s.
3 x 1 Open	1.250	0.064		
4 x 1 Closed	0.995	0.096	0.413	n.s.
4 x 1 Open	0.815	0.131		

n.s. = Not significantly different

Construction	Regression Equation	Corr. Coeff.	% prob. of corr. coeff.
2 x 1 Closed and open lap	$k_r = -0.536\ell + 1.413$	0.626	n.s.
3 x 1 Closed and open lap	$k_r = -0.672\ell + 1.189$	0.731	n.s.
4 x 1 Closed and open lap	$k_r = -0.417\ell + 0.915$	0.421	n.s.

It will now be observed from this regression analysis that none of the constructions exhibit a course/wale ratio which is constant but in each case the k_r value decreases with increase in value of stitch length.

IV. 1 x 1 CLOSED LAP VALUES

From observation of the values of the regression equations of the various parameters for the 1 x 1 closed lap it is evident that these values are different from those of all other constructions, they must, therefore, be considered separately. The values are -

1. Course Values

The regression equation of c.p.i. against $\frac{1}{\ell}$ shows no significant intercept in the tumble dry condition and gives the following relationship -

$$\text{c.p.i.} = \frac{8.95}{\ell}$$

2. Wales Values

The regression equation of w.p.i. against $\frac{1}{\ell}$ shows a significant intercept in the tumble dry condition in the relationship -

$$\text{w.p.i.} = \frac{2.70}{\ell} + 2.13$$

3. Stitch Density Values

The regression equation of s against $\frac{1}{\ell^2}$ in the tumble dry condition shows a significant intercept in the relationship

$$s = \frac{25.60}{\ell^2} + 52.5$$

4. Course/Wale Ratio Values

The regression equation of $\frac{c.p.i.}{w.p.i}$ against ℓ in the tumble dry condition shows that the relationship between the two parameters is not a constant but k_r decreases with increase in ℓ in the following relationship -

$$\frac{c.p.i.}{w.p.i.} = -1.61\,\ell + 3.22$$

V. 1 x 1 OPEN LAP VALUES

From observation of the values of the various parameters of the stitch length shown in Table 23, it is evident that the values of the 1 x 1 open lap are different from all the other constructions investigated and are as follows -

1. Course Values

The regression equation of c.p.i. against $\frac{1}{\ell}$ shows no significant intercept in the tumble dry condition and gives the following relationship -

$$c.p.i. = \frac{8.062}{\ell}$$

2. Wale Values

The regression equation of w.p.i. against $\frac{1}{\ell}$ shows no significant intercept. This differs from other constructions and, therefore, merits separate consideration.

The final relationship in the tumble dry condition is -

$$\text{w.p.i.} = \frac{4.08}{\ell}$$

3. Stitch Density Values

The relationship between stitch density and stitch length is as follows -

$$\text{Stitch density} = \frac{32.5}{\ell^2}$$

4. Course/Wale Ratio Values

The regression equation of $\frac{\text{c.p.i.}}{\text{w.p.i.}}$ against ℓ shows a positive value for the slope showing that the course/wale ratio increases with increase in stitch length. This is the only structure to behave in this manner, the relationship between course/wale ratio and stitch length being -

$$\frac{\text{c.p.i.}}{\text{w.p.i.}} = 1.514\ell + 1.690$$

VI. RECONSIDERATION OF THE 1 x 1 OPEN LAP CONSTRUCTION

The 1 x 1 open lap construction shows surprising results compared with all other constructions in the following manner -

a) The 1 x 1 open lap is completely different from the 1 x 1 closed lap while in the 2 x 1, 3 x 1 and 4 x 1 constructions the relationships between stitch length and the various fabric parameters is the same for the open and closed lap variations of the construction.

b) The k_w value has no intercept, whereas all other structures have.

c) The k_r value increases with increase in stitch length while all other constructions show a decrease in k_r value with increase in ℓ.

These results are surprising as it was anticipated that the dimensional parameters for the 1 x 1 open lap construction would be similar to that for the 1 x 1 closed lap construction. As there appears to be no obvious reason why these variations exist, it was decided to perform a short repeat experiment to verify the results obtained for this structure. The details for this experiment are given in Appendix 4 where it is shown that these results are not statistically different from those obtained in Chapter VII. The opportunity has therefore been taken to combine these results with those obtained in Chapter VII to give a total of 24 samples. The final values are -

$$\text{c.p.i.} = \frac{7.79}{\ell}$$

$$\text{w.p.i.} = \frac{4.02}{\ell}$$

$$\text{stitch density} = \frac{30.5}{\ell^2}$$

$$\frac{\text{c.p.i.}}{\text{w.p.i.}} = 1.484\ell + 1.646 .$$

VII. DISCUSSION OF THE RELATIONSHIP BETWEEN THE DIMENSIONAL PROPERTIES OF SINGLE BAR CONSTRUCTIONS AND THE STITCH LENGTH

From the above analysis of the relationship of stitch length and the dimensional parameters of single bar warp knitted constructions produced from worsted yarns, a number of 'peculiarities' in the dimensional parameters become apparent. These are -

1. The 1 x 1 Closed Lap

    a) The k_c value is different from all other structures being a significantly higher figure.

    b) The relationship between the stitch density and $\frac{1}{\ell^2}$ has an intercept and in this way differs from all other constructions.

2. The 1 x 1 Open Lap

    a) The relationship between w.p.i. and $\frac{1}{\ell}$ has no intercept and in this way differs from all other constructions.

    b) The relationship between $\frac{\text{c.p.i.}}{\text{w.p.i.}}$ and stitch length shows a positive relationship, the ratio increasing with stitch length. In all other constructions, this relationship decreases with increase in stitch length.

3. The 2 x 1, 3 x 1 and 4 x 1 Constructions

The relationship between the physical parameters and the stitch length is shown to be the same for the open and closed laps in each construction.

4. Final Values

The final regression equation of c.p.i. against $\frac{1}{\ell}$, w.p.i. against $\frac{1}{\ell}$, s against $\frac{1}{\ell^2}$ and $\frac{\text{c.p.i.}}{\text{w.p.i.}}$ against ℓ for 1 x 1, 2 x 1, 3 x 1 and 4 x 1 open and closed lap constructions produced from worsted yarns are shown in Table 28.

TABLE 28

Statistical relationships between the dimensional parameters and stitch length for fabrics in the tumble dry state

Structure	c.p.i. against $\frac{1}{\ell}$	w.p.i. against $\frac{1}{\ell}$	S against $\frac{1}{\ell^2}$	$\frac{\text{c.p.i.}}{\text{w.p.i.}}$ against ℓ
1 x 1 Closed lap	$\text{c.p.i.} = \frac{8.95}{\ell}$	$\text{w.p.i.} = \frac{2.70}{\ell} + 2.13$	$S = \frac{25.60}{\ell^2} + 52.50$	$\frac{\text{c.p.i.}}{\text{w.p.i.}} = -1.61\ell + 3.22$
1 x 1 Open lap	$\text{c.p.i.} = \frac{7.79}{\ell}$	$\text{w.p.i.} = \frac{4.02}{\ell}$	$S = \frac{30.50}{\ell^2}$	$\frac{\text{c.p.i.}}{\text{w.p.i.}} = 1.48\ell + 1.65$
2 x 1 Closed lap 2 x 1 Open lap	$\text{c.p.i.} = \frac{7.51}{\ell}$	$\text{w.p.i.} = \frac{5.07}{\ell} + 3.24$	$S = \frac{44.90}{\ell^2}$	$\frac{\text{c.p.i.}}{\text{w.p.i.}} = -0.54\ell + 1.41$
3 x 1 Closed lap 3 x 1 Open lap	$\text{c.p.i.} = \frac{7.70}{\ell}$	$\text{w.p.i.} = \frac{6.09}{\ell} + 5.80$	$S = \frac{60.90}{\ell^2}$	$\frac{\text{c.p.i.}}{\text{w.p.i.}} = -0.67\ell + 1.19$
4 x 1 Closed lap 4 x 1 Open lap	$\text{c.p.i.} = \frac{7.88}{\ell}$	$\text{w.p.i.} = \frac{8.32}{\ell} + 5.54$	$S = \frac{78.00}{\ell^2}$	$\frac{\text{c.p.i.}}{\text{w.p.i.}} = -0.42\ell + 0.92$

CHAPTER IX

NEW LOOP MODELS FOR SINGLE BAR WARP KNITTED CONSTRUCTIONS IN THE TUMBLE DRY CONDITION PRODUCED FROM WORSTED YARNS

I. INTRODUCTION

In order to explain the relationships between the dimensional parameters of single bar warp knitted constructions and the stitch length, it was decided to establish a loop model. This was considered necessary as all existing loop models used yarn count as a basis for calculation at one stage or another and it has been shown conclusively in the experimental results that yarn count has no effect on the relationship between stitch length and the dimensional parameters of single bar warp knitted structures produced from wool yarns in the wet relaxed and tumble dry conditions.

Only the most relaxed condition investigated, (i.e. the tumble dry condition), was considered in this investigation as all other relaxed states represented only conditions through which the fabric passed to achieve the most relaxed state. Further, the tumble dry condition is the most stable form of the fabric representing the condition to which the fabric will return after any distortion which has occurred during manufacture has been removed.

II. PRELIMINARY INVESTIGATION USING A TWO DIMENSIONAL MODEL

The method of investigation used to observe the detailed path of the yarn in the fabric was to take photographs of the fabrics and to measure the various components of the structure to establish the distribution of the yarn within the construction.

1. Experimental Details

Photographs were taken with a 35mm. single lens reflex camera using a bellows extension and then enlarging the resultant negatives to give a total magnification of 17 times. Owing to the difficulty of following the path of one thread due to the density of the structure, transmitted light was used mounting the samples on a glass sheet between light source and the camera.

As the results separated themselves into groups, it was decided to consider the proposed loop model in the following groupings.

i) 2 x 1, 3 x 1 and 4 x 1 closed lap constructions

ii) 2 x 1, 3 x 1 and 4 x 1 open lap constructions

iii) 1 x 1 closed lap constructions

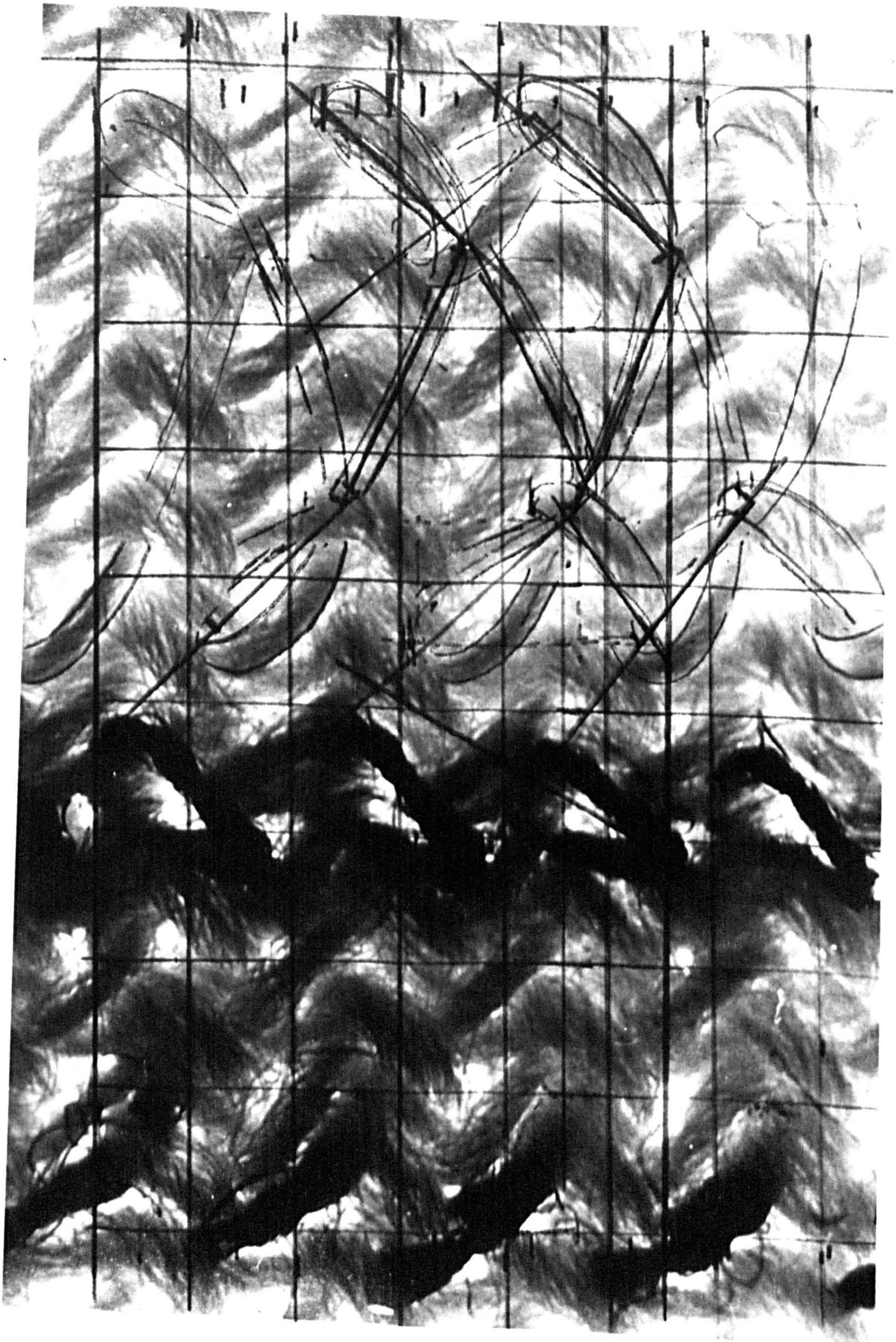
iv) 1 x 1 open lap constructions

2. Observation of Photographs for 2 x 1, 3 x 1 and 4 x 1 Closed Lap Constructions.

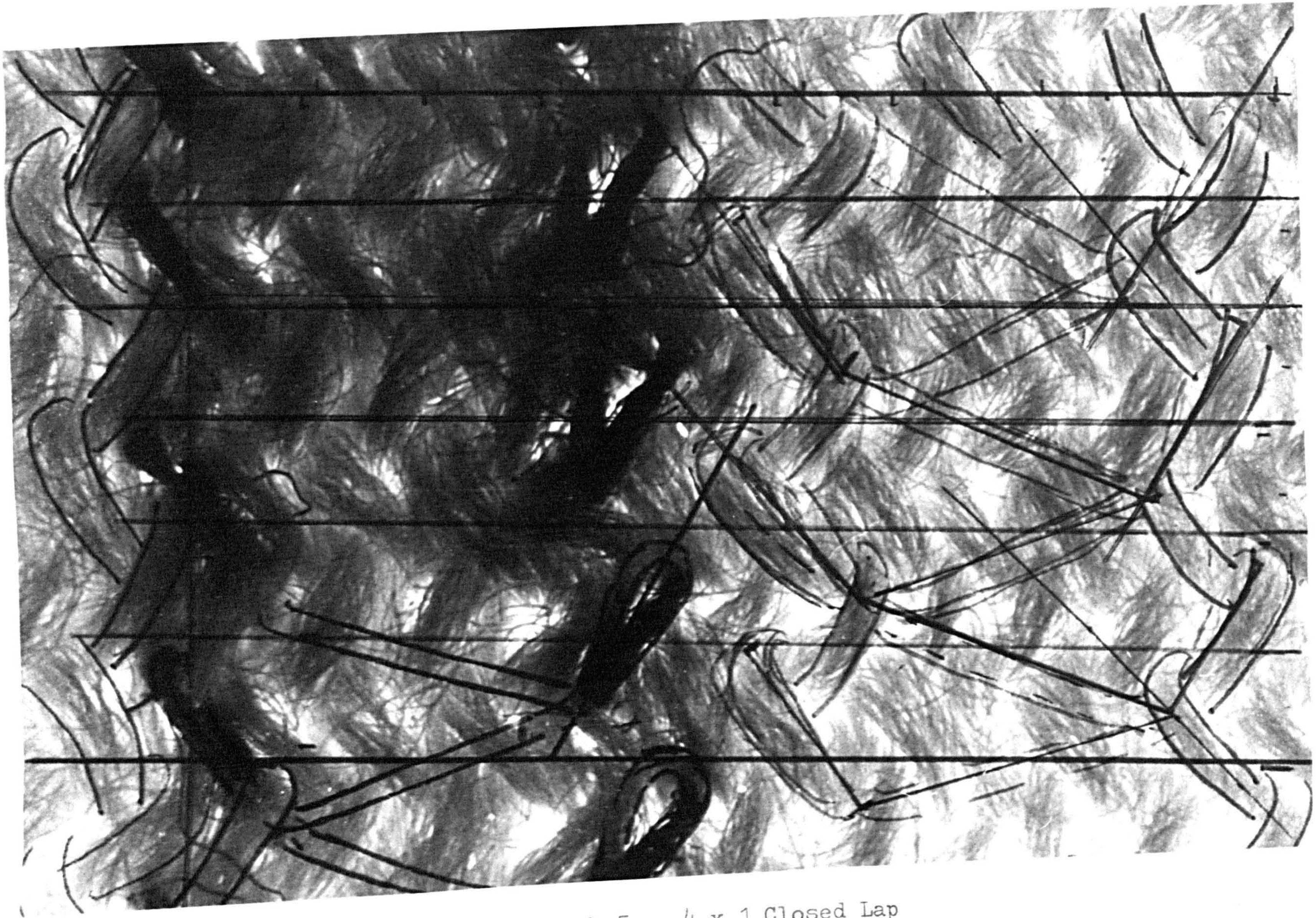
Photographs were taken of a range of stitch lengths and yarn counts in these constructions. Three of these are shown in Photographs 3 to 5.

From general observation of these photographs it can be established -

Photograph 3 2 x 1 Closed Lap



Photograph 4   3 x 1 Closed Lap



Photograph 5 4 x 1 Closed Lap

i) The loop often twists and lies out of the plane of the fabric, in some cases odd courses apparently twisting differently from even courses.

ii) As would be expected the loop lies inclined, the loops in odd courses lying in the opposite direction to those in even courses.

iii) The fact that the loop is inclined and that it twists and lies out of the plane of the fabric makes it difficult to observe the shape of the loop.

iv) It is not possible from these photographs to establish if the size of the head of the loop is related to the yarn count, or to establish if yarn compression occurs at this point.

These observed features of the structure may be used to construct the diagram shown in Fig.87, where the shape, the size and positioning of the loops are given as established from observation of the photographs of the 2 x 1 construction. In order to establish a loop model based on this structure, the stitch was considered in two separate parts in the conventional manner, i.e. the underlap and the loop. From this detailed observation of the photographs, the following features of a two dimensional model were established.

a) <u>Underlap</u>

The length of the underlap is a straight line, or nearly so, and may be considered as the hypotenuse of the right angled

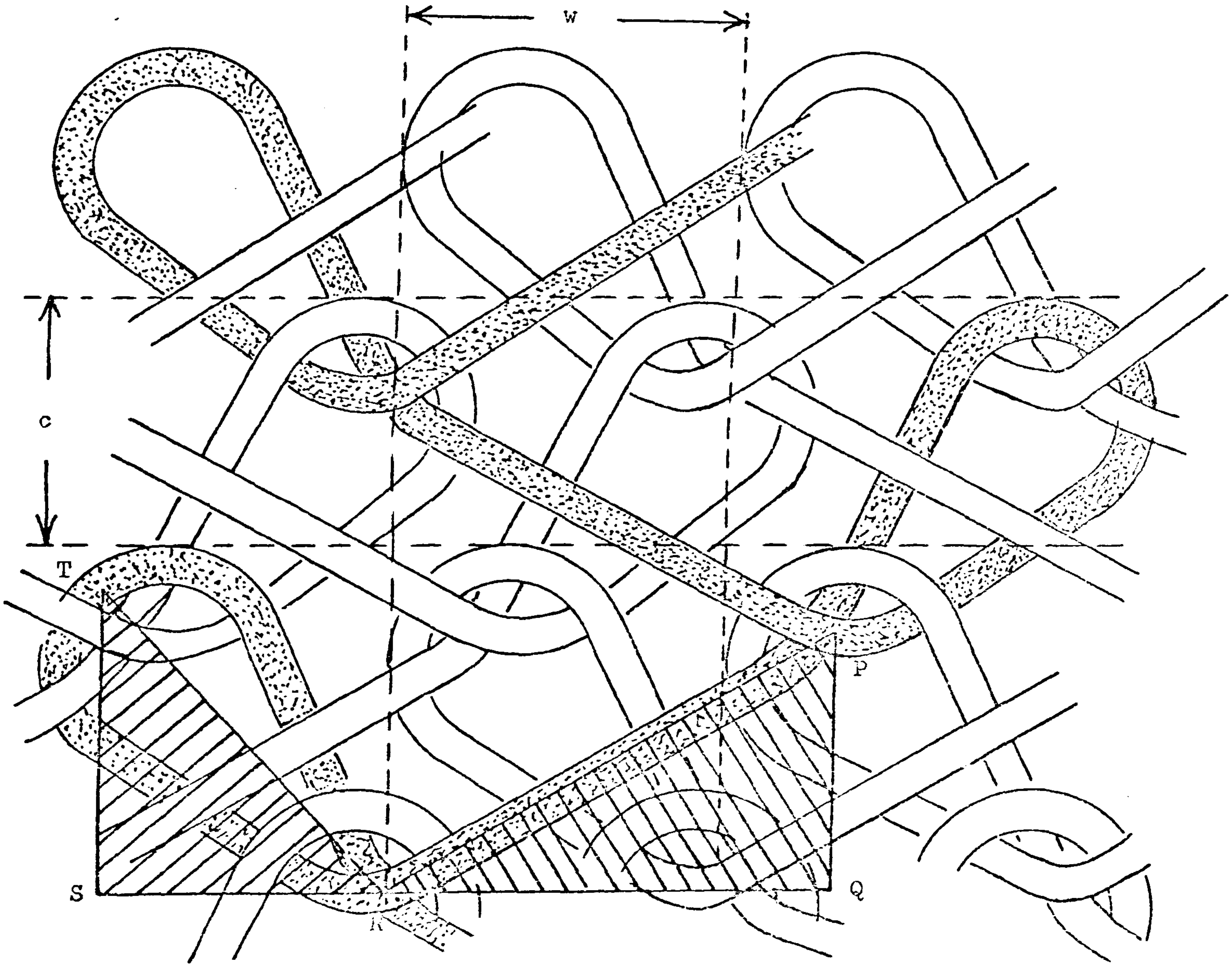


Fig. 87 2 x 1 Closed Lap

triangle F R in Fig. 87 whose height is equal to the course spacing BUF due to the inclination of the loop, the base is less than the wale spacing multiplied by the needle, (spaces moved). As a result of measurements of a number of samples, the average figures for the length of the underlap in the course direction is 1.36w for a 2 x 1 movement, 2.36w for a 3 x 1 movement and 3.36w for a 4 x 1 movement, (where w = wale spacing).

The length of the underlap can therefore be calculated as follows -

$$U = \sqrt{c^2 + (nw)^2}$$

Where n = 1.36 for 2 x 1
2.36 for 3 x 1
3.36 for 4 x 1

w = wale spacing
c = course spacing

The values for the underlap were calculated according to the above formula and compared with measurements taken on the photographs. These are shown in Table 29 and it will be observed that a good correlation between the calculated and measured value is obtained.

b) Loop

The height of the loop is equal to the length of the hypotenuse of the right angle triangle RST in Fig. 87. Due to loop inclination, the base SR is equal to 0.9w and, similarly, because of the overlap of the loops, the height is equal to 1.25c. Therefore, the height of the loop h may be calculated as follows -

$$h = \sqrt{(1.25c)^2 + (0.90w)^2}$$

TABLE 29

Comparison of the calculated value and measured value of the length of the underlap

Structure	Stitch length (in)	Calculated underlap (in)	Measured underlap (in)	% Difference
2 x 1	0.402	0.0977	0.0956	+2.2
	0.416	0.1137	0.1157	-1.6
3 x 1	0.259	0.0982	0.0946	+3.8
	0.327	0.1078	0.1068	+1.0
	0.448	0.1461	0.1477	-1.0
4 x 1	0.369	0.1264	0.1193	+5.9
	0.386	0.1386	0.1383	+0.2
	0.473	0.1499	0.1465	+2.3

TABLE 30

Comparison of the calculated values and measured value of the height of the loop

Structure	Stitch length (in)	Calculated loop height (in)	Measured loop height (in)	% Difference
2 x 1	0.402	0.0832	0.0836	+1.3
	0.416	0.1009	0.0991	+1.8
3 x 1	0.259	0.0602	0.0621	-3.0
	0.327	0.0590	0.0656	-9.2
	0.448	0.0910	0.0909	+0.1
4 x 1	0.369	0.0601	0.0624	-3.7
	0.386	0.0689	0.0691	-0.3
	0.473	0.0806	0.0799	+0.8

The values for the loop height were calculated for the fabrics illustrated in the photographs and compared with the measured values in the photographs. It will be noted that a good agreement is obtained between the two sets of results and is shown in Table 30.

c) Relationship between the length of yarn in the loop and loop height

If the amount of yarn in the underlap is subtracted from the stitch length to give the amount of yarn in the loop and if this figure is divided by the loop height, then the relationship between loop height and length of yarn in the loop can be established. This is shown in Table 31.

TABLE 31

Relationship between length of yarn in loop and loop height

Structure	Stitch length IN	Yarn in loop (y) IN	Height of loop (h) IN	$\frac{y}{h}$
2 x 1	0.402	0.3064	0.0836	3.61
	0.416	0.3169	0.0991	3.31
3 x 1	0.259	0.1644	0.0621	2.66
	0.327	0.2202	0.0656	3.36
	0.448	0.3003	0.0909	3.33
4 x 1	0.369	0.2498	0.0625	4.00
	0.386	0.2476	0.0692	3.55
	0.473	0.3265	0.0799	4.08
			Average	3.51

The results shown in Table 31 indicate that the ratio of the length of yarn in the loop to the loop height is a constant but this constant has an average value of 3.51, rather than that of 2.54 suggested by Grosberg[80].

Consideration of the value of 3.51 reveals, however, that this figure cannot be correct because if the loop were a true circle, the ratio would be equal to π (3.143). The ratio 3.51 being greater than π suggests that the loop has a greater width than height, a fact which is obviously incorrect from visual examination of the samples. In fact the loop height is greater than its width so that the ratio must be smaller than 3.143. It is clear that the estimation of the length of yarn in the underlap from this model has not been sufficient, so that the length of yarn left for the loop has been greater than that which can occur in practice. The obvious cause of this error is that no allowance has been made for the fact that the underlap and loop may be curved out of the fabric plane. Therefore, to assess more accurately the path of the thread in the fabric, it is necessary to examine the three-dimensional shape of the underlap and the loop.

III. INVESTIGATION OF THE THREE DIMENSIONAL SHAPE OF THE LOOP

1. Experimental Procedure

In the previous work, the ease with which the path of an individual thread could be traced in the fabric depended on the tightness of the construction and the particular construction under investigation. Simple constructions with large stitch lengths, e.g. 1 x 1 and 2 x 1, presented little difficulty, but in medium and tight constructions it was particularly difficult to establish the path of the yarn even though a tracer thread of different colour had been introduced for this purpose. This difficulty was experienced with both visual examination under the microscope and with close-up photography, although incidental and transmitted light were used. The latter was found to be more useful as shown by Photographs 3 to 5. Even so, the path of the individual threads was hard to follow on the more dense constructions and measurements difficult to make.

a) Macro-photography

It was decided to increase the magnification of the image obtained in all further photographs and in order to do this macro-photography was used, (i.e. a photograph in which the image on the negative is larger than the object). This was obtained by using an Olympus FTL 35mm. camera with a bellows extension and a 35mm. lens in reverse. (A normal lens is designed to produce an image on the negative smaller than the object. Since the reverse is true of macro-photography, better definition is obtained if normal lenses are reversed. In the work described, a special macro lens was not available, so a normal 35mm. lens was used in reverse).

The degree of magnification from image to negative depends on the extension of the bellows and the focal length of the lens vis:-

$$\text{Magnification} = \frac{\text{extension of bellows}}{\text{focal length of lens}}$$

The experimental conditions were :- $\frac{130 \text{ mm.}}{35 \text{ mm.}} = 3.7$

The object was focused by adjusting the camera-object distance, so keeping magnification constant.

During enlargement in the dark room, further enlargement was obtained to give a total of 35 times magnification.

b) Mounting samples in liquid

In order to follow the path of the thread more accurately, various arrangements of lighting were tried with the increased magnification, but none were found to give significantly better results than obtained previously. It was decided, therefore, to immerse the fabric in liquid of a similar refractive index to the white wool so that this would "optically disappear" and leave the tracer thread in isolation. A suitable liquid was found to be liquid paraffin.

The path of the tracer thread was observed under the microscope while immersedin liquid paraffin and also photographs were taken of fabrics thus mounted.

The effectiveness of this arrangement may be judged by observation of Photographs 6 and 7. Photograph 6 shows the effect of incidental lighting and photograph 7 shows the effect obtained with the fabric mounted in liquid paraffin.

.c) Cross section

To investigate the three dimensional shape of the knitted loop it was decided that the most suitable approach was to immerse the fabric in molten paraffin wax, then allow it to solidify and

Photograph 6

Photograph 7

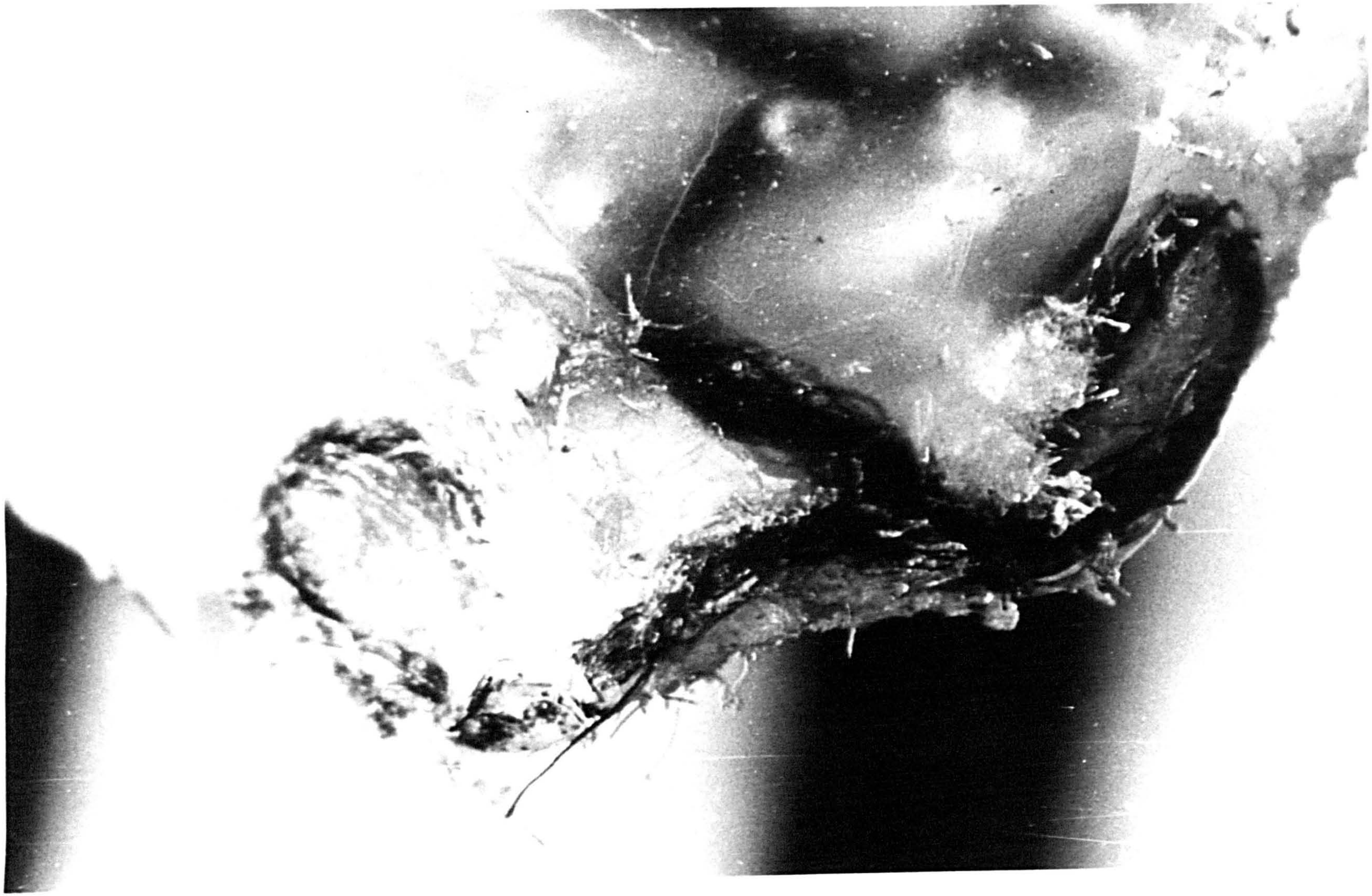
cut cross sections of the tracer thread to observe the shape and size of the loop and underlap. This would also afford the opportunity to take photographs of the various parts of the loop with subsequent more accurate measurements to establish the amount of yarn in each section of the structure.

In order to examine both the underlap and the loop, the wax was cut to expose the tracer thread being carved away along the thread in the manner shown in the isometric view in Photographs 8, 9 and 10.

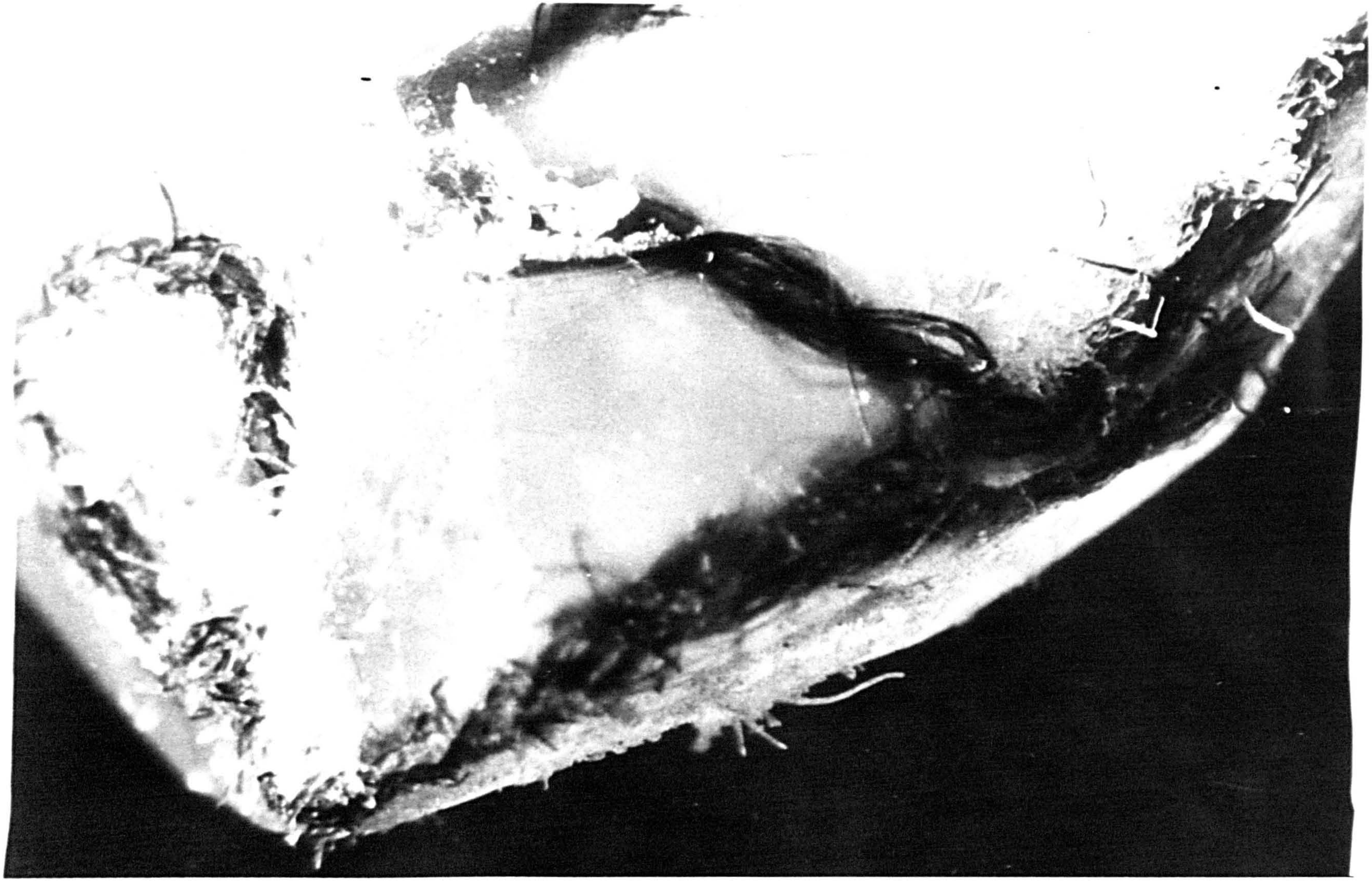
In order to investigate and photograph the yarn in the loop and the underlap, the sample was mounted on a ball-mounting so that it could be moved to any place and the loop and underlap positioned at 90 degrees to the axis of the camera. By this means it was possible to photograph, and ultimately measure, the amount of yarn in each section of the structure.
Example: Photographs 11 and 12 show the loop and underlap respectively of the sample whose isometric view is shown in Photograph 8. From these photographs, the length of yarn in the loop and underlap can be measured by placing a piece of string on the centre of the yarn in the photograph and following the contour.

d) Samples

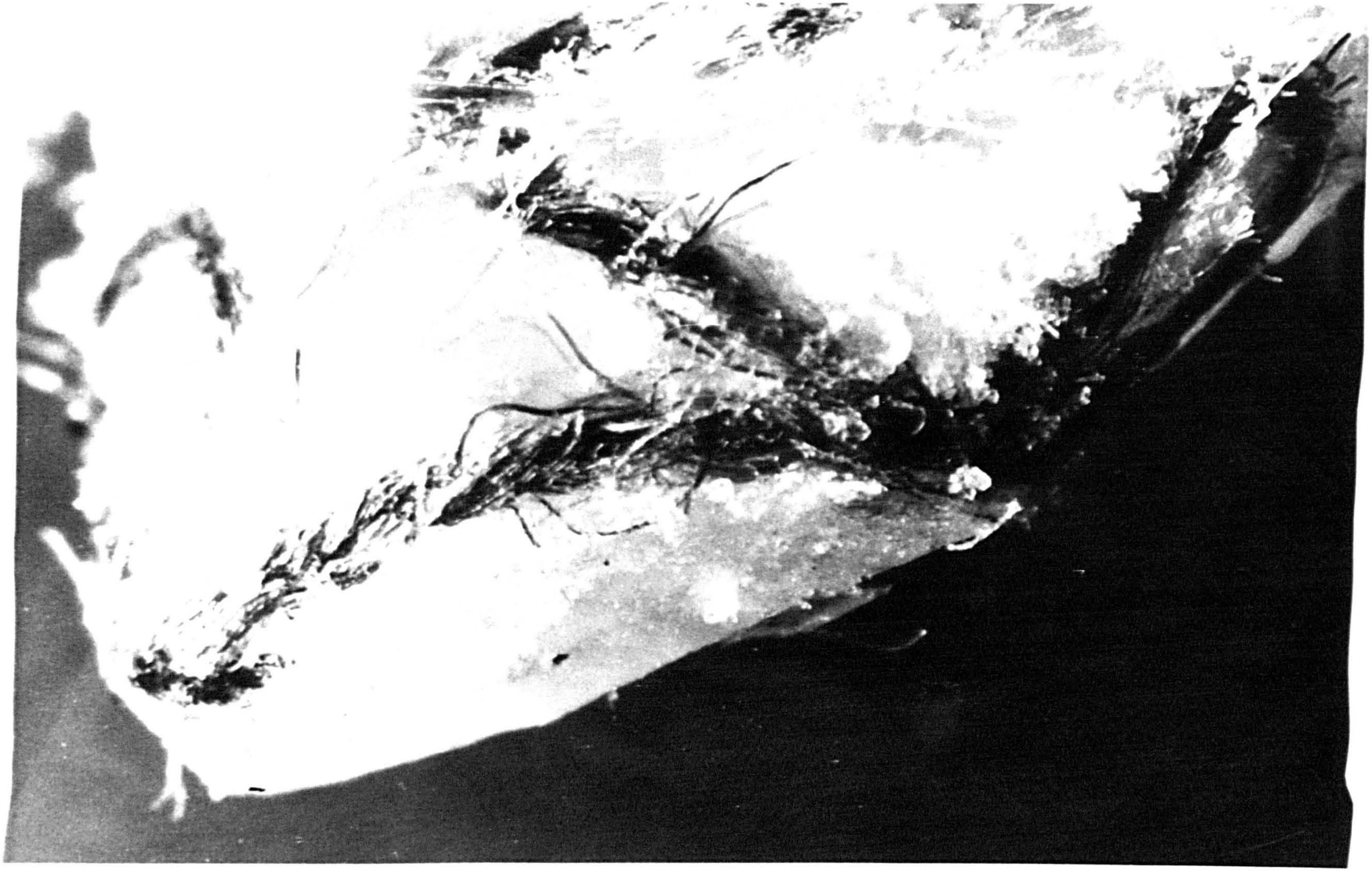
Photographs were taken of three constructions in each grouping representing a slack, medium and tight fabric in each case. The samples were also selected so that a number of yarn counts were represented in each group as follows -



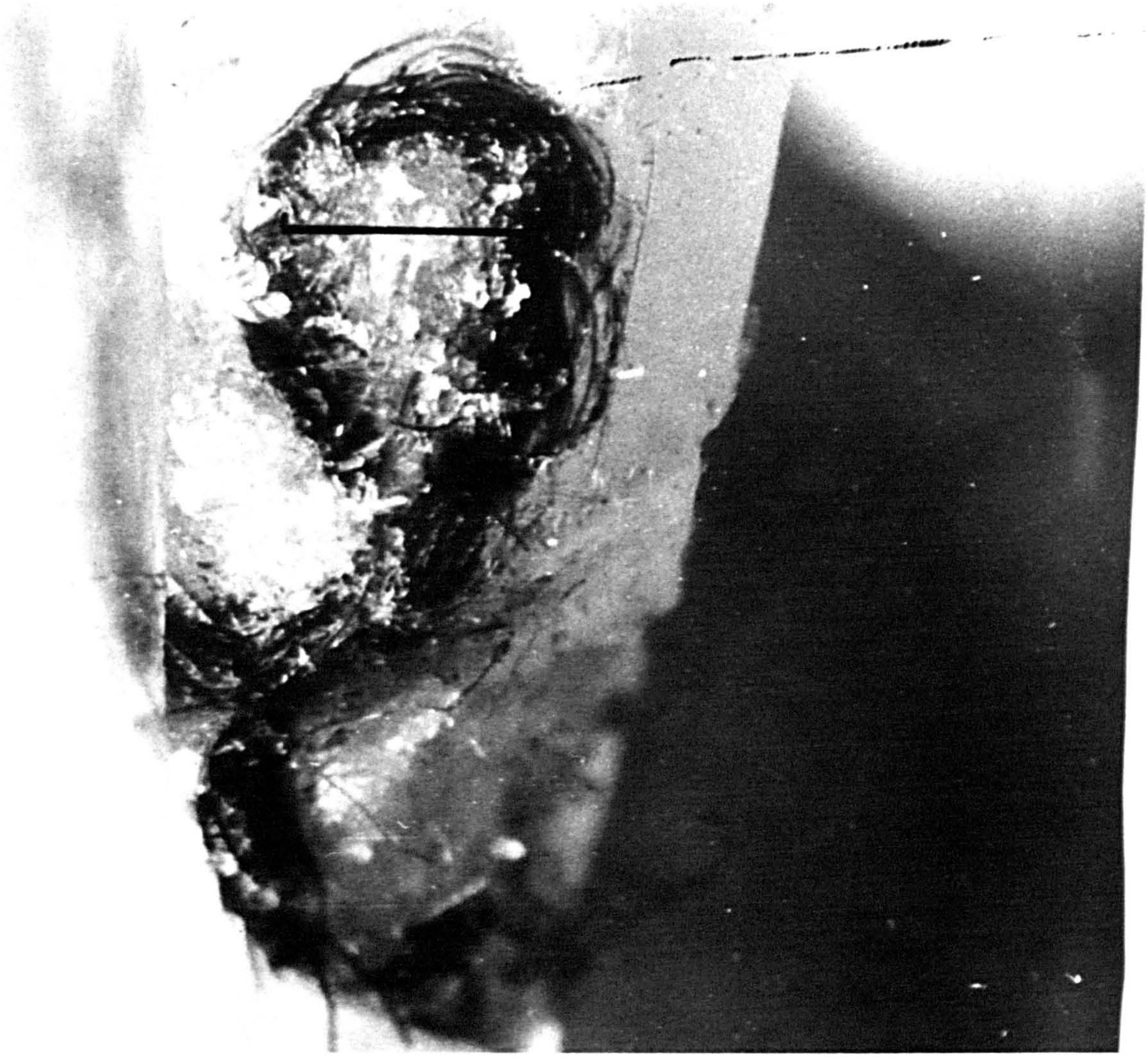
Photograph 8 2 x 1 Closed Lap (ℓ = 0.287 in)



