The development of a pile-fabric patterning system

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THE DEVELOPMENT OF A PILE-FABRIC PATTERNING SYSTEM

by

JOHN EDWARD VINE

A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy of the Loughborough University of Technology.

October 1976

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ABSTRACT

The aim of this research, sponsored by the Science Research Council, was to develop a high-speed patterning system intended primarily for application to the locked-loop pile-fabric process invented and developed in the Department of Mechanical Engineering at Loughborough University of Technology. Current commercial versions of the locked-loop pile-fabric producing machines, manufactured under N.R.D.C. licence and marketed under the trade name "Locstitch", have their market potential concentrated on the field of good quality pile-fabric production but limited to plain unpatterned types.

A survey of existing multi-end patterning systems, as used on other fabric manufacturing processes, revealed that versatility of patterning is not as yet compatible with high operational speeds. In order to produce patterned locked-loop fabrics economically, this incompatibility must be removed, thereby postulating a research criteria based on the following inter-dependent topics for achieving a complete high-speed patterning system:

(i) the development of the mechanical patterning devices required in the actual stitching-zone of the process;

(ii) the development of a pattern storage and retrieval system, and

(iii) the development of a yarn-feed system.

These three topics each formed researches in their own right, and also provided useful information applicable to other textile processes; these subsidiary aspects are discussed in conjunction with an overall appraisal of the systems developed.

A sophisticated electro-mechanical research rig was constructed in order to demonstrate that locked-loop sculpture patterned pile-fabrics could be successfully produced at high speeds. The practical outcome of the research may be assessed by the three patents that have arisen from the work and these are currently being offered to industry under licencing agreements with the National Research and Development Corporation.

The thesis concludes with an assessment of the commercial viability of the patterning system in relation to the current state of textile machinery technology.
THE COMPLETE PILE-FABRIC PATTERNING SYSTEM
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To Mr. R. Vitols, whose research on the first pile-fabric powered rig and knowledge of the technical aspects of the prototype Locstitch machine proved to be invaluable.

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CHAPTER 1

INTRODUCTION

Many types of pile fabrics are currently produced in the textile industry. Most of these can be patterned by various well established means, but the fabric and process to which this research was devoted is somewhat unconventional in its structure and method of construction. Professor G.R. Wray and Mr. G.F. Ward, members of the Department of Mechanical Engineering at Loughborough University of Technology, invented a sewing-knitting technique in 1967 that produced a double-faced pile fabric by using a type of stitch in which each pile loop was anchored or locked into a preconstructed base fabric. Henceforth this will be referred to as the 'locked-loop stitch'. Sponsored by the Science Research Council, the basic stitch was produced on a small powered research rig, capable of stitching at very high speeds, which was designed by R. Vitols. Patents for the stitch and apparatus were formulated and assigned to the National Research and Development Council so that the invention could be commercially exploited. Edgar Pickering (Blackburn) Ltd. formed a subsidiary company known as Pickering Locstitch Ltd., who entered into licencing agreements with N.R.D.C. to produce commercial machines utilising the Wray/Ward invention. The new process was given the trade name of 'LOCSTITCH'. The prototype commercial Locstitch machine was designed within the Department of Mechanical Engineering at Loughborough University of Technology and was exhibited at the 6th International Exhibition of Textile Machinery, Paris 1971, and since then the company has manufactured machines principally for export sales. The work was a classic example of university research leading to commercial application which should benefit both the textile industry and the consumer.

It may be observed from the above developments that the work contained within this report will, to some extent, be a continuation from previous researches. To avoid duplication of previously published material it would be useful if the reader had knowledge of references 1, 2, 3, 4 and 5. Reference must also be made to certain features of the commercial machine produced by Pickering Locstitch Ltd., but, as detailed changes in design may be made by the company at any time, all references to the commercial machine apply to present knowledge only.
1.1. Description of the Locked-Loop Stitch

The method of producing the locked-loop stitch has been described in several publications\(^1,2,3,4,5\), but it might help the reader if the cycle of operations were to be restated briefly here. Fig. 1.0. shows six sections through the stitching zone representing relative needle positions as the locked-loop stitch is formed. Also shown (Fig. 1.0.G.) is a pictorial view of the fabric produced. The notation and terminology used to describe the various components will be consistent throughout this thesis.

Fig. 1.0. (A): Needle N1 pierces the base fabric and forms a loop of yarn around looper L1. Needle N2 withdraws from the opposite side of the base fabric leaving a prone loop (shown black) around the base of its pile loop (shown white).

Fig. 1.0. (B): Needle N1 reaches full penetration through the base fabric while needle N2 continues to retract. At this position the looper L2 traverses (shogs) by one seam pitch displacement across the point of needle N2 and parallel to the base fabric in the weft-wise direction.

Fig. 1.0. (C): Needle N1 begins to retract from the base fabric causing a slight puckering of the yarn in the needle eye region. Needle N2 approaches the base fabric and picks up the puckered yarn from N1.

Fig. 1.0. (D): Needle N1 continues to retract leaving a 'cast-off' loop around N2 and also leaving a prone loop (shown white) around the base of its pile loop (shown black) to 'lock' the stitch. Needle N2 pierces the base fabric while forming a new pile loop around looper L2.

Fig. 1.0. (E): Needle N1 continues to retract clear of looper L1 which starts to shog by one seam pitch displacement across the point of the needle. Needle N2 further penetrates the base fabric pulling the pile loop tight against looper L2.

Fig. 1.0. (F): Needle N1 approaches the base fabric to pick up the slightly puckered yarn on needle N2 which is retracting. The cycle is completed in Fig. 1.0. (A): and the series of operations is continuously repeated to form the pile-fabric.

It will be noted that there is always a needle inserted into the base fabric at any one time; therefore, for a fabric to be produced the needles must move with the base fabric in direction F whilst they are inserted and their points will each then describe.
Fig. 1.0 THE LOCKED-LOOP STITCH
a planar orbital motion. Consequently, interacting parallel rows of sewing needles on each side of the fabric undergo these planar orbital motions as they cast off loops from one row to the corresponding row on the other side of the fabric, and each pile yarn serves to securely lock the other.

The brochure, issued by Pickering Locstitch Ltd., for the commercial machine, lists the following advantages for the 'Locstitch Fabric' and 'Locstitch Process':-

(a) Pile loops in the upper yarn are securely locked into the base fabric by means of prone loops in the lower face yarn.

(b) Similarly, pile loops in the lower face yarn are securely locked by means of prone loops in the upper face yarn.

(c) The pile loops are of similar character on each side of the base fabric.

(d) If either pile loop is pulled the structure becomes tighter.

(e) If either loop is broken the structure will not unravel.

(f) The fabric can be cut without fraying occurring.

(g) Completely different yarn types can be used on either side of the base fabric to give novel reversibility effects.

(h) Different pile heights can be produced on either side of the base fabric.

(i) The pile weight per unit area can be varied by altering either the pile height or the stitching pitch, without any variation in the total amount of prone loop yarn required.

(j) The prone loops reinforce the base fabric so that inexpensive base fabrics can be used.

(k) The locked stitch is ideal for raising and/or cropping on one or both sides of the fabric.

(l) If a locked single-face pile fabric is required, one set of pile loops can be arranged to lie flat to the fabric surface.

(m) Extremely high production rates, more that twenty times that of conventional pile fabric weaving, are realised due to the simplicity of the stitching elements used.

(n) Two interacting rows of sewing needles form the 'Locstitch', eliminating troublesome latch needles, compound needles and control plates.
The sewing needles undergo identical continuous orbital motions as they cast off loops from one to the other.

Consistency of pile height is maintained by rows of loopers against which the stitch is set.

The loopers can be precisely set, and independently varied on both sides of the base fabric by a simple control adjustment.

A simple sideways reciprocating motion of the loopers eliminates unreliable 'hooking' actions.

The continuous double loop formation, together with the positive looper system, provides a tight stitch, yet precludes the possibility of uncontrolled 'backrobbing'.

Jerky and intermittent motions are avoided by providing a smooth and continuous feed to the base fabric.

The stitches per unit length can be varied within a wide range by a single setting adjustment.

The fabric leaves the stitching zone vertically upwards to give an eye-level view on both sides.

The simplicity of the process removes the need for specialised and skilled operative labour.

The balancing features of the machine result in particularly low noise levels being achieved.