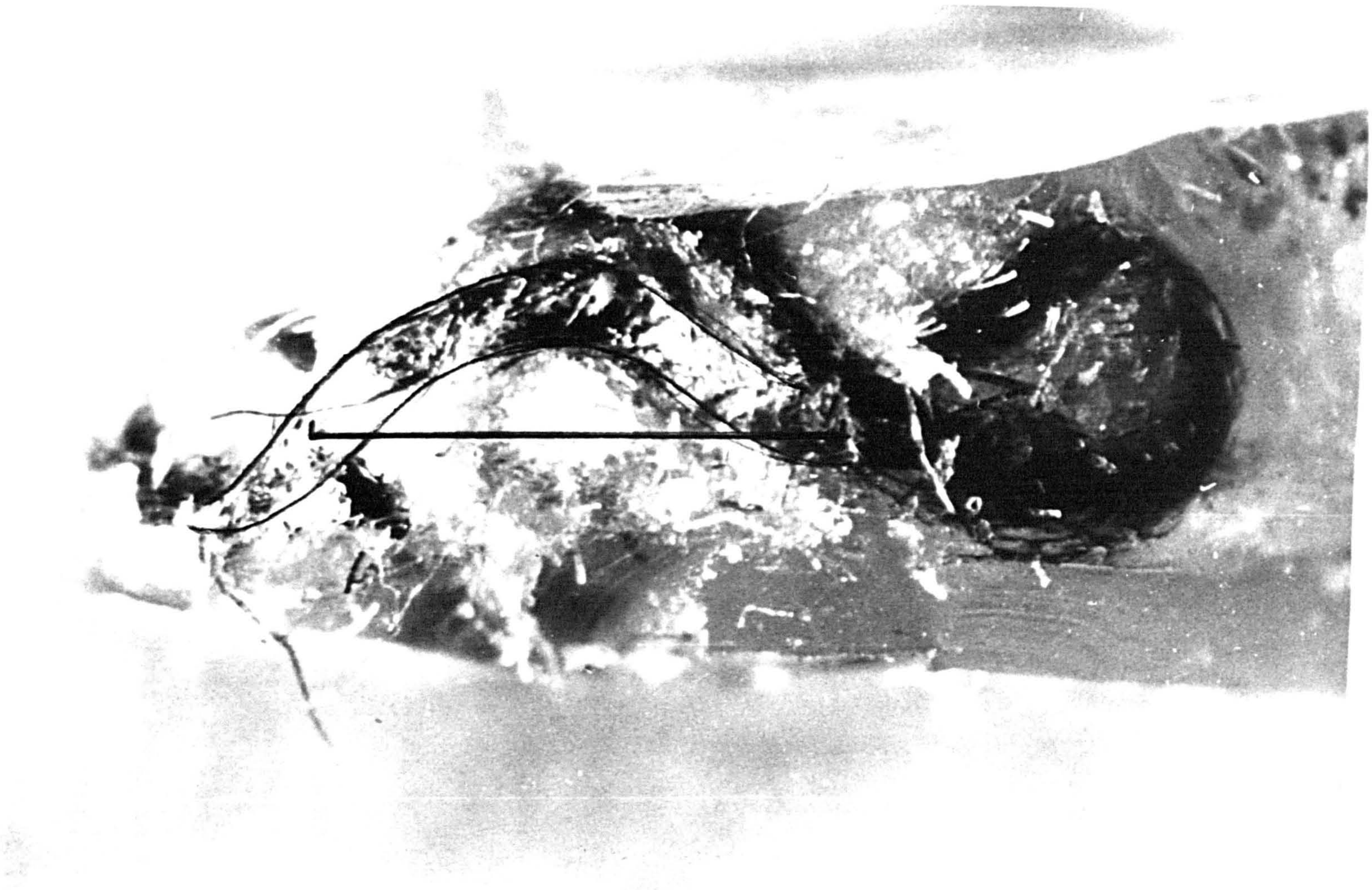
Photograph 9   3 x 1 Closed Lap (ℓ = 0.480 in)



Photograph 10   4 x 1 Closed Lap (ℓ = 0.369 in)



Photograph 11 2 x 1 Closed Lap ($\ell = 0.287$ in)



Photograph 12   2 x 1 Closed Lap (ℓ = 0.287 in)

Structure	Stitch length (in)	Count	c.p.i.	w.p.i.
1 x 1 Closed	0.362	2/32	24.41	9.30
" "	0.210	2/48	37.89	15.24
" "	0.160	1/20	55.38	18.39
1 x 1 Open	0.359	2/32	22.78	11.19
" "	0.205	1/20	40.00	19.28
" "	0.154	1/20	48.37	27.23
2 x 1 Closed	0.442	1/12	17.14	14.03
" "	0.287	1/20	25.00	19.75
" "	0.233	2/48	31.30	25.40
3 x 1 Closed	0.480	2/32	15.93	18.15
" "	0.356	1/12	21.82	21.92
" "	0.313	2/32	25.53	25.81
4 x 1 Closed	0.497	1/20	14.52	21.92
" "	0.419	1/12	19.46	24.24
" "	0.369	2/32	21.82	28.07

2. Discussion of Results for 2 x 1, 3 x 1 and 4 x 1 Closed Lap

The actual shape of the stitch formed in the fabrics under investigation was studied under the microscope and in the photographs and was found to be of a shape as that shown in Fig. 88. The yarn enters the stitch at point (a) and forms the loop, returning to run parallel with the yarn entering the loop at (b). On emerging from this loop the yarn passes up and over the incoming yarn to form the underlap (c). The underlap passes over one, two or three loops, (depending on whether a 2 x 1, 3 x 1 or

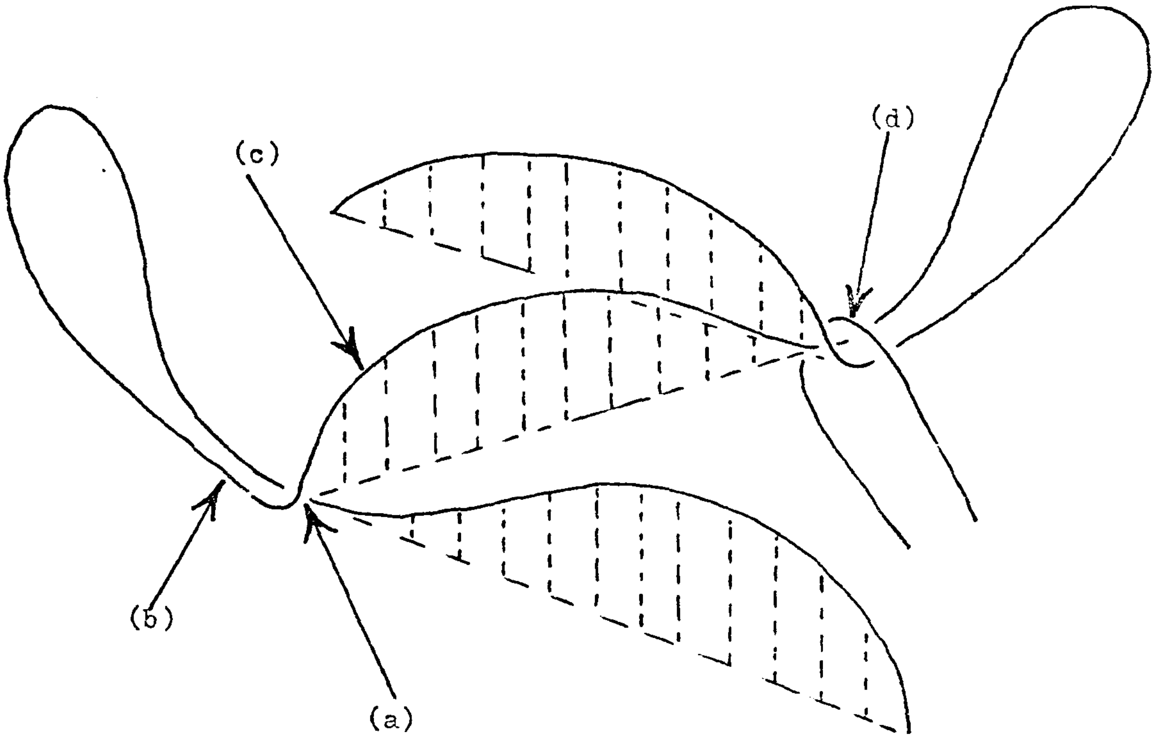


Fig. 88 Three Dimensional Shape of Structure

4 x 1 construction is considered), before entering the loop (d) to form the next course.

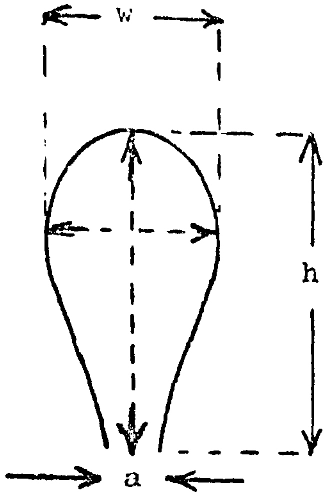
a) The loop

The size and shape of the loop was studied from the photographic evidence and it was found that it was difficult to measure the loop height accurately, it being hard to determine the point at which the height could be considered to terminate. If the point was taken at which the two arms appeared to cross, the shape was not that of an elastica. To extend the loop height beyond this point brings the parallel section of the arms into consideration at which point the yarns bend to form the curve at the commencement of the underlap so that no discernable point representing the limit of the loop height could be established.

Observation of the photographs, however, suggested that it was relatively easy to measure the loop width at its widest point and from this it is possible to calculate the loop height assuming that the loop shape is that of an elastica as all visual and photographic evidence indicates. The relationship between height and width of an elastica[88] is - $\frac{h}{w} = 2.08 - 2.72a$ (See Fig. 89).

It will be noted from the photographs that where the two arms of the loop become parallel, they are positioned one on top of the other. Thus, the loop may be represented as an elastica, where $a = o$ Hence $\frac{h}{w} = 2.08$ or $h = 2.08w$

Table 32 shows the results obtained.



$$\frac{h}{w} = 2.08 - 2.72a$$

If $a = 0$, $\frac{h}{w} = 2.08$

Therefore $h = 2.08w$

Fig. 89 Elastica

TABLE 32

Structure	Stitch length (IN)	Loop Width (IN)	Loop height (2.08 width) (IN)	Yarn in loop 2.54(2.08w) (IN)
2 x 1	0.442	1.75	3.64	9.26
	0.287	1.25	2.60	6.61
	0.233	1.10	2.29	5.81
3 x 1	0.480	1.75	3.64	9.25
	0.356	1.10	2.29	5.81
	0.313	1.10	2.29	5.81
4 x 1	0.497	1.90	3.95	10.05
	0.419	1.35	2.81	7.14
	0.369	1.30	2.50	6.87

b) The underlap

To investigate the three dimensional shape of this part of the stitch, the amount of yarn in the underlap was measured by placing a string on the curved path of the underlap and also the straight path of the underlap was measured, the yarn in the curved path being expressed as a ratio of the yarn in the straight path. This is shown in Table 33.

From this table, it will be observed that a variation exists in the difference between the curved and straight underlap, but this variation is only small and scattered. It is of considerable interest to note that the value does not change with stitch length or with structure and, therefore, the average value may be taken. This is 1.20.

TABLE 33

Structure	Stitch Length (IN)	Straight underlap (IN)	Curved Underlap (IN)	Ratio
2 x 1	0.442	4.00	4.80	1.20
	0.287	2.95	3.13	1.12
	0.233	1.90	2.30	1.23
3 x 1	0.480	4.95	6.55	1.31
	0.356	5.00	6.00	1.20
	0.313	3.90	4.60	1.18
4 x 1	0.497	5.80	5.85	1.10
	0.419	4.75	5.90	1.24
	0.369	4.50	5.15	1.14
			Average	1.20

c) Comparison of the calculated stitch length with the actual stitch length

The stitch length was calculated from the above values obtained for the loop and the underlap and compared with the known stitch length. Results obtained are shown in Table 34.

From this table, it may be observed that the calculated stitch length is less than the actual value. This may be explained when it is appreciated that in this model no allowance has been made for the fact that the underlap does not lie in a single plane but takes a three dimensional shape where it joins the loop. If an allowance were made for this, the ratio of straight to curved underlap would be greater than that given by the 1 to 1.20 ratio.

TABLE 34

Difference between calculated stitch length and actual stitch length

Structure	Stitch length (in)	Calculated loop x 35 (in)	Calculated underlap x 35 (in)	Total stitch length x 35 (in)	Actual stitch length x 35 (in)	Difference
2 x 1	0.442	9.78	4.85	14.68	15.47	-0.79
	0.287	6.61	3.13	9.74	10.05	-0.31
	0.233	5.81	2.30	8.11	8.16	-0.05
3 x 1	0.480	9.25	6.55	14.96	16.80	-1.84
	0.356	5.81	6.00	11.81	12.46	-0.65
	0.313	5.81	4.45	10.21	10.96	-0.75
4 x 1	0.497	10.05	5.85	15.90	17.39	-1.49
	0.419	7.14	5.90	13.04	14.66	-1.62
	0.369	6.87	5.15	12.02	12.91	-0.89

It is not possible to ~~actually~~ measure this curve of the underlap on the photographs, but the extent of the ratio of length of yarn in the underlap may be assessed by subtracting the length of yarn in the loop, (assuming it to be an elastica), from the total stitch length and then dividing the remainder by the 'straight length' of the underlap. The results to this approach are shown in the following Table 35

TABLE 35

Modified ratio between straight underlap and the curved underlap

Structure	Stitch length IN	loop length 2.54(2.08w) x 35 IN	Stitch length x 35 minus loop length x 35 IN	Straight underlap IN	Ratio
2 x 1	0.442	9.26	6.213	4.00	1.55
	0.287	6.61	3.433	2.95	1.16
	0.233	5.82	2.337	2.10	1.11
3 x 1	0.480	9.25	7.544	4.95	1.52
	0.356	5.81	6.650	5.00	1.32
	0.313	5.81	5.150	3.90	1.32
4 x 1	0.497	10.05	7.351	5.30	1.26
	0.419	7.14	7.524	4.50	1.67
	0.369	6.87	6.039	4.50	1.34
				Average	1.36

From this table it can be seen that the ratio of the yarn in the underlap to the straight underlap is 1.36 and that this value is independent of tightness of knitting and the structure.

d) Conclusions

From the foregoing, it has been shown that the most convenient method of establishing the amount of yarn in the stitch is to consider it in two separate parts, the loop and the underlap. The loop takes the shape of an elastica, the amount of yarn contained there-in being 2.54 times the loop height. The underlap is in a curved form, the amount of yarn used being 1.36 times the distance occupied by the straight underlap. It has been shown that both the ratio of the yarn in the loop and that of the curve of the underlap are independent of the tightness of knitting and structure for the 2 x 1, 3 x 1 and 4 x 1 range of closed lap constructions.

3. Relationship between Loop Model and Dimensional Parameters of the Knitted Structure

In considering the construction of a loop model which shows the relationship between the c.p.i. and w.p.i. to the stitch length, it is necessary to consider a two dimensional model, as two planes only, (wales and courses), are taken into consideration when calculating the stitch length. This must then be related to the three dimensional shape by introducing the required ratios for the bend of the loop and the underlap.

Observation of the loop structure and the photographs suggested that the loop and the underlap could be considered the hypotenuse of separate right-angled triangles, the horizontal axis of which was related to the w.p.i. and the vertical axis being related to the c.p.i.

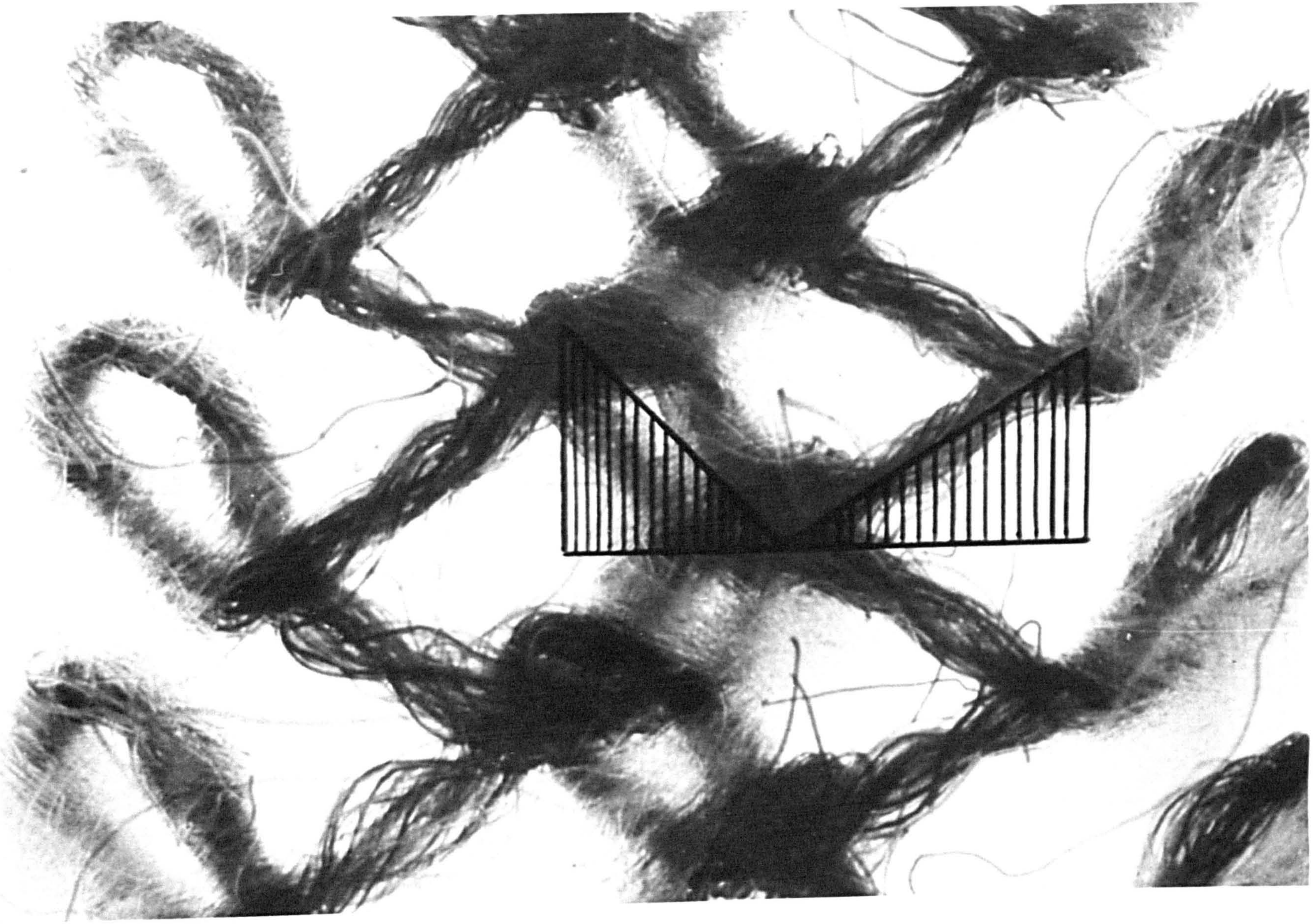
In order to assess accurately the precise relationship between the vertical and horizontal axes of the two right-angled triangles and the course and wale spacing, measurements were made of the various photographs of the nine constructions described in Part III. 1 (d) of this chapter, vis. three stitch lengths of each construction, i.e. 2 x 1, 3 x 1 and 4 x 1 closed lap constructions.

Examples of the manner in which the two triangles were constructed on each structure are shown in Photographs 13, 14 and 15.

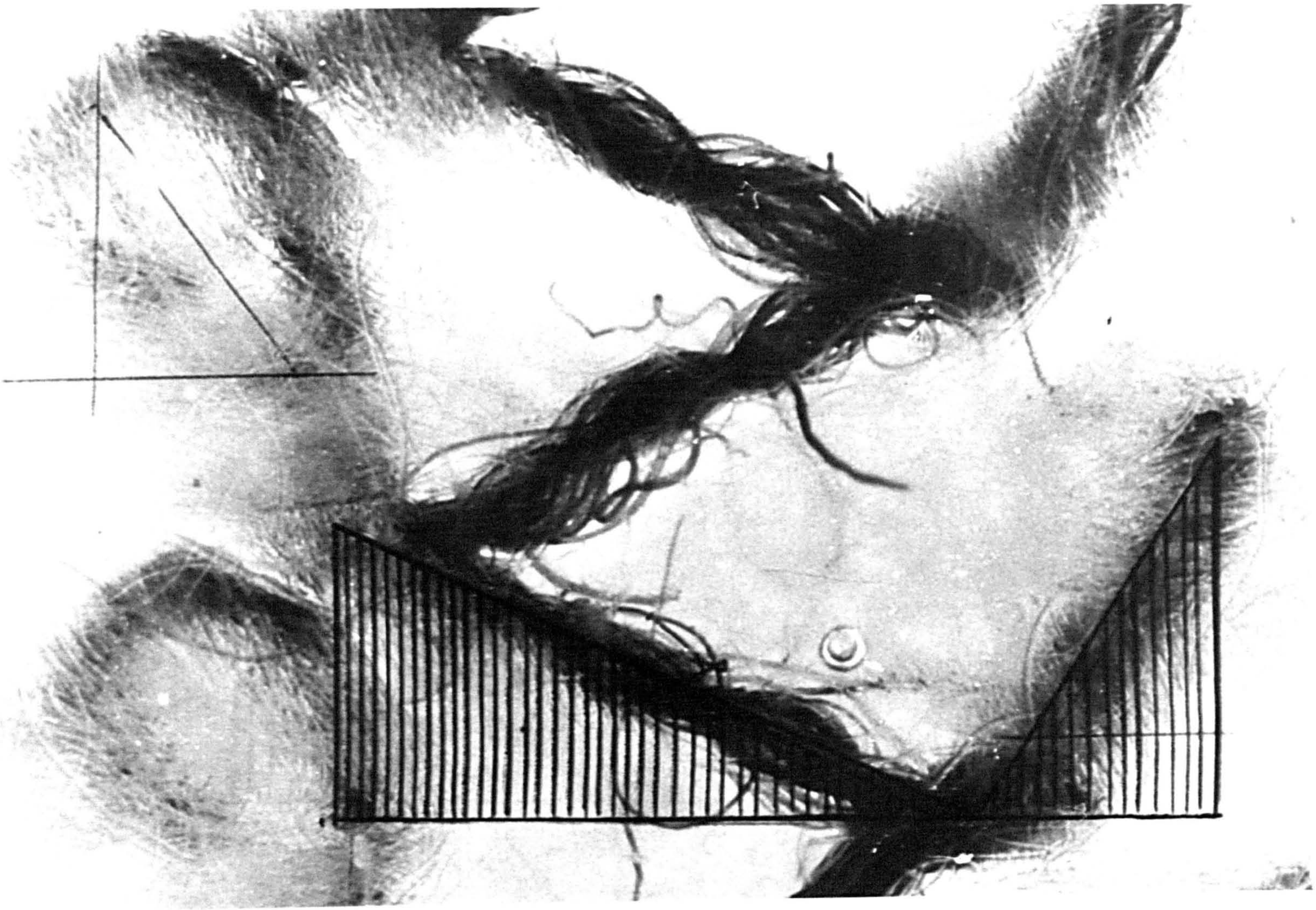
a) Loop

Owing to the fact that the loops twist and lie partially out of the plane of the fabric and due to the fact that they lean in alternate directions so that odd courses lean to the right and even courses lean to the left, the space occupied by one loop is less than one wale and greater than one course. Further, in some cases, the loops on odd courses are different to those on even courses so the following values of width and depth of the loop, (Table 36) are average values and show the width of the loop relative to the wale spacing and the height of the loop relative to course spacing.

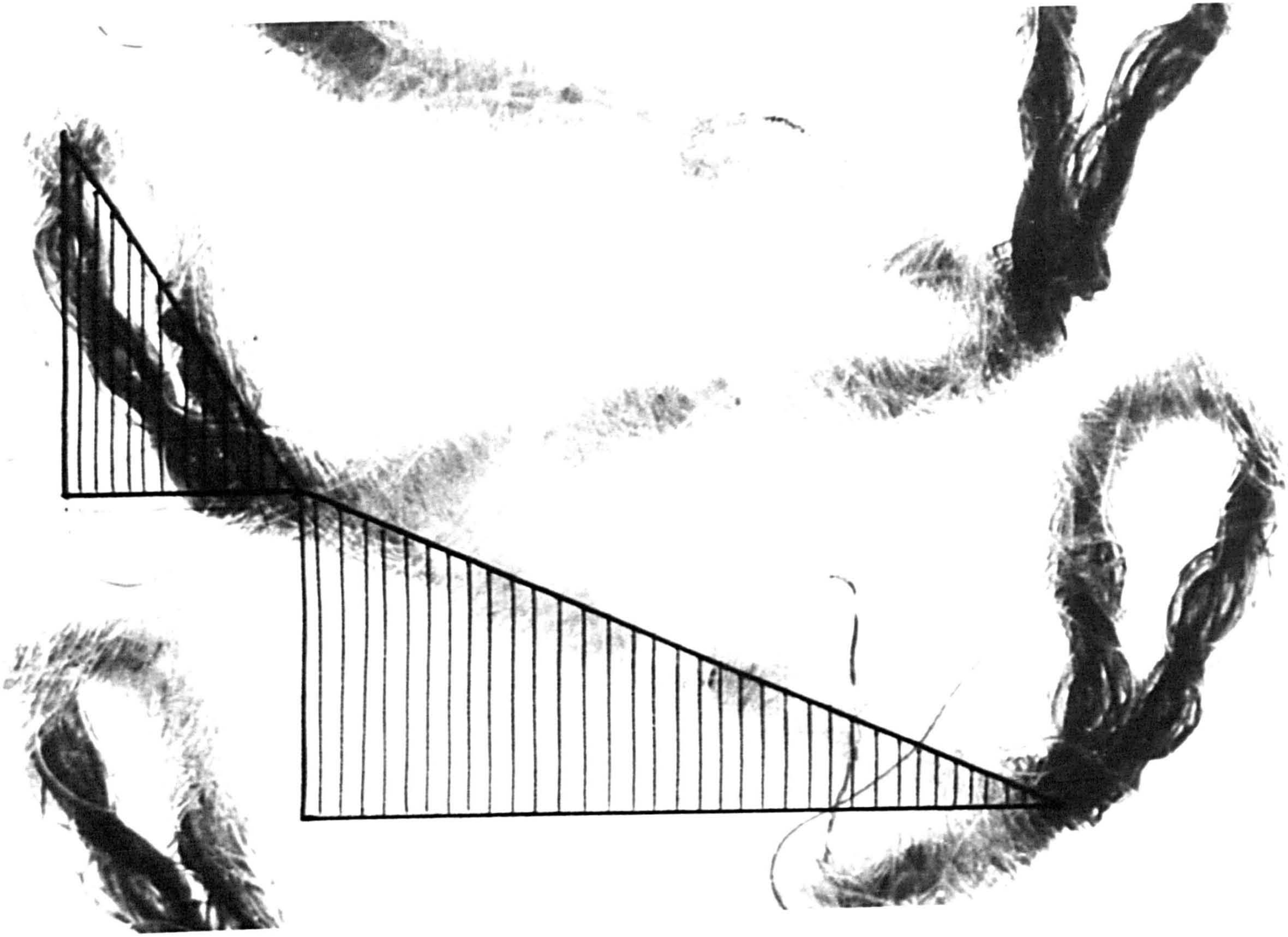
From Table 36, it will be noted that whilst a variation exists in the value of the height and base of the triangle, this variation is only small and completely scattered which suggests that this relationship is independent of the stitch length and the construction. It is, therefore, possible to take the average



Photograph 13   2 x 1 Closed Lap (ℓ = 0.233 in)



Photograph 14 3 x 1 Closed Lap (ℓ = 0.356 in)



Photograph 15 4 x 1 Closed Lap (ℓ = 0.369 in)

TABLE 36

Relationship of width and height of loop to course and wale spacing

(MEASURED IN INCHES)

Structure	Stitch length	Measurement of 1 wale in fabric	Measurement of 1 wale in photo.	Ratio	Measurement of 1 course in fabric	Measurement of 1 course in photo.	Ratio
2 x 1	0.442	2.49	2.00	0.80	2.03	2.50	1.23
	0.287	1.77	1.58	0.89	1.40	1.65	1.18
	0.233	1.38	1.45	1.05	1.12	1.55	1.38
3 x 1	0.480	1.90	1.60	0.83	2.20	2.60	1.18
	0.356	1.60	1.45	0.91	1.60	2.35	1.47
	0.313	1.36	1.15	0.85	1.37	1.85	1.35
4 x 1	0.497	1.60	1.10	0.69	2.41	3.25	1.35
	0.419	1.44	1.44	1.00	1.80	2.60	1.44
	0.369	1.25	1.25	1.00	1.60	2.11	1.32
			Average	0.89		Average	1.32

value of the height and base of the triangle for the three constructions 2 x 1, 3 x 1 and 4 x 1 in which case the height of the triangle may be said to equal 1.32c and the base equal to 0.89w, therefore the hypotenuse is equal to -

$$\sqrt{(1.32c)^2 + (0.89w)^2} \quad .. \quad .. \quad (1)$$

The values of the loops were calculated for each of the samples and compared with the values obtained in the photographs. These are shown in Table 37 and it will be noted that a good agreement is obtained.

TABLE 37

Comparison of calculated and measured photographic values of loop height

(MEASURED IN INCHES)

Structure	Stitch length	Calculated height	Measured height	% error
2 x 1	0.442	3.50	3.50	0
	0.287	2.43	2.50	+2.8
	0.233	1.92	1.90	-1.0
3 x 1	0.480	3.37	3.40	+0.8
	0.356	2.55	2.50	-2.0
	0.313	2.18	2.20	+0.9
4 x 1	0.497	3.37	3.40	+0.8
	0.419	2.70	2.80	+3.5
	0.369	2.39	2.40	+0.4

Allowance for three dimensional shape

It has been shown that the loop twists and lies into the third dimension, the fabric thickness, and that it curves at its base to commence the formation of the underlap. Thus the actual height of the loop, (assuming it to be an elastica), in the three dimensions is greater than that for the two dimensional value calculated from equation (1). The figures for the actual and calculated heights for the nine samples are compared in Table 38 as a ratio. From this table it will be observed that this ratio remains constant and is independent of the tightness of the construction and the structure, therefore, the average value may be taken. Thus the loop height is 1.09 times greater than the loop height calculated by equation (1).

$$\text{Hence loop height} = 1.09\sqrt{(1.32c)^2 + (0.89w)^2}$$

The amount of yarn in the loop is 2.54 times greater than the loop height, therefore, yarn in loop -

$$= 2.54\left(1.09\sqrt{(1.32c)^2 + (0.89w)^2}\right)$$

$$\text{or} \quad 2.78\sqrt{(1.32c)^2 + (0.89w)^2}$$

b) The underlap

The underlap may be considered as the hypotenuse of a right-angled triangle whose depth is proportional to the course spacing and whose width is proportional to the wale spacing. The nine samples were examined and measurements taken from the photographs in a similar manner to that used to determine the loop size.

TABLE 38

Relationship between the two dimensional and three dimensional loop height

(MEASURED IN INCHES)

Structure	Stitch length	$\sqrt{(1.32c)^2 + (0.89w)^2}$	x 35	Height of loop 2.08 x w	Ratio
2 x 1	0.442	0.099	3.49	3.74	1.07
	0.287	0.070	2.43	2.70	1.11
	0.233	0.055	1.92	2.39	1.25
3 x 1	0.480	0.096	3.37	3.12	0.99
	0.356	0.073	2.55	2.60	1.02
	0.313	0.062	2.17	2.49	1.15
4 x 1	0.497	0.096	3.37	3.95	1.17
	0.419	0.077	2.70	2.80	1.04
	0.369	0.068	2.39	2.49	1.04
				Average	1.09

TABLE 39

Relationship between height and width of the underlap to the course and wale spacing

(MEASURED IN INCHES)

Structure	Stitch length	Width	One Wale	Ratio	Depth	One Course	Ratio
2 x 1	0.442	3.50	2.50	1.40	2.20	2.04	1.08
	0.287	2.50	1.77	1.40	1.40	1.40	1.00
	0.233	1.90	1.37	1.37	1.00	1.12	0.89
			Average	1.39			
3 x 1	0.480	4.50	1.93	2.33	2.40	2.20	1.09
	0.356	3.50	1.60	2.19	1.70	1.60	1.06
	0.313	3.25	1.36	2.39	1.80	1.37	1.31
			Average	2.30			
4 x 1	0.497	5.20	1.60	3.25	1.70	1.41	1.20
	0.419	4.60	1.44	3.19	1.80	1.80	1.00
	0.369	4.20	1.25	3.36	1.80	1.60	1.12
			Average	3.27	Average of 3 structures		1.08

The measurements are shown in Table 39 and from this table it will be observed that the height of the right angled triangle under consideration is a little greater than one course. It will also be observed that this value is similar for each construction irrespective of the tightness of the stitch, therefore, it is reasonable to take the average of the nine samples which is 1.08c.

Examination of the values for the width of the base of the triangle under consideration reveals that the width of the triangle is dependent on the construction. This is not surprising as the length of the underlap increases from structure to structure. The 2 x 1 movement has an underlap of two needle spaces, the 3 x 1 three needle spaces and the 4 x 1, four needle spaces. The fraction by which this figure is greater than a whole number decreases with increase in lapping movement and it is suggested that this occurs because the loops become successively more vertical as the length of the underlap increases.

Thus, the length of the underlap may be calculated as follows -

$$\text{Underlap} = \sqrt{(1.08c)^2 + n^2w^2}$$

where n = 1.39 for a 2 x 1 structure

2.30 for a 3 x 1 structure

3.27 for a 4 x 1 structure

Values for the nine constructions were calculated and compared with the actual values measured from the photographs. This is shown in Table 40 where it will be observed that a good

TABLE 40

Comparison of calculated and measured photographic values of underlap

(MEASURED IN INCHES)

Structure	Stitch length	Calculated underlap	Measured underlap	% Error
2 x 1	0.442	3.96	3.90	+1.5
	0.287	2.79	2.75	-1.5
	0.233	2.18	2.15	-1.4
3 x 1	0.480	5.06	5.10	+0.8
	0.356	4.09	4.00	-2.3
	0.313	3.48	3.50	+0.6
4 x 1	0.497	5.91	6.00	+1.5
	0.419	5.17	5.10	-1.4
	0.369	4.49	4.60	+2.4

agreement is obtained between the two sets of figures.

Allowance for three dimensional shape

It has been shown at III 2 (c) above that the curved path of the underlap results in a length 1.364 times greater than the straight path. The length of the yarn in the underlap may, therefore, be calculated as follows -

$$u = 1.36 \sqrt{(1.08c)^2 + (nw)^2} \qquad .. \qquad .. \qquad (2)$$

c) Complete loop model

The complete formula for the calculation of stitch length from equations (1) and (2) above is, therefore, given by -

$$\ell = 2.78\sqrt{(1.32c)^2 + (0.89w)^2} + 1.36\sqrt{(1.08c)^2 + (nw)^2} \quad \ldots \quad \ldots \quad (3)$$

where n = 1.39 for 2 x 1

2.30 for 3 x 1

3.27 for 4 x 1

4. 2 x 1, 3 x 1 and 4 x 1 Open Lap Constructions

It has been shown in Chapter VIII that there is no difference in the relationship between the knitted parameters and the stitch length for the open and closed lap versions of the 2 x 1, 3 x 1 and 4 x 1 constructions. It is suggested, therefore, that the same loop model may be used to predict the stitch length - viz. $\ell = 2.78\sqrt{(1.32c)^2 + (0.89w)^2} + 1.36\sqrt{(1.08c)^2 + (nw)^2}$ A spot check was taken for three samples, the theoretical stitch length being calculated according to the formula and compared with the actual value. A good agreement between the two sets of results was obtained as follows -

Structure	Actual ℓ	Calculated ℓ	% Error
2 x 1 Open	0.302	0.299	-1.0
3 x 1 Open	0.369	0.364	-1.1
4 x 1 Open	0.430	0.431	+0.2

5. The Introduction of the Course/Wale Relationship

It has been shown in Chapter VII and VIII that a definite relationship exists between the wales and the courses in the single bar warp knitted constructions investigated. This relationship was investigated by analysis of the k_r values where it was shown that the 2 x 1, 3 x 1 and 4 x 1 constructions each possess a different k_r value, but that there is no difference in a statistical sense between the closed and open lap versions of each construction.

It follows, therefore, that for any given value of course spacing, there is a definite and fixed value of wale spacing which must be used in the formula given at 3(c) and 4 above in order to calculate the stitch length. This relationship must be introduced into the formula so giving a complete relationship between the courses per inch and the stitch length, or alternatively, the wales per inch and the stitch length.

Although the relationship between courses and wales was analysed in the form of the k_r relationship, this cannot be used in the formula as k_r varies with stitch length. Also, the value required is the relationship between course and wale spacing rather than that of c.p.i. and w.p.i. It was, therefore, necessary to obtain the relationship between course spacing and wale spacing by regression analysis. This, together with the relevant graphs, is shown in Appendix 5. The relationships obtained were as follows -

2 x 1 Open and Closed Lap	$w = 1.096c + 0.006$
3 x 1 Open and Closed Lap	$w = 0.728c + 0.010$
4 x 1 Open and Closed Lap	$w = 0.564c + 0.009$

These results may be substituted into formula (3) above together with the value for the number of spaces moved on the underlap, (n), to give the complete relationships between course spacing and stitch length as follows -

2 x 1 Open and Closed Lap

$$\ell = 2.78\sqrt{(1.32c)^2 + \left[0.89\,(1.096c + 0.006)\right]^2} + 1.36\sqrt{(1.08c)^2 + \left[1.39\,(1.096c + 0.006)\right]^2}$$

or

$$\ell = 2.78\sqrt{(1.32c)^2 + (0.975c + 0.005)^2} + 1.36\sqrt{(1.08c)^2 + (1.523c + 0.008)^2}$$

3 x 1 Open and Closed Lap

$$\ell = 2.78\sqrt{(1.32c)^2 + \left[0.89\,(0.728c + 0.010)\right]^2} + 1.36\sqrt{(1.08c)^2 + \left[2.30\,(0.728c + 0.010)\right]^2}$$

or

$$\ell = 2.78\sqrt{(1.32c)^2 + (0.648c + 0.009)^2} + 1.36\sqrt{(1.08c)^2 + (1.674c + 0.023)^2}$$

4 x 1 Open and Closed Lap

$$\ell = 2.78\sqrt{(1.32c)^2 + \left[0.89\,(0.564c + 0.009)\right]^2} + 1.36\sqrt{(1.08c)^2 + \left[3.27\,(0.564c + 0.009)\right]^2}$$

or

$$\ell = 2.78\sqrt{(1.32c)^2 + (0.502c + 0.008)^2} + 1.36\sqrt{(1.08c)^2 + (1.844c + 0.029)^2}$$

IV. VERIFICATION OF THE THREE DIMENSIONAL LOOP SHAPE AND THE LOOP MODELS FOR THE 1 x 1 OPEN AND CLOSED LAP CONSTRUCTIONS

1. Introduction

It has been shown in Chapters VII and VIII that the 1 x 1 closed lap and the 1 x 1 open lap possess different relationships between the dimensional parameters and the stitch length from those for the 2 x 1, 3 x 1 and 4 x 1 open and closed lap constructions.

Visual examination of the 1 x 1 open and closed lap constructions under the microscope and the photographs suggested that this difference was due to the angle at which loops lay in the fabric rather than the three dimensional shape of the loop. It was proposed, therefore, to investigate the two dimensional shape of the loop and its relationship with the course and wale spacing only, and to ignore the three dimensional effect. Then, by substituting the values obtained for the 2 x 1, 3 x 1 and 4 x 1 closed lap constructions, it would be possible to verify the results obtained for the three dimensional shape of the loop.

2. 1 x 1 Closed Lap Construction

a) Two dimensional shape

Observation of the lay of the yarn in the loop from photographs, (photograph 16 illustrating one example), led to the development of the loop structure shown in Fig.90 from which it may be seen that the height of the loop may be considered to be the hypotenuse of a right angled triangle which is related to the course and wale spacing as follows -

$$h = \sqrt{(1.53c)^2 + (0.64w)^2}$$

The underlap (u) is equal to the hypotenuse of a right angled triangle which is related to the course and wale spacing by the relationship $u = \sqrt{(0.95c)^2 + (0.5w)^2}$

The appropriate values of loop height and underlap were calculated

Photograph 16   1 x 1 Closed Lap (ℓ = 0.210 in)

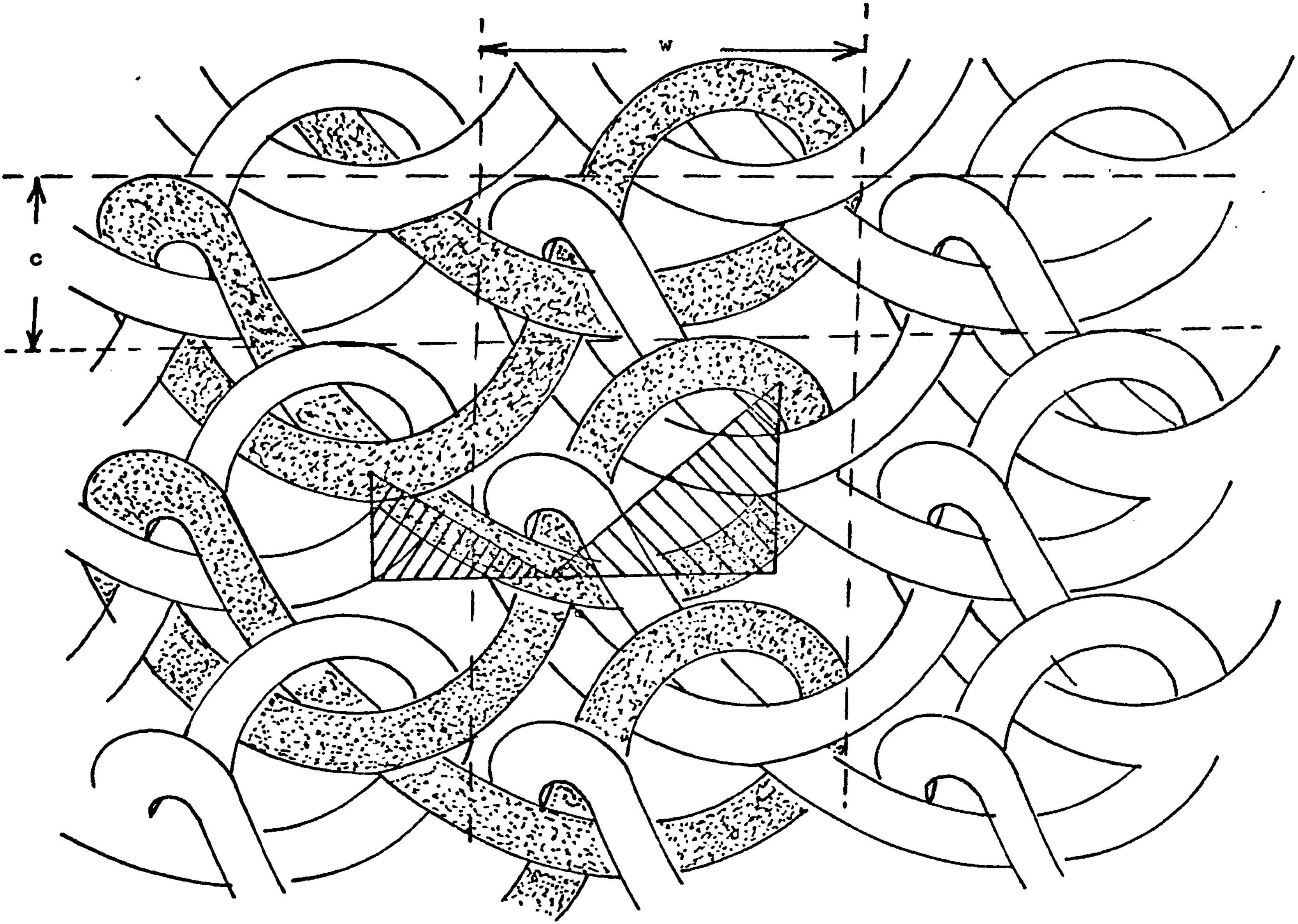


Fig. 90 1 x 1 Closed Lap

and compared with measurements on the photographs. A good agreement between calculated and measured values was obtained as may be seen from Table 41.

TABLE 41

Stitch Length (in)	Loop			Underlap		
	Measured loop ht. (in)	Calculated loop ht. (in)	% Error	Measured underlap (in)	Calculated underlap (in)	% Error
0.362	3.25	3.26	+0.3	2.40	2.32	-3.4
0.210	2.00	2.04	+2.0	1.40	1.40	zero
0.160	1.60	1.56	+2.5	1.10	1.12	+1.8

b) Three dimensional shape

Allowance for the three dimensional shape of the loop was made in the same manner as described for the 2 x 1, 3 x 1 and 4 x 1 constructions in part III of this chapter. The resultant relationship between the w.p.i. and c.p.i. and the stitch length is as follows -

$$\ell = 2.78\sqrt{(1.53c)^2 + (0.64w)^2} + 1.36\sqrt{(0.95c)^2 + (0.50w)^2}$$

The values of ℓ were calculated for the three samples used in the analysis and good agreement was obtained between the actual and calculated values as shown in Table 42.

TABLE 42

Actual stitch length (in)	Calculated stitch length (in)	% Error
0.362	0.349	-3.5
0.210	0.211	+0.3
0.160	0.165	+3.4

c) Relationship between course and wale spacing

The relationship between the course and wale spacing as obtained by regression analysis and shown in Appendix 5 is -

$$w = 2.501c + 0.011$$

This may be included in the formula for the 1 x 1 closed lap to give the complete relationship between course spacing and stitch length as follows -

$$= 2.78\sqrt{(1.53c)^2 + \left[0.64\,(2.501c + 0.011)\right]^2} + 1.36\sqrt{(0.95c)^2 + \left[0.50\,(2.501c + 0.011)\right]^2}$$

or

$$= 2.78\sqrt{(1.53c)^2 + (1.601c + 0.007)^2} + 1.36\sqrt{(0.95c)^2 + (1.251c + 0.006)^2}$$

3. 1 x 1 Open Lap Construction

a) Two dimensional shape

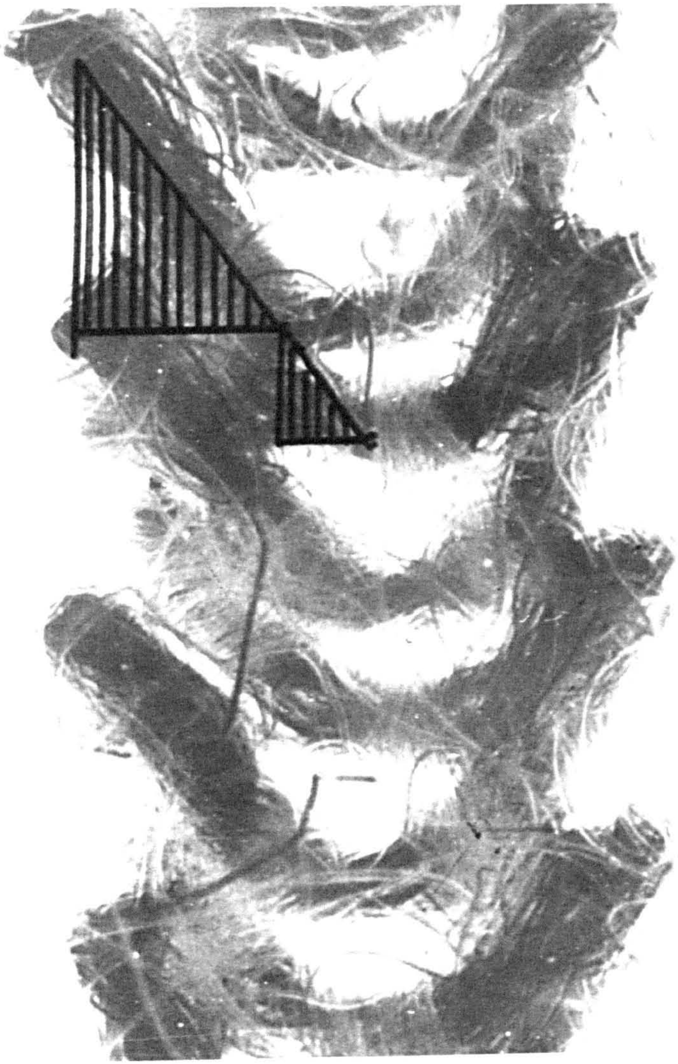
The 1 x 1 open lap construction was examined in the same manner as all other constructions in order to determine the two dimensional shape of the loop. One of the photographs used is illustrated in Photograph 17.

From this work, the loop construction in Fig. 91 was evolved and from this the following relationships between the loop height (h) and the underlap $(\bar{u})$ were obtained -

$$h = \sqrt{(2c)^2 + (0.7w)^2}$$

$$u = \sqrt{(0.7c)^2 + (0.25w)^2}$$

Values of loop height and underlap were calculated and compared



Photograph 17 1 x 1 Open Lap (ℓ = 0.154 IN)

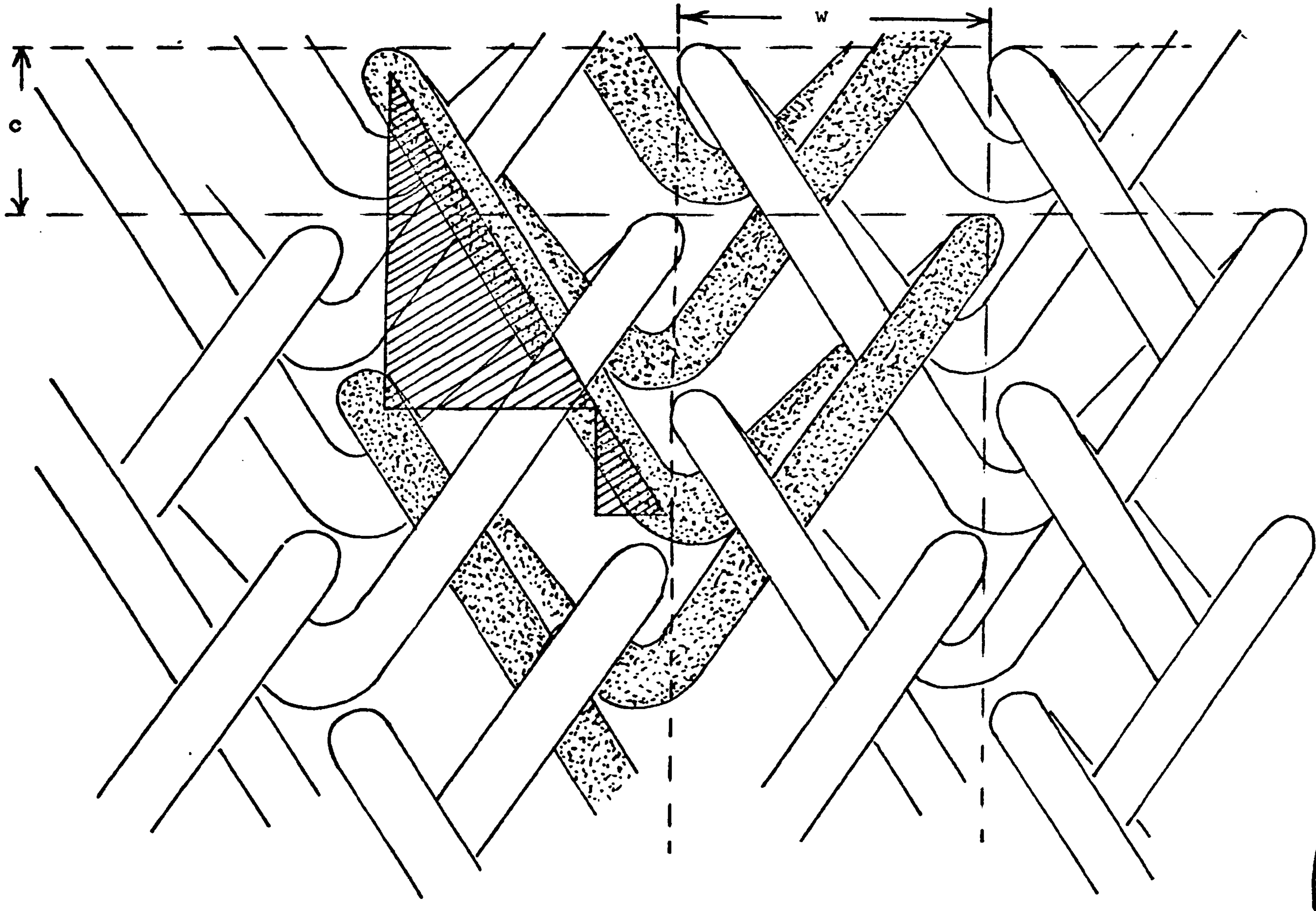


Fig. 91 1 x 1 Open Lap

with the photographs, a good agreement being obtained as shown in the following table 43.

TABLE 43

Stitch Length	Loop			Underlap		
	Measured loop ht.	Calculated loop ht.	% Error	Measured underlap	Calculated underlap	% Error
0.359	3.80	3.77	-0.8	1.30	1.33	+2.3
0.205	2.10	2.16	+2.8	0.75	0.76	+1.3
0.154	1.65	1.70	+3.0	0.60	0.60	zero

b) Three dimensional shape

Allowance for the three dimensional shape of the loop was made in the same manner as that for the 2 x 1, 3 x 1 and 4 x 1 constructions.

Thus, the resultant relationship between stitch length and the w.p.i. and c.p.i. is as follows -

$$\ell = 2.78\sqrt{(2c)^2 + (0.70w)^2} + 1.36\sqrt{(0.70c)^2 + (0.25w)^2}$$

The value of ℓ was calculated for the samples and good agreement was obtained between the calculated and actual values, as shown in Table 44.

TABLE 44

Actual stitch length	Calculated stitch length	% Error
0.359	0.351	-2.2
0.205	0.202	-1.5
0.154	0.159	+3.0

c) Relationship between course and wale spacing

The relationship between course and wale spacing as obtained by regression analysis and shown in Appendix 5 is as follows -

$$w = 2.364c - 0.011$$

This may be included in the formulae for the 1 x 1 open lap to give the complete relationship between stitch length and course spacing as follows -

$$\ell = 2.78\sqrt{(2c)^2 + [0.70\,(2.364c - 0.011)]^2} + 1.36\sqrt{(0.70c)^2 + \{0.25\,(2.364c - 0.011)\}^2}$$

or

$$\ell = 2.78\sqrt{(2c)^2 + (1.655c - 0.008)^2} + 1.36\sqrt{(0.70c)^2 + (0.591c - 0.003)^2}$$

4. Comparison of Actual and Calculated Values

The above formulae were used to calculate the stitch length for two values of c.p.i., one at each end of the experimental range of results for each construction. These values are shown plotted on the relevant graphs of c.p.i. against $\frac{1}{\ell}$, i.e. Figs. 52a, 76, 77, 78, 81, 82, 83 and 84 from which it will be observed that a good agreement with the experimental values is obtained. The actual values calculated are shown in Appendix 5.

V. CONCLUSIONS AND DISCUSSION OF RESULTS

From the work in the chapter, it has been shown that the single bar warp knitted constructions investigated namely, 1 x 1, 2 x 1, 3 x 1 and 4 x 1 closed and open lap constructions produced from worsted yarns behave in a systematic manner according to the way in which the loops lie relative to the course and wale spacing and are not influenced by the three dimensional shape of the loop which remains constant irrespective of the construction and the tightness of knitting.

In the 1 x 1 open lap construction, the loops twist and lie at 90° to the fabric plane so occupying a position in the thickness of the fabric. This is due to the fact that the loops in two adjacent wales produced from the same yarns twist towards each other. This results in a large loop and small underlap, the loop occupying the space of two courses and approximately three quarters of a wale resulting in a fairly upright loop.

In the 1 x 1 closed lap the loops lie in an entirely different manner; the crossing of the yarns at the base of the construction prevent the loops twisting in their entirety into the fabric thickness and only partial twisting occurs. The direct connection of the underlap from one wale to the adjacent wale causes the loop to lean at a much shallower angle, (nearer the horizontal), giving a smaller loop in a course direction than the 1 x 1 open lap and resulting in a larger underlap.

The remaining constructions, (2 x 1, 3 x 1 and 4 x 1 open and closed laps), behave in a similar manner to each other because the underlap of any one thread in these constructions passes over one, two or three wales between the points at which it knits. This prevents the loops from twisting out of the fabric plane in either the open or closed lap versions of the construction when compared with the 1 x 1 open lap. The loops take up a more vertical position than in the 1 x 1 closed lap again due to the fact that the underlap crosses a number of wales between the points at which the yarn knits.

The conclusions drawn from this chapter may be summarised as follows -

1. The fabrics group themselves according to the amount the loop is free to twist out of the fabric plane and the angle which the loop and underlap occupy in a two dimensional manner which influences their relationship of the course and wale spacing, resulting in three different groupings.

    1 x 1 closed lap
    1 x 1 open lap
    2 x 1, 3 x 1 and 4 x 1 open and closed lap constructions.

2. The loop takes up the shape of an elastica irrespective of the construction considered, or the tightness of knitting.
3. The ratio of the yarn in the three dimensional shape of the loop, (thickness), in relation to the two dimensional shape, (wales and courses), is the same irrespective of the structure or the tightness of the construction.
4. The ratio of the yarn in the three dimensional shape of the underlap, (thickness), to the two dimensional shape, (wales and courses), is the same irrespective of the construction and the tightness of knitting.

5. The results are independent of yarn count.

6. Since there is a definite relationship between the course spacing and the wale spacing, this fact has been incorporated into the loop model to give the following complete relationships between the course spacing and stitch length. Similar relationships may be calculated for the wale spacing and the stitch length.

1 x 1 Open lap

$$\ell = 2.78\sqrt{(2c)^2 + (1.655c - 0.008)^2} + 1.36\sqrt{(0.70c)^2 + (0.591c - 0.003)^2}$$

1 x 1 Closed Lap

$$\ell = 2.78\sqrt{(1.53c)^2 + (1.601c + 0.007)^2} + 1.36\sqrt{(0.95c)^2 + (1.251c + 0.006)^2}$$

2 x 1 Open and Closed Lap

$$\ell = 2.78\sqrt{(1.32c)^2 + (0.975c + 0.005)^2} + 1.36\sqrt{(1.08c)^2 + (1.523c + 0.008)^2}$$

3 x 1 Open and Closed Lap

$$\ell = 2.78\sqrt{(1.32c)^2 + (0.648c + 0.009)^2} + 1.36\sqrt{(1.08c)^2 + (1.674c + 0.023)^2}$$

4 x 1 Open and Closed Lap

$$\ell = 2.78\sqrt{(1.32c)^2 + (0.502c + 0.008)^2} + 1.36\sqrt{(1.08c)^2 + (1.844c + 0.029)^2}$$

CHAPTER X

CONSIDERATION OF THE DIMENSIONS OF SINGLE BAR WARP KNITTED FABRICS ON THE MACHINE

INTRODUCTION

It has been established throughout this work that the dimensional parameters of single bar warp knitted fabrics after thorough relaxation are dependent entirely on the length of yarn knitted into the loop. It is essential, therefore, for this loop length to be set accurately on the machine in order to produce a fabric to any required finished dimensions. From a practical point of view when setting up the machine, it is necessary to adjust the fabric take-up motion so that the knitting elements can accommodate the desired stitch length. Thus the relationship between stitch length and c.p.i. on the machine is particularly important. It was decided, therefore, to investigate this relationship on the 1 x 1 closed lap construction.

A preliminary experiment of the relationship between c.p.i. and ℓ on the machine can be obtained by plotting c.p.i. against $\frac{1}{\ell}$, (see Fig. 92). It will be observed from this graph that the relationship between c.p.i. and $\frac{1}{\ell}$ is a complicated one and varies with yarn count.

The work discussed in Chapter IX has established that the relationship between stitch length and the knitted fabric

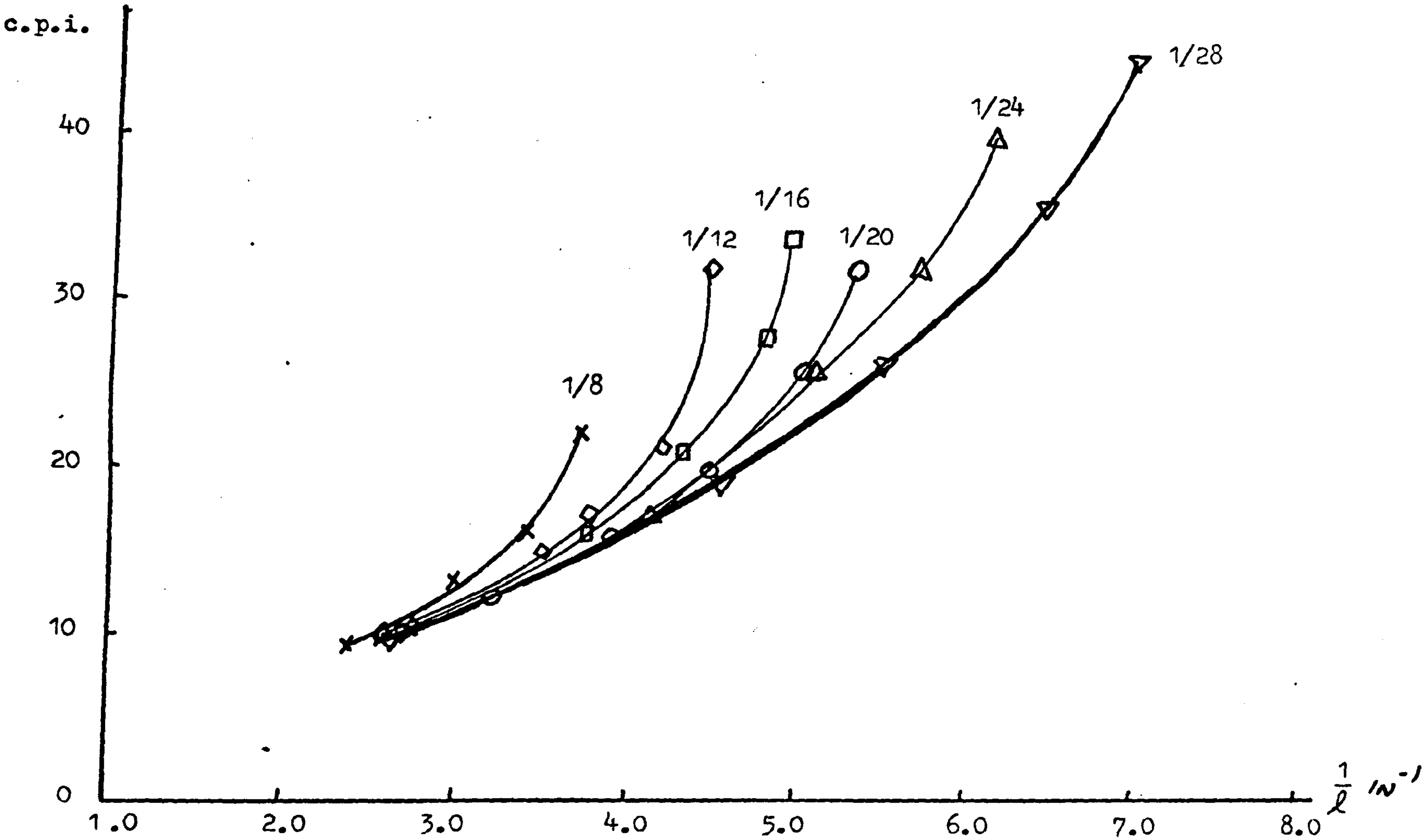


Fig. 92 Relationship between c.p.i. and $\frac{1}{l}$ for fabrics on the machine

parameters in the relaxed condition are independent of yarn count and the formulae evolved which appropriate to these conditions, therefore, do not involve yarn count. Thus they are not suitable for the fabric measured on the machine.

However, the models proposed by Allison and Grosberg, (see Chapter III), indicate that the c.p.i. of a fabric is dependent on yarn count as well as stitch length.

It was, therefore, considered worthwhile to investigate how closely the models proposed by these previous workers fitted the experimental results of the fabrics when on the machine.

PART ONE - LOOP MODELS

I. COMPARISON OF EXPERIMENTAL RESULTS WITH EXISTING LOOP MODELS

1. Allison's Formula

Allison's formula was used to calculate the appropriate values of stitch length for each value of yarn count and c.p.i. and these values may be compared with the practical results in Fig. 93. It will be observed that there is an approximate agreement between the practical values and those obtained from the formula. However, whilst this agreement is good for the 1/8's count at the lower c.p.i., the practical values differ from the calculated values above 20 c.p.i. For the 1/28's yarn, however, there is not such a good fit between the practical values and the theoretical values for any given stitch length, the discrepancy increasing with increase in c.p.i.

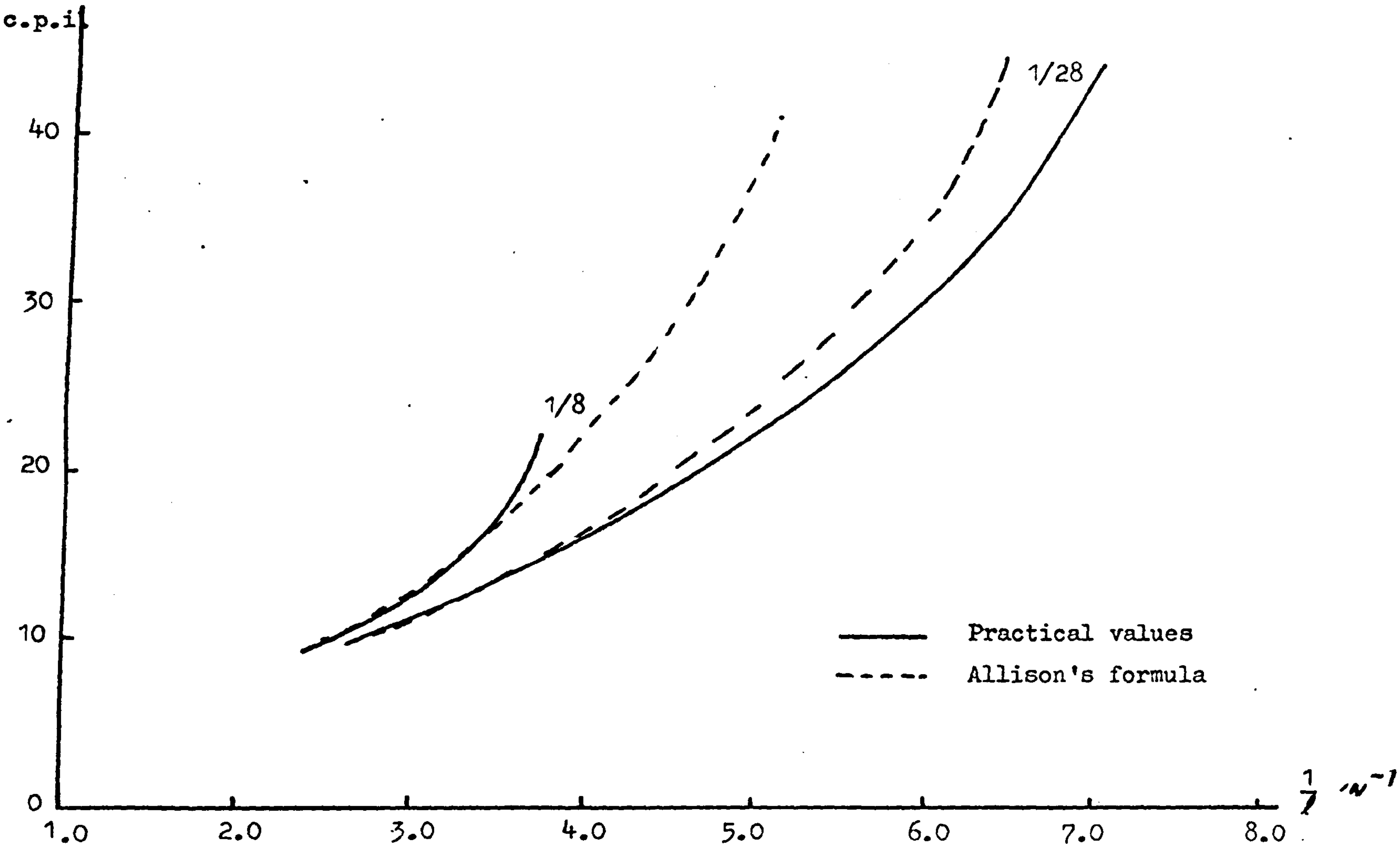


Fig. 93 Comparison of practical values with Allison's formula

2. Grosberg's Formula

The accuracy of Grosberg's formula, (see Chapter III) for machine state fabrics was then investigated in the same way. In his work, he gives two relationships between stitch length and yarn diameter and c.p.i., one for back bar and one for front bar yarns, the former being shorter as no allowance is made for plating. For a single bar fabric, therefore, the back bar formula is more appropriate. It will be seen, (Fig. 94), that this relationship fits the experimental points less accurately than that of Allison.

Thus the loop models proposed by previous workers do not offer formulae which are sufficiently accurate to predict the machine state of single bar Raschel knitted wool fabrics. This is not altogether surprising since they were developed for use with two bar constructions made from continuous filament materials and, therefore, do not take into consideration the collapse of the loop or the loop inclination present in single bar constructions.

II. PROPOSED NEW LOOP MODELS AND COMPARISON WITH EXPERIMENTAL RESULTS

It was decided to investigate whether a more accurate loop model could be established suitable for single bar constructions.

1. New Loop Model No.1

As a starting point for the shape of the loop on the machine, it was decided to consider the shape of the first loop free of the needles. The characteristic features of this loop observed by

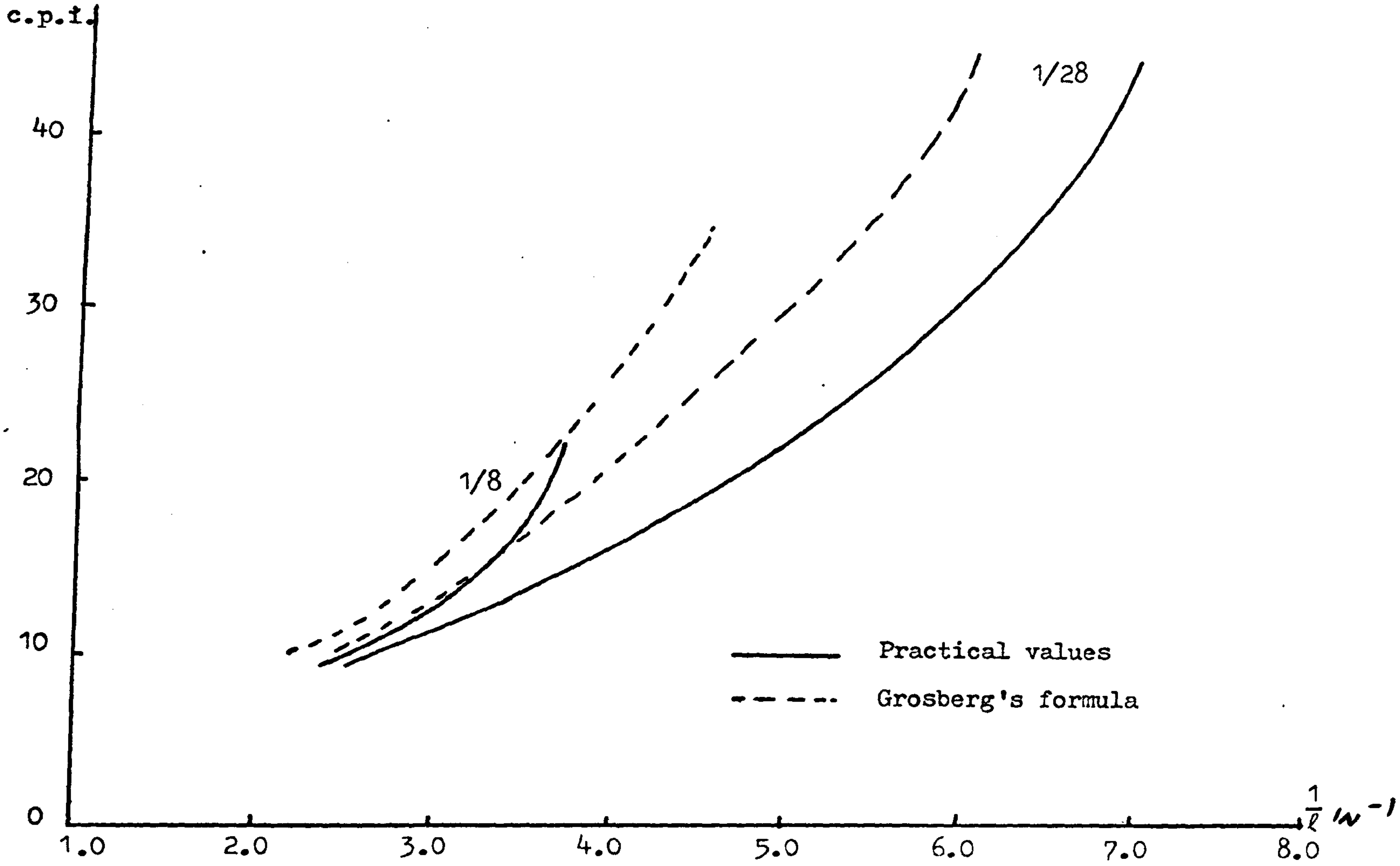


Fig. 94 Comparison of practical values with Grosberg's formula

visual examination are that (a) the loop is erect, (b) no waisting of the fabric has occurred, therefore, the wale spacing is the same as the needle spacing, and (c) the loop is held in an open position, (i.e. lies to the plane of the fabric), the WIDTH OF THE head of the loop being ~~proportional~~ EQUAL to three yarn diameters. Thus it is possible to construct a loop model as shown in Fig. 95 by considering the loop in three parts: (i) the underlap 'u', (ii) the head of the loop 'h', and (iii) the two arms 'a1' and 'a2'.

For all calculations, the following symbols are used -

g = needle spacing or $\frac{1}{\text{n.p.i.}}$

c = course spacing or $\frac{1}{\text{c.p.i.}}$

w = wale spacing or $\frac{1}{\text{w.p.i.}}$

n = length of underlap in needle spaces

Therefore, the underlap will be $\sqrt{c^2 + n^2w^2}$

The length of the yarn in the arms = $2\sqrt{c^2 + d^2}$

The length of the yarn in the head of the loop = $\frac{\pi 3d}{2}$

Hence total stitch length = $\sqrt{c^2 + n^2w^2} + 2\sqrt{c^2 + d^2} + \frac{\pi 3d}{2}$

The accuracy of this formula was checked by comparison with the practical values.

The appropriate values were calculated for the formula and plotted as c.p.i. against $\frac{1}{\ell}$ for comparison with the practical values, (Fig. 96). The value used for d was obtained from

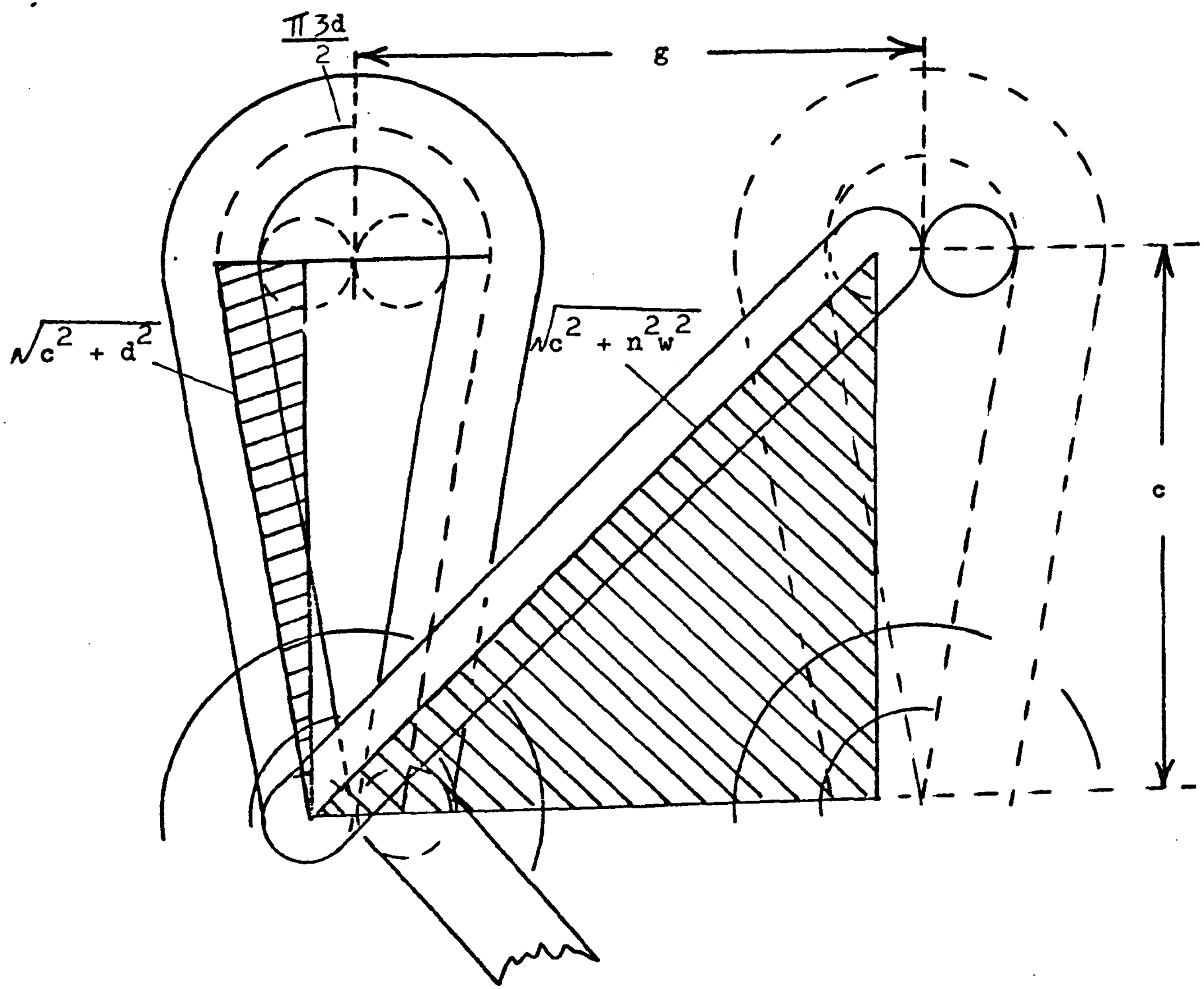


Fig. 95 New loop model No.1

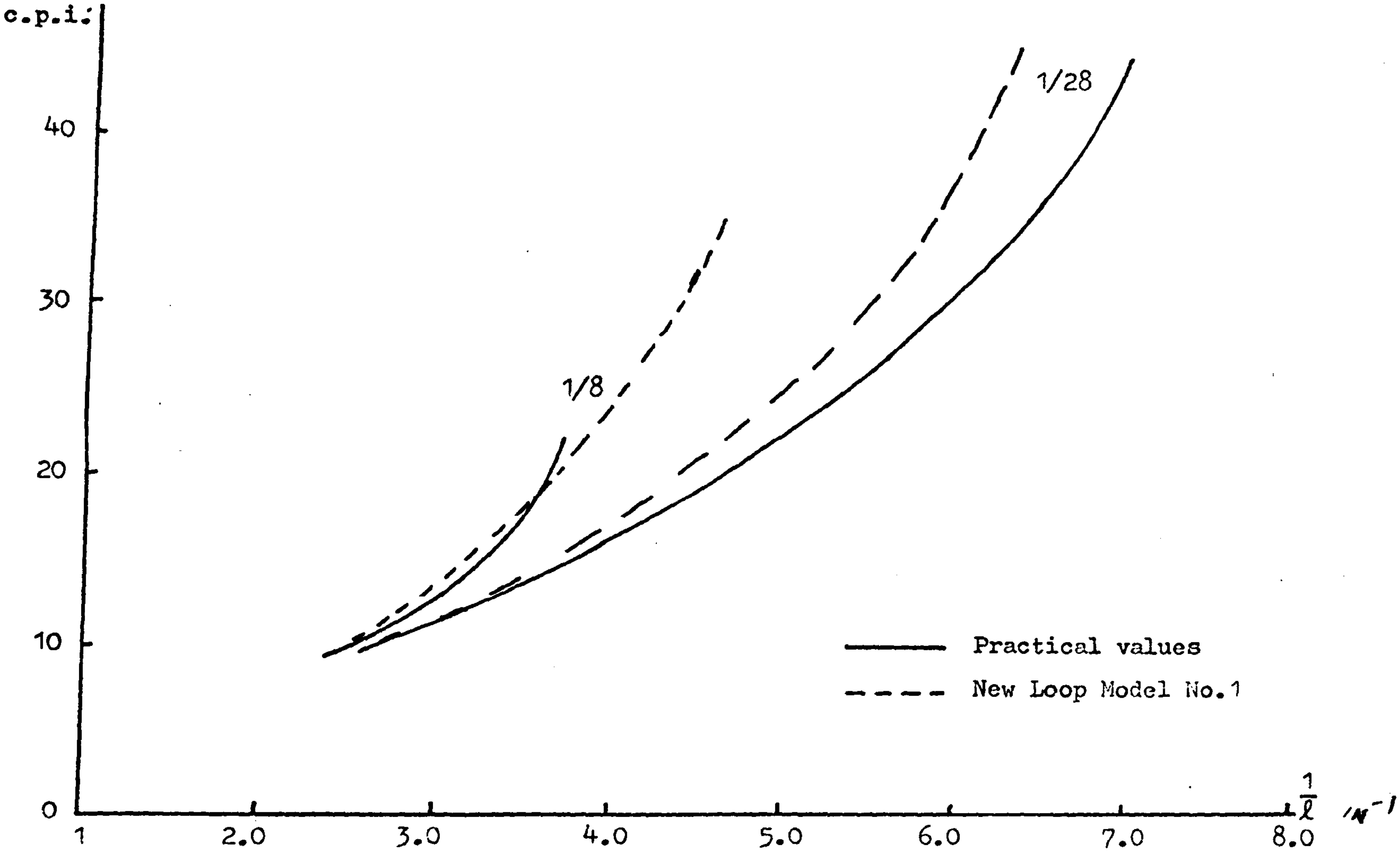


Fig. 96 Comparison of Practical Values with New Loop Model No.1

Ashenhurst's formula, $d = \frac{1}{\text{yards per pound}} \times \frac{90}{100}$. As will be observed, a poor fit was obtained, particularly with the fine counts.

2. New Loop Model No.2

Further examination of fabrics on the machine indicated that loop inclination takes place on the machine immediately after knitting. It was considered, therefore, that perhaps the conditions used to give loop model 1 were not truly representative of the structure. Hence, a second model was proposed which accommodated the suggestion that loop inclination takes place on the machine to the extent that the base of the loop occupies a position one third of the needle space distance from the head of the loop.

This gives rise to the loop model 2, (Fig. 97), as follows -

Length of underlap

$$\sqrt{(0.66g)^2 + c^2} \qquad \ldots\ldots\ldots (1)$$

The length of arms will be

$$2\sqrt{\left(\sqrt{(0.33g)^2 + c^2}\right)^2 + d^2} \qquad \ldots\ldots\ldots (2)$$

The amount of yarn in the head of the loop will be

$$\frac{\pi 3d}{2} \qquad \ldots\ldots\ldots (3)$$

Therefore, from (1), (2) and (3) above, the loop length is

$$\ell = \sqrt{(0.66g)^2 + c^2} + 2\sqrt{\left(\sqrt{(0.33g)^2 + c^2}\right)^2 + d^2} + \frac{\pi 3d}{2}$$

The appropriate values were thus calculated for this formula and these may be compared with the practical values as shown in Fig. 98.

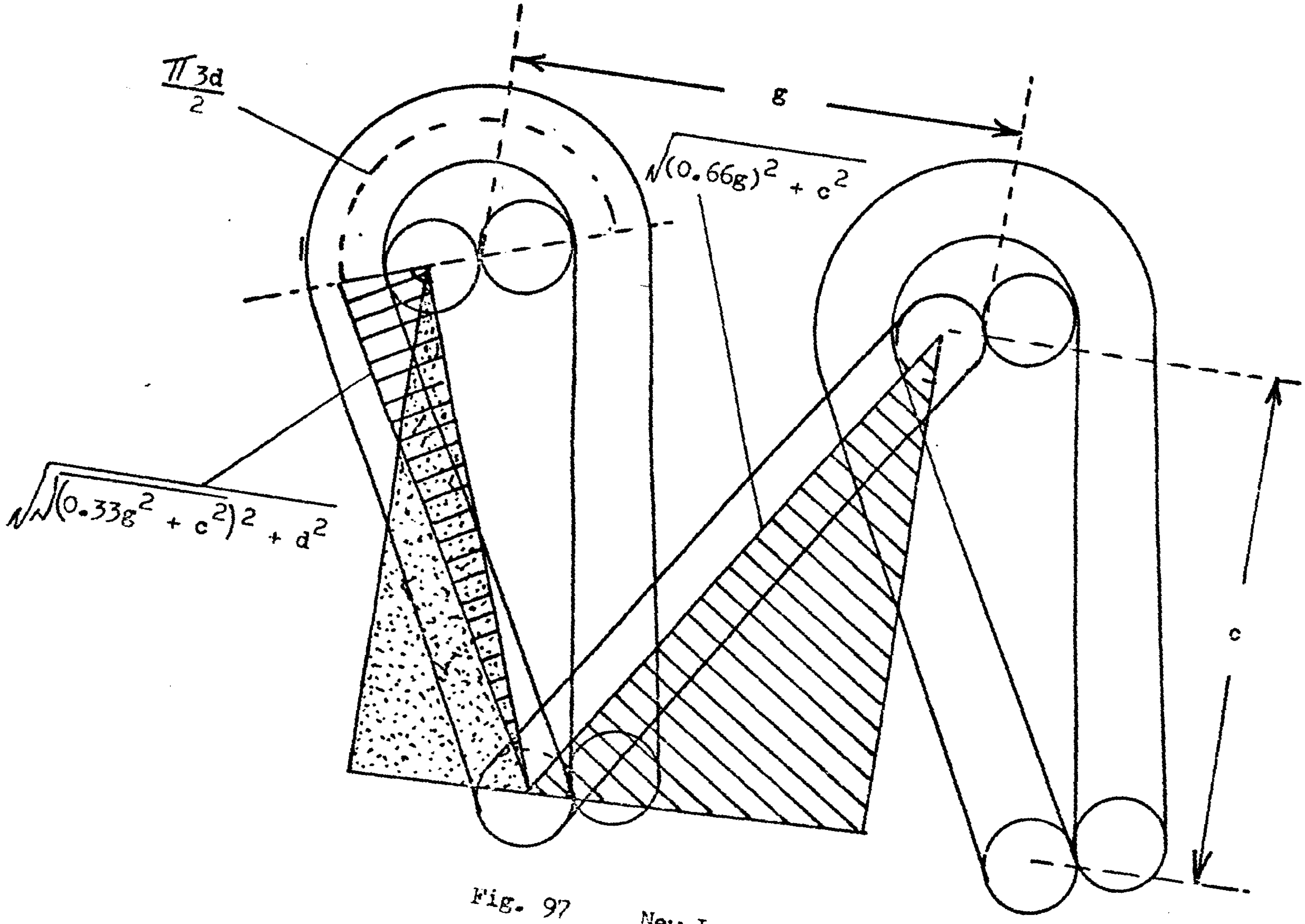


Fig. 97   New Loop Model No.2

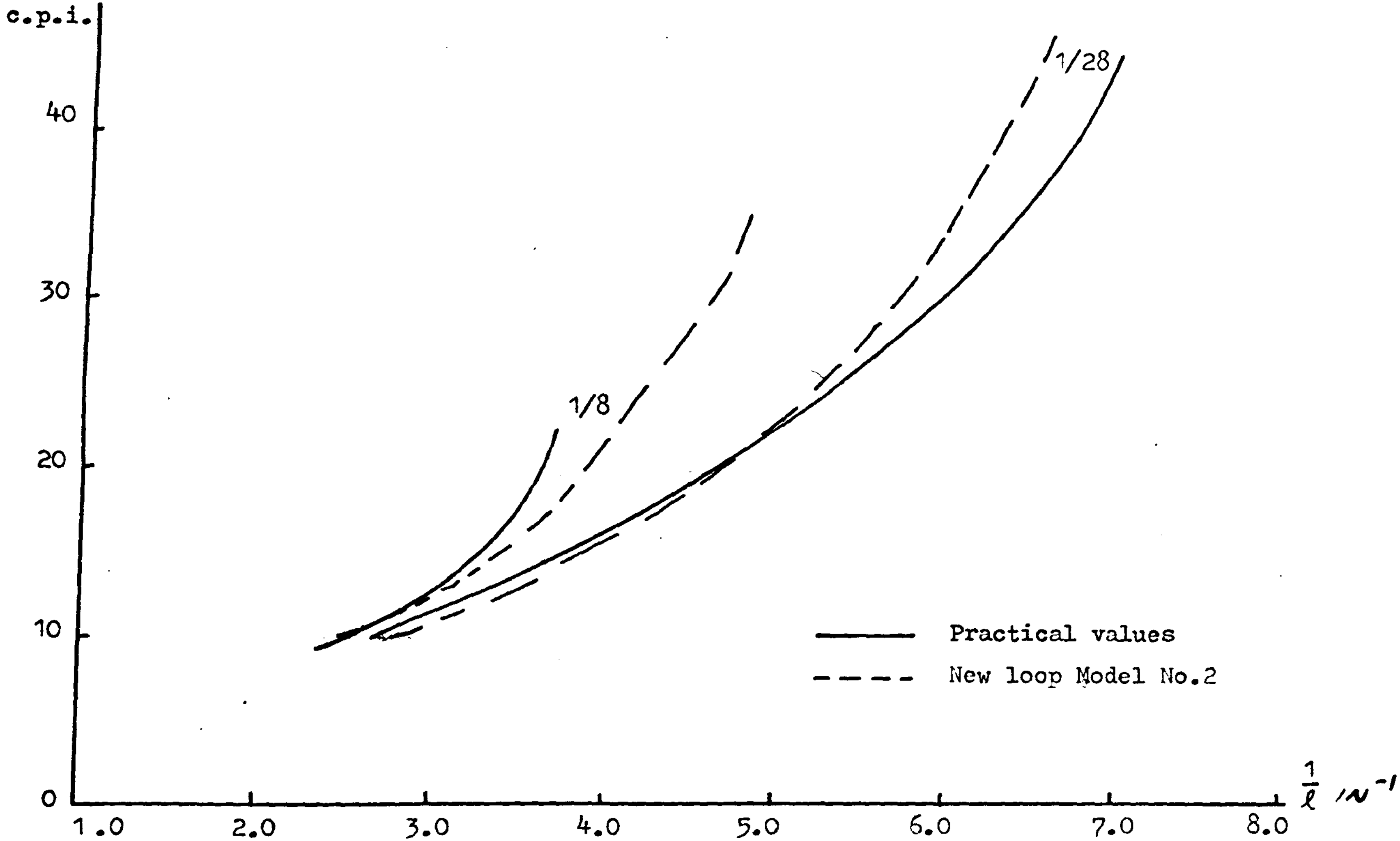


Fig. 98 Comparison of Practical Values with New Loop Model No.2

It will be realised that this formula fits the practical values obtained little better than the previous model or that of Allison, and that reasonable agreement with the practical results is only obtained over the lower range of c.p.i.