1.2. The Object of this Research Project

The basic production process as described in section 1.1., has certain versatile features which arise from the pile face on one side of the fabric being formed independently of the pile face on the other side. Therefore the pile each side of the fabric may be of different heights and/or colours. Zero pile height can be produced by removing the loopers on either side of the fabric. Coloured striped patterns can be produced by pre-threading the needles with the appropriate coloured yarns. The one factor that the above novelty features have in common is that they must all be pre-set. Neither the pile heights nor the coloured yarns can be varied automatically in-process. This means that the basic process does not cater for varying patterned fabrics, or for borders and headings around the finished product. In order that the locked-loop pile fabric should effectively compete with many of the conventional pile fabrics on the market, it is necessary
that a greater degree of patterning should be incorporated. The Science Research Council have sponsored further research work on the basic locked-loop process, part of the schedule of which is concerned with patterning. Only when patterned fabrics are produced will the full potential of the locked-loop process be realised.

1.3. Terms of Reference

This project involves a study of the fundamental concepts of patterning in relation to the needle and looper configuration existant in the current basic method of producing the locked-loop fabric. Particular emphasis is given to a study in depth of the engineering aspects of performing such patterning at or near the extremely high speeds attained with the unpatterned fabric production of the commercial machine. The ultimate aim is to provide a patterning system that will be commercially acceptable to the textile industry and economically viable to machine manufacturers and fabric producers alike.
CHAPTER 2

THE TEXTILE REQUIREMENTS

The manufacture of pile fabrics is a very competitive industry throughout the world. Textile machine designers are unceasing in their endeavours to increase the market potential for their products either by increasing output rates or by providing better patterning facilities. In order that the patterning system to be devised for the locked-loop process should be at least at par with modern developments it was deemed necessary to make a survey of systems used on competitive products.

There are two basic principles for providing the visual effect of a patterned fabric. The first is colour patterning and the second is a structural change in fabric construction. In the case of pile fabrics the latter effect is visually produced by varying the pile heights in warpwise and/or weftwise directions as fabric is produced. This may be defined as sculpturing or sculpture patterning.

2.1. Survey of Relevant Patterning Systems

Reference to the 'World Textile Abstracts', prepared by the U.K. Textile Research Associations and published by the Shirley Institute, revealed that, on a world basis, about eight patents or articles per month are published on patterning and pile fabrics. Owing to this large volume of literature it was decided to be selective with the survey and consider only the very latest reported developments over the past 3 years (i.e. from Jan. 1972 to date).

2.1.1. Surveys Conducted To Date

Most text books on specialised aspects of knitting, weaving and other fabric forming processes include sections relating to patterning devices within the scope of their own particular fields as the principles of patterning conventional pile and non-pile fabrics have been well established for many years. However, two recently published surveys are directly concerned with the latest patterning developments.

(a) Dr. M.S. Burnip describes the control of machine elements in modern knitting machinery, together with methods of pattern information storage and retrieval. His paper includes a table of companies producing knitting machines with electronic patterning control and a second table of pattern preparation systems for jacquard knitting machines.

(b) J. Robinson, in his final year project report (see also subsection 3.4.2.), included a survey of patterning control systems similar to
that given by Burnip, together with many new ideas relating directly to the locked-loop process.

No survey seemed to have been conducted to-date that was purely concerned with patterning pile fabrics; information on this particular topic was spread throughout the various basic processes such as weaving, tufting and knitting etc. Therefore it was decided to collate all the pile fabric processes with particular reference to the facilities currently available for patterning them.

2.1.2. Pile Weaving

The techniques for producing a patterned woven pile fabric are well established in the forms of terry towelling\(^1\)\(^9\) and carpet manufacture\(^1\)\(^8\) etc. In the case of terry weaving, for example, the principle of patterning resolves into systems of varying and controlling the 'shed' of warp yarns per 'pick' or 'shot' (i.e. weft insertion). By so doing differently coloured pile yarns can be caused to protrude on either side of the fabric ground warps and intermixed to form coloured patterns of pile; also areas of no pile can be produced to create sculptured patterns. The combination of both these features provides a unique versatility in the specifications for the fabrics.

In the manufacture of Wilton carpets, however, several coloured warp yarns may be used and the warp sheds are created to produce the appropriate coloured pile over pile wires inserted weftwise whilst the other coloured yarns lie flat to form the ground or backing warps. In the case of Axminster weaving the structure resembles that of hand-knotted carpets where the pattern is not controlled by the warp shedding arrangement but by inserting short tufts into the weaving zone and holding them in place by either 2, 3 or 4 weft shots. Therefore in typical Axminster constructions the maximum amount of pile yarn is utilised above the backing as effective pile since only a comparatively small part at the base of the tuft passes beneath the binding wefts, i.e. there is no pile weaving 'dead' or hidden in the backing structure as with patterned Wilton. The most common method of storing the complex pattern information for the pile weaving processes is by a series of punched cards used in conjunction with a jacquard mechanism\(^2\)\(^0\) invented in 1801. This mechanism may provide individual control to each pile warp which creates an extremely versatile patterning system. In practice, however, it is usual to commonise the heald cords in the shedding arrangement such that pattern repeats are obtained in the weftwise direction. New developments in patterning systems consist of faster, more efficient and general refinements of the basic jacquard mechanism. Normally woven sculptured pile fabrics consist of areas having pile loops and no pile loops but recent developments include systems for three pile areas
i.e. high loops, low loops and no loops. A patent\textsuperscript{13} describes the use of yarn characteristics to produce high and low pile areas where those yarns forming the low pile areas have pile loops of the same lengths as those in the high pile areas but are self restrained by their natural twist characteristics to lie inclined to the base and thus form the low pile areas. Electronic pattern control devices are being used; the information is stored in graphical form on paper and scanned photo-electrically, the signals produced making the selections for the jacquard mechanisms. However, the limitation on such systems is the large number of warp ends to be controlled.

2.1.3. Kraftamatic Process

Pile fabrics produced by inserting pile yarns into a preconstructed base fabric might generally be classified as tufted fabrics. However, because several recent versions of pile insertion techniques have used more complex stitches than the simple inserted tufted carpet stitch, it is convenient here to redefine tufting as 'single sided pile insertion without the use of knitted type loops lying flat against the base material'. The Kraftamatic process\textsuperscript{1}, developed in the U.K., produces a pile on both sides of a preconstructed base fabric together with such knitted-type loops. The process uses a complexity of eyed and latch needle motions interacting with looper fingers and latch bars. It may be that this rather complex operating technique is the reason why the literature survey revealed no evidence of either colour or sculptured pile patterning possibilities for the process.

2.1.4. Malipol Process

This East German process\textsuperscript{1} produces pile on only one surface of the fabric using hook type needles and yarn guides. There was no indication that colour or sculpture patterning was being produced by the process although pile seam interaction, said to be obtained\textsuperscript{21} by a shedding movement of the yarn guides in much the same way as conventional warp knitting, has been developed. However this cannot be regarded as effective patterning due to severe limitations in the weftwise directions and therefore it must be classified as providing 'surface interest' only.

2.1.5. Araloop Process

The stitch construction for this Czechoslovakian process\textsuperscript{1, 18, 22} is the same as that for the Malipol, although the method of production is slightly different. The process is one of the many variations of the Arachne stitch-bonding systems and there are indications that considerable developments have occurred recently. Reference 22 shows that, by seam interaction via the yarn guides and by the provision of special cams for various stitch combinations the stitch-bonded fabrics can be provided with different relief patterns. In such cases the patterns have a limited repeat length in warp and weft directions.
but the result cannot be regarded as a true pile fabric as the shapes arise due to the penetration of the fibrous backing material between the non-interlaced wales on the face of the fabric. Again, similar relief patterns can be produced by suitably finishing the fabric i.e. by utilising different shrink characteristics in the bonding yarns. The Bicolor-Araloop process duplicates the stitching mechanism on the other side of the base fabric to create a two sided pile fabric with contrasting colours on each face if required. The process offers scope for patterning possibilities independently on each side of the fabric. This may be caused either by using coloured warp threading or by feeding the threads into the needles via yarn guides which may be co-ordinated to suit the pattern requirements. Therefore patterning is the same as on other warp knitting machines i.e. by threading warp yarns and patterning chains or cams. Sculpture patterning is also claimed for the Bicolor-Araloop process by either guiding or not guiding the yarn over looper sinkers. However because this principle is closely similar to that of warp knitting the limitations in weftwise sculpture pattern repeat length are apparent.

2.1.6. Warp Knitted Pile

The common types of plush or pile fabrics are produced on a two needle bed Raschel warp knitting machine where one needle bank has been replaced by a set of plush points or loopers. The yarn guides are then moved to cooperate with both the needles and plush points to produce a knitted pile. The cycle of operations are admirably described in reference 25 and sculpture patterning is controlled by lapping or not lapping the yarn round the plush points in the normal warp knitting fashion. The Shirley Institute has recently studied the manufacture of warp knitted pile fabrics and has evolved techniques for improving the 'overfeeding' and 'overlooping' principles. Several German and Czechoslovakian patents have been filed in the past two years all claiming different approaches to pile fabric warp knitting. However, sculpture and colour pattern repeat lengths are still relatively small because of the dependence upon warp threading. The most common pattern information store for shoping the warp thread guides is the chain link system which prompted Burnip in 1973 to observe that 'so far the development of electronic patterning systems for weft knitting machines has not provoked any similar developments in warp knitting' and to argue that it was 'time for warp knitters to re-appraise electronic patterning systems'. This may indeed be occurring as reference 27 describes a recent patent for the electronic pattern control on warp knitting machines.

2.1.7. Weft Knitted Pile

The methods of producing plush or pile effects in weft knitting have
become well established since their invention 20 years ago. The usual principle involved is to feed two yarns to the needles at different angles. Special methods are then employed to draw long sinker loops with one yarn and normal sinker loops with the other thereby tending to stabilise the pile loops formed. Pattern control is achieved in the standard weft knitting manner by circular camming and jacks etc. Thus the pattern information storage and retrieval systems that are available for coloured jacquard weft knitting may be used for sculpturing a pile pattern. The result is that, like terry weaving, the specifications for the fabric produced are very versatile, although the sculptured pile may only be on one surface of the fabric, combinations of colour and pile height variants have been achieved.

2.1.8. Tufting

D. Ward's book covers, in detail, the principles of tufting pile fabrics and describes the many colour and sculptured pile patterning attachments now available. However, all such attachments are based on pile-robbing techniques in which the needles make the same stroke and the yarn is picked up by the hook or looper in the usual manner. Insufficient yarn is then fed to the needles so that, as they make a normal stroke, yarn is pulled back from the previous loop to shorten it. Colour patterns are achieved by threading the coloured yarns through different needles and then 'hiding' one of the colours by back-robbing so that the other colour has a dominant higher pile. Pattern repeat lengths are determined by the number of yarn feed rollers or devices which are usually electrically clutched in and out for different yarn feed rates and by pile yarn threading which is scrambled from the feed system by tubes to the relevant needle positions. Control systems for the feed rollers are now mainly remote electronic scanning of painted translucent films or drums via photo-electric cells. Recent developments in the colour patterning of tufted pile fabrics include the taking of yarn from a creel to form a sheet which passes through a printing unit applying colour according to a predetermined design. The sheet of yarn is then wound onto a beam which is then used on a conventional tufting machine. Another new system of patterned carpet manufacture is the Blackburn Rivet Head Carpet Process. This system uses a hollow needle to insert single tufts of pile into a backing fabric. Every needle across the full width of the needle bar can be fed selectively via as many as eight different tubes, each taking differently coloured yarn from creel decks. The required coloured yarn is selected from the relevant creel deck and is automatically cut off and fed pneumatically along a channel to the hollow needle. The needle and yarn tuft penetrate the backing fabric and as the needle starts to withdraw a small plunger
within it holds the tuft of yarn in place. Electronic pattern-control, employing a coding system based on the three elements of a binary scale, provides for up to eight colours to be used in forming patterns of any size. Sculptured effects are obtainable, either plain or colour patterned, with three heights of pile.

2.1.9. New Pile Fabric Processes

Vitols thesis included a survey of competitive products of the basic, unpatterned, locked-loop process. However, since then, new pile fabric processes have appeared in patent form and must now be considered.

(a) A patent filed by the Cosmopolitan Textile Co. Ltd., claims a stitching process (trade named 'Stitch-Lock') remarkably similar to that of the Arachne and Malo range of stitch-bonding systems. The stitch produced is the same and therefore it may be assured that the patterning specifications available for the Araloop and Malipol stitches apply for the 'Stitch-Lock'.

(b) A patent filed by G. Forstmann relates to a tufted fabric by the definition is sub-section 2.1.3. Two base fabrics lie face-to-face and are inserted with pile yarns from both sides; then separating the oppositely tufted fabrics from each other at a set spacing draws the pile as a lattice structure between the two base fabrics. Cutting this pile between the base fabrics produces two pile fabrics (similar to Wilton face-to-face weaving principle). There appears to be little scope for colour or sculpture patterning of such fabrics.

(c) A patent filed by Fieldcrest Mills Inc. describes an interesting pile weaving process with warp knitting type interactions. Looper wires run warpwise, rather than weftwise as in normal weaving, and the ground warps and wefts are woven conventionally. The pile warps run through yarn guides similar to those in warp knitting and move in and out of the ground warp shed per weft insertion. By jogging the yarn guides over the warpwise looper wires and down into the shed a pile is formed which is held by the inserted wefts. The patent illustrates a number of possible looper wire designs which are claimed to provide an enormous variety of colour and sculpture patterning possibilities. Three pile heights, any of which may be independently cut or looped, together with seam interactions warpwise, weftwise and/or diagonally are provided for. A machine designed on the principle of this patent would have more versatile patterning capabilities than the other systems mentioned in this survey.

2.1.10. General Summary

The weaving, tufting and weft knitting processes for producing sculptured and coloured pile patterns provide the most versatile arrangements
with respect to pattern repeat lengths. The remaining systems, which are in principle based on warp knitting techniques, are far more restrictive in that they depend upon yarn guiding via shogging motions to provide seam interactions for colour and pile height effects. The general trend in pattern storage and retrieval systems is towards electronic methods. This is due to the increased speed of pattern preparation and to the relatively less physical space required for the number of signals stored. Therefore, based on the above currently used techniques for patterning pile fabrics, a rational approach of the requirements for patterning the locked-loop process was formulated.

2.2. A Specification for Patterned Locked-Loop Fabric

Before a patterning system for the locked-loop pile fabric machine can be devised a specification for the end product must be decided upon. As discussed in section 2.1, there are several ways in which the fabric may be patterned but not all will be best suited to the process or to commercial exploitation. As previously stated there are two basic principles for producing the visual effect of a pattern on a fabric. The first is a colour pattern and the second is a structural change in fabric construction.

2.2.1. Colour Patterns

These can be achieved, even with the currently produced fabric simply by printing the finished material. Modern transfer printing methods can provide the colouring effect deep into the root of a pile fabric, and the locked loop structure has indeed been patterned in this manner. Simple colour patterns can also be produced by the use of coloured yarns. At present the locked-loop process lends itself to only striped patterns in the warp direction, i.e. by pre-threading the needles with the appropriate coloured yarns. However, the use of coloured yarns in the locked-loop process must be considered from the point of view of providing more intricate patterns. In this case there are two principles that may be considered, either by bringing the required colour to the foreground of the fabric surface and allowing the secondary colour to sink to the background; or by cutting the yarn at each stitch and then selecting the required coloured yarn for the following stitch. The former is the principle used for colour patterning in terry weaving, warp and weft knitting and tufting, while the latter is that used in Axminster carpet weaving and 'Rivet Head' tufting. The locked-loop process immediately imposes a limitation on any patterning method using cut yarns because it is dependent upon the yarn being threaded through the eye of a needle and to rethread yarns in-process would not be practical.
However, if two different coloured yarns were to be threaded through the eye of each needle and during the stitching cycle some form of looping element was selected to produce a pile loop in one of the colours and allow the other coloured loop to fall to zero height then a coloured yarn pattern could be produced on the surface (Fig.2.1.a.). This would produce a heavy fabric with a high yarn density at the root of the pile caused by the double thickness locking loop and by the zero height pile loop not being used in the colour affect. The system would also be very difficult to control because the two yarns would need to touch each other as they passed through the eyes of the needles and the fibrous nature of the yarn would cause sticking and snagging between the yarns as they moved relatively to each other. It would also be impractical to create an element capable of selecting one of the two coloured yarns when they would be so close together.

The locked-loop process uses different yarns each side of the base fabric. It may therefore be possible to exchange different coloured yarns onto the pile faces of either side of the structure by using the locking loop as a pile loop. Consider Fig.2.1.b., needle N2 carrying a potential locking loop has its yarn picked up by needle M1 and looper in position 'C'. Thus as needle N2 retracts it leaves behind a loop on the looper in position 'C' instead of pulling the yarn down flat to the base fabric to form the locking loop. At the same time needle M1 will pull the other coloured yarn down to zero. To change colour on the pile face of the fabric the looper would move to position 'D' and form a loop in the normal manner. This approach has possibilities but the fabric produced would no longer have a uniform structural appearance and the problems of picking up the yarn with two elements (needle and looper) creates difficulties due to the space available in the stitching zone.

The general conclusion is that the locked-loop process does not readily lend itself to colour patterning other than by printing and dyeing. Colour patterns will therefore not be considered for this particular research but there is no reason why future researchers could not make further investigations.