3. New Loop Model No.3

Further examination of the fabric on the machine suggested that the head of the loop may be of smaller diameter than considered in the previous two models. To meet this requirement, a third loop model was proposed in which it was suggested that the two arms of the following loop pass through the head of the loop under consideration, one above the other, as opposed to side by side in a horizontal plane as suggested in the previous two models. As a result, the diameter of the head of the loop will be equal to 2d. (Fig. 99).

Therefore, the stitch length equals -

$$\ell = \sqrt{(0.66g)^2 + c^2} + 2\sqrt{\left(\sqrt{(0.33g)^2 + c^2}\right)^2 + d^2} + \frac{\pi 2d}{2}$$

The results of the model are shown in Fig. 100 and it will be observed that, although this model gives results in agreement with the practical results for the fine counts, it does not satisfy the coarse counts.

III. COMPARISON OF LOOP MODELS

Of the three new proposed loop models, number 3 was the worst fit as, although it provided a good fit for the fine counts, it possessed a narrow spread, resulting in a poor fit for the medium and coarse counts.

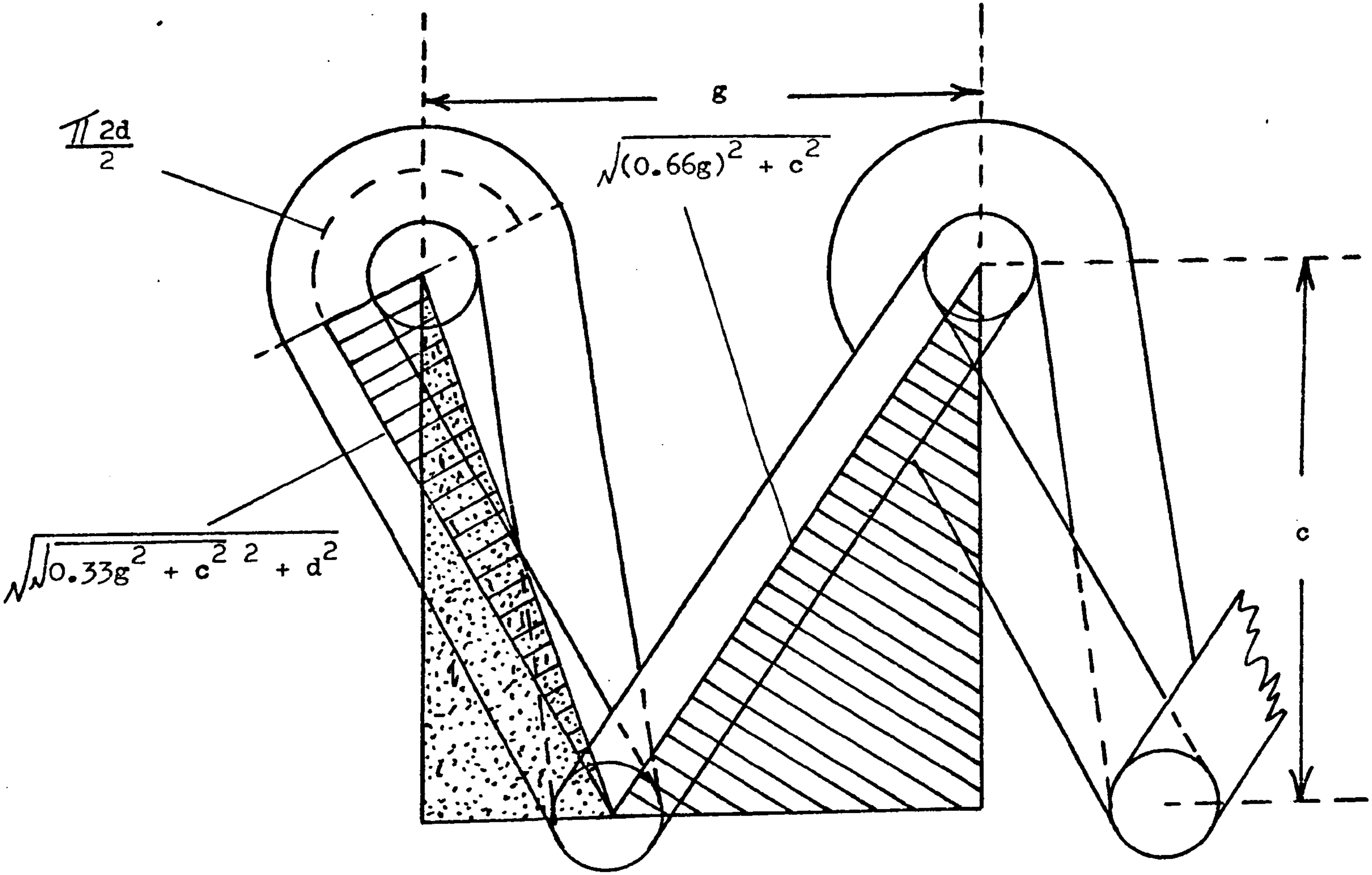


Fig. 99 New Loop Model No.3

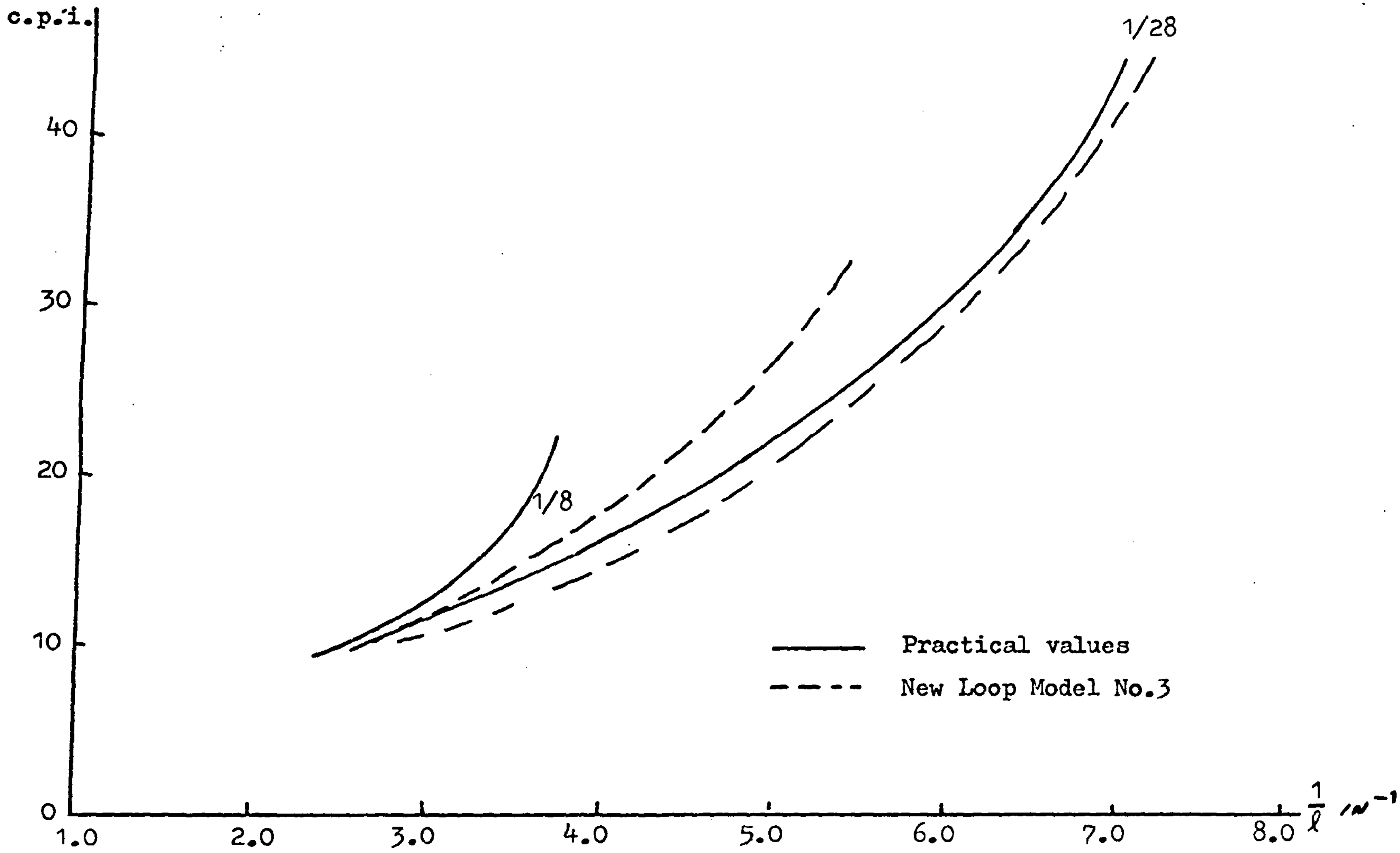


Fig. 100 Comparison of Practical Values with New Loop Model No.3

Model number 1 provided a good fit at the lower count range but although it possesses a greater spread than model number 3, a poor fit is obtained for the fine count range.

Model number 2 fits the centre range of the practical results and is, therefore, better suited for development than the other two models and gave very similar results to that of Allison.

Of the existing loop models, Allison's provides a better fit to the practical results than Grosberg's.

It was decided, therefore, to dispense with Grosberg's model and the proposed new loop models 1 and 3 in further studies and to use only model number 2 and comparison with Allison's.

IV. SUMMARY ON THE ACCURACY OF THE SIMPLE LOOP MODELS

It can be seen from the above that simple loop models of the type investigated are not suitable in their present form to predict accurately the experimental results obtained for the c.p.i. on the machine and the stitch length.

It will be realised that for each model examined and for a given c.p.i. value, the difference in the calculated $\frac{1}{\ell}$ value, allowing for change in count, was not as great as the difference obtained practically. Hence, it is evident that no simple modification such as allowing for -

(a) different loop inclination

(b) different diameter relationships in the head of the loop

(c) the three dimensional effect of the yarn within the loop

or (d) values of yarn diameter calculated from formulae other than that of Ashenhurst -

will improve the accuracy of the loop model, but merely "weight" the results towards one end of the scale or the other. Therefore, to obtain a more accurate loop model, either (a) some factor needs to be introduced which varies with yarn count to increase the spread of the results, or (b) some factor on the machine may have occurred in the production of the original samples which may be affected by yarn count and which has not been taken into consideration in the loop models.

To investigate this more fully, detailed observation of knitting conditions on the machine was undertaken.

PART TWO - EXPERIMENTAL INVESTIGATION

I. MACHINE COMPARISON

For this investigation, observations were made on a 24 gauge machine. It was necessary, therefore, to establish if similar practical results of c.p.i. and stitch length were obtained. Worsted yarns of counts 2/16's and 2/56's were used and fabrics were knitted to a range of c.p.i. from these two yarns. Details of these fabrics measured on the machine are given in Table 45. The samples were made on the same number of needles as for the original samples on the 32 gauge machine.

When these results were plotted graphically and compared with those obtained on the 32 gauge machine, (see Fig. 101), it will be noted that the experimental results for the 32 gauge machine are

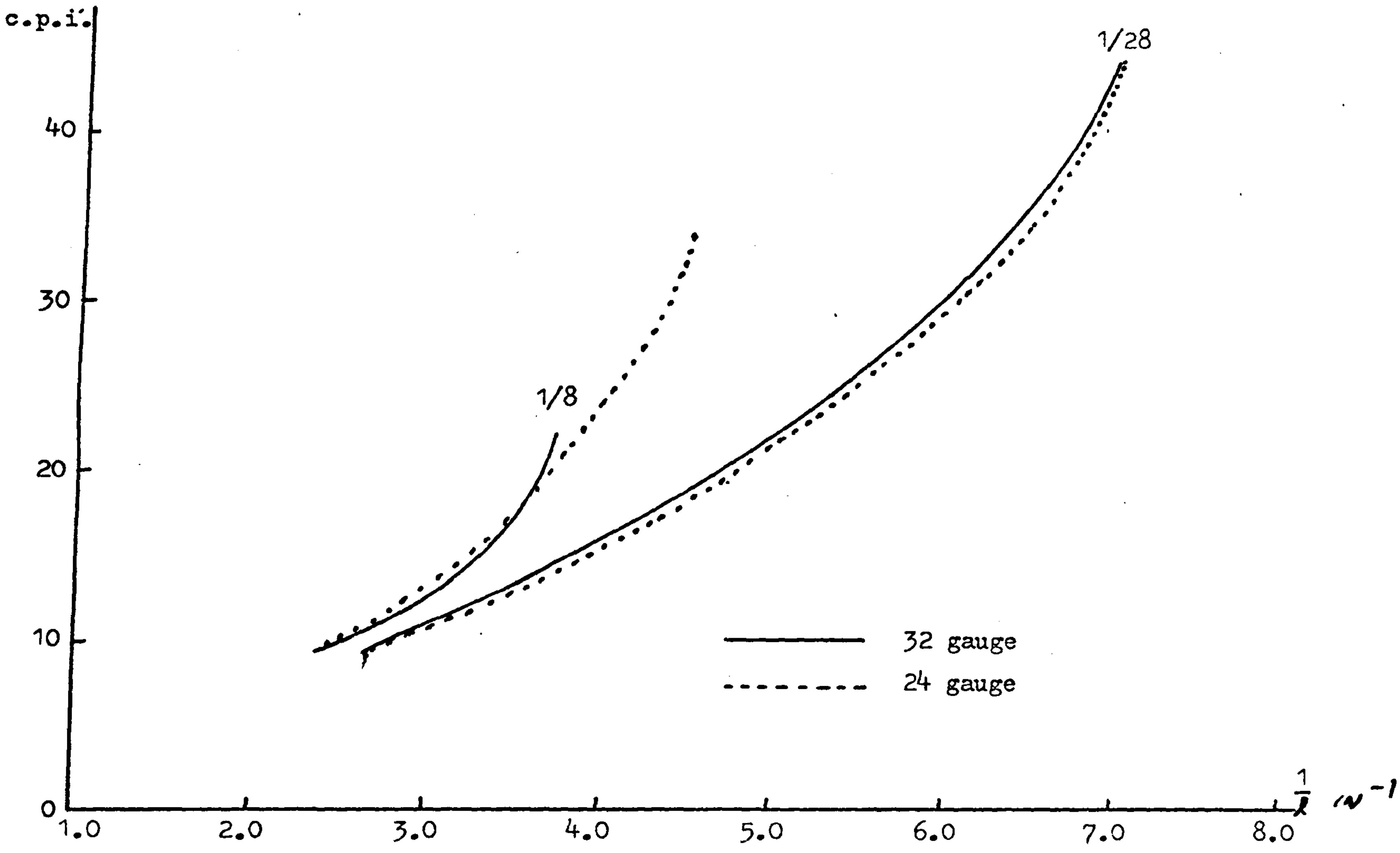


Fig. 101 Comparison of 32 and 24 gauge samples

TABLE 45

Samples produced on the 24 gauge machine

2/16		
C.P.I. on machine	Stitch length (IN)	1 / stitch length
10	0.3792	2.637
17	0.2750	3.636
30	0.2229	4.406
35	0.2125	4.706

2/56		
C.P.I. on machine	Stitch length (IN)	1 / stitch length
10	0.3458	2.892
18	0.2188	4.571
31	0.1583	6.316
35	0.1520	6.575
42	0.1437	6.956

the same as those for the 24 gauge machine with a small exception of the results for the 2/16's yarn above 20 c.p.i. This discrepancy can be explained by the fact that the coarser gauge machine has greater space between the knitting elements for the accommodation of yarn so allowing a greater number of c.p.i. before jamming occurs. However, the similarity between the two sets of results below 20 c.p.i. on the coarse counts and for the whole range of fine counts is surprising, as for any given c.p.i. a larger stitch length would have been anticipated on the 24 gauge machine than the 32 gauge, because the difference in needle spacing, consequently the difference in length of underlap, would have been expected to require a different stitch length. This fact is reflected by comparing the practical results with the theoretical results calculated by the formula for the new loop model 2 given in Part One of this chapter. This comparison is shown in Fig.102. It will be observed that a worse fit is obtained for the 24 gauge samples than the 32 gauge results in that the coarse counts show a greater discrepancy between the calculated and experimental values but a similarity exists in that the fine counts are more in error than the coarse counts.

These observations suggest that the results from the two machines are comparable but that some factor not taken into consideration in the formula must have influenced the results.

Although all the earlier experiments on the 32 gauge machine had been conducted at a constant warp tension, the

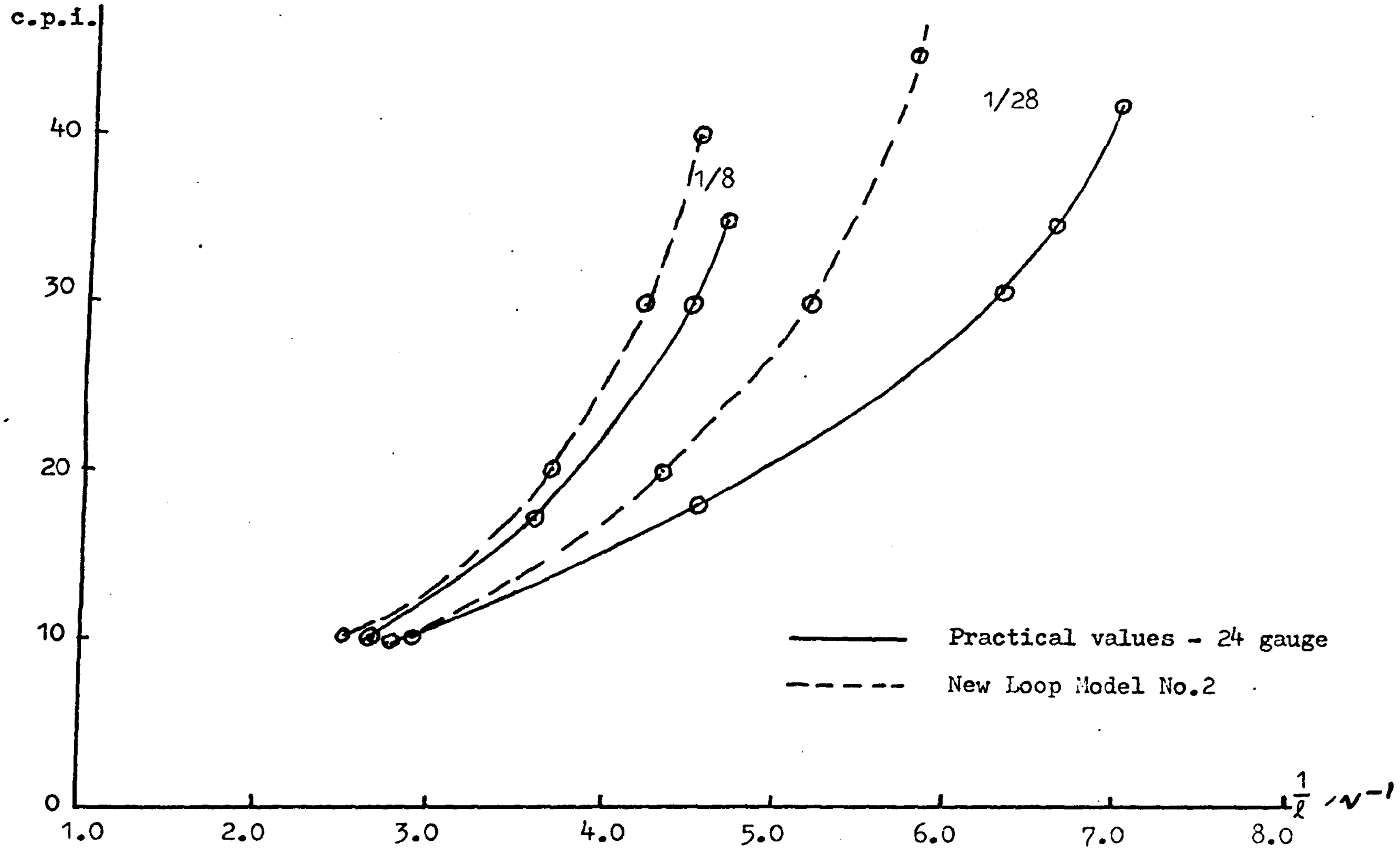


Fig. 102 Comparison of New Loop Model No.2 with 24 gauge samples

magnitude of this tension had been considered unimportant as it had been established in Chapter IV, that the knitting tension did not influence the dimensional parameters of the 1 x 1 closed lap construction produced from wool yarns when the fabric had been relaxed in the tumble dry condition. However, the results quoted above suggest that it is possible for the warp tension to affect the relationship between the stitch length and the c.p.i. of the fabric when measured on the machine.

As the 24 gauge machine was equipped with a positive gear take-up mechanism, it was suitable for experiments involving warp tension and take-up setting while the original 32 gauge machine was not. The following experiments were undertaken to establish the effects of tension on the relationship between the c.p.i. of the fabric measured on the machine and the stitch length.

II. EXPERIMENT TO INVESTIGATE THE EFFECT OF WARP TENSION ON THE RELATIONSHIP BETWEEN C.P.I. AND STITCH LENGTH ON THE MACHINE

A set of samples were produced consisting of two yarn counts, 2/16's and 2/56's, and three different courses per inch of each count. Each setting of c.p.i. was produced at two different yarn tensions approximately 10 grams per end and approximately 30 grams per end. The following results were obtained as shown in Table 46.

From these results, it is clear that for the same reading of c.p.i. by piece glass on the machine there is a range of stitch lengths which can be obtained according to the warp tension. It is also clear that this variation will be dependent on yarn count

TABLE 46

Effect of Warp Tension

2/16				2/56			
C.P.I.	Tension (GRAMS)	Stitch length (IN)	$\frac{1}{\text{stitch length}}$	C.P.I.	Tension (GRAMS)	Stitch length (IN)	$\frac{1}{\text{stitch length}}$
34.0	30	0.208	4.800	36.0	30	0.152	6.575
34.0	10	0.235	4.247	36.0	10	0.179	5.581
22.0	30	0.254	3.937	22.0	30	0.198	5.050
22.0	10	0.270	3.692	22.0	10	0.208	4.800
9.5	30	0.401	2.494	9.5	30	0.364	2.741
9.5	10	0.416	2.403	9.5	10	0.372	2.681

TABLE 47

Effect of Warp Tension on Yarn Count

2/16					2/56				
C.P.I.	Tight Stitch Length (IN)	Slack Stitch Length (IN)	Difference (IN)	% Difference	C.P.I.	Tight Stitch Length (IN)	Slack Stitch Length (IN)	Difference (IN)	% Difference
34.0	0.235	0.208	0.027	13.0	36.0	0.179	0.152	0.027	17.8
22.0	0.270	0.254	0.016	6.3	22.0	0.208	0.198	0.010	5.0
9.5	0.416	0.401	0.015	3.7	9.5	0.372	0.364	0.008	2.2

and c.p.i. as shown in Table 47.

If these results are now plotted and compared with the theoretical values from loop model 2, (Fig. 103), it is immediately obvious that the calculated values for the loop model are a good fit for the fabrics produced at the low warp tension, i.e. those produced at 10 grams per end. The experimental results are in good agreement with those predicted from loop model 2 and Allison.

The results obtained for those fabrics produced at a high warp tension of 30 grams per end, however, do not agree with the loop model. These results are very similar to those of the original fabrics.

It was known that the original fabrics, (i.e. both those produced on the 32 gauge machine and the first fabrics produced on the 24 gauge machine), were produced at a high tension because the fabrics were only 120 wales wide, this being a narrow width for the size of the machine.

It is clear from these results that the proposed loop model will accurately predict the relationship between the dimensions of the fabric and the length of the yarn in the stitch on the machine if the warp tension conditions are slack, whereas under these high tension conditions the proposed model does not apply.

This is not surprising since, as the warp tension is increased, the stitch length of the fabric will change without any corresponding change in c.p.i. as measured by a piece glass.

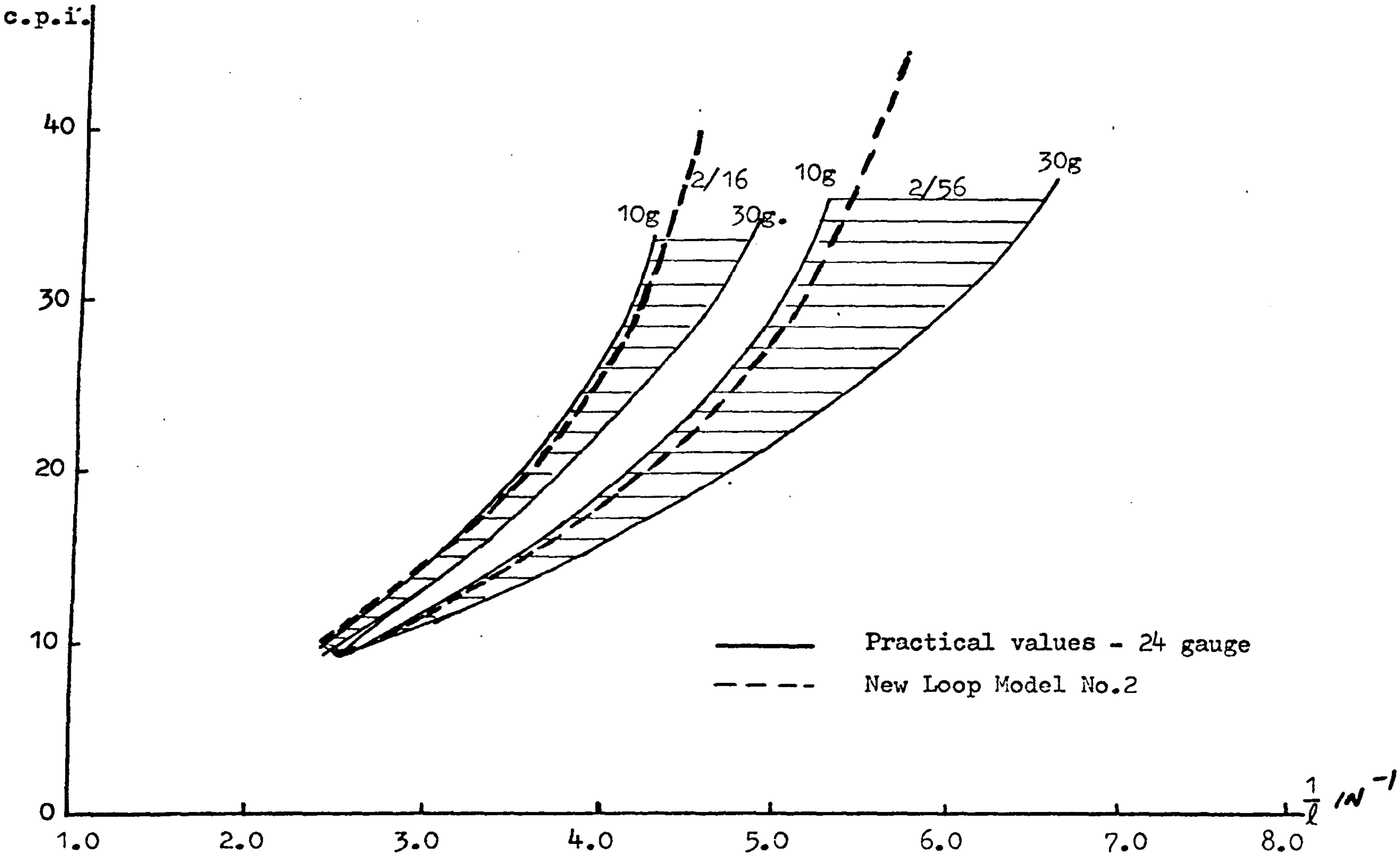


Fig. 103 Effect of Warp Tension

Obviously, one formula cannot fit both these cases.

For a complete understanding of the problem, it is necessary to explain the cause of the disagreement between theoretical and practical results obtained under these high warp tension conditions.

III. INVESTIGATION TO ESTABLISH THE CAUSE OF THE LACK OF AGREEMENT BETWEEN THE EXPERIMENTAL RESULTS AND THEORETICAL MODELS FOR FABRICS PRODUCED AT HIGH WARP TENSIONS

1. Introduction

By careful examination of the fabric on the machine it was observed that fabrics produced at low tensions were uniform in construction but that those fabrics produced under high tension conditions showed considerable distortion. This distortion, caused by the fabric "waisting-in", gave a variation in course spacing from the point at which the fabric was formed to the point it passed onto the take-up roller.

This variation is important because the course spacing used in the calculations was obtained from a piece glass reading and if this is at variance with the course spacing at the point where the loop is formed, an error could be introduced which could account for the lack of agreement between the experimental values and the theoretical values at high warp tensions.

2. Variation in Course Spacing

a) Record of variation in course spacing

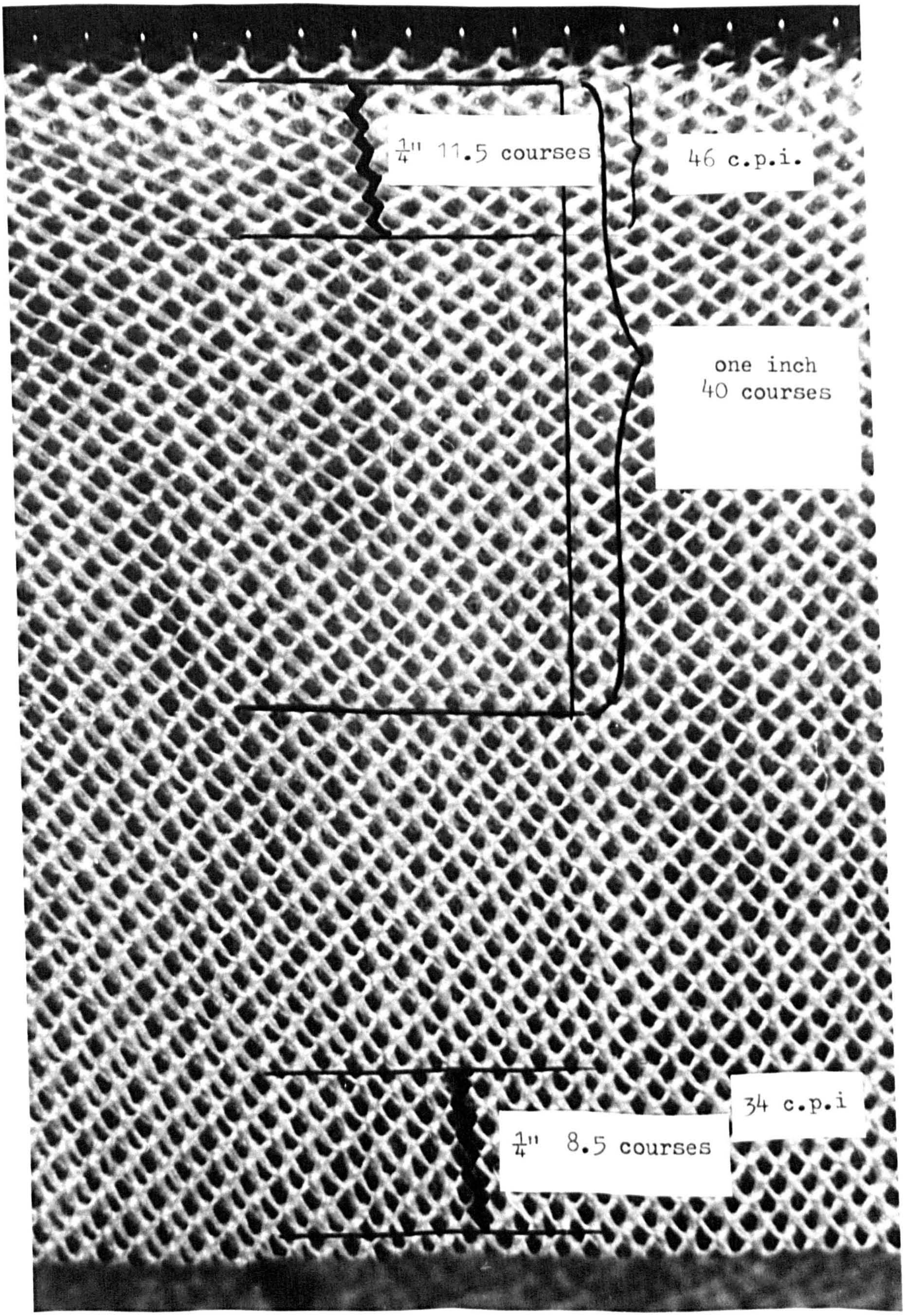
In order to record this variation in course spacing between tight and slack fabrics, photographs were taken of the fabrics for record purposes by mounting a camera on a tripod in such a manner that the whole of the fabric from the trick plate to the take-up roller could be shown on the photograph. The camera used was a 35mm. single lens reflex using a standard 50mm. lens. The film was Ilford Pan F with an A.S.A. rating of 32 and illumination was by electronic flash positioned at 45 degrees to the plane of the fabric.

Photograph 18 shows the effect of variation in course spacing on a tight fabric produced from 2/56's yarn with a piece glass reading of 40 c.p.i. The course spacing at the trick plate is equivalent to 46 c.p.i. while that at the take-up roller is equivalent to 34 c.p.i.

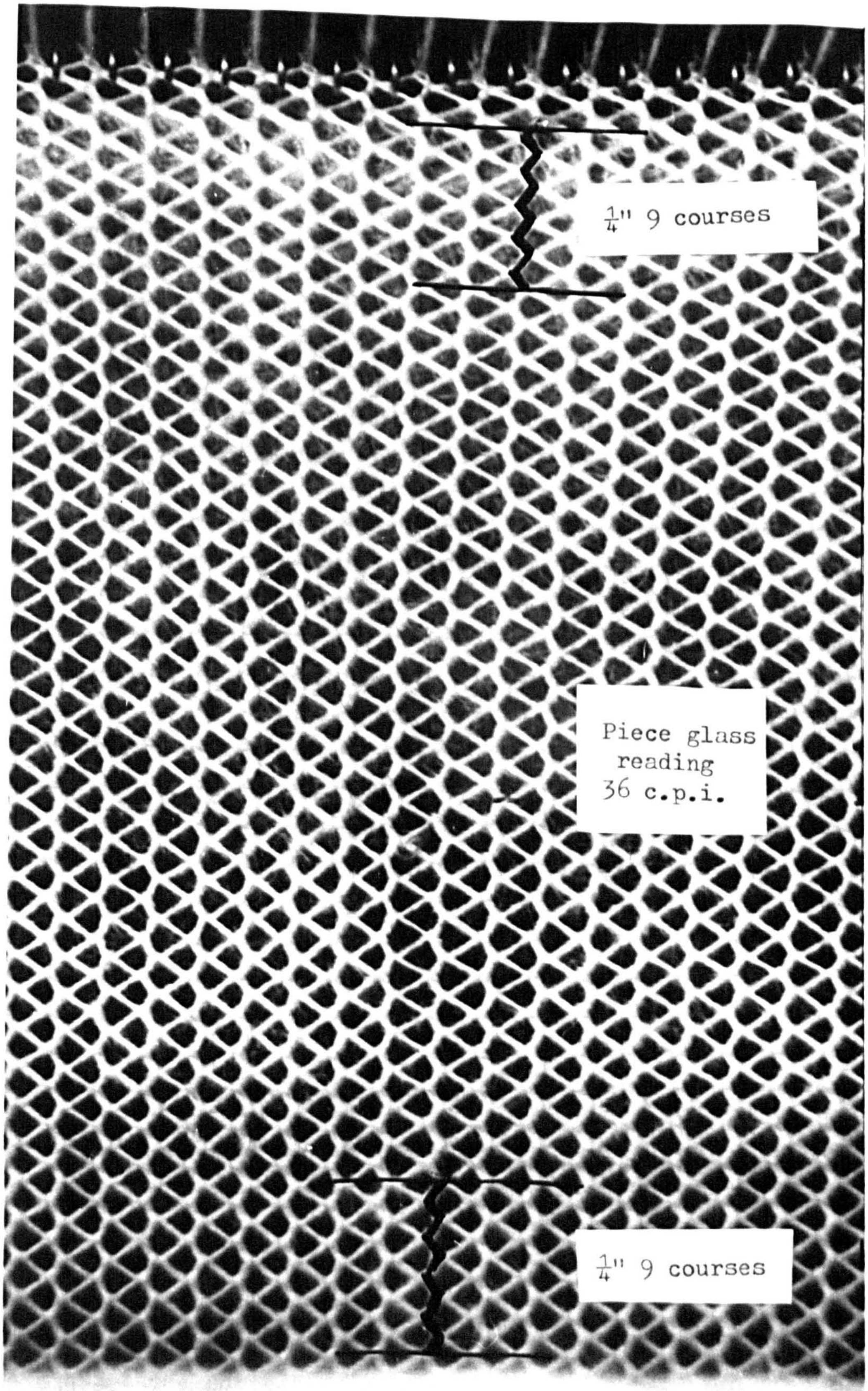
Photograph 19 shows a slack fabric produced from 2/56's with a piece glass reading of 36 c.p.i. This shows a more uniform fabric with the course spacing the same at the trick plate as at the take-up roller.

b) Relationship of variation with c.p.i. and count

To investigate the above further, a piece of paper was marked with two marks $\frac{1}{4}$" apart. This was placed on the machine as close to the trick plate as possible and the courses per $\frac{1}{4}$" counted. It was then placed as close to the take-up rollers as possible and again the courses per $\frac{1}{4}$" counted. The following results were obtained:-



Photograph 18



Photograph 19

Count	C.P.I. by piece glass	C.P.I. at trick plate	C.P.I. at take-up roller
2/56	40	46	34
2/56	10	10	10
2/16	34	36	32
2/16	10	10	10

Thus it can be established that the variation in course spacing between the trick plate and the take-up rollers varies with c.p.i. and with the yarn count. At 10 c.p.i. piece glass reading, no variation was shown on 2/16's or 2/56's count, but at higher c.p.i. both yarns displayed a variation. At the point where the loop is formed, the course spacing is 15% less than that indicated by piece glass on the 2/56's and 6% less on the 2/16's.

c) Substitution of modified c.p.i. in loop model

From the above results a graph was constructed, (Fig. 104), of c.p.i. by piece glass against c.p.i. by measurement near to the knitting point, (i.e. the first $\frac{1}{4}$" from the needles), it being assumed that a straight line relationship exists between the two parameters. From this, modified values of c.p.i. against $\frac{1}{l}$ were calculated and plotted to compare with the practical values. This is shown in Fig. 105.

From these graphs it will be observed that only a small difference is obtained between the original calculated values for model 2 and those corrected for c.p.i.

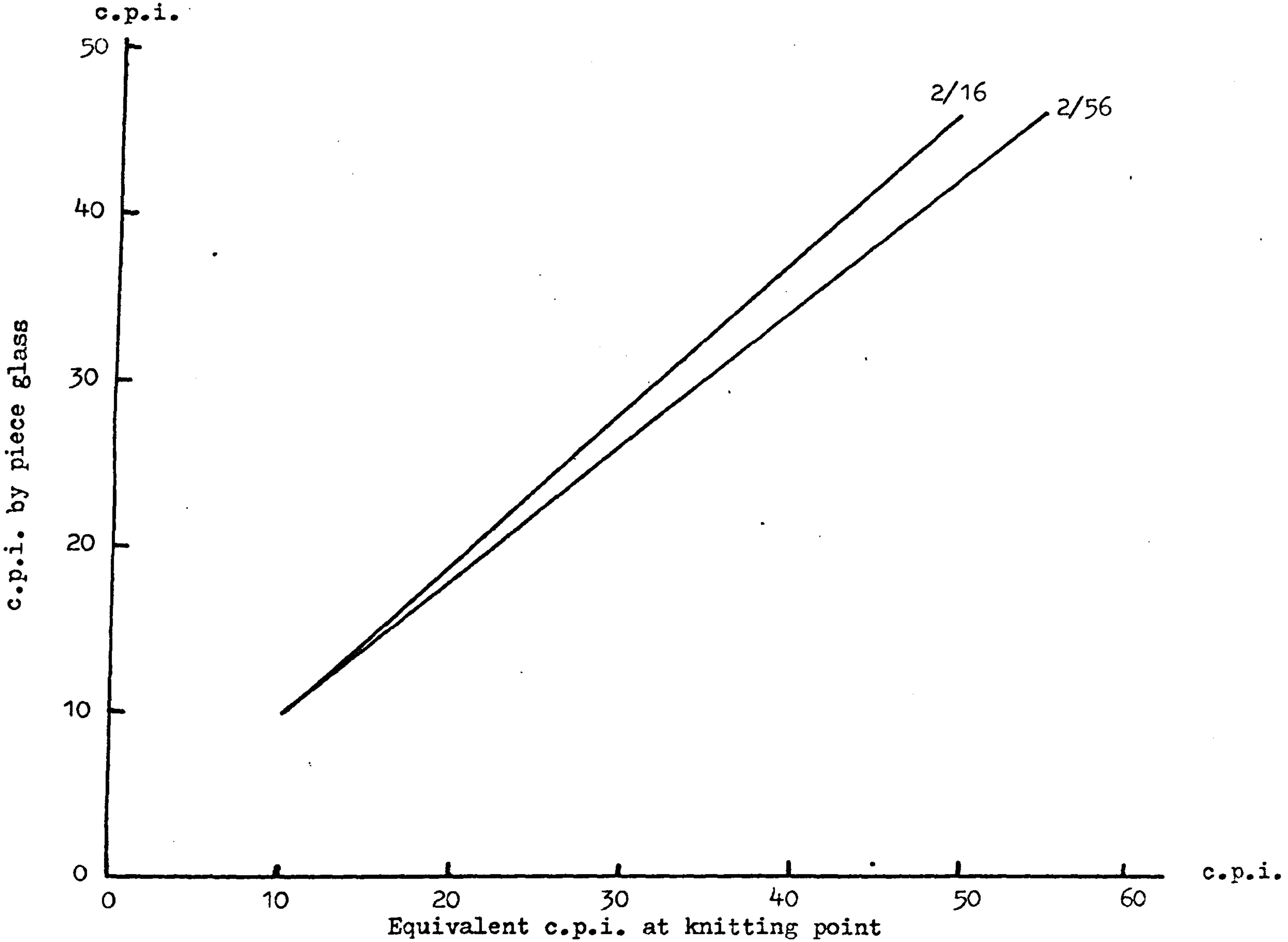


Fig. 104

Relationship between c.p.i. by piece glass and size of loop at knitting point

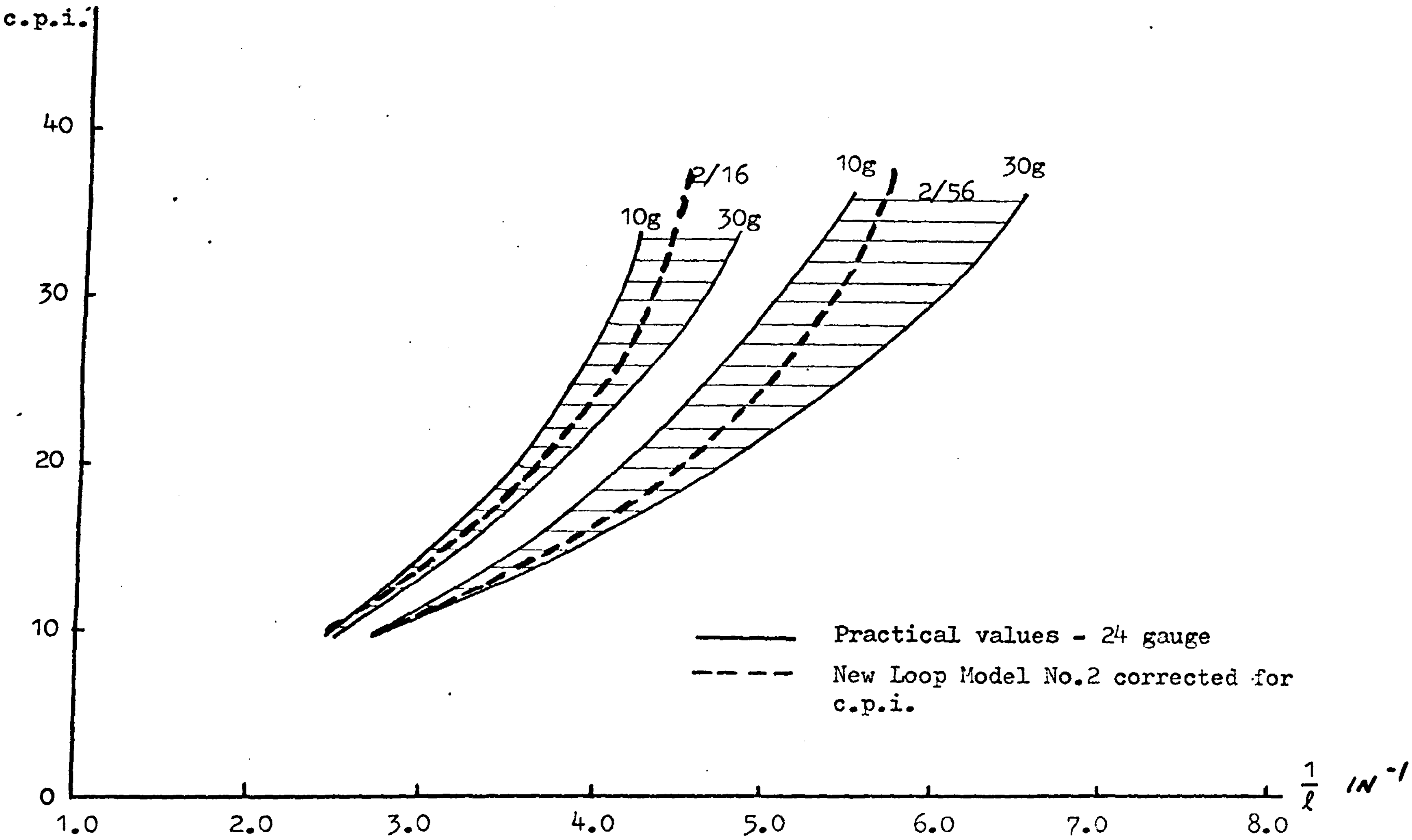


Fig. 105 Comparison of Model No.2 corrected for c.p.i. with practical values

This correction, however, represents a considerable improvement at the lower c.p.i., but not such a marked degree of improvement above 25 c.p.i. It is evident, therefore, that some other factor must be influencing the practical results in the tight fabrics.

3. Yarn Diameter

a) Introduction

The remaining factor which has been used in the calculation of loop length in the loop models which may be subject to error is yarn diameter. The yarn diameter is, however, not used in isolation but in the calculation of the size of the head of the loop by the assumption that the head lies in a shape predicted by the formula, $\frac{\pi 3d}{2}$.

In order to investigate the effect of yarn diameter and to establish the shape of the head of the loop, photographs were taken of the first few courses of fabric off the needles. This was performed with the same photographic set up as described previously except that to obtain the required degree of magnification, a 135mm. lens was used in conjunction with a 3 diopter close-up lens, mounted on a bellows extension.

b) Observation of photographs

No attempt was made to measure the diameter of the yarn from the photographs as it was considered that no reliable results could be obtained because -

(i) The diameter of a fibrous yarn varies greatly due to its inherent irregularity and the outstanding surface fibre.

(ii) The only use of yarn diameter is in the calculation at points where the yarn crosses and therefore is compressed at these points. The yarn cannot be measured at these points as the loop twists and lies out of the plane of the photograph.

(iii) The diameter used in the calculation is that suggested by Ashenhurst and is an empirical value suitable for use in the calculation of maximum set simple woven fabrics. Under the compression conditions present in a knitted construction, these values need not necessarily apply.

It was considerd that a more practical approach was to obtain the length of yarn in the head of the loop and hence from this the effective diameter of the yarn.

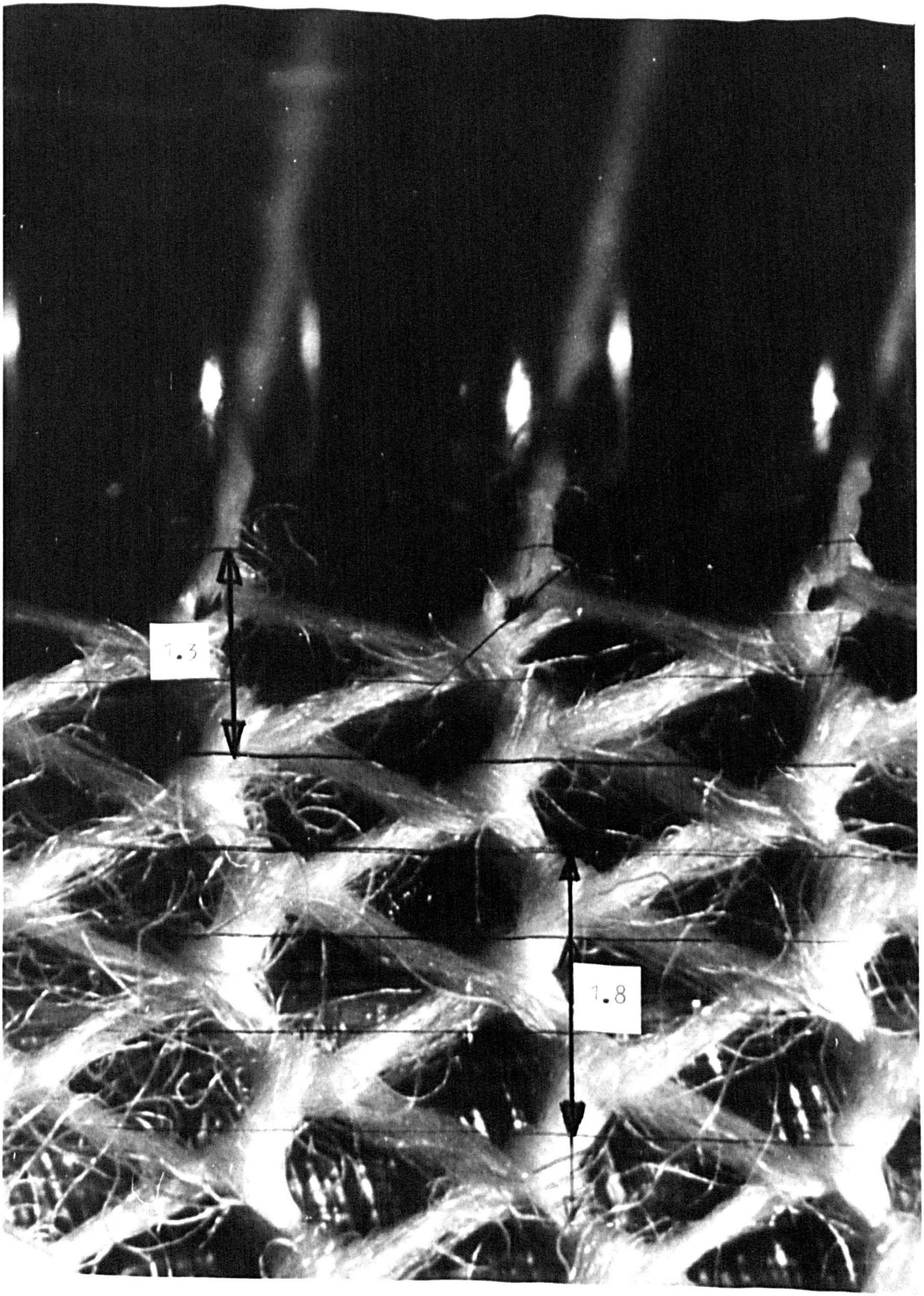
The loop model used has three parts, (1) the underlap, (2) the arm and (3) the head of the loop. The first two can be measured accurately from the photographs. If these correspond to the calculated values, then it may be assumed that the method of calculating these is suitable. The sum of the length of yarn in these two parts of the loop may then be subtracted from the known stitch length so indicating the amount of yarn in the head of the loop.

c) Measurement of loop parts on photographs

It was considered that the various parts of the loop should be measured on the photographs on the first loop free of the needles, but examination of the photographs revealed that the length of the various components measured on this course varied considerably according to the position in the knitting cycle at which the photograph was taken. In fact, variation occurred over the first three courses. If measurements were taken on the 5th, 6th and 7th courses, however, a constant figure was obtained. This variation on courses 1, 2 and 3 may be demonstrated by the simple example of measuring the course spacing on photographs 20, 21 and 22 all of which show a fabric with 36 c.p.i. by piece glass but at different positions in the knitting cycle. The average course spacing over the first three courses is as follows -

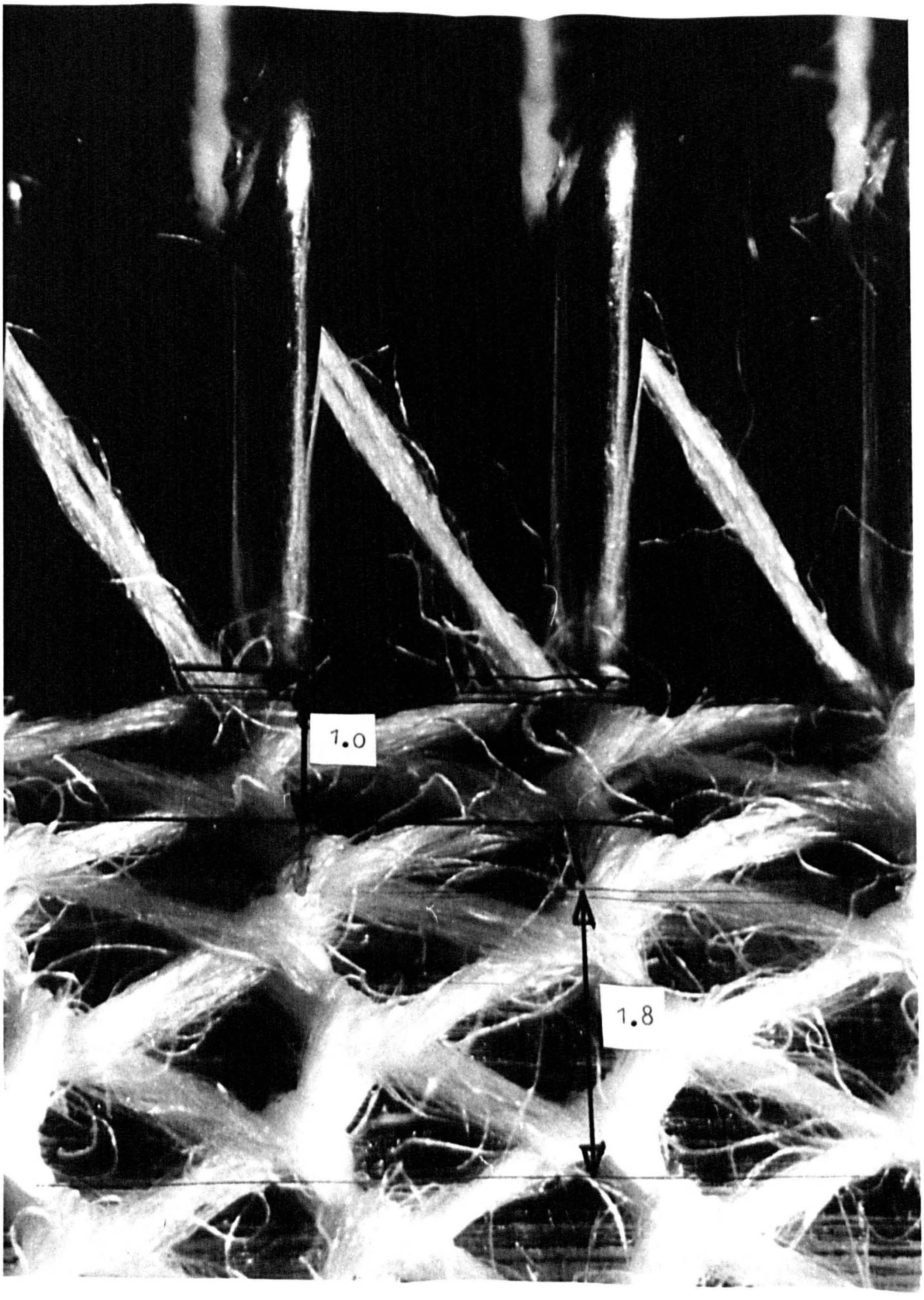
Photograph	Course Spacing (average of courses 1, 2 & 3)	Equivalent c.p.i.
20	0.018 IN	55
21	0.021 IN	46
22	0.039 IN	76

If, however, the average course spacing is measured on courses 5, 6 and 7, then the following results are obtained -



Photograph 20

Photograph 21



Photograph 22

Photograph	Course Spacing (average of courses 5, 6 & 7)	Equivalent c.p.i.
20	0.023 in	42
21	0.023 in	42
22	0.023 in	42

This shows that the fabric is subject to change over the first three courses and that measurements cannot be taken from the photographs on these courses which could be used in the calculations outlined above to obtain the amount of yarn in the head of the loop. All following measurements were, therefore, taken on courses 5, 6 and 7.

d) Length of yarn in head of loop by subtraction

The following results were obtained by this approach from Photograph 21 showing a fabric produced from 2/56's with 36 c.p.i. knitted tight, i.e. 30 grams per end.

C.P.I. by piece glass	C.P.I. from photograph	Calculated underlap at 42 c.p.i.	Measured underlap	Calculated arm at 42 cpi.	Measured arm
36	42	0.060	0.060	0.037	0.037

Therefore total yarn in the two arms and underlap =

$$0.075 + 0.060 = 0.135 \text{ in}$$

Known stitch length = 0.156

Therefore yarn in head of loop = 0.156 - 0.135 = 0.021 in

Thus the amount of yarn in the head of the loop is considerably less than that allowed for in the loop model. It is not possible from the available evidence to separate the two factors affecting this, i.e. yarn compression and shape of the head of the loop; possibly both are responsible in part for the effect. Thus, by substituting the new value of 0.021 for the length of yarn in the head of the loop in the formula, the following values were obtained:-

C.P.I.	$\frac{1}{\text{stitch length}}$ (in^{-1})
10	2.910140
20	4.730570
30	5.739177
45	6.493422

It will be noted that the amount of yarn in the head of the loop is 50% of that allowed for in the original loop model. Therefore, if a loop shape of $\frac{\pi 3d}{\ell^2}$ is assumed, the yarn diameter would be 0.0044 inches, as opposed to 0.0089 as used in the calculations.

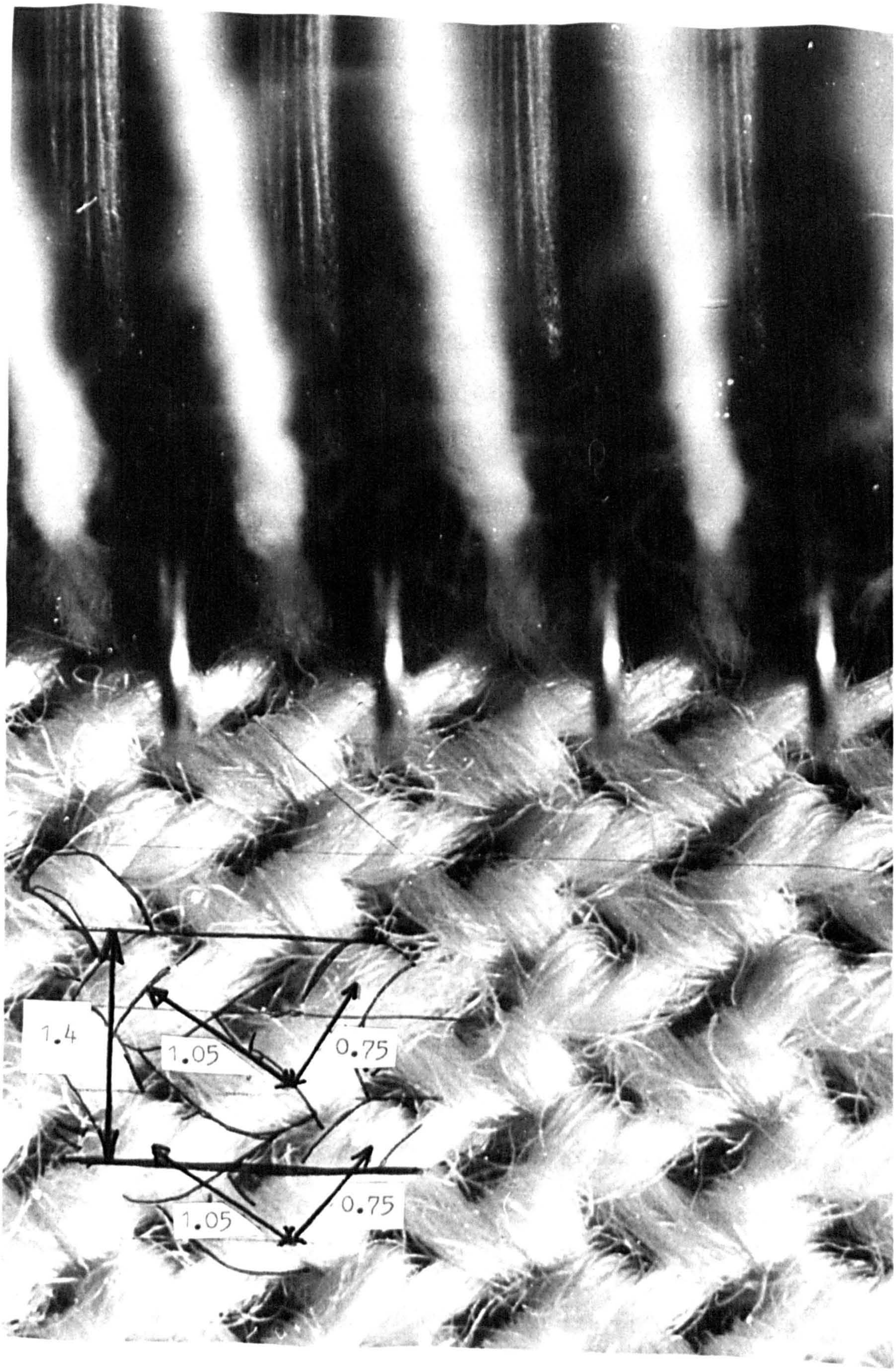
The same procedure was now repeated for the 2/16's count using Photograph 23 and the following results were obtained.

C.P.I. by piece glass	C.P.I. measured from photo	Underlap Calculated at 35 c.p.i.	Measured Underlap	Calculated arm at 35 c.p.i.	Measured arm
34	36	0.062	0.062	0.044	0.044

Therefore total yarn in the two arms and underlap = 0.151

Known stitch length = 0.208

Therefore yarn in head of loop = 0.208 - 0.151
= 0.057 inches



Photograph 23

This value of 0.057 is smaller than that used in the proposed loop model which was 0.078 representing a loss of 27%.

By substituting the new value, the following results were obtained.

C.P.I.	$\frac{1}{\text{stitch length}}$
10	2.619494
20	3.984222
30	4.654930
40	5.004353

The new results were now plotted and compared with the practical values obtained from the tight fabrics and it will be observed that a much better fit is achieved, (Fig. 106).

IV. CONCLUSIONS

It has been established that the relationship between the c.p.i. and the stitch length can be fairly accurately predicted for the 1 x 1 closed lap construction by the loop model No.2 provided that the warp tension is low, in the region of 10 grams per end or lower, and that this prediction is more accurate than the relationship suggested by Grosberg, but similar to that suggested by Allison.

At warp tensions in the region of 30 grams per end, however, the prediction is not accurate for the following reasons -

i) The course spacing varies from the point of loop formation at the trick plate to the point at which the fabric passes onto the take-up roller. Therefore, a

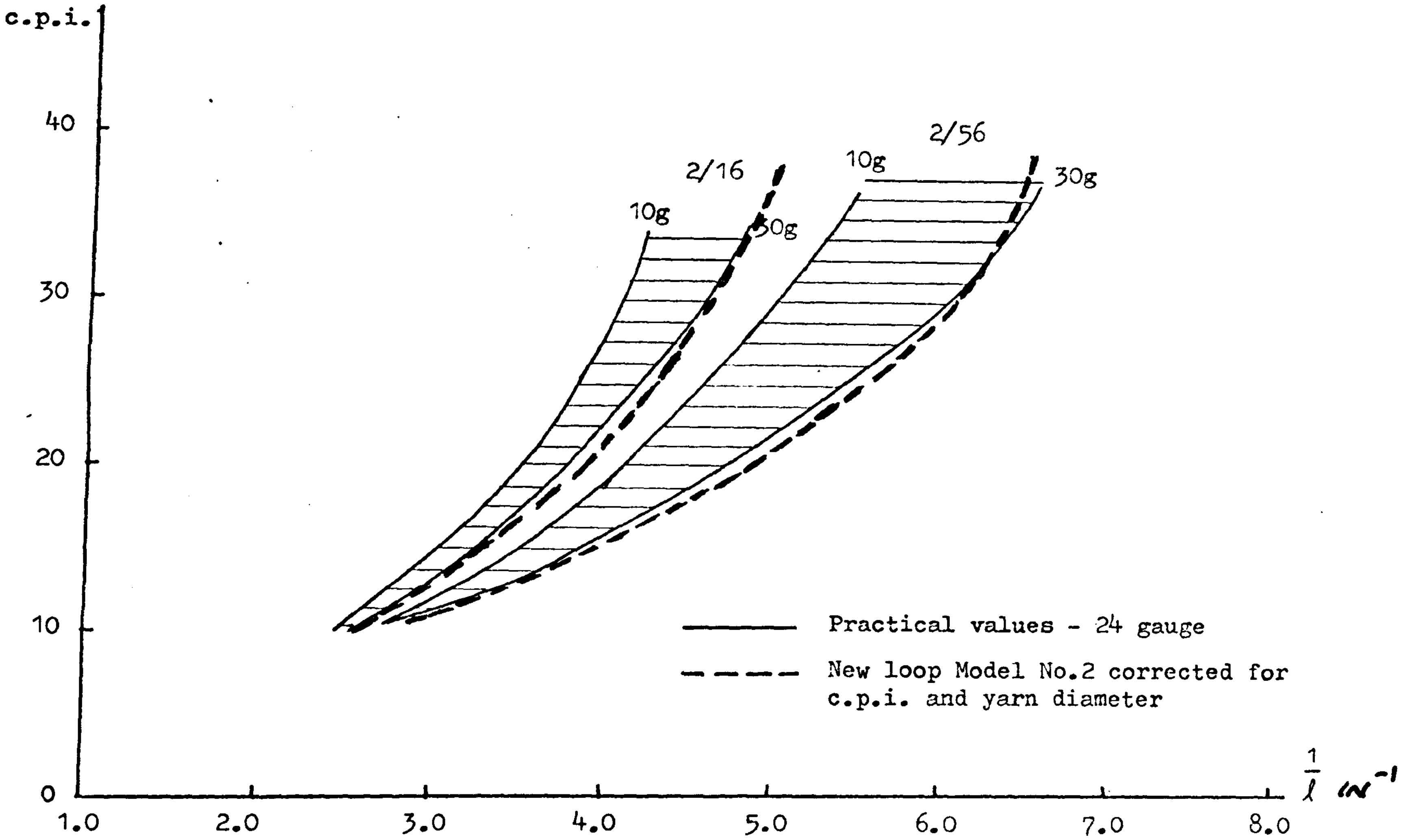


Fig. 106

Comparison of Model No.2 correct for c.p.i. and yarn diameter with practical values

reading taken by piece glass is an 'average' value and not comparable to that used in the loop model.
This course variation is not constant but varies with count and courses per inch. No variation was shown on any count at 10 c.p.i. but at high c.p.i. the 2/16's showed a course spacing of 1/36 inch at the trick plate and 1/32 inch at the take-up roller with a piece glass reading of 32 c.p.i., while the 2/56's showed a variation of 1/46 inch at the trick plate to 1/34 inch at the take-up roller with a piece glass reading of 40 c.p.i.

ii) At high warp tensions, the amount of yarn used in the head of the loop is less than that predicted by the loop model and this varies according to yarn count, the 1/16's showing 27% less, while the 2/56's show 50% less. This is no doubt due to the compression of the yarn at the head of the loop where the yarns cross but the loop twists and lies out of the plane of the photograph, so that it is impossible to see the actual lay of the yarn at this point.

CHAPTER XI

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

Summary

This thesis is an account of an investigation into the dimensional parameters of single bar warp knitted constructions produced from worsted yarns and their relationship with stitch length.

The constructions investigated are the open and closed lap versions of 1 x 1, 2 x 1, 3 x 1 and 4 x 1 lapping movements. Each construction is produced in a number of stitch lengths and a range of yarn counts from 1/8's to 1/28's and their equivalent two-fold yarns.

The first three chapters form an introduction to the subject, Chapter I explaining the basic principles of warp knitting and fabric construction with reference to trade practice to sufficient depth to afford understanding of any technical terms used in this work.

Chapter II traces the history of warp knitting from the introduction of the hand warp frame through the application of power to the specialised high speed units used in modern industry today. The development of fabric structure is also outlined with the transition from natural fibres, such as wool and cotton, to the fine denier man-made yarns.

A review of the previous work by researchers in the field, both in weft knitting and warp knitting, is given in Chapter III.

The type of machine used for the production of the samples was a bench top Raschel machine, capable of making fabrics from small hand wound warps being ideal for research work as samples can be produced from small lots of yarn quickly with ease. This machine and its associated mechanisms are described in Chapter IV.

From the work in Chapter III it was not clear which relaxation treatment may give the most relaxed state of the warp knitted fabric and since other workers on warp knitted fabrics had experienced difficulty in relaxing fabrics, it was decided to perform a short experiment to evaluate the effect of various relaxation treatments. This is described in Chapter V.

Chapter VI contains a thorough investigation of the dimensional properties of the 1 x 1 closed lap construction. As this construction is considered the basic single bar construction, a detailed investigation was undertaken into the effects of yarn count, the relationship between the parameters and stitch length, and the felting properties of the fabric when treated in a Cubex washing machine.

Investigations into the dimensional properties by observing the dimensions of the fabrics during relaxation of the 2 x 1, 3 x 1 and 4 x 1 closed lap constructions and the 1 x 1, 2 x 1, 3 x 1 and 4 x 1 open lap constructions were undertaken in Chapter VII with a summary of the work conducted on these constructions in Chapter VIII.

Chapters IX and X conclude the work by the construction of loop models to investigate the yarn in the two and three dimensional shape of the loop. A number of loop models were suggested to fit the various fabric groupings discussed in the thesis. A separate loop model is proposed for fabrics on the machine and the effect of knitting tension is discussed.

Conclusions

From the investigations conducted in this work, it is shown that for the relaxation of single bar warp knitted constructions produced from worsted yarns, it is necessary to wet out the fabrics and to dry them while tumbling to achieve the most thorough relaxation. Fabrics wet-out and left to dry on a flat surface do not relax to the same extent and tumbling in the dry condition has little or no effect on the relaxation treatment.

The dimensions of single bar warp knitted constructions investigated in the tumble dry condition are dependent solely on the stitch length and it has been shown by detailed investigation that count and ply of yarn have no effect on this relationship. It is shown that a good correlation between the knitted parameters of c.p.i., w.p.i. and stitch density with the stitch length exists. The results were analysed in terms of k_c, k_w, k_s and k_r but these relationships ~~is~~ ARE not necessarily a constant and the actual value varies according to the parameters, the construction and the state of relaxation.

In the tumble dry condition, the most relaxed condition investigated, the fabrics group themselves according to the freedom of the yarn to move within the construction. The following table shows the grouping and the values for the various parameters investigated.

Structure	c.p.i. against $\frac{1}{\ell}$	w.p.i. against $\frac{1}{\ell}$	S against $\frac{1}{\ell^2}$
1 x 1 Closed	$\text{c.p.i.} = \frac{8.95}{\ell}$	$\text{w.p.i.} = \frac{2.70}{\ell} + 2.13$	$S = \frac{25.60}{\ell^2} + 52.50$
1 x 1 Open	$\text{c.p.i.} = \frac{7.79}{\ell}$	$\text{w.p.i.} = \frac{4.02}{\ell}$	$S = \frac{30.50}{\ell^2}$
2 x 1 Closed 2 x 1 Open	$\text{c.p.i.} = \frac{7.51}{\ell}$	$\text{w.p.i.} = \frac{5.07}{\ell} + 3.24$	$S = \frac{44.90}{\ell^2}$
3 x 1 Closed 3 x 1 Open	$\text{c.p.i.} = \frac{7.70}{\ell}$	$\text{w.p.i.} = \frac{6.09}{\ell} + 5.80$	$S = \frac{60.90}{\ell^2}$
4 x 1 Closed 4 x 1 Open	$\text{c.p.i.} = \frac{7.88}{\ell}$	$\text{w.p.i.} = \frac{8.32}{\ell} + 5.54$	$S = \frac{78.00}{\ell^2}$

On felting, the 1 x 1 closed lap construction behaves in similar manner to the plain weft knitted construction, and on analysis by plotting c.p.i. and w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$, the results separate themselves according to yarn count and, accordingly, the k_c, k_w and k_s values are count dependent. The k_r value, however, is a constant once the fabric has become felted, with a value of 2.69.

When analysed in terms of cover factor, however, by plotting the k values against the reciprocal of cover factor, (i.e. $\ell\sqrt{N}$), the k values of the felted fabrics fall in a straight line indicating that the rate of felting of these fabrics is independent of yarn count and stitch length and related only to the cover factor in the fabric.

The models proposed for the tumble dried condition suggest that in this state of relaxation the loop takes up the form of an elastica irrespective of its construction and the three dimensional shape of the structure is also constant irrespective of the construction. The different groupings of the fabrics investigated occurs because of the manner in which the loop and underlap lies in relation to the course and wale spacing and not the three dimensional configuration of the construction. If the course/wale relationship observed on the relaxed fabrics is also applied, the following relationships between stitch length and course spacing are obtained -

1 x 1 Closed Lap

$$\begin{aligned}\ell = {} & 2.78\sqrt{(1.53c)^2 + (1.601c + 0.007)^2} \\ & + 1.36\sqrt{(0.95c)^2 + (1.251c + 0.006)^2}\end{aligned}$$

1 x 1 Open Lap

$$\begin{aligned}\ell = {} & 2.78\sqrt{(2c)^2 + (1.655c - 0.008)^2} \\ & + 1.36\sqrt{(0.70c)^2 + (0.591c - 0.003)^2}\end{aligned}$$

2 x 1 Open and Closed Lap

$$\begin{aligned}\ell = {} & 2.78\sqrt{(1.32c)^2 + (0.975 + 0.005)^2} \\ & + 1.36\sqrt{(1.08c)^2 + (1.523c + 0.008)^2}\end{aligned}$$

3 x 1 Open and Closed Lap

$$\begin{aligned}\ell = {} & 2.78\sqrt{(1.32c)^2 + (0.648c + 0.009)^2} \\ & + 1.36\sqrt{(1.08c)^2 + (1.674c + 0.023)^2}\end{aligned}$$

4 x 1 Open and Closed Lap

$$\ell = 2.78\sqrt{(1.32c)^2 + (0.502c + 0.008)^2} + 1.36\sqrt{(1.08c)^2 + (1.844c + 0.029)^2}$$

A different loop model is proposed for the fabrics on the machine since in this state it has been found that the relationship between c.p.i. and ℓ is (a) count dependent and (b) affected by warp tensions. These experimental results have been explained by suggesting that (a) with high warp tensions the yarn becomes compressed giving an effective diameter which is tension dependent., and (b) the fabric is distorted resulting in a variation in the size of the loop from the knitting point to the take-up roller.

Suggestions for Further Work

This work has been concerned with the production of single bar fabrics from worsted yarns in order to establish the basic fundemental relationship between the knitted parameters and the stitch length, but as single bar fabrics are not used industrially, an obvious continuation of this work would be in the use of two bar constructions, in which both bars knit and in which one bar knits and one bar lays-in. It would also be interesting to apply the stitch length and c.p.i. relationships established in this work to two bar constructions to see if the values indicated gave a balanced construction.

Further and deeper investigation into the loop model would be of considerable usefulness in establishing the lay of the yarn in two bar constructions. The technique described here could be extended by marking the yarn or wax to give datum points for measuring the various sections of the construction to relate one photograph with another.

Although the loop model gave good correlation between the calculated and actual values, it was noticed that the short stitch lengths tended to be undervalued and the larger stitch lengths over-valued, and an investigation into this aspect could well prove worthwhile.

It is generally accepted in the trade that the bench top model is not suitable for producing samples for weight and finished courses and w.p.i. and it is necessary to use a large scale trial on full size machines to obtain these values. An investigation into the effects of tension and their comparison with full size machines could well suggest the importance of establishing knitting tension as a means of sample production. A fact on which little is known at the present time.

In the following appendices, the stitch length (ℓ) is measured in inches.

APPENDIX ONE

SAMPLE 1

Count: 1/12 wor. Structure: 1 x 1 Closed Lap

$\ell = 0.186$ $\ell^2 = 0.034$ $\frac{1}{\ell} = 5.376$ $\frac{1}{\ell^2} = 29.41$ $\frac{1}{\ell\sqrt{N}} = 1.555$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	40.00	7.44	16.00	2.98	640.0	21.76	2.50
Dry Relaxed	43.63	8.12	15.09	2.81	658.4	22.38	2.89
Wet Relaxed	45.00	8.37	15.53	2.79	698.8	24.17	2.90
5 min. Dry Tumble	45.28	8.28	16.22	3.02	734.4	24.97	2.79
10 min. Dry Tumble	45.74	8.51	16.41	3.05	750.6	25.52	2.79
15 min. Dry Tumble	45.85	8.53	16.32	3.04	748.3	25.44	2.81
20 min. Dry Tumble	45.85	8.53	16.32	2.93	748.3	25.44	2.81
60 min. Dry Tumble	45.60	8.48	16.35	2.94	745.6	25.34	2.79
Tumble Dry	46.75	8.70	16.49	3.07	770.9	26.60	2.84

SAMPLE 2

Count: 1/12 wor. Structure: 1 x 1 Closed Lap

$\ell = 0.199$ $\ell^2 = 0.039$ $\frac{1}{\ell} = 5.025$ $\frac{1}{\ell^2} = 25.64$ $\frac{1}{\ell\sqrt{N}} = 1.456$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.00	5.97	16.00	3.18	480.0	18.72	1.88
Dry Relaxed	36.54	7.27	14.22	2.70	519.6	20.26	2.57
Wet Relaxed	40.81	8.12	14.54	2.76	593.3	23.40	2.81
5 min. Dry Tumble	41.14	8.19	15.09	3.00	620.8	24.31	2.73
10 min. Dry Tumble	41.86	8.33	15.20	3.02	636.3	24.81	2.75
15 min. Dry Tumble	41.61	8.28	15.31	3.05	637.1	24.85	2.72
20 min. Dry Tumble	41.37	8.23	15.23	2.89	630.1	24.57	2.72
60 min. Dry Tumble	41.86	8.33	15.35	2.91	642.6	25.12	2.73
Tumble Dry	43.10	8.60	16.41	3.27	707.3	28.01	2.63

SAMPLE 3

Count: 1/12 wor.   Structure: 1 x 1 Closed Lap

$\ell = 0.232$ $\ell^2 = 0.053$ $\frac{1}{\ell} = 4.31$ $\frac{1}{\ell^2} = 18.86$ $\frac{1}{\ell\sqrt{N}} = 1.247$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.00	4.64	16.00	3.70	320.0	16.96	1.25
Dry Relaxed	28.45	6.60	12.30	2.82	349.9	18.54	2.31
Wet Relaxed	34.95	8.11	12.30	2.82	429.8	23.13	2.84
5 min. Dry Tumble	35.12	8.15	13.09	3.04	459.7	24.37	2.68
10 min. Dry Tumble	35.12	8.15	13.24	3.07	465.0	24.64	2.65
15 min. Dry Tumble	35.64	8.27	13.22	3.07	471.2	24.97	2.70
20 min. Dry Tumble	35.12	8.15	13.15	3.02	461.8	24.50	2.67
60 min. Dry Tumble	35.50	8.24	13.30	3.05	472.2	25.00	2.67
Tumble Dry	36.36	8.44	14.22	3.30	517.0	27.82	2.56

SAMPLE 4

Count: 1/12 wor.   Structure: 1 x 1 Closed Lap

$\ell = 0.365$ $\ell^2 = 0.133$ $\frac{1}{\ell} = 2.74$ $\frac{1}{\ell^2} = 7.51$ $\frac{1}{\ell\sqrt{N}} = 0.794$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.65	16.00	5.84	160.0	21.28	0.63
Dry Relaxed	17.34	6.33	7.71	2.77	133.7	17.78	2.25
Wet Relaxed	21.75	7.94	8.23	2.96	179.0	23.84	2.64
5 min. Dry Tumble	23.25	8.49	8.74	3.19	203.2	27.03	2.66
10 min. Dry Tumble	23.07	8.42	8.90	3.25	205.3	27.31	2.59
15 min. Dry Tumble	23.45	8.56	8.93	3.26	209.4	27.85	2.63
20 min. Dry Tumble	23.52	8.59	8.83	3.17	207.7	27.62	2.66
60 min. Dry Tumble	23.52	8.59	8.74	3.14	205.6	27.33	2.69
Tumble Dry	25.25	9.20	9.52	3.48	240.4	31.92	2.65

SAMPLE 5

Count: 2/32 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.172$ $\ell^2 = 0.029$ $\frac{1}{\ell} = 5.814$ $\frac{1}{\ell^2} = 34.4$ $\frac{1}{\ell\sqrt{N}} = 1.453$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	40.00	6.88	16.00	2.75	640.0	18.56	2.50
Dry Relaxed	48.00	8.26	15.60	2.65	748.8	21.7	3.08
Wet Relaxed	49.45	8.51	16.66	2.83	823.8	24.37	2.97
5 min. Dry Tumble	50.13	8.62	17.35	2.98	869.8	25.22	2.89
10 min. Dry Tumble	50.00	8.60	17.50	3.01	875.0	25.36	2.86
15 min. Dry Tumble	50.00	8.60	17.39	2.99	869.5	25.23	2.88
20 min. Dry Tumble	50.42	8.67	17.35	2.94	874.8	25.36	2.91
60 min. Dry Tumble	50.00	8.60	17.56	2.98	878.0	25.46	2.85
Tumble Dry	50.70	8.72	18.08	3.11	916.7	27.04	2.80

SAMPLE 6

Count:2/32 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.188$ $\ell^2 = 0.035$ $\frac{1}{\ell} = 5.319$ $\frac{1}{\ell^2} = 28.57$ $\frac{1}{\ell\sqrt{N}} = 1.333$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.00	5.64	16.00	3.00	480.0	16.81	1.88
Dry Relaxed	38.70	7.28	14.54	2.61	562.7	19.72	2.66
Wet Relaxed	44.44	8.36	15.38	2.76	683.5	24.15	2.89
5 min. Dry Tumble	45.00	8.46	16.12	3.03	725.4	25.39	2.79
10 min. Dry Tumble	45.00	8.46	16.24	3.05	730.8	25.58	2.77
15 min. Dry Tumble	45.00	8.46	16.16	3.04	727.2	25.45	2.78
20 min. Dry Tumble	45.00	8.46	16.14	2.90	726.3	25.42	2.79
60 min. Dry Tumble	45.00	8.46	16.21	2.91	729.5	25.53	2.78
Tumble Dry	45.57	8.57	16.97	3.19	773.3	27.34	2.69

SAMPLE 7

Count: 2/32 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.219$ $\ell^2 = 0.047$ $\frac{1}{\ell} = 4.566$ $\frac{1}{\ell^2} = 21.27$ $\frac{1}{\ell\sqrt{N}} = 1.142$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.00	4.39	16.00	3.50	320.0	15.04	1.25
Dry Relaxed	31.30	6.86	12.80	2.68	401.0	18.83	2.45
Wet Relaxed	37.89	8.30	13.33	2.79	505.0	24.22	2.84
5 min. Dry Tumble	38.09	8.34	14.09	3.09	536.7	25.50	2.70
10 min. Dry Tumble	38.58	8.45	14.15	3.10	545.9	25.66	2.73
15 min. Dry Tumble	38.50	8.43	14.22	3.11	547.5	25.73	2.71
20 min. Dry Tumble	38.13	8.35	14.22	2.98	542.0	25.50	2.68
60 min. Dry Tumble	38.70	8.48	14.22	2.98	550.0	25.86	2.72
Tumble Dry	38.10	8.33	14.91	3.27	568.0	27.21	2.56

SAMPLE 8

Count: 2/32 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.361$ $\ell^2 = 0.130$ $\frac{1}{\ell} = 2.77$ $\frac{1}{\ell^2} = 7.69$ $\frac{1}{\ell\sqrt{N}} = 0.694$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.61	16.00	5.75	160.0	20.80	0.62
Dry Relaxed	22.16	8.00	7.44	2.67	165.0	21.43	2.98
Wet Relaxed	23.6	8.52	8.00	2.88	188.8	24.60	2.95
5 min. Dry Tumble	24.16	8.72	8.69	3.14	210.0	27.29	2.78
10 min. Dry Tumble	24.57	8.87	8.83	3.19	216.9	28.20	2.78
15 min. Dry Tumble	24.32	8.97	8.88	3.21	216.0	28.08	2.74
20 min. Dry Tumble	24.48	8.84	8.88	3.19	217.0	28.25	2.76
60 min. Dry Tumble	24.65	8.90	8.83	3.17	218.0	28.25	2.79
Tumble Dry	25.00	9.02	9.82	3.54	246.0	31.99	2.55