2.2.2. Structure Change Patterns

Changes in the structure of a fabric to create a patterned effect are quite common in the textile industry. The conventional pile fabric production systems produce structural changes by altering the pile height in-process usually from a pile area to a non-pile area as discussed in section 2.1. The locked-loop process lends itself to in-process pile height variations and the effect produced has been outlined previously by R. Vitols et al. However, no engineering solution has yet been offered. Fig.2.2.
(a) DOUBLE YARN STRUCTURE

(b) YARN TRANSFER STRUCTURE USING LOCKING LOOP AS A PILE LOOP

Fig 2.1 COLOURED YARN STITCHES
Fig 2.2  PILE HEIGHT VARIATIONS
shows the effect of pile height variation in one stitching seam and if this seam were to be controlled independently from neighbouring seams a patterned pile effect could be produced. It was therefore decided that this type of patterning (sculpturing) for the locked-loop process, should be developed.

In order to investigate pile height variations further, a manually-operated locked-loop stitching rig was manufactured (Fig.2.3.). The rig used standard needles but the looper elements were adjustable independently to move them at varying distances from the base fabric to create different pile heights.

2.2.3. Ideal Specification

The ideal specification for the fabric with a varying pile height would be one that provides multiple height variations independently in warp and weft directions to produce undulating effects or sharp contrasts. However, because of the density of stitching in both warp and weft directions, i.e. 2 mm (0.078") spacing between seams in the weft direction and a maximum of 14 stitches per inch in the warp direction (as in the currently produced machine) the fabric is relatively 'open' in structure and an undulating pattern would not be clearly seen by eye. To study the contrasts in pile height the manually-operated rig was used to determine what difference in pile heights were required in order that they may be visually discernable. Fig.2.4.a. shows samples using maximum pile height available with the manual rig of 5 mm (0.2") and minimum pile height of 1.8 mm (0.07") the lowest available with the type of looper used. It may be observed that the pattern is clearly visible but the effectiveness would be reduced should either the maximum pile height be reduced or the minimum be increased. Fig.2.4.b. is a sample using the minimum pile height and zero pile height; again the pattern is clearly visible but in this case the effectiveness of the pattern would be improved if a zero pile height was to be maintained while the piled area was increased in height. It is clear from the two examples of Fig.2.4. that the locked-loop process would possess greater versatility of operation should a sculpturing device be incorporated that could provide in-process pile height variations of maximum, minimum and zero and in which the maximum and minimum heights could be independently varied. The ideal specification with respect to pattern repeat length would be an unlimited system in both warp and weft directions.

2.2.4. Compromise

The gauge of the needles and loopers in current use on the Locstitch machine is 13 per inch i.e. 2 mm (0.078") seam spacing. Whatever pile height selection device is used it must be independent for each needle in order that a pattern can be produced. Therefore each selection device must be packed into a 2 mm pitch. For the purpose of this research it was not considered
Fig 2.3 THE MANUAL RIG

29
Fig 2.4 SCULPTURED SAMPLES
necessary to go to this extreme; thus, to demonstrate the principle, it was
decided to accept the compromise that one selection device would control two
loopers at 4 mm (0.156") pitch but that the system in principle must even-
tually lend itself to individual looper control. In sub-section 2.2.3, it
was suggested that a system that could produce maximum, minimum and zero
pile heights would be most desirable. This could involve a method of
selecting a minimum of two positions using a third position as datum. The
pattern information storage would thus become complicated as well as the
looper control. Once again it was decided to accept the compromise that an
'on-off' method of selection would be better suited to this research, but
that the system should lend itself to treble selections. This gives the
possibility of producing two types of sculptured patterns:—
either (a) Production of a high pile and a low pile,
or (b) Production of a pile and zero pile.

The two types are illustrated in Fig. 2.4. (a) and (b) respectively.
The first type (a) has a full face coverage of the base fabric producing a
'rich-looking' material but the amount of yarn used is relatively high. The
second type (b) requires less yarn but the base fabric 'grins' through the
stitching, thus necessitating a fairly good quality base fabric which might
have to be precoloured to suit the yarns used. Both types of sculptured
pile fabric would be acceptable for different markets, e.g. type (a) for
towelling, upholstery etc., and type (b) for bedspreads, curtains etc., and
therefore both systems must be considered. The basic specifications for the
fabrics to be produced are:—

**Specification I**

(a) Two pile heights produced in-process.
(b) Maximum and minimum pile heights independently preset.
(c) Selection made per stitch in the warp direction and per
two seams in the weft direction.
(d) Pattern repeat length unlimited in both warp and weft
directions.

**Specification II**

(a) One pile height and zero pile produced in-process.
(b) The pile height preset.
(c) Selection made per stitch in the warp direction and per
two seams in the weft direction.
(d) Pattern repeat length unlimited in both warp and weft
directions.
CHAPTER 3
DEVELOPMENT OF THE LOCKED-LOOP PROCESS TO-DATE

3.1. The First Powered Rig (1969)

The Wray/Ward dual invention of the locked-loop stitch and the method of producing it by sewing needles was furthered considerably when the pile fabric was first produced at speed on a powered research rig, since previously it had only been manufactured by simple hand operated apparatus. The rig, illustrated in Fig.3.1., was designed and developed by R. Vitols and sponsored by S.R.C. It is necessary to discuss the main stitching elements of this rig here, since a detailed understanding of their characteristics was to prove useful during the course of the present work.

3.1.1. Needle Motions

Fig.3.2. is a cross-sectional view through the stitching zone and drive shafts. The eccentrics (1) on the drive shafts serve to reciprocate a link (2) to which is secured the needle bar (3). This link (2) is stabilized by another link (4) suspended from a rocking segment (5) having variable length adjustment via the slot and locking arrangement shown. The segment is rocked by linkages (6) which are also driven by eccentrics (1) on the drive shafts. The whole linkage system is duplicated on the other side of the base fabric (8) to drive the other needle bar (7). The resultant needle motions are a harmonic reciprocating movement to effect the penetrations and withdrawals from the base fabric combined with a vertical rise and fall movement derived from the rocking segment (5) so that when a needle bank has penetrated the base fabric it moves essentially with the base fabric. This latter movement is adjustable according to the stitching pitch desired, by adjusting the effective length of the rocking segment (5). Fig.3.3. illustrates the resultant orbits, produced by these combined movements, at the needle point in relation to the base fabric.

Vitols also attempted an ingenious 'interdigitized' needle system for providing a reaction to the needle piercing force thereby minimizing the base fabric deflection. This was done by duplicating the linkage system on both sides of the base fabric but driving them half-a-cycle out of phase with the original linkage. The result consisted of four needle bars each with the needles pitched at twice the finished fabric seam pitch, two opposing needle bars interacting half-a-cycle out of phase with the extra interdigitized pair of needle bars. However, it was found that adequate fabric support guides, Fig.3.2.(9),
Fig. 3.1  GENERAL VIEW OF FIRST POWERED RIG
Fig. 3.2 SECTIONAL VIEW OF FIRST POWERED RIG
Fig 3.3 NEEDLE ORBITS USED ON FIRST POWERED RIG
and high base fabric tensioning kept the base fabric deflections within acceptable working limits and so the extra pair of needles was removed. The retention of the interdigitized linkage served to dynamically balance the stitching linkage thereby producing an extremely smooth-running rig.

3.1.2. Looper Configuration

The loopers were in the form of hooks, Fig.3.4.(a), which moved up to the yarns between the base fabric and the extracted needles; having hooked the loops of yarn the loopers then moved down to allow the needles to re-penetrated the fabric. The hooked ends of the loopers were necessarily rather small to suit the gauge of the needles (12 per inch) and consequently the loops occasionally slipped off the hooks when the latter moved away from the needles. To prevent this, a shogging motion (i.e. side-ways in the weft-wise direction of the base fabric) was introduced such that the loopers moved up to the yarns and then across to hold the loops firmly (see Fig.3.4.b).

3.1.3. General Appraisal

The powered test rig served to demonstrate the production of locked-loop fabric at speeds up to 1300 stitches per minute, which was a particularly remarkable achievement considering that all the loopers and needles were individually hand-made. The addition of the shogging motion to the looper hooks solved the immediate problem of yarn slip-off but the rig still exhibited a certain amount of random pile height variation per stitch and this will be discussed later in sub-section 4.1.2. The balancing of the linkage system by an out-of-phase duplicating linkage produced a low noise level rig and even permitted the use of clear plastic shaft support plates to facilitate photography. The main criticism of the rig related to the inaccessibility to the stitching zone and finished pile fabric in that the linkage mechanism driving the needles was positioned in such a manner that threading the needles was a very awkward procedure. Moreover, the finished pile fabric moved downwards so that it could not be inspected closely until many stitches had been produced. However, both of these criticisms were rather unfair in that they relate purely to commercial requirements, which was not the fundamental objective of producing the research rig which, for expediency, was designed around an existing obsolescent cast iron machine tool bed. Nevertheless, these criticisms must not be ignored when constructing more advanced rigs.
Fig. 3.4  HOOKED LOOPERS USED ON FIRST POWERED RIG
3.2. Undergraduate Projects (1967 to 1972)

There have been several undergraduate final year projects relating to the locked-loop process since it was first conceived. Prior to the construction of the first powered rig, B. Linger and J.E. Vine considered some of the basic concepts involved in producing the locked-loop fabric, but their work was confined to feasibility studies. M.R. Kneal investigated innovative 'stop motion' devices and yarn breakage detection systems. J.B. Gerrard produced a solution for a variable intermittent yarn feed device but its use could only be applied to constant pile height fabrics. Unfortunately this vast amount of background study provided no basis for developing a sculpturing system on the locked-loop process.