SAMPLE 9

Count: 1/20 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.0157$ $\ell^2 = 0.024$ $\frac{1}{\ell} = 6.369$ $\frac{1}{\ell^2} = 41.6$ $\frac{1}{\ell\sqrt{N}} = 1.427$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	40.00	6.28	16.00	2.51	640.0	15.36	2.50
Dry Relaxed	50.56	7.94	16.32	2.44	825.0	19.80	3.10
Wet Relaxed	56.25	8.83	17.58	2.63	988.8	24.37	3.20
5 min. Dry Tumble	55.21	8.67	18.22	2.86	1005.9	24.10	3.03
10 min. Dry Tumble	56.07	8.80	18.39	2.89	1031.1	24.75	3.05
15 min. Dry Tumble	55.81	8.76	18.28	2.87	1020.2	24.50	3.05
20 min. Dry Tumble	56.16	8.82	18.28	2.74	1026.0	24.60	3.07
60 min. Dry Tumble	55.81	8.76	18.32	2.74	1022.0	24.50	3.05
Tumble Dry	57.14	8.97	18.93	2.97	1082.0	26.61	3.02

SAMPLE 10

Count: 1/20 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.175$ $\ell^2 = 0.030$ $\frac{1}{\ell} = 5.714$ $\frac{1}{\ell^2} = 33.3$ $\frac{1}{\ell\sqrt{N}} = 1.279$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.00	5.25	16.00	2.80	480.0	14.40	1.87
Dry Relaxed	43.11	7.54	15.09	2.56	650.0	19.51	2.86
Wet Relaxed	48.64	8.51	15.71	2.67	764.1	23.40	3.10
5 min. Dry Tumble	48.12	8.42	16.56	2.90	796.9	23.90	2.91
10 min. Dry Tumble	48.25	8.44	16.66	2.92	803.8	24.12	2.90
15 min. Dry Tumble	48.51	8.49	16.56	2.90	803.3	24.10	2.93
20 min. Dry Tumble	48.12	8.42	16.56	2.81	797.0	23.90	2.91
60 min. Dry Tumble	48.12	8.42	16.64	2.82	801.0	24.00	2.89
Tumble Dry	51.42	9.00	17.78	3.11	914.0	27.98	2.89

SAMPLE 11

Count: 1/20 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.217$ $\ell^2 = 0.047$ $\frac{1}{\ell} = 4.648$ $\frac{1}{\ell^2} = 21.27$ $\frac{1}{\ell\sqrt{N}} = 1.032$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.00	4.34	16.00	3.48	320.0	15.04	1.25
Dry Relaxed	33.48	7.27	12.19	2.55	408.0	19.17	2.75
Wet Relaxed	38.87	8.44	12.95	2.71	503.3	23.70	3.00
5 min. Dry Tumble	38.50	8.36	13.73	2.98	528.6	24.80	2.80
10 min. Dry Tumble	38.50	8.36	13.99	3.03	538.6	25.30	2.75
15 min. Dry Tumble	38.91	8.44	13.97	3.03	543.6	25.55	2.78
20 min. Dry Tumble	38.70	8.40	13.91	2.92	538.0	25.30	2.78
60 min. Dry Tumble	38.70	8.40	13.99	2.93	541.0	25.40	2.77
Tumble Dry	40.45	8.78	14.41	3.13	583.0	27.40	2.81

SAMPLE 12

Count: 1/20 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.356$ $\ell^2 = 0.126$ $\frac{1}{\ell} = 2.812$ $\frac{1}{\ell^2} = 7.911$ $\frac{1}{\ell\sqrt{N}} = 0.629$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.56	16.00	5.70	160.0	20.16	0.62
Dry Relaxed	19.20	6.72	7.61	2.66	146.0	18.40	2.52
Wet Relaxed	23.58	8.25	8.04	2.81	189.5	24.00	2.93
5 min. Dry Tumble	24.98	8.74	8.22	2.92	205.3	25.95	3.04
10 min. Dry Tumble	25.08	8.77	8.83	3.14	221.5	27.90	2.84
15 min. Dry Tumble	24.96	8.73	8.83	3.14	220.4	27.86	2.83
20 min. Dry Tumble	24.91	8.71	8.76	3.06	218.0	27.50	2.84
60 min. Dry Tumble	24.94	8.72	8.83	3.09	220.0	27.70	2.82
Tumble Dry	26.2	9.30	9.16	3.25	240.0	30.24	2.86

SAMPLE 13

Count: 2/48 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.156$ $\ell^2 = 0.024$ $\frac{1}{\ell} = 6.41$ $\frac{1}{\ell^2} = 41.66$ $\frac{1}{\ell\sqrt{N}} = 1.311$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	40.00	6.24	16.00	2.50	640.0	15.36	2.50
Dry Relaxed	54.54	8.51	16.41	2.56	895.0	21.50	3.32
Wet Relaxed	54.13	8.44	18.18	2.84	984.0	23.60	2.98
5 min. Dry Tumble	56.25	8.78	19.04	2.97	1071.0	25.70	2.95
10 min. Dry Tumble	56.25	8.78	17.27	2.69	971.4	23.31	3.26
15 min. Dry Tumble	55.81	8.71	19.04	2.97	1062.6	25.50	2.93
20 min. Dry Tumble	56.25	8.78	19.04	2.97	1071.0	25.70	2.95
60 min. Dry Tumble	56.25	8.78	19.04	2.97	1071.0	25.70	2.95
Tumble Dry	57.14	8.90	20.00	3.12	1143.0	27.77	2.86

SAMPLE 14

Count: 2/48 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.175$ $\ell^2 = 0.030$ $\frac{1}{\ell} = 5.714$ $\frac{1}{\ell^2} = 33.3$ $\frac{1}{\ell\sqrt{N}} = 1.169$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.00	5.25	16.00	2.80	480.0	14.40	1.87
Dry Relaxed	45.56	7.97	14.98	2.62	682.5	20.50	3.04
Wet Relaxed	50.00	8.75	16.41	2.78	820.5	25.14	3.05
5 min. Dry Tumble	49.58	8.68	17.27	3.02	856.6	25.69	2.87
10 min. Dry Tumble	49.79	8.71	17.46	3.06	869.3	26.08	2.85
15 min. Dry Tumble	49.65	8.69	17.44	3.05	865.9	25.98	2.85
20 min. Dry Tumble	49.79	8.71	17.39	3.04	865.0	25.97	2.86
60 min. Dry Tumble	50.00	8.75	17.42	3.04	871.0	26.13	2.87
Tumble Dry	50.70	8.90	18.18	3.18	922.0	28.20	2.79

SAMPLE 15

Count: 2/48 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.215 \quad \ell^2 = 0.046 \quad \frac{1}{\ell} = 4.651 \quad \frac{1}{\ell^2} = 21.73 \quad \frac{1}{\ell\sqrt{N}} = 0.952$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.00	4.30	16.00	3.42	320.0	14.72	1.25
Dry Relaxed	34.28	7.37	12.62	2.70	433.0	19.90	2.72
Wet Relaxed	39.34	8.46	13.55	2.84	533.00	24.60	2.90
5 min. Dry Tumble	39.77	8.55	14.67	3.15	583.4	26.84	2.71
10 min. Dry Tumble	40.00	8.60	14.67	3.03	586.8	26.99	2.73
15 min. Dry Tumble	40.44	8.70	14.74	3.17	596.1	27.42	2.74
20 min. Dry Tumble	40.44	8.70	14.67	3.10	593.0	27.27	2.76
60 min. Dry Tumble	40.44	8.70	14.67	3.10	593.0	27.27	2.76
Tumble Dry	40.77	8.77	15.39	3.31	628.0	28.99	2.65

SAMPLE 16

Count: 2/48 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.325 \quad \ell^2 = 0.105 \quad \frac{1}{\ell} = 3.077 \quad \frac{1}{\ell^2} = 9.52 \quad \frac{1}{\ell\sqrt{N}} = 0.629$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.25	16.00	5.20	160.0	16.80	0.62
Dry Relaxed	20.57	6.69	7.85	2.55	161.0	16.95	2.62
Wet Relaxed	22.36	7.27	8.79	2.90	196.5	21.08	2.54
5 min. Dry Tumble	24.16	7.85	9.38	3.05	226.6	23.79	2.58
10 min. Dry Tumble	24.48	8.00	9.46	3.07	231.6	24.32	2.59
15 min. Dry Tumble	24.00	7.80	9.34	3.06	224.2	23.54	2.57
20 min. Dry Tumble	24.48	8.00	9.41	3.10	230.0	24.80	2.60
60 min. Dry Tumble	24.65	8.01	9.58	3.10	236.0	24.79	2.57
Tumble Dry	26.70	8.67	9.82	3.19	262.0	27.69	2.72

APPENDIX TWO

SAMPLE 17

Count: 1/8 worsted

Structure: 1 x 1 Closed Lap

$\ell = 0.408$ $\ell^2 = 0.167$ $\frac{1}{\ell} = 2.449$ $\frac{1}{\ell^2} = 5.999$ $\ell\sqrt{N} = 1.155$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	4.08	16.00	6.53	160.00	18.09	0.62
Wet Relaxed	18.46	7.54	8.14	3.32	150.19	25.04	2.27
Tumble Dry	22.15	9.04	8.65	3.53	191.60	31.94	2.56
½ hr. Cubex	31.58	12.89	13.04	5.33	411.90	68.66	2.42
1 hr. Cubex	36.55	14.92	14.29	5.83	522.12	87.04	2.55
1½ hrs. Cubex	38.71	15.80	15.38	6.28	595.53	99.27	2.51
2 hrs. Cubex	40.00	16.33	15.89	6.49	635.76	105.98	2.51

SAMPLE 18

Count: 1/8 worsted

Structure: 1 x 1 Closed Lap

$\ell = 0.328$ $\ell^2 = 0.107$ $\frac{1}{\ell} = 3.051$ $\frac{1}{\ell^2} = 9.320$ $\ell\sqrt{N} = 0.927$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	13.00	4.26	16.00	5.25	208.00	22.26	0.81
Wet Relaxed	24.00	7.86	9.80	3.21	235.10	25.23	2.44
Tumble Dry	27.69	9.07	10.44	3.42	288.96	31.01	2.65
½ hr. Cubex	31.91	10.46	12.87	4.22	410.70	44.07	2.47
1 hr. Cubex	36.55	11.98	14.54	4.77	531.61	57.04	2.51
1½ hrs. Cubex	38.50	12.62	15.33	5.02	590.45	63.36	2.51
2 hrs. Cubex	41.86	13.72	16.01	5.25	670.21	71.91	2.61

SAMPLE 19

Count: 1/8 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.290$ $\ell^2 = 0.084$ $\frac{1}{\ell} = 3.445$ $\frac{1}{\ell^2} = 11.876$ $\ell\sqrt{N} = 0.821$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	16.00	4.64	16.00	4.64	256.00	21.50	1.00
Wet Relaxed	27.17	7.88	11.43	3.32	310.51	26.14	2.37
Tumble Dry	31.30	9.08	11.71	3.40	366.49	30.86	2.67
½ hr. Cubex	34.29	9.95	13.41	3.89	459.70	38.71	2.55
1 hr. Cubex	37.50	10.88	14.54	4.22	545.45	45.93	2.57
1½ hrs. Cubex	39.69	11.52	15.34	4.45	609.07	51.28	2.58
2 hrs. Cubex	41.86	12.18	16.45	4.77	688.59	57.98	2.54

SAMPLE 20

Count: 1/8 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.268$ $\ell^2 = 0.072$ $\frac{1}{\ell} = 3.731$ $\frac{1}{\ell^2} = 13.926$ $\ell\sqrt{N} = 0.758$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	22.00	5.90	16.00	4.29	352.00	25.34	1.37
Wet Relaxed	32.73	8.77	12.00	3.22	392.73	28.20	2.72
Tumble Dry	34.29	9.19	12.63	3.38	433.08	31.09	2.71
½ hr. Cubex	34.88	9.35	13.56	3.63	472.99	33.96	2.57
1 hr. Cubex	37.81	10.13	14.03	3.76	530.73	38.11	2.69
1½ hrs. Cubex	38.96	10.44	15.45	4.14	602.10	43.23	2.52
2 hrs. Cubex	41.10	11.01	16.17	4.33	664.62	47.72	2.54

SAMPLE 21

Count: 1/12 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.423$ $\ell^2 = 0.179$ $\frac{1}{\ell} = 2.365$ $\frac{1}{\ell^2} = 5.593$ $\ell\sqrt{N} = 1.465$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	3.81	16.00	6.77	144.00	25.78	0.56
Wet Relaxed	18.70	7.91	7.11	3.01	132.99	23.78	2.62
Tumble Dry	21.18	8.95	8.28	3.50	175.25	31.33	2.55
½ hr. Cubex	36.73	15.53	14.12	5.97	518.60	92.73	2.60
1 hr. Cubex	42.35	17.91	16.22	6.86	686.80	122.80	2.61
1½ hrs. Cubex	44.44	18.80	17.14	7.25	761.90	136.23	2.59
2 hrs. Cubex	46.75	19.77	18.04	7.63	843.67	150.857	2.59

SAMPLE 22

Count: 1/12 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.285$ $\ell^2 = 0.081$ $\frac{1}{\ell} = 3.512$ $\frac{1}{\ell^2} = 12.346$ $\ell\sqrt{N} = 0.986$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	15.00	4.27	16.00	4.56	240.00	19.44	0.94
Wet Relaxed	30.00	8.54	10.55	3.00	316.48	25.63	2.84
Tumble Dry	31.30	8.91	11.43	3.25	357.96	28.98	2.73
½ hr. Cubex	40.45	11.52	15.48	4.41	626.31	50.73	2.61
1 hr. Cubex	44.44	12.65	17.14	4.88	761.90	61.71	2.59
1½ hrs. Cubex	48.65	13.85	18.60	5.30	905.09	73.31	2.61
2 hrs. Cubex	50.70	14.53	19.51	5.55	989.34	80.14	2.59

SAMPLE 23

Count: 1/12 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.233$ $\ell^2 = 0.054$ $\frac{1}{\ell} = 4.299$ $\frac{1}{\ell^2} = 18.484$ $\ell\sqrt{N} = 0.806$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	21.00	4.89	16.00	3.73	336.00	18.14	1.31
Wet Relaxed	36.00	8.37	12.80	2.98	460.80	24.93	2.81
Tumble Dry	37.50	8.72	13.33	3.10	499.99	27.05	2.81
½ hr. Cubex	40.91	9.51	15.69	3.65	641.71	34.72	9.52
1 hr. Cubex	44.44	10.34	16.90	3.93	751.17	40.64	2.62
1½ hrs. Cubex	48.32	11.24	18.48	4.30	892.78	48.30	2.61
2 hrs. Cubex	51.43	11.96	19.83	4.61	1020.07	51.19	2.59

SAMPLE 24

Count: 1/12 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.225$ $\ell^2 = 0.051$ $\frac{1}{\ell} = 4.444$ $\frac{1}{\ell^2} = 18.763$ $\ell\sqrt{N} = 0.779$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	32.00	7.20	16.00	3.60	512.00	26.11	2.00
Wet Relaxed	38.92	8.76	13.33	3.00	518.92	26.26	2.91
Tumble Dry	40.00	9.00	13.91	3.13	556.52	28.16	2.87
½ hr. Cubex	41.38	9.31	15.89	3.58	657.68	33.22	2.60
1 hr. Cubex	45.00	10.12	16.78	3.78	755.24	38.21	2.68
1½ hrs. Cubex	48.00	10.80	18.18	4.09	872.73	44.16	2.63
2 hrs. Cubex	50.25	11.32	19.50	4.40	980.00	50.00	2.62

SAMPLE 25

Count: 1/12 worsted　　　　**Structure: 1 x 1 Closed Lap**

$\ell = 0.215$　$\ell^2 = 0.046$　$\frac{1}{\ell} = 4.660$　$\frac{1}{\ell^2} = 21.739$　$\ell\sqrt{N} = 0.743$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	27.00	5.80	16.00	3.44	432.00	19.87	1.69
Wet Relaxed	41.14	8.82	13.52	2.90	556.30	25.59	3.04
Tumble Dry	41.86	8.98	14.54	3.12	608.88	28.01	8.98
½ hr. Cubex	43.37	9.30	16.55	3.50	717.90	33.02	2.62
1 hr. Cubex	46.15	9.90	14.67	3.78	814.48	37.47	3.14
1½ hrs. Cubex	48.65	10.43	18.75	4.02	912.16	41.96	2.59
2 hrs. Cubex	50.00	10.72	19.40	4.13	975.00	44.60	2.50

SAMPLE 26

Count: 1/16 worsted　　　　**Structure: 1 x 1 Closed Lap**

$\ell = 0.372$　$\ell^2 = 0.1385$　$\frac{1}{\ell} = 2.687$　$\frac{1}{\ell^2} = 7.220$　$\ell\sqrt{N} = 1.489$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.72	16.00	5.95	160.00	22.16	0.62
Wet Relaxed	20.28	7.55	8.89	3.33	182.68	25.24	2.15
Tumble Dry	25.26	9.10	9.60	3.57	242.53	33.59	2.63
½ hr. Cubex	41.86	15.58	14.86	5.53	622.07	86.16	2.81
1 hr. Cubex	48.00	17.87	16.78	6.25	805.59	111.57	2.86
1½ hrs. Cubex	50.00	18.61	18.60	6.92	930.23	128.84	2.68
2 hrs. Cubex	52.94	19.70	19.51	7.26	1032.99	143.07	2.71

SAMPLE 27

Count: 1/16 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.264$ $\ell^2 = 0.070$ $\frac{1}{\ell} = 3.789$ $\frac{1}{\ell^2} = 14.388$ $\ell\sqrt{N} = 1.055$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	16.00	4.22	16.00	4.22	256.00	17.92	1.00
Wet Relaxed	32.00	8.44	11.56	3.05	370.12	25.72	2.76
Tumble Dry	34.29	9.04	12.15	3.21	416.63	28.96	2.82
½ hr. Cubex	45.57	12.02	16.90	4.45	772.50	54.10	2.70
1 hr. Cubex	49.31	13.01	17.92	4.72	882.50	61.70	2.76
1½ hrs. Cubex	53.73	14.17	19.90	5.25	1007.20	74.90	2.70
2 hrs. Cubex	57.14	15.07	20.60	5.42	1172.01	82.30	2.78

SAMPLE 28

Count: 1/16 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.231$ $\ell^2 = 0.053$ $\frac{1}{\ell} = 4.324$ $\frac{1}{\ell^2} = 18.727$ $\ell\sqrt{N} = 0.925$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	21.00	4.85	16.00	3.70	336.00	17.81	1.31
Wet Relaxed	37.89	8.76	12.97	2.99	491.60	26.25	2.92
Tumble Dry	40.00	9.25	13.15	3.04	526.02	28.09	3.04
½ hr. Cubex	44.23	10.22	16.24	3.75	718.15	38.35	2.72
1 hr. Cubex	51.43	11.89	18.87	4.36	970.35	51.82	2.72
1½ hrs. Cubex	54.54	12.61	19.87	4.59	1083.68	57.87	2.74
2 hrs. Cubex	57.32	13.25	20.98	4.85	1202.62	64.22	2.73

SAMPLE 29

Count: 1/16 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.210$ $\ell^2 = 0.044$ $\frac{1}{\ell} = 4.768$ $\frac{1}{\ell^2} = 22.779$ $\ell\sqrt{N} = 0.839$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	28.00	5.88	16.00	3.36	448.00	19.71	1.75
Wet Relaxed	44.31	9.29	13.91	2.92	616.45	27.06	3.18
Tumble Dry	43.64	9.15	14.77	3.10	644.47	28.29	2.95
½ hr. Cubex	46.75	9.80	17.42	3.65	814.28	35.75	2.68
1 hr. Cubex	50.70	10.63	18.24	3.82	924.69	40.59	2.78
1½ hrs. Cubex	53.73	11.28	19.83	4.16	1065.74	46.79	2.70
2 hrs. Cubex	57.14	11.98	21.29	4.47	1216.88	53.42	2.68

SAMPLE 30

Count: 1/16 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.204$ $\ell^2 = 0.0416$ $\frac{1}{\ell} = 4.898$ $\frac{1}{\ell^2} = 24.038$ $\ell\sqrt{N} = 0.816$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	34.00	6.94	16.00	3.26	544.00	22.63	2.12
Wet Relaxed	43.64	8.91	15.00	3.06	654.54	27.23	2.90
Tumble Dry	45.00	9.18	15.24	3.11	685.71	28.53	2.95
½ hr. Cubex	46.15	9.42	17.52	3.57	808.53	33.63	2.63
1 hr. Cubex	50.00	10.20	18.60	3.80	930.23	38.70	2.68
1½ hrs. Cubex	53.73	10.97	20.74	4.23	1114.56	46.37	2.59
2 hrs. Cubex	57.14	11.66	22.00	4.50	1254.21	52.22	2.60

SAMPLE 31

Count: 1/20 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.3611 \quad \ell^2 = 0.130 \quad \frac{1}{\ell} = 2.769 \quad \frac{1}{\ell^2} = 7.675 \quad \ell\sqrt{N} = 1.615$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.61	16.00	5.78	160.00	20.80	0.62
Wet Relaxed	21.18	7.65	8.00	2.89	169.41	22.07	2.64
Tumble Dry	25.71	9.28	8.89	3.21	228.57	29.78	2.89
½ hr. Cubex	43.01	15.53	17.33	6.26	745.31	97.11	2.48
1 hr. Cubex	51.43	18.57	20.55	7.42	1056.75	137.69	2.50
1½ hrs. Cubex	56.69	20.47	22.64	8.18	1283.61	167.25	2.50
2 hrs. Cubex	58.35	21.07	22.97	8.29	1340.02	174.60	2.54

SAMPLE 32

Count: 1/20 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.243 \quad \ell^2 = 0.059 \quad \frac{1}{\ell} = 4.114 \quad \frac{1}{\ell^2} = 16.949 \quad \ell\sqrt{N} = 1.087$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	16.00	3.89	16.00	3.89	256.00	15.10	1.00
Wet Relaxed	33.49	8.14	12.00	2.92	401.88	23.71	2.79
Tumble Dry	36.00	8.75	12.31	2.99	443.07	26.14	2.92
½ hr. Cubex	52.17	12.68	18.68	4.54	974.45	57.49	2.79
1 hr. Cubex	57.14	13.89	20.78	5.05	1187.38	70.06	2.74
1½ hrs. Cubex	62.07	15.08	22.73	5.52	1410.65	83.23	2.78
2 hrs. Cubex	65.45	15.90	23.97	5.83	1569.34	92.59	2.72

SAMPLE 33

Count: 1/20 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.194$ $\ell^2 = 0.038$ $\frac{1}{\ell} = 5.161$ $\frac{1}{\ell^2} = 26.667$ $\ell_N\sqrt{N} = 0.866$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	22.00	4.27	16.00	3.10	332.00	13.38	1.37
Wet Relaxed	43.64	8.45	14.54	2.82	634.71	23.80	2.99
Tumble Dry	45.00	8.72	15.24	2.95	685.71	25.71	2.95
½ hr. Cubex	51.43	9.96	19.51	3.78	1003.48	37.63	2.63
1 hr. Cubex	58.06	11.25	22.22	4.30	1290.32	48.39	2.61
1½ hrs. Cubex	63.16	12.23	24.49	4.74	1546.72	58.00	2.57
2 hrs. Cubex	67.92	13.16	26.37	5.11	1791.41	67.18	2.57

SAMPLE 34

Count: 1/20 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.163$ $\ell^2 = 0.026$ $\frac{1}{\ell} = 6.154$ $\frac{1}{\ell^2} = 37.879$ $\ell_N\sqrt{N} = 0.727$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	31.00	5.05	16.00	2.61	496.00	12.90	1.94
Wet Relaxed	55.38	9.00	17.14	2.79	949.45	25.06	3.23
Tumble Dry	53.33	8.67	18.11	2.94	966.04	25.50	2.94
½ hr. Cubex	56.25	9.14	19.67	3.20	1106.56	29.21	2.85
1 hr. Cubex	58.06	9.43	20.98	3.41	1218.13	32.16	2.76
1½ hrs. Cubex	62.07	10.09	21.82	3.54	1354.22	38.75	2.84
2 hrs. Cubex	65.45	10.64	23.69	3.85	1550.75	40.94	2.76

SAMPLE 35

Count: 1/20 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.149$ $\ell^2 = 0.022$ $\frac{1}{\ell} = 6.698$ $\frac{1}{\ell^2} = 45.045$ $\ell\sqrt{N} = 0.568$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	43.00	6.41	16.00	2.38	688.00	15.14	2.69
Wet Relaxed	60.00	8.96	18.82	2.81	1129.41	25.07	3.18
Tumble Dry	60.00	8.96	19.20	2.87	1152.00	25.57	3.12
½ hr. Cubex	60.50	9.03	21.68	3.24	1311.74	29.12	2.79
1 hr. Cubex	60.50	9.03	22.37	3.34	1353.30	30.04	2.70
1½ hrs. Cubex	65.45	9.77	22.92	3.42	1500.39	33.31	2.85
2 hrs. Cubex	66.75	10.00	24.79	3.70	1622.83	36.03	2.63

SAMPLE 36

Count: 1/24 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.349$ $\ell^2 = 0.122$ $\frac{1}{\ell} = 2.869$ $\frac{1}{\ell^2} = 8.2304$ $\ell\sqrt{N} = 1.708$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.49	16.00	5.58	160.00	19.52	0.62
Wet Relaxed	24.00	8.37	8.28	2.88	198.62	24.13	2.89
Tumble Dry	26.67	9.30	8.89	3.10	237.03	28.80	2.99
½ hr. Cubex	51.43	17.93	15.00	5.23	771.43	93.73	3.42
1 hr. Cubex	61.02	21.27	18.25	6.36	1113.61	135.30	3.34
1½ hrs. Cubex	64.29	22.41	19.62	6.84	1261.53	153.28	3.27
2 hrs. Cubex	66.67	23.24	29.94	7.30	1396.16	169.63	3.18

SAMPLE 37

Count: 1/24 worsted　　　　Structure: 1 x 1 Closed Lap

$\ell = 0.240$　$\ell^2 = 0.058$　$\frac{1}{\ell} = 4.162$　$\frac{1}{\ell^2} = 17.3611$　$\ell\sqrt{N} = 1.177$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	17.00	4.08	16.00	3.84	272.00	15.78	1.06
Wet Relaxed	36.92	8.87	12.00	2.88	443.08	25.52	3.07
Tumble Dry	38.92	9.35	12.31	2.96	478.99	27.59	3.16
½ hr. Cubex	56.69	13.62	18.39	4.42	1042.63	60.05	3.08
1 hr. Cubex	63.72	15.30	21.50	5.17	1370.25	78.93	2.96
1½ hrs. Cubex	71.57	17.19	24.91	5.97	1780.00	61.45	2.87
2 hrs. Cubex	76.11	18.28	25.18	6.05	1916.72	110.40	3.02

SAMPLE 38

Count: 38　　　　Structure: 1 x 1 Closed Lap

$\ell = 0.196$　$\ell^2 = 0.038$　$\frac{1}{\ell} = 5.106$　$\frac{1}{\ell^2} = 26.110$　$\ell\sqrt{N} = 0.959$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	23.00	4.51	16.00	3.14	368.00	13.98	1.44
Wet Relaxed	45.00	8.81	14.12	2.76	635.29	24.33	3.18
Tumble Dry	46.15	9.04	14.54	2.85	671.32	25.71	3.17
½ hr. Cubex	53.73	10.52	18.90	3.70	1015.39	38.89	2.84
1 hr. Cubex	63.16	12.37	21.72	4.25	1371.75	52.54	2.90
1½ hrs. Cubex	69.77	13.66	23.53	4.62	1641.58	62.87	2.96
2 hrs. Cubex	72.00	14.10	26.09	5.11	1878.26	71.94	2.75

SAMPLE 39

Count: 1/24 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.171$ $\ell^2 = 0.029$ $\frac{1}{\ell} = 5.854$ $\frac{1}{\ell^2} = 34.364$ $\ell\sqrt{N} = 0.837$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.00	5.13	16.00	2.74	480.00	13.92	1.87
Wet Relaxed	53.33	9.11	16.27	2.78	867.79	25.25	3.27
Tumble Dry	51.43	8.78	16.55	2.83	851.23	24.77	3.10
½ hr. Cubex	56.69	9.68	19.92	3.40	1129.15	32.86	2.86
1 hr. Cubex	63.16	10.79	22.60	3.86	1427.29	41.53	2.79
1½ hrs. Cubex	68.83	11.76	24.00	4.10	1652.01	48.07	2.86
2 hrs. Cubex	72.73	12.42	26.09	4.46	1897.23	55.21	2.78

SAMPLE 40

Count: 1/24 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.153$ $\ell^2 = 0.023$ $\frac{1}{\ell} = 6.545$ $\frac{1}{\ell^2} = 42.918$ $\ell\sqrt{N} = 0.748$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	40.00	6.12	16.00	2.45	640.00	14.72	2.50
Wet Relaxed	60.00	9.16	18.46	2.82	1107.69	25.81	3.24
Tumble Dry	57.60	8.80	18.46	2.82	1063.38	24.78	3.11
½ hr. Cubex	61.02	9.32	21.24	3.24	1295.93	30.19	2.87
1 hr. Cubex	63.16	9.64	21.82	3.33	1377.98	32.11	2.89
1½ hrs. Cubex	66.67	10.18	23.76	3.63	1584.15	36.91	2.80
2 hrs. Cubex	70.59	10.78	25.81	3.94	1821.63	42.44	2.73

SAMPLE 41

Count: 1/18 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.395$ $\ell^2 = 0.1561$ $\frac{1}{\ell} = 2.531$ $\frac{1}{\ell^2} = 6.406$ $\ell\sqrt{N} = 2.091$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.50	3.75	16.00	6.30	152.00	23.73	0.59
Wet Relaxed	18.95	7.49	8.00	3.16	151.58	23.66	2.36
Tumble Dry	23.23	9.18	7.74	3.06	179.81	28.07	2.99
½ hr. Cubex	48.00	18.96	15.48	6.12	743.22	116.02	3.09
1 hr. Cubex	60.00	23.71	20.00	7.90	1200.00	187.32	3.00
1½ hrs. Cubex	65.45	25.86	21.05	8.32	1377.99	215.10	3.10
2 hrs. Cubex	69.23	27.35	22.64	8.94	1567.49	244.68	3.05

SAMPLE 42

Count: 1/28 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.257$ $\ell^2 = 0.066$ $\frac{1}{\ell} = 3.892$ $\frac{1}{\ell^2} = 15.175$ $\ell\sqrt{N} = 1.359$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	15.5	3.98	16.00	4.11	248.00	16.37	0.97
Wet Relaxed	34.30	8.84	10.91	2.80	374.50	24.65	3.10
Tumble Dry	36.00	9.25	11.71	3.01	420.00	27.80	3.08
½ hr. Cubex	58.73	15.09	19.80	4.92	1162.00	76.70	2.99
1 hr. Cubex	64.00	16.90	22.90	5.88	1468.18	96.75	2.80
1½ hrs. Cubex	68.50	17.60	26.70	6.85	1811.32	119.37	2.56
2 hrs. Cubex	72.80	18.70	27.90	7.17	2020.74	133.83	2.64

SAMPLE 43

Count: 1/28 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.220 \quad \ell^2 = 0.048 \quad \frac{1}{\ell} = 4.54 \quad \frac{1}{\ell^2} = 20.66 \quad \ell\sqrt{N} = 1.165$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	19.50	4.29	16.00	3.52	312.00	14.98	1.22
Wet Relaxed	42.35	9.32	12.80	2.82	542.12	26.24	3.30
Tumble Dry	41.14	9.06	13.71	3.02	564.24	27.31	2.99
½ hr. Cubex	57.69	12.70	20.76	4.58	1197.76	57.97	2.77
1 hr. Cubex	68.44	15.06	24.24	5.34	1659.17	80.30	2.82
1½ hrs. Cubex	72.72	16.01	26.09	5.74	1897.23	91.83	2.78
2 hrs. Cubex	74.53	16.40	28.23	6.21	2104.48	101.86	2.63

SAMPLE 44

Count: 1/28 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.156 \quad \ell^2 = 0.024 \quad \frac{1}{\ell} = 6.429 \quad \frac{1}{\ell^2} = 41.49 \quad \ell\sqrt{N} = 0.823$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	36.00	5.62	16.00	2.50	576.00	13.82	2.25
Wet Relaxed	57.60	8.96	18.82	2.93	1084.23	26.13	3.05
Tumble Dry	60.00	9.33	18.82	2.93	1129.41	27.22	3.18
½ hr. Cubex	64.29	10.00	21.43	3.33	1377.55	33.20	2.99
1 hr. Cubex	72.00	11.20	22.86	3.55	1645.71	39.66	3.15
1½ hrs. Cubex	73.47	11.42	24.24	3.77	1781.07	42.92	3.03
2 hrs. Cubex	79.12	12.30	26.37	4.10	2086.70	50.29	2.99

SAMPLE 45

Count: 1/28 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.143$ $\ell^2 = 0.020$ $\frac{1}{\ell} = 6.990$ $\frac{1}{\ell^2} = 49.02$ $\ell\sqrt{N} = 0.757$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	45.00	6.43	16.00	2.14	720.00	14.40	2.81
Wet Relaxed	68.57	9.81	20.00	2.86	1371.43	27.98	3.42
Tumble Dry	65.45	9.36	20.43	2.92	1336.94	27.27	3.20
½ hr. Cubex	67.92	9.71	23.01	3.29	1562.98	31.88	2.95
1 hr. Cubex	70.59	10.09	23.76	3.40	1677.34	34.22	2.97
1½ hrs. Cubex	72.00	10.30	25.00	3.57	1800.00	36.72	2.88
2 hrs. Cubex	73.77	10.55	27.12	3.88	2000.55	40.81	2.72

SAMPLE 46

Count: 2/16 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.385$ $\ell^2 = 0.148$ $\frac{1}{\ell} = 2.599$ $\frac{1}{\ell^2} = 6.761$ $\ell\sqrt{N} = 1.088$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.85	16.00	6.16	160.00	23.68	0.62
Wet Relaxed	19.73	7.59	8.45	3.24	166.50	24.62	2.46
Tumble Dry	22.50	8.66	8.89	3.42	200.00	29.58	2.53
½ hr. Cubex	31.30	12.04	12.90	4.96	403.90	59.74	2.42
1 hr. Cubex	34.61	13.32	14.12	5.43	488.68	72.28	2.45
1½ hrs. Cubex	35.29	13.58	14.86	5.72	524.49	77.57	2.37
2 hrs. Cubex	37.50	14.43	18.04	6.94	676.69	100.08	2.07

SAMPLE 47

Count: 2/16 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.290 \quad \ell^2 = 0.084 \quad \frac{1}{\ell} = 3.445 \quad \frac{1}{\ell^2} = 11.876 \quad \ell\sqrt{N} = 0.821$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	16.00	4.64	16.00	4.64	256.00	21.50	1.00
Wet Relaxed	27.69	8.03	10.90	3.17	310.00	25.35	3.05
Tumble Dry	30.64	8.89	11.71	3.40	358.69	30.20	2.61
½ hr. Cubex	32.73	9.50	13.23	3.84	432.99	36.46	2.43
1 hr. Cubex	35.29	10.24	14.72	4.27	519.67	43.76	2.39
1½ hrs. Cubex	37.50	10.88	15.38	4.46	576.92	48.58	2.43
2 hrs. Cubex	39.56	11.48	16.33	4.74	645.88	54.38	2.42

SAMPLE 48

Count: 2/16 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.259 \quad \ell^2 = 0.0674 \quad \frac{1}{\ell} = 3.850 \quad \frac{1}{\ell^2} = 14.837 \quad \ell\sqrt{N} = 0.735$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	21.00	5.44	16.00	4.14	336.00	22.65	1.31
Wet Relaxed	32.73	8.20	12.30	3.20	402.79	27.15	2.65
Tumble Dry	33.96	8.82	12.80	3.32	434.72	29.30	2.65
½ hr. Cubex	35.29	9.17	13.87	3.60	489.63	33.00	2.54
1 hr. Cubex	36.55	9.49	14.54	3.78	531.60	35.83	2.51
1½ hrs. Cubex	37.89	9.84	15.20	3.94	575.61	38.80	2.49
2 hrs. Cubex	40.00	10.39	16.00	4.15	640.00	43.14	2.50

SAMPLE 49

Count: 2/16 worsted **Structure:** 1 x 1 Closed Lap

$\ell = 0.257$ $\ell^2 = 0.066$ $\frac{1}{\ell} = 3.892$ $\frac{1}{\ell^2} = 15.175$ $\ell\sqrt{N} = 0.726$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	25.00	6.42	16.00	4.11	400.00	26.40	1.56
Wet Relaxed	33.49	8.60	12.00	3.08	401.86	26.18	2.79
Tumble Dry	34.29	8.81	12.63	3.24	433.08	28.54	2.71
½ hr. Cubex	34.61	8.89	14.12	3.63	488.68	32.20	2.45
1 hr. Cubex	35.64	9.16	14.81	3.81	528.05	34.80	2.40
1½ hrs. Cubex	37.50	9.63	15.29	3.93	573.25	37.78	2.45
2 hrs. Cubex	39.56	10.16	16.33	4.19	645.88	42.56	2.42

SAMPLE 50

Count: 2/24 worsted **Structure:** 1 x 1 Closed Lap

$\ell = 0.387$ $\ell^2 = 0.149$ $\frac{1}{\ell} = 2.585$ $\frac{1}{\ell^2} = 6.684$ $\ell\sqrt{N} = 1.339$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.87	16.00	6.19	160.00	23.84	0.62
Wet Relaxed	20.57	7.96	8.57	3.31	176.33	26.38	2.39
Tumble Dry	22.50	8.70	9.23	3.57	207.69	31.07	2.43
½ hr. Cubex	36.00	13.92	15.89	6.15	572.18	85.59	2.26
1 hr. Cubex	40.91	15.82	17.52	6.78	716.65	107.21	2.33
1½ hrs. Cubex	42.35	16.38	18.46	7.14	781.90	116.97	2.29
2 hrs. Cubex	43.37	16.78	19.35	7.49	839.48	125.59	2.24

SAMPLE 51

Count: 2/24 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.264$ $\ell^2 = 0.069$ $\frac{1}{\ell} = 3.789$ $\frac{1}{\ell^2} = 14.388$ $\ell\sqrt{N} = 0.914$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	17.00	4.49	16.00	4.22	272.00	18.77	1.06
Wet Relaxed	31.04	8.26	12.00	3.17	375.65	26.11	2.60
Tumble Dry	32.73	8.63	12.80	3.38	418.91	29.11	2.55
½ hr. Cubex	36.47	9.62	15.09	3.98	550.55	38.26	2.41
1 hr. Cubex	39.65	10.46	16.32	4.30	645.20	44.55	1.77
1½ hrs. Cubex	43.37	11.14	17.59	4.64	763.17	53.04	2.46
2 hrs. Cubex	50.49	13.32	19.20	5.06	969.42	67.37	2.62

SAMPLE 52

Count: 2/24 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.217$ $\ell^2 = 0.047$ $\frac{1}{\ell} = 4.615$ $\frac{1}{\ell^2} = 21.322$ $\ell\sqrt{N} = 0.750$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	25.00	5.42	16.00	3.47	400.00	18.80	1.56
Wet Relaxed	40.00	8.66	14.12	3.06	564.70	26.48	2.83
Tumble Dry	40.00	8.66	15.00	3.25	600.00	28.14	2.66
½ hr. Cubex	41.38	8.96	16.55	3.58	684.90	32.12	2.49
1 hr. Cubex	42.35	9.17	16.78	3.63	710.82	33.34	2.52
1½ hrs. Cubex	45.00	9.75	18.04	3.91	812.03	38.08	2.49
2 hrs. Cubex	46.75	10.13	19.20	4.16	897.66	42.10	2.43

SAMPLE 53

Count: 2/24 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.213 \quad \ell^2 = 0.045 \quad \frac{1}{\ell} = 4.706 \quad \frac{1}{\ell^2} = 22.173 \quad \ell\sqrt{N} = 0.736$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	32.00	6.82	16.00	3.41	512.00	23.04	2.00
Wet Relaxed	40.00	8.50	14.12	3.00	564.70	25.47	2.83
Tumble Dry	40.00	8.50	15.00	3.19	600.00	27.06	2.66
½ hr. Cubex	41.86	8.89	16.60	3.53	694.78	31.33	2.52
1 hr. Cubex	41.96	8.92	16.90	3.59	709.15	31.98	2.48
1½ hrs. Cubex	43.64	9.27	17.78	3.78	775.75	34.99	2.45
2 hrs. Cubex	45.86	9.74	18.52	3.93	849.25	38.30	2.47

SAMPLE 54

Count: 2/32 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.369 \quad \ell^2 = 0.136 \quad \frac{1}{\ell} = 2.712 \quad \frac{1}{\ell^2} = 7.36 \quad \ell\sqrt{N} = 1.475$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	11.00	4.06	16.00	5.90	176.00	23.94	0.69
Wet Relaxed	21.18	7.81	8.89	3.28	188.23	25.58	2.38
Tumble Dry	24.83	9.15	9.60	3.54	238.34	32.39	2.58
½ hr. Cubex	38.79	14.30	17.39	6.41	674.66	91.69	2.22
1 hr. Cubex	44.44	16.39	19.51	7.19	867.20	117.85	2.27
1½ hrs. Cubex	47.621	17.56	20.69	7.63	985.22	133.89	2.30
2 hrs. Cubex	50.70	18.69	22.02	8.12	1116.42	151.72	2.30

SAMPLE 55

Count: 2/32 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.261$ $\ell^2 = 0.068$ $\frac{1}{\ell} = 3.830$ $\frac{1}{\ell^2} = 14.684$ $\ell\sqrt{N} = 1.044$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	16.00	4.18	16.00	4.18	256.00	17.41	1.00
Wet Relaxed	31.30	8.17	11.57	3.02	362.07	24.66	2.70
Tumble Dry	34.29	8.95	12.63	3.30	433.08	29.49	2.71
½ hr. Cubex	45.00	11.75	17.14	4.48	771.43	52.53	2.62
1 hr. Cubex	51.43	13.43	19.67	5.14	1011.71	68.90	2.61
1½ hrs. Cubex	53.73	14.03	21.24	5.54	1141.19	77.71	2.52
2 hrs. Cubex	57.14	14.92	21.82	5.70	1246.75	84.90	2.61

SAMPLE 56

Count: 2/32 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.208$ $\ell^2 = 0.043$ $\frac{1}{\ell} = 4.816$ $\frac{1}{\ell^2} = 23.256$ $\ell\sqrt{N} = 0.830$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	23.00	4.78	16.00	3.33	368.00	15.82	1.44
Wet Relaxed	42.35	8.79	14.33	2.97	606.84	26.09	2.95
Tumble Dry	42.35	8.79	15.00	3.11	635.29	27.32	2.82
½ hr. Cubex	44.12	9.16	17.67	3.66	777.50	33.42	2.86
1 hr. Cubex	48.00	9.96	19.20	3.99	921.60	39.63	2.50
1½ hrs. Cubex	52.74	10.83	20.76	4.31	1083.19	46.58	2.54
2 hrs. Cubex	54.96	11.41	22.43	4.66	1232.79	53.01	2.45

SAMPLE 57

Count: 2/32 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.182$ $\ell^2 = 0.033$ $\frac{1}{\ell} = 5.496$ $\frac{1}{\ell^2} = 30.303$ $\ell\sqrt{N} = 0.728$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	31.00	5.64	16.00	2.91	496.00	16.37	1.94
Wet Relaxed	49.65	9.03	16.55	3.01	821.88	27.12	2.99
Tumble Dry	49.65	9.03	17.14	3.12	851.23	28.09	2.89
½ hr. Cubex	50.28	9.15	19.05	3.46	957.70	31.60	2.63
1 hr. Cubex	50.28	9.15	19.43	3.53	977.08	32.24	2.58
1½ hrs. Cubex	52.94	9.63	20.81	3.79	1101.98	36.36	2.54
2 hrs. Cubex	54.54	9.92	22.21	4.04	1220.50	40.00	3.42

SAMPLE 58

Count: 2/32 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.173$ $\ell^2 = 0.030$ $\frac{1}{\ell} = 5.783$ $\frac{1}{\ell^2} = 33.557$ $\ell\sqrt{N} = 0.692$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	40.00	6.92	16.00	2.77	640.00	19.20	2.50
Wet Relaxed	53.33	9.22	17.14	2.96	914.28	27.25	3.11
Tumble Dry	53.33	9.22	17.14	2.96	914.28	27.25	3.11
½ hr. Cubex	52.44	9.15	19.35	3.35	1024.66	30.53	2.73
1 hr. Cubex	53.89	9.32	19.05	3.29	1026.52	30.59	2.82
1½ hrs. Cubex	54.96	9.50	20.69	3.58	1137.14	33.89	2.65
2 hrs. Cubex	57.14	9.88	22.10	3.82	1262.82	37.63	2.58

SAMPLE 59

Count: 2/40 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.350$ $\ell^2 = 0.123$ $\frac{1}{\ell} = 2.857$ $\frac{1}{\ell^2} = 8.163$ $\ell\sqrt{N} = 1.565$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.50	16.00	5.60	160.00	19.68	0.63
Wet Relaxed	24.83	8.69	9.23	3.23	229.17	28.07	2.68
Tumble Dry	26.67	9.33	10.43	3.65	278.28	34.09	2.55
½ hr. Cubex	37.89	13.26	16.45	5.76	623.35	76.36	2.30
1 hr. Cubex	48.65	17.03	18.46	6.46	898.13	110.02	2.63
1½ hrs. Cubex	51.43	18.00	19.83	6.94	1020.07	124.96	2.59
2 hrs. Cubex	56.25	19.69	20.98	7.34	1180.07	144.56	2.68

SAMPLE 60

Count: 2/40 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.256$ $\ell^2 = 0.065$ $\frac{1}{\ell} = 3.913$ $\frac{1}{\ell^2} = 15.337$ $\ell\sqrt{N} = 1.143$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	16.00	4.10	16.00	4.10	256.00	16.64	1.00
Wet Relaxed	35.12	8.97	12.30	3.14	432.27	28.18	2.85
Tumble Dry	36.00	9.20	13.33	3.41	480.00	31.30	2.70
½ hr. Cubex	48.00	12.26	18.60	4.75	893.02	58.22	2.57
1 hr. Cubex	55.38	14.15	20.99	5.37	1159.00	75.25	3.56
1½ hrs. Cubex	58.06	14.83	23.19	5.92	1346.42	87.79	2.50
2 hrs. Cubex	60.00	15.33	24.00	6.13	1440.00	93.89	2.50

SAMPLE 61

Count: 2/40 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.224$ $\ell^2 = 0.050$ $\frac{1}{\ell} = 4.472$ $\frac{1}{\ell^2} = 20.04$ $\ell\sqrt{N} = 1.000$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.00	4.48	16.00	3.58	320.00	16.00	1.25
Wet Relaxed	38.92	8.70	13.71	3.07	533.74	26.63	2.83
Tumble Dry	40.00	8.94	15.00	3.35	600.00	29.94	2.66
½ hr. Cubex	45.00	10.06	18.10	4.05	814.48	40.64	2.48
1 hr. Cubex	50.00	11.18	20.34	4.55	1016.94	50.75	2.45
1½ hrs. Cubex	54.54	12.20	22.30	4.99	1216.62	60.71	2.44
2 hrs. Cubex	59.02	13.20	24.36	5.45	1433.96	71.75	2.42

SAMPLE 62

Count: 2/40 worsted   Structure: 1 x 1 Closed Lap

$\ell = 0.199$ $\ell^2 = 0.039$ $\frac{1}{\ell} = 5.035$ $\frac{1}{\ell^2} = 25.381$ $\ell\sqrt{N} = 0.888$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	26.00	5.17	16.00	3.18	416.00	16.22	1.62
Wet Relaxed	45.00	8.94	15.00	2.98	675.00	26.59	3.00
Tumble Dry	45.00	8.94	16.27	3.23	732.20	28.85	2.76
½ hr. Cubex	47.06	9.35	17.78	3.53	836.60	32.96	2.64
1 hr. Cubex	51.43	10.21	19.35	3.84	995.39	39.22	2.65
1½ hrs. Cubex	55.38	11.00	20.94	4.16	1159.89	45.70	2.64
2 hrs. Cubex	59.01	11.72	22.64	4.47	1336.22	52.65	2.60

SAMPLE 63

Count: 2/40 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.186$ $\ell^2 = 0.035$ $\frac{1}{\ell} = 5.373$ $\frac{1}{\ell^2} = 28.902$ $\ell\sqrt{N} = 0.832$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	32.00	5.95	16.00	2.98	512.00	17.92	2.00
Wet Relaxed	49.65	9.24	15.74	2.93	781.46	27.04	3.15
Tumble Dry	48.00	8.93	16.84	3.13	808.42	27.97	2.85
½ hr. Cubex	50.28	9.36	18.55	3.75	934.00	32.64	2.50
1 hr. Cubex	53.97	10.04	20.51	3.82	1107.14	38.31	2.63
1½ hrs. Cubex	56.69	10.55	22.75	4.23	1289.69	44.62	2.49
2 hrs. Cubex	60.50	11.26	24.59	4.58	1487.80	51.48	2.46

SAMPLE 64

Count: 2/48 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.382$ $\ell^2 = 0.146$ $\frac{1}{\ell} = 2.618$ $\frac{1}{\ell^2} = 6.859$ $\ell\sqrt{N} = 1.871$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.00	3.82	16.00	6.11	160.00	23.36	0.62
Wet Relaxed	21.18	8.09	8.57	3.27	181.51	26.46	2.46
Tumble Dry	24.83	9.48	9.41	3.59	233.67	34.07	2.63
½ hr. Cubex	42.53	16.25	15.73	6.01	669.24	97.58	2.70
1 hr. Cubex	50.70	19.36	18.66	7.13	946.27	137.97	2.71
1½ hrs. Cubex	57.14	21.82	20.98	8.01	1198.80	174.78	2.72
2 hrs. Cubex	58.06	22.17	23.76	9.07	1379.75	201.17	2.44

SAMPLE 65

Count: 2/48 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.246$ $\ell^2 = 0.060$ $\frac{1}{\ell} = 4.068$ $\frac{1}{\ell^2} = 16.556$ $\ell\sqrt{N} = 1.204$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	17.00	4.18	16.00	3.94	272.00	16.32	1.06
Wet Relaxed	36.00	8.85	13.19	3.24	474.72	28.67	2.72
Tumble Dry	36.92	9.08	14.12	3.47	521.26	31.48	2.61
½ hr. Cubex	47.00	11.55	18.18	4.47	854.50	51.61	2.58
1 hr. Cubex	54.54	13.41	21.82	5.36	1190.08	71.88	2.49
1½ hrs. Cubex	60.91	14.97	23.62	5.81	1438.90	86.91	2.57
2 hrs. Cubex	64.29	15.80	25.81	6.34	1658.98	100.20	2.49

SAMPLE 66

Count: 2/48 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.196$ $\ell^2 = 0.038$ $\frac{1}{\ell} = 5.106$ $\frac{1}{\ell^2} = 26.110$ $\ell\sqrt{N} = 0.959$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	26.00	5.10	16.00	3.14	416.00	15.81	1.62
Wet Relaxed	48.98	9.59	16.00	3.13	783.67	30.01	3.06
Tumble Dry	46.45	9.09	16.55	3.24	768.85	29.45	2.80
½ hr. Cubex	49.65	9.72	19.58	3.83	972.04	37.23	2.53
1 hr. Cubex	53.73	10.52	21.11	4.13	1134.17	43.44	2.54
1½ hrs. Cubex	60.00	11.75	23.08	4.52	1384.61	53.03	2.59
2 hrs. Cubex	64.29	12.59	25.92	5.07	1666.15	63.81	2.48

SAMPLE 67

Count: 2/48 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.175$ $\ell^2 = 0.031$ $\frac{1}{\ell} = 5.714$ $\frac{1}{\ell^2} = 32.68$ $\ell\sqrt{N} = 0.857$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	32.00	5.60	16.00	2.80	512.00	15.87	2.00
Wet Relaxed	53.33	9.33	17.45	3.05	930.91	28.49	3.05
Tumble Dry	51.43	9.00	18.46	3.23	949.45	29.05	2.78
½ hr. Cubex	54.96	9.62	20.51	3.59	1127.42	34.50	2.67
1 hr. Cubex	58.06	10.16	21.62	3.78	1255.44	38.44	2.68
1½ hrs. Cubex	60.91	10.66	23.39	4.09	1424.88	43.60	2.60
2 hrs. Cubex	65.45	11.45	25.00	4.37	1636.36	50.07	2.61

SAMPLE 68

Count: 2/48 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.163$ $\ell^2 = 0.027$ $\frac{1}{\ell} = 6.128$ $\frac{1}{\ell^2} = 37.594$ $\ell\sqrt{N} = 0.800$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	40.00	6.52	16.00	2.61	640.00	17.28	2.50
Wet Relaxed	57.60	9.39	18.46	3.01	1063.39	28.29	3.11
Tumble Dry	57.60	9.39	19.20	3.13	1105.92	29.42	3.00
½ hr. Cubex	57.78	9.42	21.37	3.49	1234.94	32.85	2.70
1 hr. Cubex	58.73	9.58	22.09	3.59	1293.08	34.40	2.65
1½ hrs. Cubex	61.02	9.95	23.41	3.82	1428.69	38.03	2.60
2 hrs. Cubex	63.83	10.41	25.26	4.12	1612.54	42.89	2.52

SAMPLE 69

Count: 2/56 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.311$ $\ell^2 = 0.097$ $\frac{1}{\ell} = 3.208$ $\frac{1}{\ell^2} = 10.309$ $\ell\sqrt{N} = 1.645$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	12.00	3.73	16.00	4.98	192.00	18.62	0.75
Wet Relaxed	25.26	7.87	10.67	3.32	269.50	26.13	2.36
Tumble Dry	28.80	8.96	11.71	3.65	337.16	32.37	2.46
½ hr. Cubex	56.25	17.53	21.64	6.74	1217.31	118.08	2.79
1 hr. Cubex	63.16	19.68	25.32	7.89	1598.93	155.10	2.49
1½ hrs. Cubex	67.54	21.05	26.67	8.31	1801.12	174.71	2.53
2 hrs. Cubex	70.87	22.08	28.64	8.92	2029.58	196.87	2.47

SAMPLE 70

Count: 2/56 worsted Structure: 1 x 1 Closed Lap

$\ell = 0.219$ $\ell^2 = 0.048$ $\frac{1}{\ell} = 4.557$ $\frac{1}{\ell^2} = 20.79$ $\ell\sqrt{N} = 1.161$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	19.00	4.16	16.00	3.50	304.00	14.59	1.19
Wet Relaxed	37.89	8.31	13.91	3.05	527.23	25.36	2.72
Tumble Dry	40.00	8.78	15.24	3.34	609.52	29.32	2.62
½ hr. Cubex	57.78	12.68	21.47	4.71	1240.46	59.67	2.69
1 hr. Cubex	64.52	14.15	24.74	5.43	1596.27	76.78	2.60
1½ hrs. Cubex	69.23	15.19	26.08	5.72	1806.01	86.87	2.65
2 hrs. Cubex	71.57	15.70	27.49	6.03	1967.57	94.64	2.60

SAMPLE 71

Count: 2/56 worsted **Structure:** 1 x 1 Closed Lap

$\ell = 0.181$ $\ell^2 = 0.033$ $\frac{1}{\ell} = 5.530$ $\frac{1}{\ell^2} = 30.675$ $\ell\sqrt{N} = 0.957$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	26.00	4.71	16.00	2.90	416.00	13.73	1.62
Wet Relaxed	50.00	9.04	16.33	2.95	816.32	26.61	3.06
Tumble Dry	48.00	8.68	17.45	3.16	837.82	27.31	2.74
½ hr. Cubex	56.25	10.17	21.58	3.90	1214.03	39.58	2.60
1 hr. Cubex	63.38	11.46	24.54	4.44	1555.34	50.70	2.58
1½ hrs. Cubex	70.59	12.76	26.67	4.82	1882.35	61.36	2.64
2 hrs. Cubex	72.58	13.12	28.23	5.10	2049.33	66.80	2.57

SAMPLE 72

Count: 2/56 worsted **Structure:** 1 x 1 Closed Lap

$\ell = 0.148$ $\ell^2 = 0.022$ $\frac{1}{\ell} = 6.779$ $\frac{1}{\ell^2} = 46.083$ $\ell\sqrt{N} = 0.780$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	36.00	5.33	16.00	2.37	576.00	12.67	2.25
Wet Relaxed	62.07	9.15	20.00	2.95	1241.38	26.94	3.10
Tumble Dry	59.02	8.70	20.57	3.07	1231.64	26.73	2.82
½ hr. Cubex	62.07	9.15	22.73	3.35	1410.65	30.61	2.73
1 hr. Cubex	66.67	9.83	24.90	3.67	1659.74	30.02	2.67
1½ hrs. Cubex	69.23	10.21	25.86	3.81	1790.44	38.85	2.67
2 hrs. Cubex	73.02	10.77	27.71	4.09	2023.71	43.91	2.63

SAMPLE 73

Count: 2/56 worsted

Structure: 1 x 1 Closed Lap

$\ell = 0.143$ $\ell^2 = 0.020$ $\frac{1}{\ell} = 7.017$ $\frac{1}{\ell^2} = 49.261$ $\ell\sqrt{N} = 0.754$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	44.00	6.29	16.00	2.29	704.00	14.08	2.75
Wet Relaxed	62.61	8.92	20.00	2.85	1252.17	25.42	3.13
Tumble Dry	62.61	8.92	20.43	2.91	1278.81	25.96	3.06
½ hr. Cubex	61.33	8.74	24.00	3.42	1471.89	29.88	2.55
1 hr. Cubex	66.18	9.43	24.74	3.53	1637.35	33.24	2.67
1½ hrs. Cubex	69.50	9.90	25.78	3.67	1791.57	36.37	2.69
2 hrs. Cubex	71.57	10.99	27.71	3.95	1983.48	40.26	2.58

SAMPLE

Count:

Structure: 1 x 1 Closed Lap

$\ell =$ $\ell^2 =$ $\frac{1}{\ell} =$ $\frac{1}{\ell^2} =$ $\ell\sqrt{N} =$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine							
Wet Relaxed							
Tumble Dry							
½ hr. Cubex							
1 hr. Cubex							
1½ hrs. Cubex							
2 hrs. Cubex							

APPENDIX THREE

SAMPLE 74

Count: 1/12 Worsted Structure: 2x1 Closed Lap

$\ell = 0.442$ $\ell^2 = 0.1950$ $\frac{1}{\ell} = 2.262$ $\frac{1}{\ell^2} = 5.12$ $\ell\sqrt{N} = 1.531$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.0	4.42	16.0	7.07	160	31.2	0.62
Dry Relaxed	14.3	6.31	10.9	4.81	155	30.3	1.31
Wet Relaxed	13.6	6.00	12.6	5.57	171	33.4	1.08
Tumble Dry	17.1	7.58	14.0	6.12	240	47.0	1.22

SAMPLE 75

Count: 1/12 Worsted Structure: 2x1 Closed Lap

$\ell = 0.313$ $\ell^2 = 0.0979$ $\frac{1}{\ell} = 3.195$ $\frac{1}{\ell^2} = 10.22$ $\ell\sqrt{N} = 1.084$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	17.0	5.32	16.0	5.00	272	26.4	1.06
Dry Relaxed	20.1	6.29	15.7	4.91	318	30.9	1.28
Wet Relaxed	20.4	6.40	17.3	5.41	353	34.6	1.18
Tumble Dry	23.8	7.46	18.6	5.82	443	43.4	1.28

SAMPLE 76

Count: 1/12 Worsted Structure: 2x1 Closed Lap

$\ell = 0.264$ $\ell^2 = 0.0696$ $\frac{1}{\ell} = 3.788$ $\frac{1}{\ell^2} = 14.36$ $\ell\sqrt{N} = 0.914$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	25.0	6.60	16.0	4.22	400	27.6	1.56
Dry Relaxed	26.5	6.99	17.8	4.69	470	32.8	1.49
Wet Relaxed	25.7	6.79	19.1	5.21	507	35.3	1.30
Tumble Dry	28.3	7.48	21.6	5.71	612	42.7	1.30

SAMPLE 77

Count: 2/32 Worsted Structure: 2x1 Closed Lap

$\ell = 0.402$ $\ell^2 = 0.1616$ $\frac{1}{\ell} = 2.49$ $\frac{1}{\ell^2} = 6.18$ $\ell\sqrt{N} = 1.608$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	3.62	16.0	6.43	144	23.2	0.56
Dry Relaxed	17.3	6.07	11.0	4.43	191	30.9	1.57
Wet Relaxed	16.7	6.71	14.5	5.84	243	39.3	1.14
Tumble Dry	19.2	7.72	16.2	6.49	311	50.2	1.19

SAMPLE 78

Count: 2/32 Worsted Structure: 2x1 Closed Lap

$\ell = 0.272$ $\ell^2 = 0.0739$ $\frac{1}{\ell} = 3.68$ $\frac{1}{\ell^2} = 13.53$ $\ell\sqrt{N} = 1.088$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	22.0	5.98	16.0	4.35	352	25.7	1.38
Dry Relaxed	25.3	6.87	17.3	4.70	436	32.3	1.46
Wet Relaxed	25.3	6.87	20.2	5.50	514	38.0	1.25
Tumble Dry	27.5	7.47	22.2	6.04	611	45.1	1.24

SAMPLE 79

Count: 2/32 Worsted Structure: 2x1 Closed Lap

$\ell = 0.244$ $\ell^2 = 0.0595$ $\frac{1}{\ell} = 4.10$ $\frac{1}{\ell^2} = 16.80$ $\ell\sqrt{N} = 0.976$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.0	7.32	16.0	3.90	480	28.3	1.88
Dry Relaxed	31.0	7.57	18.6	4.53	511	34.3	1.67
Wet Relaxed	29.4	7.17	22.1	5.38	647	38.5	1.33
Tumble Dry	31.3	9.64	24.2	5.91	758	45.1	1.29

SAMPLE 80

Count: 1/20 Worsted Structure: 2x1 Closed Lap

$\ell = 0.416$ $\ell^2 = 0.1730$ $\frac{1}{\ell} = 2.40$ $\frac{1}{\ell^2} = 5.78$ $\ell\sqrt{N} = 1.860$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.0	4.16	16.0	6.66	160	27.7	0.63
Dry Relaxed	16.7	6.93	10.5	4.35	174	30.1	1.59
Wet Relaxed	15.3	6.40	14.5	6.05	223	38.6	1.05
Tumble Dry	18.2	7.56	14.4	5.99	262	45.3	1.26

SAMPLE 81

Count: 1/20 Worsted Structure: 2x1 Closed Lap

$\ell = 0.287$ $\ell^2 = 0.0823$ $\frac{1}{\ell} = 3.48$ $\frac{1}{\ell^2} = 12.15$ $\ell\sqrt{N} = 1.283$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	17.0	4.88	16.0	4.59	272	22.3	1.06
Dry Relaxed	23.1	6.62	15.5	4.46	358	29.5	1.49
Wet Relaxed	22.5	6.45	18.3	5.24	412	33.9	1.23
Tumble Dry	25.0	7.17	19.7	5.66	493	40.6	1.27

SAMPLE 82

Count: 1/20 Worsted Structure: 2x1 Closed Lap

$\ell = 0.236$ $\ell^2 = 0.055$ $\frac{1}{\ell} = 4.24$ $\frac{1}{\ell^2} = 17.98$ $\ell\sqrt{N} = 1.055$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.0	7.08	16.0	3.78	480	26.4	1.88
Dry Relaxed	29.3	6.91	19.0	4.49	557	31.0	1.54
Wet Relaxed	28.8	6.79	20.6	4.87	596	33.1	1.40
Tumble Dry	30.2	7.14	23.2	5.47	703	39.1	1.30

SAMPLE 83

Count: 2/48 Worsted Structure: 2x1 Closed Lap

$\ell = 0.377$ $\ell^2 = 0.1421$ $\frac{1}{\ell} = 2.65$ $\frac{1}{\ell^2} = 7.03$ $\ell\sqrt{N} = 1.847$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.0	3.77	16.0	6.03	160	22.7	0.63
Dry Relaxed	15.1	5.70	13.8	4.82	193	27.5	1.18
Wet Relaxed	17.1	6.46	14.9	5.60	255	36.2	1.15
Tumble Dry	19.3	7.30	17.2	6.48	334	47.5	1.13

SAMPLE 84

Count: 2/48 Worsted Structure: 2x1 Closed Lap

$\ell = 0.259$ $\ell^2 = 0.0670$ $\frac{1}{\ell} = 3.86$ $\frac{1}{\ell^2} = 14.92$ $\ell\sqrt{N} = 1.269$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	27.0	6.99	16.0	4.14	432	28.9	1.69
Dry Relaxed	24.2	6.26	17.8	4.60	429	22.7	1.36
Wet Relaxed	25.3	6.56	22.1	5.71	561	37.6	1.15
Tumble Dry	29.3	7.58	23.5	6.09	689	46.2	1.24

SAMPLE 85

Count: 2/48 Worsted Structure: 2x1 Closed Lap

$\ell = 0.233$ $\ell^2 = 0.0542$ $\frac{1}{\ell} = 4.29$ $\frac{1}{\ell^2} = 18.45$ $\ell\sqrt{N} = 1.141$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	22.0	5.13	16.0	3.73	352	19.0	1.38
Dry Relaxed	29.5	6.87	19.5	4.55	575	31.2	1.51
Wet Relaxed	28.2	6.57	22.9	5.32	646	35.0	1.24
Tumble Dry	31.3	7.29	25.4	5.91	795	43.1	1.23

SAMPLE 86

Count: 1/12 Worsted Structure: 3x1 Closed Lap

$\ell = 0.478$ $\ell^2 = 0.2284$ $\frac{1}{\ell} = 2.092$ $\frac{1}{\ell^2} = 4.37$ $\ell\sqrt{N} = 1.656$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	4.30	16.0	7.65	144	32.8	0.56
Dry Relaxed	14.2	6.80	13.4	6.45	191	91.5	1.06
Wet Relaxed	13.0	6.24	15.7	7.50	204	97.8	0.83
Tumble Dry	16.4	7.86	17.2	8.22	282	64.2	0.96

SAMPLE 87

Count: 1/12 Worsted Structure: 3x1 Closed Lap

$\ell = 0.356$ $\ell^2 = 0.1267$ $\frac{1}{\ell} = 2.809$ $\frac{1}{\ell^2} = 7.89$ $\ell\sqrt{N} = 1.233$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.0	7.12	16.0	5.70	320	40.3	1.25
Dry Relaxed	19.6	7.00	17.6	6.26	345	43.8	1.12
Wet Relaxed	18.8	6.71	19.7	7.03	372	47.2	0.95
Tumble Dry	21.8	7.77	21.9	7.80	478.3	60.6	1.00

SAMPLE 88

Count: 1/12 Worsted Structure: 3x1 Closed Lap

$\ell = 0.325$ $\ell^2 = 0.1056$ $\frac{1}{\ell} = 3.077$ $\frac{1}{\ell^2} = 9.46$ $\ell\sqrt{N} = 1.126$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	25.0	8.13	16.0	5.20	400	42.0	1.56
Dry Relaxed	23.4	7.60	19.4	6.30	453	47.9	1.21
Wet Relaxed	21.1	6.86	21.9	7.12	462	48.8	0.96
Tumble Dry	24.0	7.80	23.7	7.72	568	60.1	1.01

SAMPLE 89

Count: 2/32 Worsted Structure: 3x1 Closed Lap

$\ell = 0.480$ $\ell^2 = 0.2304$ $\frac{1}{\ell} = 2.08$ $\frac{1}{\ell^2} = 4.34$ $\ell\sqrt{N} = 1.92$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	8.00	3.84	16.0	7.68	128	29.4	0.50
Dry Relaxed	14.5	6.98	13.3	6.30	193	44.5	1.09
Wet Relaxed	13.6	6.51	16.8	8.08	229	52.8	0.81
Tumble Dry	15.9	7.65	18.1	8.72	289	66.5	0.88

SAMPLE 90

Count: 2/32 Worsted Structure: 3x1 Closed Lap

$\ell = 0.355$ $\ell^2 = 0.1260$ $\frac{1}{\ell} = 2.82$ $\frac{1}{\ell^2} = 7.93$ $\ell\sqrt{N} = 1.42$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	6.39	16.0	5.68	288	36.3	1.13
Dry Relaxed	20.0	7.10	18.2	6.45	363	45.8	1.10
Wet Relaxed	19.5	6.90	21.3	7.57	415	52.3	0.91
Tumble Dry	22.1	7.86	23.2	8.23	515	64.9	0.96

SAMPLE 91

Count: 2/32 Worsted Structure: 3x1 Closed Lap

$\ell = 0.313$ $\ell^2 = 0.0979$ $\frac{1}{\ell} = 3.20$ $\frac{1}{\ell^2} = 10.21$ $\ell\sqrt{N} = 1.252$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.0	9.39	16.0	5.01	480	46.6	1.88
Dry Relaxed	23.4	7.32	20.3	6.34	474	46.4	1.15
Wet Relaxed	22.8	7.13	23.7	7.41	540	52.9	0.96
Tumble Dry	25.5	7.99	25.8	8.07	657	64.3	0.99

SAMPLE 92

Count: 1/20 Worsted Structure: 3x1 Closed Lap

$\ell = 0.448$ $\ell^2 = 0.2007$ $\frac{1}{\ell} = 2.23$ $\frac{1}{\ell^2} = 4.98$ $\ell\sqrt{N} = 2.003$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	4.03	16.0	7.17	144	28.8	0.56
Dry Relaxed	14.9	6.69	13.4	6.02	201	40.3	1.11
Wet Relaxed	13.9	6.22	17.3	7.75	240	48.2	0.80
Tumble Dry	16.1	7.19	18.4	8.23	296	59.4	0.87

SAMPLE 93

Count: 1/20 Worsted Structure: 3x1 Closed Lap

$\ell = 0.327$ $\ell^2 = 0.1069$ $\frac{1}{\ell} = 3.06$ $\frac{1}{\ell^2} = 9.35$ $\ell\sqrt{N} = 1.462$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.0	6.54	16.0	5.23	320	33.9	1.25
Dry Relaxed	21.2	6.92	17.8	5.81	376	40.0	1.20
Wet Relaxed	20.3	6.63	22.1	7.21	449	48.0	0.92
Tumble Dry	22.7	7.40	23.2	7.57	524	56.0	0.98

SAMPLE 94

Count: 1/20 Worsted Structure: 3x1 Closed Lap

$\ell = 0.259$ $\ell^2 = 0.0670$ $\frac{1}{\ell} = 3.86$ $\frac{1}{\ell^2} = 14.92$ $\ell\sqrt{N} = 1.158$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.0	7.77	16.0	4.14	480	32.2	1.88
Dry Relaxed	25.5	6.61	20.8	5.33	530	35.5	1.23
Wet Relaxed	23.6	6.11	24.6	6.37	581	38.9	0.96
Tumble Dry	26.9	6.95	26.2	6.79	705	47.2	1.02

SAMPLE 95

Count: 2/48 Worsted Structure: 3x1 Closed Lap

$\ell = 0.425$ $\ell^2 = 0.1806$ $\frac{1}{\ell} = 2.35$ $\frac{1}{\ell^2} = 5.53$ $\ell\sqrt{N} = 2.082$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	3.83	16.0	6.80	144	25.9	0.56
Dry Relaxed	14.8	6.31	14.7	6.04	207	39.3	1.01
Wet Relaxed	15.0	6.37	20.0	8.50	300	54.2	0.75
Tumble Dry	17.6	7.46	21.9	9.31	387	69.9	0.80

SAMPLE 96

Count: 2/48 Worsted Structure: 3x1 Closed Lap

$\ell = 0.283$ $\ell^2 = 0.0800$ $\frac{1}{\ell} = 3.53$ $\frac{1}{\ell^2} = 12.5$ $\ell\sqrt{N} = 1.386$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.0	5.66	16.0	4.53	320	25.6	1.25
Dry Relaxed	26.2	7.41	20.5	5.81	536	42.9	1.28
Wet Relaxed	25.7	7.27	26.7	7.54	686	54.9	0.96
Tumble Dry	28.6	8.09	29.1	8.23	829	66.3	0.98

SAMPLE 97

Count: 2/48 Worsted Structure: 3x1 Closed Lap

$\ell = 0.279$ $\ell^2 = 0.0778$ $\frac{1}{\ell} = 3.58$ $\frac{1}{\ell^2} = 12.85$ $\ell\sqrt{N} = 1.367$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.0	8.37	16.0	4.46	480	37.0	1.88
Dry Relaxed	26.3	7.33	21.6	6.03	568	44.2	1.22
Wet Relaxed	24.7	6.88	26.0	7.25	642	49.9	0.95
Tumble Dry	27.7	7.73	29.1	8.11	806	62.7	0.95

SAMPLE 98

Count: 1/12 Worsted Structure: 4x1 Closed Lap

$\ell = 0.519$ $\ell^2 = 0.2693$ $\frac{1}{\ell} = 1.927$ $\frac{1}{\ell^2} = 3.71$ $\ell\sqrt{N} = 1.789$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	4.67	16.0	8.30	144	38.7	0.56
Dry Relaxed	12.6	6.56	15.5	8.00	196	52.8	0.81
Wet Relaxed	12.5	6.49	17.9	9.28	223	60.3	0.70
Tumble Dry	14.9	7.72	20.4	10.6	303	81.7	0.73

SAMPLE 99

Count: 1/12 Worsted Structure: 4x1 Closed Lap

$\ell = 0.419$ $\ell^2 = 0.1755$ $\frac{1}{\ell} = 2.387$ $\frac{1}{\ell^2} = 5.69$ $\ell\sqrt{N} = 1.451$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	15.0	6.29	16.0	6.70	240	42.0	0.94
Dry Relaxed	17.0	7.12	19.0	7.98	323	56.8	0.89
Wet Relaxed	15.4	6.47	22.9	9.58	353	62.0	0.66
Tumble Dry	19.5	8.15	24.2	10.2	471	82.8	0.80

SAMPLE 100

Count: 1/12 Worsted Structure: 4x1 Closed Lap

$\ell = 0.381$ $\ell^2 = 0.1451$ $\frac{1}{\ell} = 2.625$ $\frac{1}{\ell^2} = 6.89$ $\ell\sqrt{N} = 1.320$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.0	7.62	16.0	6.09	320	46.4	1.25
Dry Relaxed	20.3	7.75	20.0	7.62	406	59.0	1.02
Wet Relaxed	19.0	7.26	22.5	8.59	429	62.3	0.85
Tumble Dry	21.2	8.07	25.6	9.75	541	78.7	0.83

SAMPLE 101

Count: 2/32 Worsted Structure: 4x1 Closed Lap

$\ell = 0.516$ $\ell^2 = 0.2662$ $\frac{1}{\ell} = 1.94$ $\frac{1}{\ell^2} = 3.75$ $\ell\sqrt{N} = 2.064$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	4.64	16.0	8.26	144	38.3	0.56
Dry Relaxed	13.3	6.85	15.8	8.17	210	56.0	0.84
Wet Relaxed	12.5	6.46	20.0	10.3	250	66.5	0.63
Tumble Dry	15.1	7.77	21.9	11.3	331	88.1	0.69

SAMPLE 102

Count: 2/32 Worsted Structure: 4x1 Closed Lap

$\ell = 0.430$ $\ell^2 = 0.1849$ $\frac{1}{\ell} = 2.33$ $\frac{1}{\ell^2} = 5.40$ $\ell\sqrt{N} = 1.720$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	15.0	6.45	16.0	6.88	240	44.4	0.94
Dry Relaxed	15.7	6.76	19.3	8.29	302	56.0	0.82
Wet Relaxed	15.5	6.65	22.1	9.49	343	63.4	0.70
Tumble Dry	18.3	7.88	24.6	10.6	450	83.2	0.74

SAMPLE 103

Count: 2/32 Worsted Structure: 4x1 Closed Lap

$\ell = 0.369$ $\ell^2 = 0.1361$ $\frac{1}{\ell} = 2.71$ $\frac{1}{\ell^2} = 7.34$ $\ell\sqrt{N} = 1.476$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	22.0	8.12	16.0	5.90	352	47.9	1.38
Dry Relaxed	20.6	7.59	20.5	7.59	421	57.3	1.00
Wet Relaxed	19.2	7.08	25.6	9.44	492	67.0	0.75
Tumble Dry	21.8	8.05	28.1	10.3	603	83.4	0.78

SAMPLE 104

Count: 1/20 Worsted Structure: 4x1 Closed Lap

$\ell = 0.497$ $\ell^2 = 0.2470$ $\frac{1}{\ell} = 2.01$ $\frac{1}{\ell^2} = 4.04$ $\ell\sqrt{N} = 2.223$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	4.47	16.0	7.95	144	35.6	0.56
Dry Relaxed	13.3	6.63	16.0	7.95	213	52.7	0.83
Wet Relaxed	12.1	6.01	20.6	10.3	250	61.7	0.59
Tumble Dry	14.5	7.21	21.9	10.9	318	78.5	0.66

SAMPLE 105

Count: 1/20 Worsted Structure: 4x1 Closed Lap

$\ell = 0.386$ $\ell^2 = 0.1490$ $\frac{1}{\ell} = 2.59$ $\frac{1}{\ell^2} = 6.71$ $\ell\sqrt{N} = 1.726$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.0	7.72	16.0	6.18	320	47.7	1.25
Dry Relaxed	18.7	7.24	19.5	7.53	366	54.4	0.96
Wet Relaxed	17.1	6.61	24.6	9.50	421	62.7	0.70
Tumble Dry	20.0	7.72	25.8	9.96	516	76.8	0.77

SAMPLE 106

Count: 1/20 Worsted Structure: 4x1 Closed Lap

$\ell = 0.355$ $\ell^2 = 0.1260$ $\frac{1}{\ell} = 2.82$ $\frac{1}{\ell^2} = 7.93$ $\ell\sqrt{N} = 1.588$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	25.0	8.88	16.0	5.68	400	50.4	
Dry Relaxed	21.9	7.79	21.0	7.47	462	58.2	1.04
Wet Relaxed	20.6	7.30	25.6	9.08	527	66.4	0.80
Tumble Dry	22.4	7.94	27.8	9.87	623	78.5	0.80

SAMPLE 107

Count: 2/48 Worsted Structure: 4x1 Closed Lap

$\ell = 0.473$ $\ell^2 = 0.2237$ $\frac{1}{\ell} = 2.11$ $\frac{1}{\ell^2} = 4.47$ $\ell\sqrt{N} = 2.317$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.0	4.73	16.0	7.57	160	35.8	0.63
Dry Relaxed	13.0	6.14	18.4	8.69	258	53.3	0.71
Wet Relaxed	13.3	6.30	22.4	10.6	298	66.7	0.60
Tumble Dry	16.1	7.73	24.2	11.5	390	87.2	0.67

SAMPLE 108

Count: 2/48 Worsted Structure: 4x1 Closed Lap

$\ell = 0.363$ $\ell^2 = 0.1317$ $\frac{1}{\ell} = 2.76$ $\frac{1}{\ell^2} = 7.59$ $\ell\sqrt{N} = 1.778$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	22.0	7.99	16.0	5.81	352	46.1	1.38
Dry Relaxed	19.3	7.02	21.9	7.96	424	55.8	0.90
Wet Relaxed	18.0	6.53	26.7	9.68	481	63.3	0.68
Tumble Dry	21.7	7.87	29.1	10.5	632	83.2	0.75

SAMPLE 109

Count: 2/48 Worsted Structure: 4x1 Closed Lap

$\ell = 0.355$ $\ell^2 = 0.1260$ $\frac{1}{\ell} = 2.82$ $\frac{1}{\ell^2} = 7.93$ $\ell\sqrt{N} = 1.739$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	28.0	9.94	16.0	5.68	448	56.4	1.75
Dry Relaxed	19.2	6.82	23.5	8.35	451	57.0	0.82
Wet Relaxed	18.0	6.39	27.8	9.87	500	63.0	0.65
Tumble Dry	22.2	7.89	30.2	10.7	670	84.4	0.74

SAMPLE 110

Count: 2/16 Worsted Structure: 1x1 Open Lap

$\ell = 0.393$ $\ell^2 = 0.154$ $\frac{1}{\ell} = 2.544$ $\frac{1}{\ell^2} = 6.49$ $\ell\sqrt{N} = 1.111$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.0	3.93	16.0	6.29	160	24.6	0.63
Dry Relaxed	18.0	7.07	8.00	3.14	144	22.2	2.25
Wet Relaxed	19.0	7.48	9.09	3.57	173	26.7	2.09
Tumble Dry	20.8	8.20	10.3	4.06	215	33.2	2.02

SAMPLE 111

Count: 2/16 Worsted Structure: 1x1 Open Lap

$\ell = 0.254$ $\ell^2 = 0.064$ $\frac{1}{\ell} = 3.934$ $\frac{1}{\ell^2} = 15.62$ $\ell\sqrt{N} = 0.718$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	4.57	16.0	4.06	288	18.4	1.13
Dry Relaxed	28.2	7.17	12.6	3.21	356	22.8	2.24
Wet Relaxed	31.3	7.95	14.5	3.69	455	29.1	2.15
Tumble Dry	31.3	7.95	15.7	3.40	492	31.5	1.99

SAMPLE 112

Count: 2/16 Worsted Structure: 1x1 Open Lap

$\ell = 0.209$ $\ell^2 = 0.044$ $\frac{1}{\ell} = 4.768$ $\frac{1}{\ell^2} = 22.78$ $\ell\sqrt{N} = 0.593$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	25.0	5.23	16.0	3.34	400	17.6	1.56
Dry Relaxed	35.1	7.36	16.0	3.35	561	24.7	2.20
Wet Relaxed	36.0	7.52	18.0	3.77	649	27.9	1.99
Tumble Dry	36.0	7.52	18.4	3.94	678	29.2	1.96

SAMPLE 113

Count: 2/32 Worsted　　Structure: 1x1 Open Lap

$\ell = 0.230$　$\ell^2 = 0.052$　$\frac{1}{\ell} = 4.337$　$\frac{1}{\ell^2} = 19.23$　$\ell\sqrt{N} = 0.920$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	4.14	16.0	3.68	288	15.0	1.13
Dry Relaxed	36.9	8.49	13.7	3.15	506	26.3	2.69
Wet Relaxed	35.3	8.12	17.1	3.94	605	31.5	2.06
Tumble Dry	34.9	8.04	18.7	4.31	655	34.1	1.90

SAMPLE 114

Count: 2/32 Worsted　　Structure: 1x1 Open Lap

$\ell = 0.158$　$\ell^2 = 0.024$　$\frac{1}{\ell} = 6.315$　$\frac{1}{\ell^2} = 41.67$　$\ell\sqrt{N} = 0.632$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	34.0	5.37	16.0	2.53	544	13.1	2.13
Dry Relaxed	51.4	8.12	20.9	3.30	1073	25.7	2.46
Wet Relaxed	48.8	7.69	25.3	3.99	1228	29.5	1.93
Tumble Dry	49.3	7.79	26.7	4.22	1317	31.6	1.85

SAMPLE 115

Count: 2/32 Worsted　　Structure: 1x1 Open Lap

$\ell = 0.147$　$\ell^2 = 0.021$　$\frac{1}{\ell} = 6.792$　$\frac{1}{\ell^2} = 47.62$　$\ell\sqrt{N} = 0.588$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	45.0	6.62	16.0	2.35	720	15.1	2.81
Dry Relaxed	55.4	8.14	21.8	3.21	1208	25.4	2.54
Wet Relaxed	52.2	7.67	26.4	3.88	1357	28.9	1.98
Tumble Dry	52.4	7.70	27.5	4.04	1442	30.3	1.90

SAMPLE 116

Count: 2/48 Worsted Structure: 1x1 Open Lap

$\ell = 0.318$ $\ell^2 = 0.101$ $\frac{1}{\ell} = 3.144$ $\frac{1}{\ell^2} = 9.90$ $\ell\sqrt{N} = 1.557$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	11.0	3.50	16.0	5.09	176	17.8	0.69
Dry Relaxed	21.2	6.73	9.06	2.88	191	19.4	2.34
Wet Relaxed	24.0	7.63	11.4	3.63	274	27.7	2.10
Tumble Dry	26.7	8.48	13.7	4.36	365	36.9	1.95

SAMPLE 117

Count: 2/48 Worsted Structure: 1x1 Open Lap

$\ell = 0.227$ $\ell^2 = 0.051$ $\frac{1}{\ell} = 4.390$ $\frac{1}{\ell^2} = 19.61$ $\ell\sqrt{N} = 1.111$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	4.09	16.0	3.63	288	14.7	1.13
Dry Relaxed	32.7	7.43	12.8	2.90	418	21.4	2.56
Wet Relaxed	35.3	8.01	17.1	3.89	605	30.8	2.06
Tumble Dry	36.7	8.34	19.7	4.46	722	36.8	1.87

SAMPLE 118

Count: 2/48 Worsted Structure: 1x1 Open Lap

$\ell = 0.172$ $\ell^2 = 0.029$ $\frac{1}{\ell} = 5.806$ $\frac{1}{\ell^2} = 34.48$ $\ell\sqrt{N} = 0.842$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	27.0	4.64	16.0	2.75	432	12.5	1.69
Dry Relaxed	48.0	8.26	17.8	3.06	853	24.7	2.70
Wet Relaxed	46.7	8.04	23.1	3.97	1078	31.3	2.03
Tumble Dry	46.7	8.04	25.8	4.44	1206	35.0	1.81

SAMPLE 119

Count: 1/28 Worsted Structure: 1x1 Open Lap

$\ell = 0.344$ $\ell^2 = 0.118$ $\frac{1}{\ell} = 2.903$ $\frac{1}{\ell^2} = 0.118$ $\ell\sqrt{N} = 1.820$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.0	3.44	16.0	5.50	160	18.9	0.63
Dry Relaxed	24.0	8.26	8.27	2.85	198	23.4	2.90
Wet Relaxed	25.7	8.84	8.54	2.94	219	25.9	3.01
Tumble Dry	23.1	9.67	10.0	3.44	281	33.2	2.81

SAMPLE 120

Count: 1/28 Worsted Structure: 1x1 Open Lap

$\ell = 0.236$ $\ell^2 = 0.055$ $\frac{1}{\ell} = 4.235$ $\frac{1}{\ell^2} = 18.18$ $\ell\sqrt{N} = 1.248$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	4.25	16.0	3.78	288	15.8	1.13
Dry Relaxed	36.9	8.71	12.5	2.94	460	25.3	2.96
Wet Relaxed	34.0	8.01	14.8	3.50	503	27.7	2.29
Tumble Dry	36.7	8.67	16.0	3.78	587	32.3	2.30

SAMPLE 121

Count: 1/28 Worsted Structure: 1x1 Open Lap

$\ell = 0.155$ $\ell^2 = 0.024$ $\frac{1}{\ell} = 6.428$ $\frac{1}{\ell^2} = 41.67$ $\ell\sqrt{N} = 0.820$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	29.0	4.50	16.0	2.45	464	11.1	1.81
Dry Relaxed	49.6	7.70	18.5	2.86	916	22.0	2.69
Wet Relaxed	54.5	8.45	21.2	3.29	1158	27.8	2.57
Tumble Dry	53.3	8.27	24.0	3.72	1279	30.7	2.22

SAMPLE 122

Count: 2/16 Worsted Structure: 2x1 Open Lap

$\ell = 0.444$ $\ell^2 = 0.197$ $\frac{1}{\ell} = 2.250$ $\frac{1}{\ell^2} = 5.08$ $\ell\sqrt{N} = 1.255$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	4.00	16.0	7.10	144	28.4	0.56
Dry Relaxed	13.6	6.03	12.6	5.61	171	33.8	1.07
Wet Relaxed	16.0	7.10	14.1	6.27	225	44.3	1.13
Tumble Dry	18.0	7.99	15.3	6.82	276	54.5	1.17

SAMPLE 123

Count: 2/16 Worsted Structure: 2x1 Open Lap

$\ell = 0.319$ $\ell^2 = 0.101$ $\frac{1}{\ell} = 3.130$ $\frac{1}{\ell^2} = 9.90$ $\ell\sqrt{N} = 0.902$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	15.0	4.78	16.0	5.10	240	24.2	0.94
Dry Relaxed	20.0	6.38	16.5	5.28	331	33.4	1.21
Wet Relaxed	22.1	7.04	18.3	5.84	404	40.9	1.20
Tumble Dry	23.1	7.36	18.7	5.95	430	43.5	1.24