3.3. Commercial Machine (1970 onwards)

The engineering aspects of the commercial 'LOCSTITCH' machine (Fig.3.5.) produced by Pickering Locstitch Ltd., the prototype version of which was designed by G.R. Wray and G.F. Ward at Loughborough University of Technology 1970, must be considered in some depth, as the author's research rig for producing sculptured pile fabric was based on the standard prime movers of this machine. However, only the areas relevant to the actual stitching process are discussed here, ancillary equipment and control systems being disregarded.

3.3.1. Specifications

The specifications given below relate to the stitching capabilities of the commercial machines, which should be either adhered to or improved on where possible when making further developments.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needle Gauge</td>
<td>Nominal 13 per inch - 0.078 inches</td>
</tr>
<tr>
<td></td>
<td>(Nominal 52 per 10 cm. - 1.981 mm.)</td>
</tr>
<tr>
<td>Sewing Width</td>
<td>3 metres</td>
</tr>
<tr>
<td>Stitching Pitch</td>
<td>Variable increments of 6, 8, 10, 12, or 14 stitches per inch (24, 32, 40, 48, or 56 stitches per 10 cm.)</td>
</tr>
<tr>
<td>Pile Height</td>
<td>Infinitely variable on either fabric face from 0.070 inches (1.8 mm.) through to 0.200 inches (5 mm.). Also zero pile height can be obtained simply by omitting loopers.</td>
</tr>
<tr>
<td>Speeds</td>
<td>Operating speed - 750 double stitches per minute. Inspection and setting up speed 50 double stitches per minute</td>
</tr>
</tbody>
</table>
Fig. 3.5  THE PROTOTYPE LOCSTITCH MACHINE
3.3.2. Needle Motions

The needle bars on the commercial machine are driven by a cam/linkage system which is completely different from the needle mechanism of the first powered rig. Fig. 3.6. illustrates the conjugate cam modules, several of which are stationed along the sewing width at 16 inch intervals to provide needle bar stability and these are provided on both sides of the base fabric. The primary conjugate cam set (1) mounted on the main drive shaft (2) reciprocates the link (3) via a bell crank (4). This provides the primary motion to the needle bar (5). The secondary motion is derived from another conjugate cam set (6) which, through the various links (7), provides a movement at point (8) on the main needle bar link (3). The length of link (9) may be adjusted in order to obtain changes in secondary needle displacement, thereby creating the variable stitching pitches listed in sub-section 3.3.1. Fig. 3.7.(a) is a curve representing the primary displacement of the needle points. The motion between positions 13 and 7, which correspond to the needles moving into the base fabric, is a parabolic function. The needle retractive motion between 7 and 13 is a cycloidal function and the combined effect of the two motions produce a quick-return action for the needles. Fig. 3.7.(b) is a plot of the secondary displacement of the needles relative to the point at which the needles first enter the base fabric. The full line represents the displacement motion for maximum stitching pitch and the dotted line that for minimum pitch. It is obvious from this graph that the secondary cam design was based on the maximum stitching pitch position because of the straight-line portion, indicating constant velocity equal to base fabric speed. When stitching pitch adjustment is made however, the secondary displacement becomes distorted in the area where a straight line is ideally required. Further comment about this distortion will be made in section 9.1.2. Fig. 3.8. shows the resultant orbits of the needle points produced by the cam modules. The critical positions of the orbits are, the needle penetration point (1) which is the datum point of the orbits, the positions at which yarn pick-off occurs (6) and (16), and the needle point clearance when looper shogging occurs, i.e. between (11) and (14).

3.3.3. Looper Configuration

The looper elements used on the commercial machine are assembled in the form of a reed by being cast into a plastic strip illustrated in Fig. 3.9.(a). Fig. 3.8. shows the relative positions of the needle orbits to the looper settings (from 0.070" to 0.200").
Fig 3.6  CONJUGATE CAM MODULE
(a) NEEDLE PRIMARY DISPLACEMENT

(b) NEEDLE SECONDARY DISPLACEMENT

(c) LOOPER SHOOGING DISPLACEMENT

Fig. 3.7 NEEDLE & LOOPER DISPLACEMENT CURVES
Fig. 3.8 NEEDLE ORBITS ON COMMERCIAL MACHINES
Fig 3.9 STITCHING ELEMENTS USED ON COMMERCIAL MACHINE
It will be noticed that the looper is moved at a 75° angle to the base fabric when it is preset to a particular pile height; this is presumably to maintain clearance between the loopers and needle bar. Banks of looper reeds are mounted on a sliding member so that they can be shogged transversely between the base fabric and the needle points. The shogging drive to the looper banks is derived from a barrel cam situated at one end of the machine. The total displacement of the loopers is 0.078"; i.e. the needle gauge, and they make one pass per needle cycle. Therefore the total cycle of the shogging motion is twice the cycle time of the needles. Fig. 3.7.(c) shows the shogging displacement curve of the loopers in relation to the needle motions.

3.3.4. General Appraisal

The cam modules are situated such that the finished pile fabric, which is produced in an upward direction, can be viewed immediately after stitching. Machine balancing is achieved by various counterweights built into the cam module linkages and also by positioning a weighted motion system between the cam modules, which are stationed at 18 inch intervals along the sewing width of the machine. Thus the total needle motion system is very stable, compact, and quiet. However, the primary cam displacement curves, consisting of cycloidal and parabolic functions, do not produce the most favourable acceleration characteristics and it would seem that there is room for further improvements. The shogging member, on which the looper reeds are mounted, is constrained by a slideway lined with a low friction material. This slideway poses certain alignment problems especially on large sewing width machines. The rolling action of the barrel cam follower, which drives the shogging member, must also exhibit certain undesirable dynamic characteristics. There is always scope for improvement of every design and although it is not within the terms of reference for this project it was considered that suggestions for improvement to the standard machine should at least be recorded. Chapter 9 of this thesis was therefore devoted to certain design recommendations for improving the needle and looper motions of the standard commercial Locstitch machine.

3.4. Project Work Running Concurrently (1973-1974)

The development of the locked-loop pile fabric patterning system forms only a part of the present work that is currently being undertaken within the Department of Mechanical Engineering, Loughborough
Some of this work has not as yet been published and thus can only be mentioned briefly.

3.4.1. Linkage Synthesis

Postgraduate research into the computer synthesis of a needle motion linkage is being carried out\textsuperscript{12}. The object of the research is to replace the cam modules (Fig. 3.6) with a pure linkage system that produces a suitable needle orbit for the locked-loop process. The elimination of expensive precision ground conjugate cams should prove most beneficial to the dynamic characteristics of the process. At undergraduate level a design exercise is being conducted to convert the computer synthesised systems into practical engineering applications.

3.4.2. Sculpturing

Final year project student, J. Robinson, has been working on the development of a pile sculpturing system for the locked-loop process, within similar terms of reference to this work. Robinson's report\textsuperscript{13} is now to hand and it contains many useful references to textile patterning devices as stated in sub-section 2.1.1. However, Robinson's suggestions for sculpturing the locked-loop fabric contains certain dubious engineering features that would need further investigation, and his report was too late for these to be made in the time available for completing the particular sculpturing system described in this thesis.

3.4.3. Dynamic Analysis

Work has recently started at undergraduate level into dynamic considerations of the looper manipulation mechanism designed in sub-section 4.3.6. Detailed analysis will be important when the design is appraised from the commercial application viewpoint. Time did not permit such an analysis to be thoroughly considered in this report and thus the undergraduate project\textsuperscript{14}, when submitted, could provide some useful 'back-up' information.

3.4.4. Yarn Feed

The formation of different loop heights in-process involves the feeding of varying yarn quantities per stitch or per pattern change. This will require a specialized yarn feed system. A discussion of the problem and a solution is offered in section 6.2., but more detailed investigations are also being carried out by an undergraduate project student\textsuperscript{15}. It is hoped that the outcome of both these studies will result in a practical commercial system which may be of use to other pile fabric processes as well as the locked-loop stitch process.
CHAPTER 4

DESIGN OF A RESEARCH RIG FOR SCULPTURING

4.1. A Study of the Looper Requirements

The object of this study was to determine what components and motion requirements were needed in the stitching zone in order that a sculpturing system could be engineered to suit the basic terms of reference, (section 1.3.) The study involved an analysis of the exact locked-loop stitch formation principles. Investigations were made into the relationships between the needle points, needle eyes, and the yarn itself, together with considerations of the effects that the base fabric and different shaped looping elements might have.

4.1.1. The Necessity for Loopers

The locked-loop stitching process is such that if there were no looping elements at all, zero height pile would be produced. This is because as the eye of the needle penetrates the base fabric the yarn is dragged from the pile loop just formed as well as from the supply yarn (Fig. 4.1.a). This would occur even if the supply yarn tension was zero because of the frictional drag produced on the yarn between the needle flank and the base fabric; there would be no control over the tension in that portion of yarn which has been forced through the base fabric, and the yarn would not travel through the needle eye at this stage thereby resulting in the pile loop being pulled down to zero height. This effect was observed on the powered rig (section 3.1) when the yarn dropped off the hooked looping elements. As this occurred the pile height was continuously reduced until the needle reached bottom dead centre (Fig. 4.1.b). However, if, prior to the needle eye penetrating the base fabric, a metered amount of yarn was to be 'pumped' or 'injected' into the cycle then there would be too much yarn for the needle stroke to accommodate and a pile loop could be formed without loopers (Fig. 4.2.a). To ensure that this excess yarn required was not produced at the yarn supply side of the needle eye, a hollow needle could be used. This idea was postulated by Vitols1 for making non-sculptured fabrics and indeed hollow needles are not uncommon in the tufting industry (sub-section 2.1.8). However, for the locked-loop process the hollow needle bore would need to be in the region of 1 mm (0.040") diameter to allow the various irregularities in the yarn to pass through. There would need to be in the region of 0.33 mm (0.015") minimum metal thickness around the bore if the needles are not to be too brittle and this thickness needs to be increased in the region where the
Needle Path

Supply Yarn

Base Fabric

(a)

Needle Path

Hooked Looper

Loop just dropping off hook

Needle B.D.C.

Loop height will be reduced by $x/2$

(b)

Fig. 4.1 PILE HEIGHT CHANGE WITH NEEDLE PENETRATION
Large amount of yarn injected into cycle

Needle at B.D.C.

Pile formed

(a)

Needle T.D.C.

Yarn available for small pile height

Yarn available for large pile height

(b)

(c)

Fig. 4.2 POSSIBLE PILE HEIGHT CONTROL WITHOUT LOOPERS
complementary needle picks off the yarn as this would occur over a hollow section (Fig. 4.2.b). Apart from the obviously difficult needle manufacturing problems, the cross-section of the needle would become 1.90 mm (0.075") thick which means that the use of 13 gauge needles (2 mm 0.078" pitch) would not be possible. Even if interdigitized needles were to be used (sub-section 3.1.1) the base fabric distortion in the weft direction would be too excessive. Instead of using hollow needles the stroke of the needles could be increased when outside the base fabric since this would create the necessary extra yarn for producing varying pile loops (Fig. 4.2.c) However, because the needles are also required to pick up the yarn from the complementary needle, not only would the stroke have to vary but also the dynamic characteristics. This would impose great engineering difficulties if applied to individual needles per stitch when forming a sculptured pattern. Thus it would seem impractical to develop a sculpturing system without the use of some form of looping element. The criterion is that yarn, in varying quantities, must pass through the needle eyes by overcoming the frictional drag between the needle flanks and the base fabric and apparently this may only be achieved by pulling the yarn tightly over a pre-positioned looping element.

4.1.2. Hooked Loopers

Two ways of controlling the pile height are possible when using hooked loopers:

(a) By forming maximum pile height every time but controlling the instant in the cycle when the yarn drops off the hook, such that further penetration of the needle drags the pile loop to a certain height. This yarn drop-off timing position would be very critical because at high speeds (750 st/min. say) a variation of position of, say 10 milliseconds, represents a needle travel of 3 mm (0.12") which would cause a pile variation of about 1.6 mm (1/16") (Fig. 4.3.a). Due to the inherent yarn characteristics of variable elasticity etc., this critical yarn drop-off position could not be guaranteed and a pile height random variation of 1.6 mm (1/16") would not be acceptable. This phenomena was observed on the powered rig (section 3.1.) when the loop yarn tension becomes too great for the hooks to hold and the yarns drop off the hooks at different needle penetration positions.

(b) The second possibility of varying the pile height with hooked loopers would be to move them in and out to set positions depending on the pile height required and then to drop off all the looped yarns at the same time on the retraction stroke of the needles, i.e. when the latter is demanding no more yarn (Fig. 4.3.b) After each pile loop formation the loopers would have to be shogged to drop off the yarns positively so that large loops would not be carried back downwards into the stitching zone.
Needle B.D.C.

Max. height

Pile height produced = Max. height - \( \frac{X}{2} \)

(a)

Yarn just dropping off hook

Max. height

Pile height produced = Max. height

(b)

Hooked loopers at controlled pile height

At this position yarn can be shogged off looper

B.D.C.

Large support beam to carry looper control box

Separate drive shaft for looper movements

Looper control box

(c)

Hooked loopers

Needle drive cam module

Yarn feed

Main drive shaft

Fig. 4.3 POSSIBLE PILE HEIGHT CONTROL WITH HOOKED LOOPERS
when the loopers move to pick up the next yarn loop. This would create no immediate problems, but the total machine layout must be considered from the viewpoint of applying individual controls to each hooked looper to vary its position and thus produce a sculptured pattern. Fig. 4.3.c indicates that a large support beam would be required to carry the looper control box across the stitching width of the machine and a separate drive shaft or prime mover would also have to span the stitching width to manipulate the individual loopers. The sculptured pile produced would not be visible for many stitches after production due to the position of the looper control box and the needle accessibility would be considerably reduced thereby creating difficulties when threading the needles. Therefore any system with the hooked loopers positioned on the pile formed side of the needles would probably be commercially unacceptable. However, the concept of hooked loopers should not be completely dismissed, as the possibility exists of using inverted hooks, as shown in Fig. 4.4.a, whereby varying the pile height could be achieved by varying either dimensions x or y. The main problem occurs in removing the yarn from the hook. If this were not done positively the pile would be dragged back into the stitching zone, thus causing entanglements. Shogging to remove the loop could only be done when needle N1 (Fig. 4.4.a) has left the fabric but at this stage the needle N2 will have pierced the base fabric thereby restricting any shogging motion. In order to shog and miss N2 the hooked looper could be shaped as in Fig. 4.4.b. It will be apparent from this illustration that a reed type looper, as used by the inventors for their design of the current commercial Locstitch machine (sub-section 3.3.3.), has evolved from such thinking, since the necessity for a hook is thereby removed.

4.1.3. Back-Robbing

The technique of back-robbing the yarn from a pile loop is used extensively for sculpturing tufted fabrics (sub-section 2.1.8.) and therefore must be considered as a possibility for sculpturing the locked-loop process. To achieve this the needle must reach bottom dead centre with the yarn tight over a looping element and as the needle retracts, the yarn must be dropped off the looper. Then upon further needle retraction the yarn would need to be stopped from travelling through the needle eye by providing, in effect, a reverse yarn feed at the same rate as the needle retraction (Fig. 4.4.c). This approach appears to have distinct possibilities except for one undesirable feature. It will be observed from Fig. 4.4.c that the path through which the yarn is to be robbed from loop 'A' passes through the base fabric and a locking loop 'B', around the complementary needle N1, out of the base fabric and again through the locking loop 'B'
Fig. 4.4 POSSIBLE INVERTED HOOKED LOOPERS AND BACK-ROBBING
At this point in the cycle needle N1 is also tending to increase the tightening effect of the locking loop 'B' as the yarn is pulled tight over the looper Ll. Therefore, it was envisaged that high yarn tensions would be involved in the stitching zone just when the required reverse yarn feed would need to be applied. Trials were carried out on the manually operated rig (sub-section 2.2.2. Fig.2.3.) in order to quantify the effects of these high yarn tensions. The tests were not exhaustive due to the unavailability of different types of yarn, but the general result was that most yarn of the types likely to be used on the locked-loop process broke before enough tension was applied for a satisfactory back-robbing of the pile-loop. However, the needles were static when these tests were performed and the situation could well improve should the needles be moving with their correct orbital motions. Therefore, it was decided to postpone the technique of back-robbing until later in the research programme when the needle dynamics could be taken into account, (section 7.2.).