SAMPLE 124

Count: 2/16 Worsted Structure: 2x1 Open Lap

$\ell = 0.302$ $\ell^2 = 0.091$ $\frac{1}{\ell} = 3.302$ $\frac{1}{\ell^2} = 10.99$ $\ell\sqrt{N} = 0.854$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.0	6.04	16.0	4.83	320	29.1	1.25
Dry Relaxed	22.5	6.79	17.1	5.18	385	35.1	1.31
Wet Relaxed	24.5	7.39	19.5	5.89	477	43.5	1.25
Tumble Dry	25.4	7.66	20.2	6.09	511	46.6	1.26

SAMPLE 125

Count: 2/32 Worsted Structure: 2x1 Open Lap

$\ell = 0.261$ $\ell^2 = 0.068$ $\frac{1}{\ell} = 3.829$ $\frac{1}{\ell^2} = 14.70$ $\ell\sqrt{N} = 1.044$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	4.70	16.0	4.18	288	19.5	1.13
Dry Relaxed	24.4	6.37	20.0	5.22	488	33.2	1.22
Wet Relaxed	26.3	6.86	22.6	5.91	594	40.4	1.16
Tumble Dry	29.0	7.58	23.3	6.08	676	46.0	1.24

SAMPLE 126

Count: 2/32 Worsted Structure: 2x1 Open Lap

$\ell = 0.251$ $\ell^2 = 0.063$ $\frac{1}{\ell} = 3.977$ $\frac{1}{\ell^2} = 15.87$ $\ell\sqrt{N} = 1.004$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	36.0	9.04	16.0	4.02	576	36.3	2.25
Dry Relaxed	30.0	7.53	19.2	4.82	576	36.3	1.56
Wet Relaxed	29.5	7.41	22.6	5.68	668	42.1	1.30
Tumble Dry	31.3	7.86	22.9	5.76	718	45.2	1.36

SAMPLE 127

Count: 2/32 Worsted Structure: 2x1 Open Lap

$\ell = 0.237$ $\ell^2 = 0.056$ $\frac{1}{\ell} = 4.210$ $\frac{1}{\ell^2} = 17.86$ $\ell\sqrt{N} = 0.948$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	30.0	7.11	16.0	3.79	480	26.9	1.88
Dry Relaxed	30.6	7.26	20.0	4.74	612	34.3	1.53
Wet Relaxed	31.3	7.42	23.8	5.63	743	41.7	1.32
Tumble Dry	31.9	7.56	24.4	5.77	777	43.5	1.31

SAMPLE 128

Count: 2/48 Worsted Structure: 2x1 Open Lap

$\ell = 0.362$ $\ell^2 = 0.131$ $\frac{1}{\ell} = 2.758$ $\frac{1}{\ell^2} = 7.63$ $\ell\sqrt{N} = 1.773$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	11.0	3.98	16.0	5.79	176	23.1	0.69
Dry Relaxed	16.4	5.92	14.1	5.11	230	30.3	1.16
Wet Relaxed	19.0	6.89	16.7	6.03	317	41.6	1.14
Tumble Dry	22.1	7.99	18.9	6.84	417	54.7	1.17

SAMPLE 129

Count: 2/48 Worsted Structure: 2x1 Open Lap

$\ell = 0.261$ $\ell^2 = 0.068$ $\frac{1}{\ell} = 3.829$ $\frac{1}{\ell^2} = 14.70$ $\ell\sqrt{N} = 1.278$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	4.70	16.0	4.18	288	19.6	1.13
Dry Relaxed	23.2	6.06	21.8	5.69	506	34.4	1.06
Wet Relaxed	26.9	7.01	23.5	6.14	632	43.0	1.14
Tumble Dry	30.2	7.89	24.6	6.42	744	50.6	1.23

SAMPLE 130

Count: 2/48 Worsted Structure: 2x1 Open Lap

$\ell = 0.230$ $\ell^2 = 0.052$ $\frac{1}{\ell} = 4.337$ $\frac{1}{\ell^2} = 19.23$ $\ell\sqrt{N} = 1.126$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	25.0	5.75	16.0	3.68	400	20.8	1.56
Dry Relaxed	28.8	6.62	22.8	5.26	658	34.2	1.26
Wet Relaxed	31.6	7.26	26.1	6.00	823	42.8	1.21
Tumble Dry	34.6	7.96	27.9	6.42	965	50.2	1.24

SAMPLE 131

Count: 1/28 Worsted Structure: 2x1 Open Lap

$\ell = 0.377$ $\ell^2 = 0.142$ $\frac{1}{\ell} = 2.647$ $\frac{1}{\ell^2} = 7.04$ $\ell\sqrt{N} = 1.994$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.0	3.77	16.0	6.03	160	22.7	0.63
Dry Relaxed	15.3	5.77	13.3	5.03	204	29.0	1.15
Wet Relaxed	17.7	6.68	14.2	5.35	251	35.7	1.25
Tumble Dry	18.9	7.14	16.4	6.19	311	44.2	1.15

SAMPLE 132

Count: 1/28 Worsted Structure: 2x1 Open Lap

$\ell = 0.261$ $\ell^2 = 0.068$ $\frac{1}{\ell} = 3.829$ $\frac{1}{\ell^2} = 14.70$ $\ell\sqrt{N} = 1.380$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	17.0	4.44	16.0	4.17	272	18.5	1.06
Dry Relaxed	25.7	6.71	20.0	5.22	514	35.0	1.28
Wet Relaxed	27.5	7.17	20.2	5.26	554	37.7	1.36
Tumble Dry	29.7	7.76	22.2	5.80	661	44.9	1.34

SAMPLE 133

Count: 1/28 Worsted Structure: 2x1 Open Lap

$\ell = 0.208$ $\ell^2 = 0.043$ $\frac{1}{\ell} = 4.800$ $\frac{1}{\ell^2} = 23.25$ $\ell\sqrt{N} = 1.100$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	26.0	5.41	16.0	3.33	416	17.9	1.63
Dry Relaxed	32.7	6.81	22.8	4.75	748	32.2	1.43
Wet Relaxed	34.6	7.20	25.3	5.25	874	37.6	1.37
Tumble Dry	36.1	7.50	26.4	5.28	915	39.3	1.37

SAMPLE 134

Count: 2/16 Worsted Structure: 3x1 Open Lap

$\ell = 0.476$ $\ell^2 = 0.226$ $\frac{1}{\ell} = 2.099$ $\frac{1}{\ell^2} = 4.42$ $\ell\sqrt{N} = 1.346$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	9.00	4.28	16.0	7.61	144	32.5	0.56
Dry Relaxed	12.8	6.12	16.0	7.62	205	46.5	0.81
Wet Relaxed	15.4	7.32	16.9	8.04	260	58.8	0.91
Tumble Dry	16.5	6.90	17.5	8.35	254	57.4	0.83

SAMPLE 135

Count: 2/16 Worsted Structure: 3x1 Open Lap

$\ell = 0.383$ $\ell^2 = 0.147$ $\frac{1}{\ell} = 2.608$ $\frac{1}{\ell^2} = 6.81$ $\ell\sqrt{N} = 1.084$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	14.0	5.36	16.0	6.13	224	32.9	0.88
Dry Relaxed	17.6	6.73	18.5	7.08	324	47.6	0.95
Wet Relaxed	18.8	7.22	20.7	7.92	389	56.9	0.91
Tumble Dry	20.2	7.75	21.3	8.18	432	63.1	0.95

SAMPLE 136

Count: 2/16 Worsted Structure: 3x1 Open Lap

$\ell = 0.369$ $\ell^2 = 0.136$ $\frac{1}{\ell} = 2.706$ $\frac{1}{\ell^2} = 7.35$ $\ell\sqrt{N} = 1.043$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.0	7.38	16.0	5.90	320	43.5	1.25
Dry Relaxed	19.4	7.18	19.2	7.08	373	50.8	1.01
Wet Relaxed	20.1	7.42	21.8	8.05	438	59.7	0.92
Tumble Dry	21.2	7.81	22.0	8.12	466	63.4	0.96

SAMPLE 137

Count: 2/32 Worsted   Structure: 3x1 Open Lap

$\ell = 0.325$ $\ell^2 = 0.105$ $\frac{1}{\ell} = 3.076$ $\frac{1}{\ell^2} = 9.52$ $\ell\sqrt{N} = 1.300$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	5.85	16.0	5.20	288	30.2	1.12
Dry Relaxed	20.0	6.50	23.4	7.61	468	49.2	0.85
Wet Relaxed	22.8	7.40	26.1	8.48	594	62.4	0.87
Tumble Dry	25.2	8.18	25.0	8.14	630	66.2	1.00

SAMPLE 138

Count: 2/32 Worsted   Structure: 3x1 Open Lap

$\ell = 0.304$ $\ell^2 = 0.092$ $\frac{1}{\ell} = 3.287$ $\frac{1}{\ell^2} = 10.87$ $\ell\sqrt{N} = 1.216$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	33.0	10.0	16.0	4.86	528	48.6	2.06
Dry Relaxed	24.8	7.55	20.9	6.34	518	47.7	1.19
Wet Relaxed	24.5	7.44	25.3	7.68	618	56.9	0.97
Tumble Dry	25.9	7.88	25.5	7.76	662	60.9	1.02

SAMPLE 139

Count: 2/32 Worsted   Structure: 3x1 Open Lap

$\ell = 0.302$ $\ell^2 = 0.091$ $\frac{1}{\ell} = 3.302$ $\frac{1}{\ell^2} = 10.99$ $\ell\sqrt{N} = 1.208$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	28.0	8.46	16.0	4.83	448	40.8	1.75
Dry Relaxed	24.0	7.25	21.8	6.59	523	47.6	1.13
Wet Relaxed	23.2	7.01	25.8	7.79	599	54.5	0.90
Tumble Dry	25.5	7.71	24.5	7.39	625	56.9	1.04

SAMPLE 140

Count: 2/48 Worsted Structure: 3x1 Open Lap

$\ell = 0.391$ $\ell^2 = 0.152$ $\frac{1}{\ell} = 2.553$ $\frac{1}{\ell^2} = 6.58$ $\ell\sqrt{N} = 1.915$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	11.0	4.30	16.0	6.26	176	26.7	0.69
Dry Relaxed	13.3	5.21	20.0	7.82	266	40.5	0.67
Wet Relaxed	16.7	6.55	23.1	9.02	386	58.7	0.73
Tumble Dry	19.9	7.78	23.3	9.11	463	70.4	0.85

SAMPLE 141

Count: 2/48 Worsted Structure: 3x1 Open Lap

$\ell = 0.305$ $\ell^2 = 0.093$ $\frac{1}{\ell} = 3.272$ $\frac{1}{\ell^2} = 10.75$ $\ell\sqrt{N} = 1.493$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	5.49	16.0	4.88	288	26.8	1.13
Dry Relaxed	20.6	6.27	24.0	7.32	493	45.9	0.86
Wet Relaxed	22.6	6.90	27.6	8.41	624	58.1	0.82
Tumble Dry	26.7	8.13	28.2	8.61	752	70.0	0.94

SAMPLE 142

Count: 2/48 Worsted Structure: 3x1 Open Lap

$\ell = 0.293$ $\ell^2 = 0.085$ $\frac{1}{\ell} = 3.412$ $\frac{1}{\ell^2} = 11.76$ $\ell\sqrt{N} = 1.435$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	25.0	7.33	16.0	4.69	400	34.0	1.56
Dry Relaxed	22.5	6.59	24.0	7.03	540	45.9	0.94
Wet Relaxed	24.3	7.13	27.9	8.18	678	57.7	0.87
Tumble Dry	26.4	7.70	27.9	8.18	733	62.3	0.95

SAMPLE 143

Count: 1/28 Worsted Structure: 3x1 Open Lap

$\ell = 0.422$ $\ell^2 = 0.178$ $\frac{1}{\ell} = 2.368$ $\frac{1}{\ell^2} = 5.62$ $\ell\sqrt{N} = 2.232$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.0	4.22	16.0	6.75	160	28.5	0.63
Dry Relaxed	13.8	5.84	17.1	7.23	237	42.2	0.81
Wet Relaxed	17.3	7.30	17.8	7.50	307	54.8	0.97
Tumble Dry	18.2	7.67	19.9	8.39	361	64.3	0.91

SAMPLE 144

Count: 1/28 Worsted Structure: 3x1 Open Lap

$\ell = 0.308$ $\ell^2 = 0.094$ $\frac{1}{\ell} = 3.243$ $\frac{1}{\ell^2} = 10.64$ $\ell\sqrt{N} = 1.629$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	17.0	5.24	16.0	4.93	272	25.6	1.06
Dry Relaxed	20.9	6.43	22.8	7.04	477	44.8	0.92
Wet Relaxed	23.7	7.29	25.0	7.70	592	55.6	0.95
Tumble Dry	25.9	7.97	26.5	8.18	687	64.6	0.97

SAMPLE 145

Count: 1/28 Worsted Structure: 3x1 Open Lap

$\ell = 0.272$ $\ell^2 = 0.073$ $\frac{1}{\ell} = 3.673$ $\frac{1}{\ell^2} = 13.70$ $\ell\sqrt{N} = 1.439$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	26.0	7.02	16.0	4.35	416	30.4	1.63
Dry Relaxed	24.0	6.53	22.8	6.22	548	40.0	1.05
Wet Relaxed	25.2	6.85	26.7	7.25	671	49.0	0.95
Tumble Dry	27.9	7.59	27.6	7.50	769	56.2	1.01

SAMPLE 146

Count: 2/16 Worsted Structure: 4x1 Open Lap

$\ell = 0.519$ $\ell^2 = 0.269$ $\frac{1}{\ell} = 1.925$ $\frac{1}{\ell^2} = 3.72$ $\ell\sqrt{N} = 1.467$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	10.0	5.19	16.0	8.30	160	43.0	0.63
Dry Relaxed	12.1	6.28	18.5	9.58	223	60.1	0.66
Wet Relaxed	14.0	7.27	20.0	10.4	280	75.3	0.70
Tumble Dry	15.4	8.02	20.5	10.6	316	85.2	0.75

SAMPLE 147

Count: 2/16 Worsted Structure: 4x1 Open Lap

$\ell = 0.451$ $\ell^2 = 0.203$ $\frac{1}{\ell} = 2.215$ $\frac{1}{\ell^2} = 4.93$ $\ell\sqrt{N} = 1.275$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	14.0	6.31	16.0	7.22	224	45.5	0.88
Dry Relaxed	16.0	7.22	19.2	8.61	307	62.4	0.83
Wet Relaxed	16.7	7.55	22.8	10.3	382	77.7	0.73
Tumble Dry	17.6	7.93	23.2	10.4	407	82.7	0.76

SAMPLE 148

Count: 2/16 Worsted Structure: 4x1 Open Lap

$\ell = 0.430$ $\ell^2 = 0.184$ $\frac{1}{\ell} = 2.322$ $\frac{1}{\ell^2} = 5.43$ $\ell\sqrt{N} = 1.216$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	20.0	8.60	16.0	6.88	320	58.9	1.25
Dry Relaxed	17.1	7.37	19.2	8.26	329	60.5	0.89
Wet Relaxed	17.8	7.66	23.3	10.0	415	76.4	0.77
Tumble Dry	18.6	8.01	23.3	10.0	435	80.0	0.80

SAMPLE 149

Count: 2/32 Worsted Structure: 4x1 Open Lap

$\ell = 0.438$ $\ell^2 = 0.191$ $\frac{1}{\ell} = 2.278$ $\frac{1}{\ell^2} = 5.23$ $\ell\sqrt{N} = 1.752$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	11.0	4.82	16.0	7.01	176	33.6	0.69
Dry Relaxed	13.6	5.95	22.8	10.0	310	59.3	0.59
Wet Relaxed	15.5	6.80	25.8	11.3	400	76.5	0.60
Tumble Dry	17.9	7.84	27.3	11.9	488	93.3	0.66

SAMPLE 150

Count: 2/32 Worsted Structure: 4x1 Open Lap

$\ell = 0.383$ $\ell^2 = 0.146$ $\frac{1}{\ell} = 2.608$ $\frac{1}{\ell^2} = 6.85$ $\ell\sqrt{N} = 1.532$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	25.0	9.58	16.0	6.13	400	58.4	1.56
Dry Relaxed	19.4	7.45	21.8	8.36	424	62.0	0.89
Wet Relaxed	19.8	7.57	27.3	10.4	539	78.7	0.73
Tumble Dry	21.2	8.11	27.0	10.3	571	83.4	0.78

SAMPLE 151

Count: 2/32 Worsted Structure: 4x1 Open Lap

$\ell = 0.381$ $\ell^2 = 0.145$ $\frac{1}{\ell} = 2.618$ $\frac{1}{\ell^2} = 6.90$ $\ell\sqrt{N} = 1.524$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	19.0	7.24	16.0	6.10	304	44.1	1.19
Dry Relaxed	17.6	6.69	24.0	9.14	421	61.1	0.73
Wet Relaxed	18.2	6.93	27.9	10.6	507	73.6	0.65
Tumble Dry	20.2	7.70	28.9	11.0	584	84.8	0.70

SAMPLE 152

Count: 2/48 Worsted Structure: 4x1 Open Lap

$\ell = 0.419$ $\ell^2 = 0.175$ $\frac{1}{\ell} = 2.384$ $\frac{1}{\ell^2} = 5.71$ $\ell\sqrt{N} = 2.052$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	11.0	4.61	16.0	6.70	176	30.8	0.69
Dry Relaxed	13.1	5.48	24.0	10.0	314	55.0	0.55
Wet Relaxed	16.0	6.70	27.6	11.5	441	77.2	0.58
Tumble Dry	19.1	8.02	26.2	11.8	540	94.6	0.73

SAMPLE 153

Count: 2/48 Worsted Structure: 4x1 Open Lap

$\ell = 0.365$ $\ell^2 = 0.133$ $\frac{1}{\ell} = 2.737$ $\frac{1}{\ell^2} = 7.52$ $\ell\sqrt{N} = 1.787$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	18.0	6.57	16.0	5.84	176	23.4	1.12
Dry Relaxed	17.1	6.26	25.3	9.22	433	57.6	0.68
Wet Relaxed	18.5	6.77	29.3	10.7	543	72.2	0.63
Tumble Dry	21.9	8.01	29.3	10.7	642	85.4	0.75

SAMPLE 154

Count: 2/48 Worsted Structure: 4x1 Open Lap

$\ell = 0.361$ $\ell^2 = 0.130$ $\frac{1}{\ell} = 2.769$ $\frac{1}{\ell^2} = 7.69$ $\ell\sqrt{N} = 1.768$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	29.0	10.5	16.0	5.78	464	60.3	1.81
Dry Relaxed	20.0	7.22	22.3	8.06	446	58.0	0.90
Wet Relaxed	20.0	7.22	28.6	10.3	571	74.3	0.70
Tumble Dry	22.8	8.22	28.9	10.4	658	85.6	0.79

SAMPLE 155

Count: 1/28 Worsted Structure: 4x1 Open Lap

$\ell = 0.455 \quad \ell^2 = 0.207 \quad \frac{1}{\ell} = 2.195 \quad \frac{1}{\ell^2} = 4.83 \quad \ell\sqrt{N} = 2.407$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	11.0	5.01	16.0	7.28	176	36.4	0.69
Dry Relaxed	12.4	5.65	20.9	9.49	259	53.6	0.60
Wet Relaxed	14.8	10.4	23.1	10.5	341	70.8	0.64
Tumble Dry	16.6	7.55	24.2	11.0	402	83.2	0.68

SAMPLE 156

Count: 1/28 Worsted Structure: 4x1 Open Lap

$\ell = 0.413 \quad \ell^2 = 0.170 \quad \frac{1}{\ell} = 2.416 \quad \frac{1}{\ell^2} = 5.88 \quad \ell\sqrt{N} = 2.185$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	11.0	4.54	16.0	6.61	176	29.9	1.69
Dry Relaxed	13.8	5.72	23.4	9.67	324	55.2	0.59
Wet Relaxed	15.6	6.44	26.7	11.0	415	70.6	0.58
Tumble Dry	18.1	7.47	26.7	11.4	501	85.2	0.68

SAMPLE 157

Count: 1/28 Worsted Structure: 4x1 Open Lap

$\ell = 0.355 \quad \ell^2 = 0.126 \quad \frac{1}{\ell} = 2.812 \quad \frac{1}{\ell^2} = 7.94 \quad \ell\sqrt{N} = 1.878$

Condition	c.p.i.	k_c	w.p.i.	k_w	S.D.	k_s	k_r
On Machine	19.0	6.75	16.0	5.68	304	38.3	1.19
Dry Relaxed	18.0	6.39	25.3	8.97	454	57.3	0.71
Wet Relaxed	18.7	6.66	28.9	10.3	542	68.3	0.65
Tumble Dry	21.7	7.70	29.4	10.4	637	80.4	0.74

APPENDIX FOUR

APPENDIX FOUR

REPEAT TEST 1 x 1 OPEN LAP TUMBLE DRY RESULTS

Count	ℓ	$\frac{1}{\ell}$	c.p.i.	kc	w.p.i.	kw	S	ks	kr
2/32	0.359	2.79	22.50	8.10	11.19	4.01	255	32.84	1.89
	0.219	4.57	33.44	7.35	20.33	4.45	731	35.01	1.65
	0.180	5.56	45.00	8.10	24.24	4.36	1027	33.27	1.86
1/20	0.336	2.98	21.80	7.30	10.39	3.49	251	28.43	2.10
	0.205	4.88	36.73	7.50	19.28	3.95	771	32.38	1.91
	0.154	6.49	46.75	7.20	26.23	4.03	1242	29.45	1.78
2/48	0.341	2.93	24.82	8.45	10.39	3.54	260	30.21	2.39
	0.152	6.58	48.64	7.40	26.23	3.98	1237	28.57	1.85
	0.129	7.75	57.14	8.00	28.57	3.68	1562	25.92	2.00
1/12	0.408	2.45	20.34	8.30	8.94	3.65	168	28.30	2.28
	0.255	3.92	30.20	7.71	15.33	3.92	465	30.19	1.96
	0.204	4.90	36.36	7.42	19.75	4.03	718	28.87	1.84

Regression Analysis of 1 x 1 Open Lap Repeat Test in the Tumble Dry Condition

Regression Equation	Standard Error		Standard deviation about Regression line	Corr. Coeff.	Student's t-test of intercept
	m	c			
c.p.i. = $\frac{7.029}{\ell} + 2.630$	0.410	1.781	1.432	0.988	n.s.
w.p.i. = $\frac{4.123}{\ell} + 0.761$	0.315	1.486	1.424	0.980	n.s.
$S = \frac{26.860}{\ell^2} + 70.25$	1.284	34.81	55.420	0.976	n.s.
$k_r = 1.522\ell + 1.586$	1.041	0.107	0.276	0.433	**

** significant at the 1 to 0.1% level

n.s. = not significantly different from zero

The intercept value for c.p.i. against $\frac{1}{\ell}$, w.p.i. against $\frac{1}{\ell}$ and S against $\frac{1}{\ell^2}$ are not significatnly different from zero. The values were, therefore, recalculated to pass through zero giving the following results -

$$\text{c.p.i.} = \frac{7.531}{\ell}$$

$$\text{w.p.i.} = \frac{3.969}{\ell}$$

$$S = \frac{28.86}{\ell^2}$$

It is shown in the following table that these values and that for the k_r are not different from the results obtained in Chapter VII and therefore may be combined to give the results as outlined in Chapter VIII.

Structure	Regression Equation	Variation about Regression line	Student's t-test Probability Slopes are same
Ch. VII	$\text{c.p.i.} = \frac{8.06}{\ell}$	0.0027	n.s.
Repeat Test	$\text{c.p.i.} = \frac{7.53}{\ell}$	0.0041	
Ch. VII	$\text{w.p.i.} = \frac{4.08}{\ell}$	0.0054	n.s.
Repeat Test	$\text{w.p.i.} = \frac{3.97}{\ell}$	0.0078	
Ch. VII	$S = \frac{32.50}{\ell^2}$	12.5800	n.s.
Repeat Test	$S = \frac{28.86}{\ell^2}$	13.6700	

Slope and Intercept Analysis k_r against

Slope Analysis

Construction	Slope	Standard error of slope	Variance of difference between slope	Student's t-test probability slopes are same
Chapter VII.	1.514	1.039	1.562	n.s.
Repeat test	1.522	1.041		

Intercept

Construction	Intercept	Standard error of Intercept	Variance of difference between Intercept	Student's t-test probability intercepts are same
Chapter VII.	1.690	0.103	0.284	n.s.
Repeat test	1.586	0.107		

n.s. = not significantly different from zero

APPENDIX FIVE

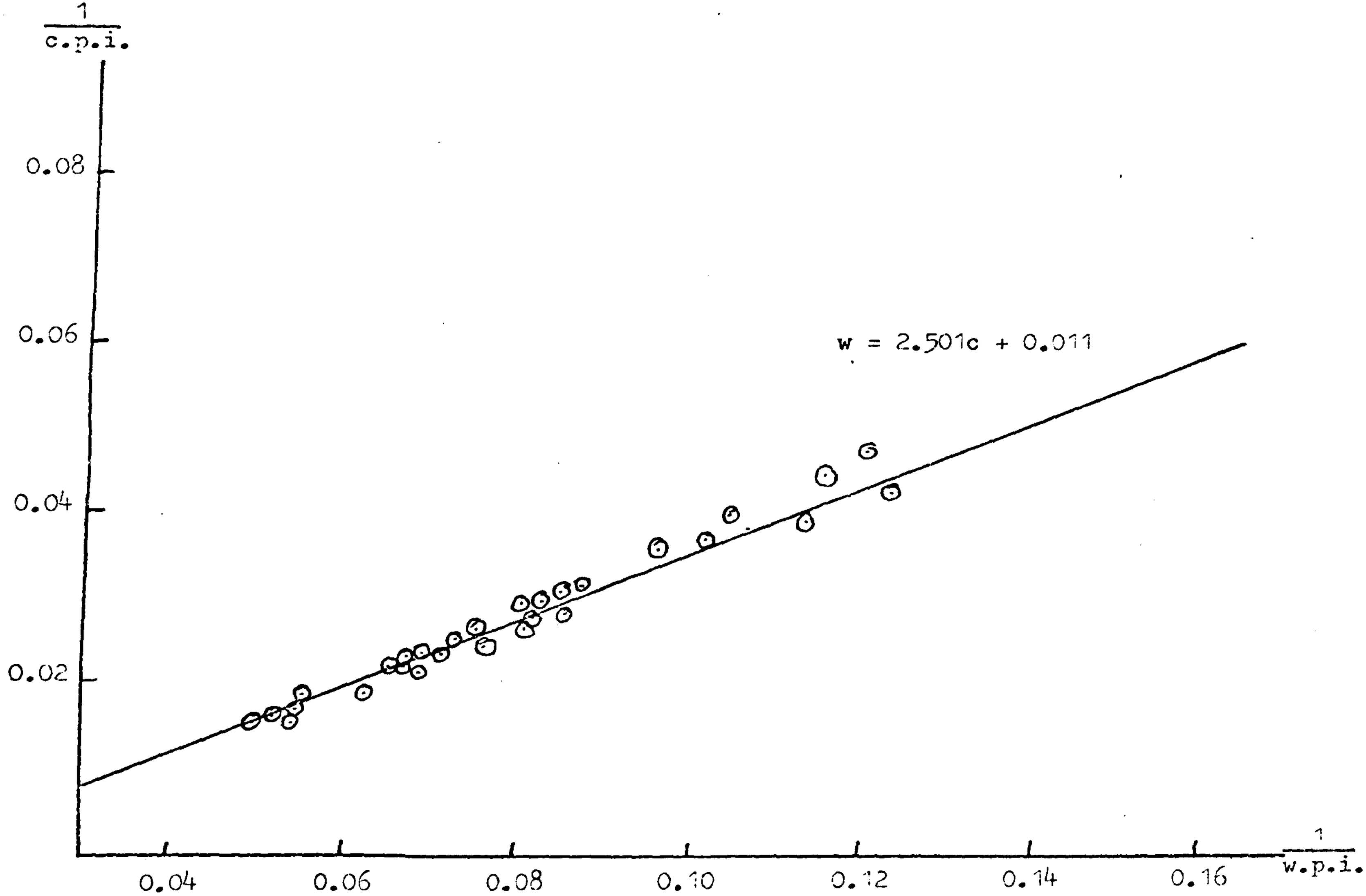


Fig. 107 Relationship between $\frac{1}{c.p.i.}$ and $\frac{1}{w.p.i.}$ for 1 x 1 Closed Lap

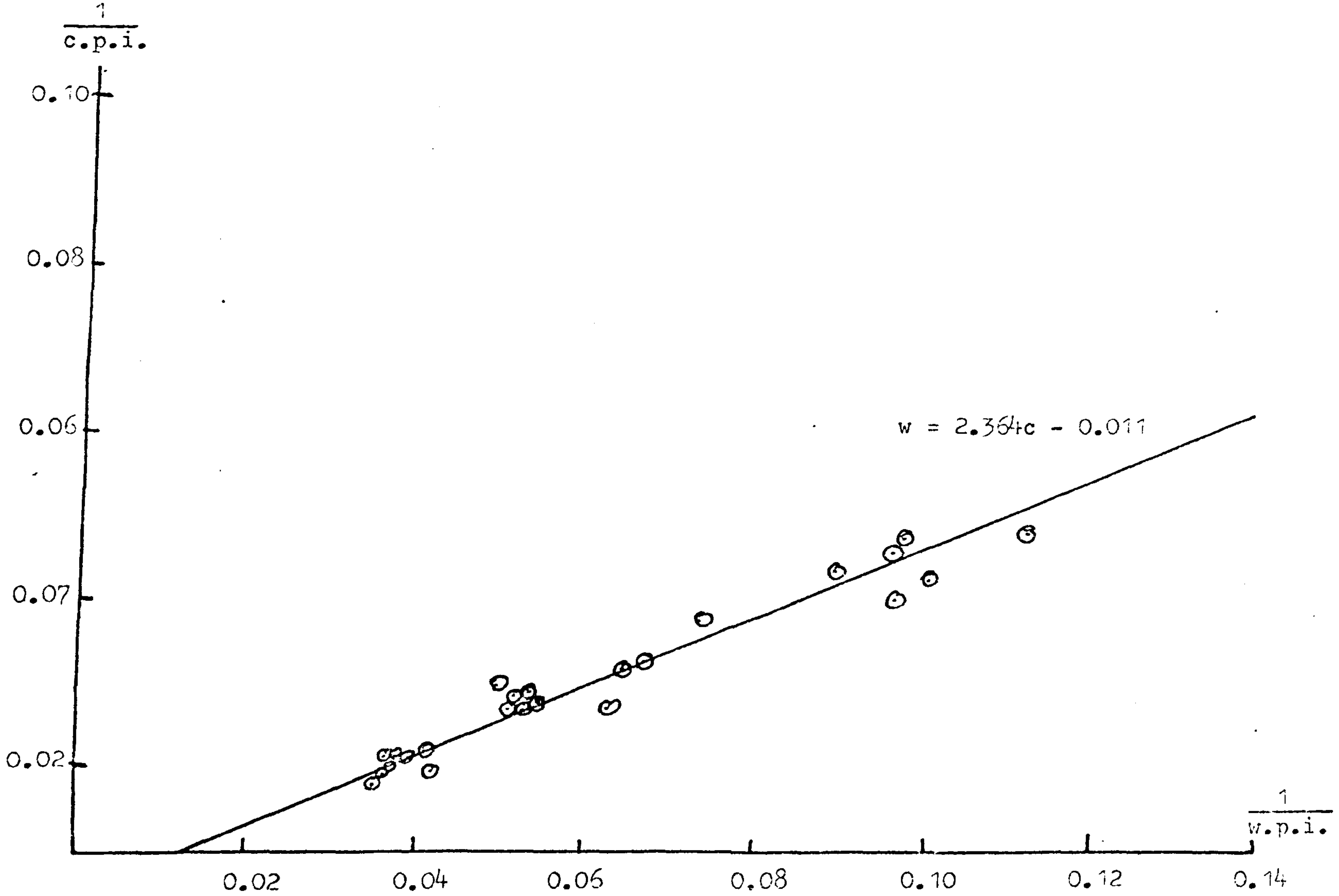


Fig. 108 Relationship between $\frac{1}{c.p.i.}$ and $\frac{1}{w.p.i.}$ for 1 x 1 Open Lap

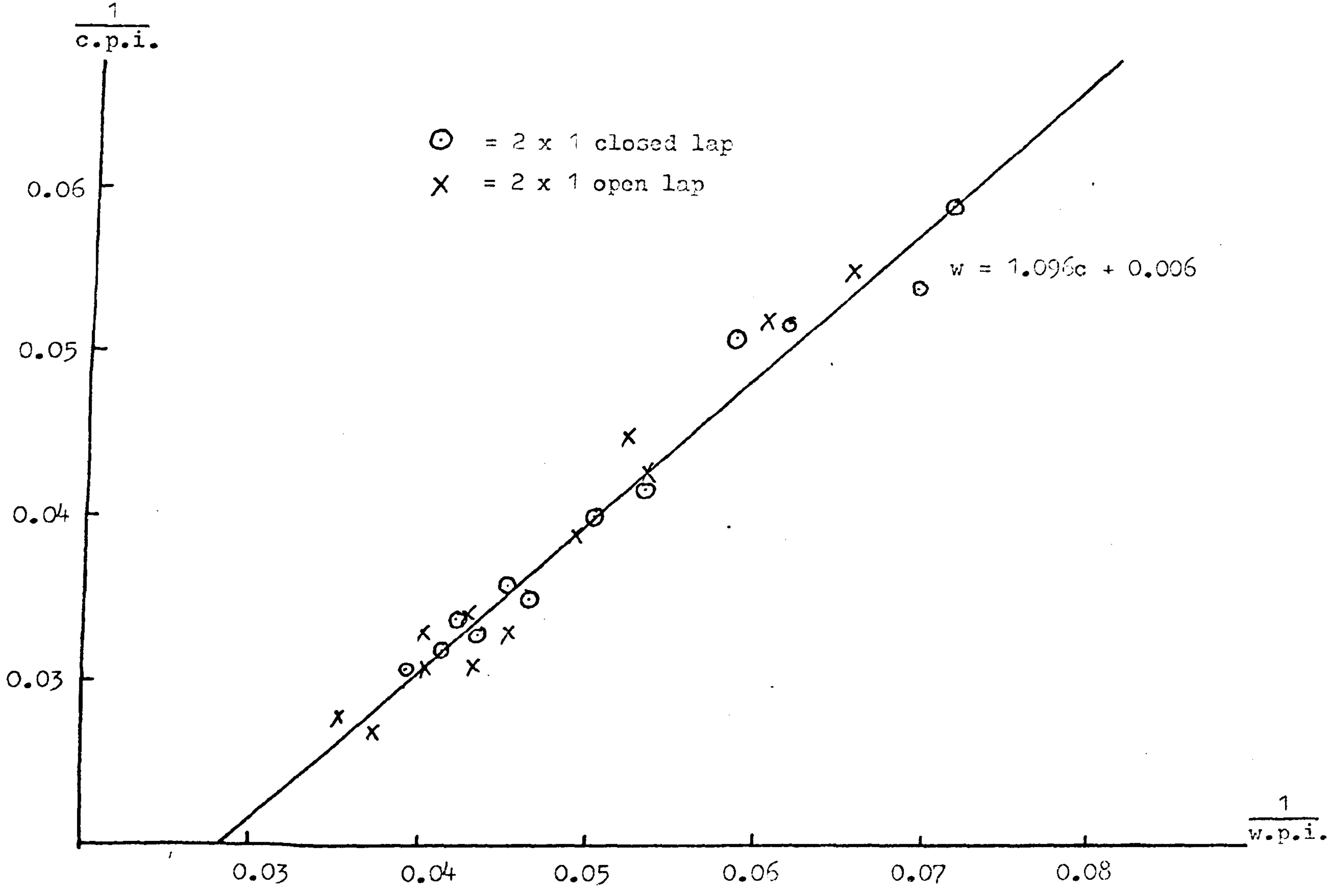


Fig. 109 Relationship between $\frac{1}{\text{c.p.i.}}$ and $\frac{1}{\text{w.p.i.}}$ 2 x 1 Open and Closed Lap

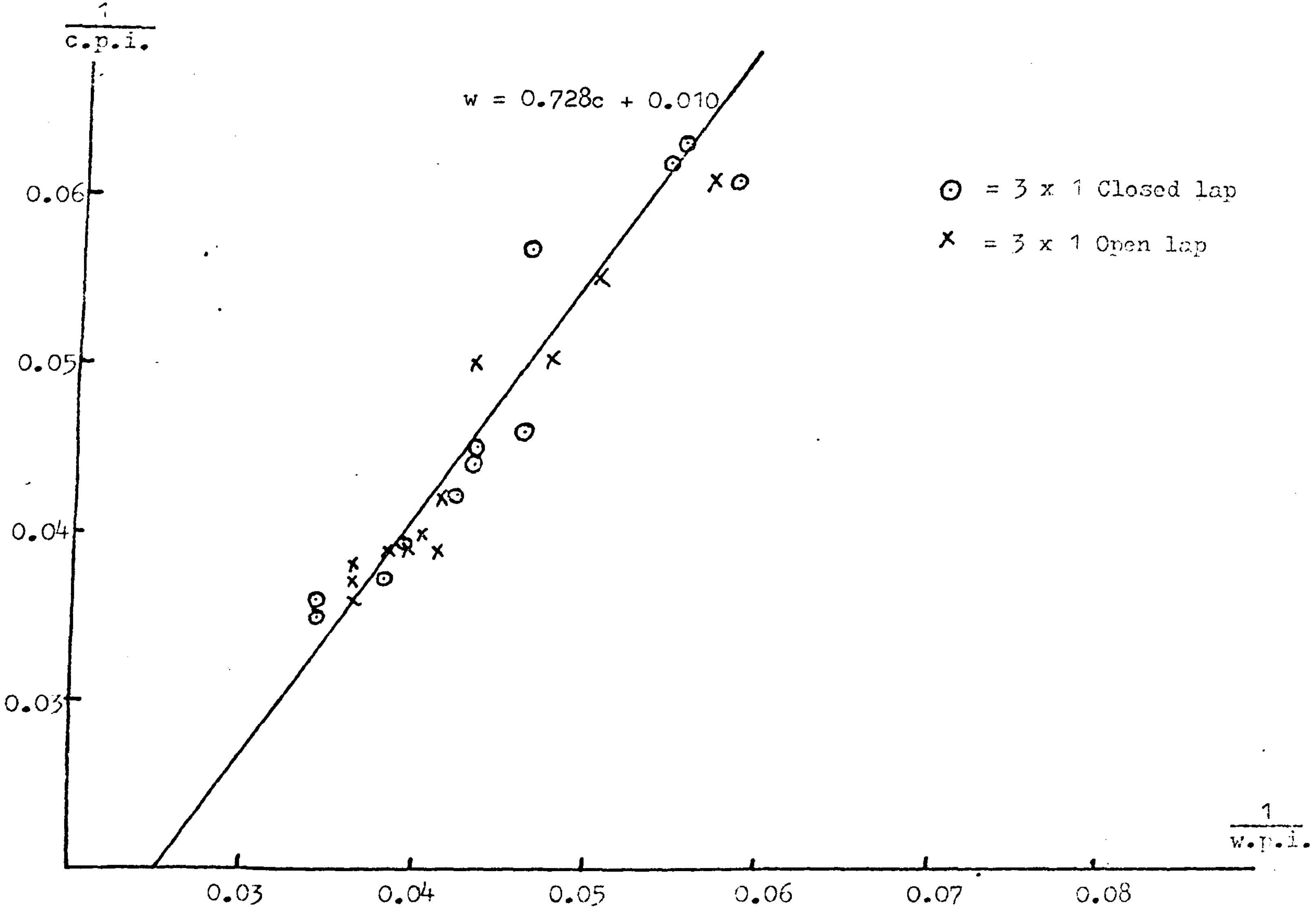


Fig. 110 Relationship between $\frac{1}{c.p.i.}$ and $\frac{1}{w.p.i.}$ for 3 x 1 Open and Closed Lap

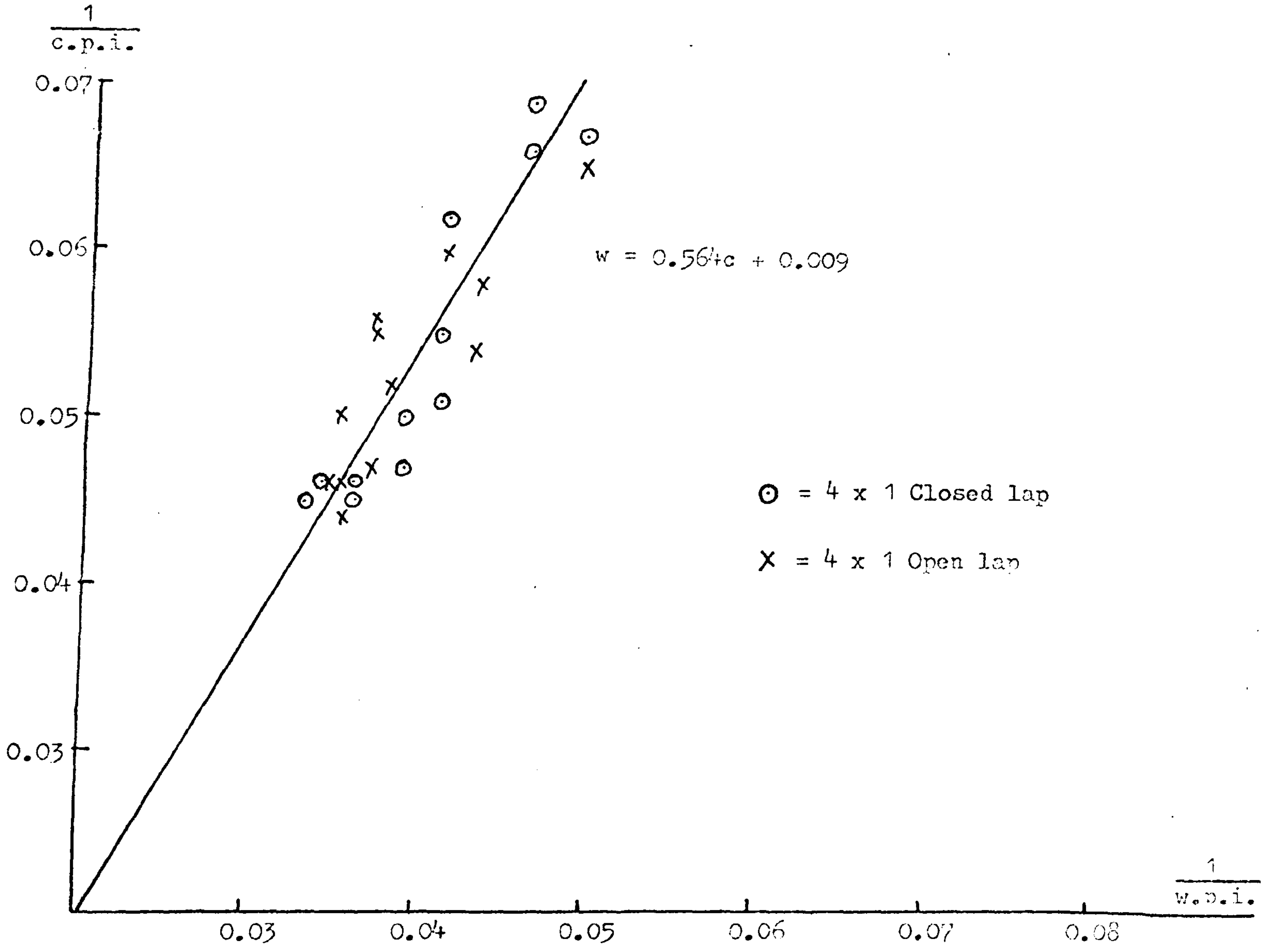


Fig. 111 Relationship between $\frac{1}{c.p.i.}$ and $\frac{1}{w.p.i.}$ for 4 x 1 Open and Closed Lap

Values of $\frac{1}{\ell}$ Calculated from Loop Model

	c.p.i.	$\frac{1}{\ell}$
2 x 1 Open and Closed Lap	20	2.68
" " " " "	30	3.93
3 x 1 Open and Closed Lap	20	2.64
" " " " "	30	3.75
4 x 1 Open and Closed Lap	20	2.59
" " " " "	15	2.00
1 x 1 Closed Lap	30	3.36
" " "	60	6.40
1 x 1 Open Lap	20	2.27
" " "	50	6.40

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