4.1.4. Reed Type Loopers

The reed-type loopers, as described in sub-section 3.3.3. are positive and produce a uniform pile height, but they do exhibit certain unsatisfactory characteristics. Improvements to these characteristics of the standard looping element will be suggested in section 9.2. as they are not immediately relevant to the development of a sculpturing system, although, if adopted, the suggestions should improve pattern reliability. However, the design of the reed looper end must be resolved at this stage. When a small reed tip, as illustrated in Fig.3.9.(b) was used, large pile height loops occasionally slipped off the reed prematurely and, as the needle continued its penetration into the base fabric, the pile loop was pulled down to zero height. This problem was overcome on the commercial machine by increasing the reed tip length (Fig.3.9.(c)). However, with the longer reed tip and with the machine set to the smaller stitching pitches, two or three needle cycles elapse before loop slip-off occurs (Fig.4.5.(a)). This situation would be unacceptable if the looper is to be moved to different pile height settings per stitch for sculpturing. Although increasing the looper tip length apparently overcame the problem of yarn slip-off on the commercial machine, it was believed that the real solution may have resulted from the method of adjusting the loopers. Consider Fig.4.5.(b) which shows the needle, yarn, and looper relationships when looper shogging is about to occur. The looper set at 1.8 mm (0.070") pile height is well positioned to pick-up the yarn but the looper set at 5.0 mm (0.2") pile height is dubiously positioned for yarn pick-up and the likelihood of the yarn
Several loops over looper

Loops slip off after 3 cycles

Needle position when looper is shogging

Proposed large pile height setting

Existing small pile height setting

Existing large pile height setting

Needle Path

Fig. 4.5 CHARACTERISTICS OF STANDARD LOOPER SETTINGS
slipping off the looper end is apparent. There seems to be no real justification for adjusting the loopers in a plane inclined at $75^\circ$ to the base fabric. It was therefore concluded that looper adjustment could be perpendicular to the base fabric and the need for long reed tips might then be eliminated. The use of reed-type loopers for producing a sculptured locked-loop pile fabric has been shown to offer more favourable conditions than the other looping methods discussed above, and therefore the development of a patterning system resolves into providing suitable reed looper manipulation and selection devices.

4.1.5. A Looper Orbit

It is apparent from the previous sub-section that the most difficult sculpturing system to develop would be one that produces fabric to specification I (sub-section 2.2.4. high loops and low loops). This is because low loops would need to be forcibly slipped off the loopers before the latter could move to a high pile height setting. In the case of fabric made to specification II (sub-section 2.2.4. pile loops and zero height loops) the zero height loops would not be formed over the loopers at all and it is envisaged that the premature yarn slip-off occurring on small length reed tips could be used to advantage to create specification II sculpturing. Therefore the decision was made that this research should be concentrated on solving the problems for developing the most difficult sculpturing system, and thus the information acquired during the research would then provide a valuable basis on which to develop simpler systems. The remainder of this chapter is consequently devoted to the study of making a two pile-height sculptured fabric to specification I.

Fig. 4.6(a) shows a proposed orbital relationship between the looper and needle point. The reason for the movement from C to D would be to cast-off a small height loop, which must be done because simply moving the looper to a high position (C to A) would pull and distort the small loop stitches. The looper starts to move down from C to D when the yarn has been picked off the penetrating needle by the complementary needle. When the needle has travelled from D' to A' the looper has returned to the horizontal position and then shogs sideways. As the needle re-enters the base fabric the looper moves towards the base fabric also but is stopped short by an amount equal to the pile height required. Thus, as the pile height is varied, the looper orbit changes (see Fig. 4.6. b). In sub-section 4.1.1. it was concluded that the yarn would need to be pulled tight over the looper in order to drag the yarn through the needle eye. This means that at high pile heights the yarn tension may be such that instead
Needle point motion when looper is shogging

Looper Orbit

Looper position during shogging

Needle Path

(a)

Fig. 4.6 POSSIBLE LOOPER ORBITAL DISPLACEMENTS
of the yarn slipping off the looper end it could be dragged down with the
looper into the stitching zone between the gaps of adjacent needles. To
avoid this a slightly modified orbit is proposed as in Fig. 4.6. (c)
using a base orbit and then creating a yarn tension relief motion before
returning the looper to the reset, high pile, position. To study the
motions in more detail, one cycle of the needle orbit was divided into the
16 equal time-intervals drawn in Figs. 4.7. to 4.10. Loopers L1 have an
assumed selection of minimum pile-height, and to show the orbital relation-
ships in one cycle only, loopers L2 have an assumed selection of maximum
pile height.

Left-hand side of base fabric - L1 shown selecting the minimum
pile-height:-
Station 1: Needle N1 is at the datum point 1 of its orbit. Looper L1
is at the reset position and has been selected to produce a
minimum height pile loop.
Station 2: Needle N1 has pierced the base fabric securing the yarn over
the looper. To avoid the unnecessary travel of yarn through
the needle eye and over the looper end, the latter begins to
move towards the base fabric at twice the needle penetration
rate.
Station 3: Needle N1 continues its penetration into the base fabric and
looper L1 maintains its control of the yarn loop.
Station 4: Needle N1 continues its penetration as looper L1 reaches the
minimum pile-height position and dwells.
Station 5: Needle N1 continues its penetration but, as L1 is in a dwell
position the yarn tightens around the looper and begins to
travel through the needle eye demanding yarn from the supply.
Station 6: Ditto.
Station 7: Needle N1 reaches B.D.C. (bottom dead centre), so no more
yarn is demanded from the supply. Looper L1 now commences
to move downwards between adjacent needles in order to slip
off the low height loop.
Station 8: Needle N1 starts to retract to cause the yarn to pucker into
a loop between the needle eye and the fabric so that the
incoming needle N2 can easily pick-up the stitch. L1 has
slipped off its loop and is returning to the reset position.
Station 9: N1 retracts further, and L1 is returning to the reset position.
Station 10: Ditto.
Station 11: N1 is still retracting. L1 reaches the reset position and
Station 12: N1 has almost completely retracted, and L1 dwells in a mid-position of its shog (see Fig. 3.7.c.) while at the reset position.

Station 13: Ditto.

Station 14: N1 commences to move towards the base fabric and L1 has almost completed shogging.

Station 15: N1 moves towards the base fabric. L1 has finished shogging but remains in the reset position to allow slack yarn to be taken up.

Station 16: N1 moves towards the base fabric. L1 is about to move to the next selected pile height position.

Recycling then occurs as from Station 1 and during the next cycle the looper L1 makes the 'return shog' back to the position shown in station 1.

Right-hand side of base fabric - L2 shown selecting the maximum pile-height:-

Station 1: Needle N2 is retracting from the base fabric, Looper L2 has just cast-off a minimum height pile loop and is returning to its reset position.

Station 2: Needle N2 is leaving the base fabric as looper L2 rises to a reset position clear of N1.

Station 3: Needle N2 continues to retract. Looper L2 is now at the reset position and is about to shog sideways.

Station 4: Needle N2 is about to reverse direction. Looper L2 dwells at the reset position while shogging occurs and while pattern selection takes place.

Station 5: L2 is shogging across N2, taking up the slack yarn.

Station 6: Ditto.

Station 7: L2 has finished shogging as N2 now moves towards N1 for yarn pick-off.

Station 8: N2 picks up the yarn from N1. Pattern selection has been made for the maximum pile loop.

Station 9: N2 is at the datum point 9 of the orbit and L2 is about to move to the required pile-height setting.

Station 10: N2 penetrates the base fabric and L2 is arrested at the maximum pile position.

Station 11: Ditto.

Station 12: Ditto.
Station 13: Ditto.
Station 14: Ditto.
Station 15: N2 is at B.D.C. and no more yarn is demanded by the needles. L2 commences to move down the gap between adjacent needles in order to slip off the loop formed. Notice that L2 moves slightly towards the base fabric to relieve the yarn tension around it.
Station 16: N2 starts to retract so that NL can easily pick-off the locking loop provided. L2 has slipped off the high-pile loop and is moving to the reset position.

Recycling then occurs as in station 1 and during the next cycle the looper Ll makes the 'return shog' back to the position shown in station 1.

It may be observed from Figs. 4.7 to 4.10 that the looper orbit is so arranged that three elements per needle pitch are never simultaneously grouped side-by-side i.e. the loopers of the L.H.S. are never sandwiched by the needles of the R.H.S. and vice-versa. This is not provided for on the existing commercial Locstitch machine and therefore this proposed orbital looper system removes the necessity for critical looper/needle clearances.

Having decided upon the looper motion to be employed, the task was then to design and build a research rig to demonstrate the principles and prove the sculpturing system.

4.2. Basic Rig Construction

The research rig was built as a foreshortened version of the commercial machine, using only two standard cam modules, one to each side of a narrow width (200 mm 8 inches) base fabric. The housing for the cam modules was a welded fabrication which simulated the main structure of the commercial machine and allowed the cam followers and linkages to be conveniently lubricated, (Fig. 4.11). A chain and gear arrangement connected the two main drive shafts of the cam modules and also provided the standard barrel cam with a 2 : 1 speed reduction, (Fig. 4.12). The arrangement for driving the two main shafts is illustrated in Fig. 4.13 and consists of a slow-speed drive (1) and a variable high-speed drive (2). The variable-speed pulley system (3) provided the necessary control of base fabric tension and feed rate. The fact that the existing standard needle drive cam modules and the standard barrel cam for looper shogging were used, imposed certain limitations on the design of the sculpturing system, but in the time available for this research it would not have been possible to redesign and build new units. Moreover, the position of the cam modules in relation to each other created a space of only 100 mm (4 inches) between the housing and the
Fig 4.7 ELEMENT RELATIONSHIPS
Fig 4.8 ELEMENT RELATIONSHIPS

5 - 8
Fig 4.9 ELEMENT RELATIONSHIPS
9 - 12
63
Fig 4.10 ELEMENT RELATIONSHIPS
13 - 16
Fig. 4.11 STANDARD CAM MODULE USED ON THE RESEARCH RIG
Fig. 4.12  BARREL CAM ARRANGEMENT USED ON THE RESEARCH RIG
Fig. 4.13 DRIVE SYSTEM USED ON THE RESEARCH RIG
base fabric; and this was a restricting criterion for the design of the looper manipulation mechanism which had to fit into that space.

4.3. Looper Manipulation Mechanism (Specification I)

4.3.1. Initial Ideas

The looper orbital motion sketched in Fig. 4.6.(c) could be generated by a simple 4-bar linkage, but in order to change the orbit for varying pile-heights requires a selectable linkage system. Therefore it was decided to break down the orbit into two displacement components; a primary motion at right angles to the base fabric and a secondary motion parallel to the base fabric. The primary motion could then be selected to stop at a required pile height setting independently for each looper, while the secondary motion could be common to all loopers. Thus the system evolves into a prime mover or driving mechanism with lightly-loaded selection devices.

4.3.2. Basic 4-Bar Looper

Within the space limitations of the research rig a 4 bar linkage was designed to produce a primary looper motion essentially at $90^\circ$ to the base fabric, (Fig. 4.14 a). The driving link (1) may be oscillated, and at predetermined positions arrested to hold the looper at a particular pile height. Also, by providing link (2) with a vertical displacement, the desired secondary looper motion could be achieved.

4.3.3. Trigger Mechanism

The design of the basic 4-bar linkage was modified as in Fig.4.14 b so that a lightly loaded trigger mechanism could be incorporated. A prime mover (7) common to all loopers may be oscillated on the tail (3) to move the looper backwards and forwards and the trigger (4) fired to hold the linkage at a preset position. Thus only small forces are generated in the looper links and the holding forces are transmitted to pivot (5) instead of to the firing device (6).

4.3.4. Hydraulics - Pneumatics - Electronics

The devices used for firing the looper triggers depend upon two factors, firstly the method of pattern information storage and retrieval and secondly the time available during the needle cycle for firing the triggers. At the maximum commercial machine stitching speed of 750 cycles/min the needle cycle time is 0.080s, and the need to provide sufficient time for the looper to be accelerated and decelerated consequently reduces the period in which the actual trigger firing can occur. The maximum time available for trigger firing was assessed at this stage to be 0.035s, i.e. the maximum time the loopers could be allowed to dwell at the reset position. Therefore the system becomes dependent upon reading pattern information at 12.5 Hz
Fig. 4.14  BASIC 4-BAR LOOPER  
LINKAGE
frequency and operating the triggers at the same frequency but only utilizing 0.035s of the period. At these speeds, mechanical pattern reading did not seem practical and therefore hydraulic actuation was considered. Rotary valves could be used to meet the frequency requirements but unfortunately direct reading of patterns cannot be obtained with such devices and consequently the pattern information would need to be transmitted electrically into the hydraulic system via solenoid valves. This seemed to present unnecessary pattern information conversions and therefore further study of this method was abandoned. A paper tape with a pattern array punched into it could, however, be read pneumatically and, via fluidic logic circuitry and turbulence amplifiers, the triggers could be operated with air-cylinder plungers. Further investigation however revealed that, whilst the logic in general would be capable of 12.5 Hz frequency, the response of the input and output devices could not be expected to operate at much above 7 Hz to allow for full transmission time through the logic and for the reaction time of feedback signals so generated on the program system itself. Therefore because of the time restrictions for completing this research it was decided not to pursue the possibilities of uprating the performance of such pneumatic reading devices. The remaining alternative was to operate the triggers electronically, and, after evaluating the use of piezo-electric crystals and similar sophisticated items, the problem resolved into a study of the performance characteristics of electromagnetic components.

4.3.5. Solenoid Response

It was intended to independently operate the loopers as grouped pairs (see sub-section 2.2.4.) so that the pitch of the triggers would be 4 mm (0.156") to such that the latching mechanism was in a staggered arrangement. This then governed the physical size and weight of the triggers and the largest one in the stagger was used for experimentation in conjunction with electro-magnetic components. Fig. 4.15(a) shows the small experimental test rig used, the largest trigger (1) pivoted at (2) to the trigger by opposing the magnetic force. The travel of the latching end of the trigger (4) was set to 1 mm (0.040") to give adequate engagement and disengagement tolerances on the 4-bar looper drive link (Fig. 4.14 b, item 3) and would alleviate any problems due to trigger bouncing which might occur. Therefore the ends (5) of the largest and smallest triggers were required to move approximately 3.2 mm (1/8") and 1.6 mm (1/16") respectively. Fig. 4.15 (b) shows a solenoid that was manufactured to attempt a direct pull on the trigger but
Fig 4.15 APPARATUS FOR TESTING SOLENOID RESPONSE
at the displacements required the energy losses in the air gap were far too great and there was no appreciable trigger response. Fig. 4.15 (c) is a commercially produced moving iron core solenoid that offered an alternative both in physical size and performance. However, at its continuous rated voltage (24 volts) the response time, for operating the trigger against any reasonable spring load, was outside the 0.035s required. To improve the response time a 100 volt pulse was applied to the solenoid for 0.010s which overcame the inertia of the trigger and fired it, then the voltage was instantaneously dropped to a 24 volts holding load so that the solenoid would not burn out. By operating it in this manner the response time of the trigger could be varied between 0.017s and 0.024s depending upon the spring return load and the 100 volt pulse time. It was also important to maintain the 0.035s for returning the trigger (i.e. solenoid de-energized) which was dependent upon the magnetic field decay time and the return spring load. Further experimentation produced a set of conditions that would result in a trigger speed suitable for the application. These conditions were 100 volt pulse for 0.012s dropping to 24 volt holding load and spring return force of 56gf (0.125 lbf) producing the resultant response time for the trigger of 0.020s in both the energized and de-energized modes of operation. This response time was well inside the 0.035s maximum allowable period and therefore it was decided to design a sculpturing system with the selection mechanism based on the independent operation of these solenoids.

4.3.6. Complete Design

Fig. 4.16 is a transverse sectional drawing of the mechanism designed for sculpturing the fabric on one pile face. The looper motion is split into primary and secondary modes via the 'swan-necked' arms (1) and (2) respectively. The primary cam (5) on the main shaft (6) of the machine reciprocates the 'nodding-bar' (7) on the tail of the looper 4-bar linkage (8), providing the near straight-line motion of point (9) perpendicular to the base fabric. When the 'nodding-bar' (7) moves to its lowest position, the loopers are at the reset part of the cycle and they must dwell there until pattern selection is made. The pattern selection is achieved by firing the triggers (10) with the solenoids (11) to arrest tail (8) such that as the 'nodding-bar' (7) is raised away from tail (8) the loopers 4-bar linkage (12), (13), (14) and (15) is arrested in a preset position, thereby resulting in a high pile. Naturally, if the trigger is not required to fire, the result would be a low pile-height as the leaf spring (16) would keep the tail (8) of the looper 4-bar linkage in contact with the raised 'nodding-bar' (7). The secondary cam (17) on the main shaft of the machine reciprocates a second 4-bar linkage (18), (19), (20) and (21) which is
Fig 4.16 SECTIONAL VIEW OF SCULPTURING MECHANISM
common for each looper element, although links (20) and (21) are merely provided for stabilization purposes. The motion of the secondary cam (17) lowers the looper elements to achieve yarn loop slip-off; when this occurs - the individual looper 4-bar linkages (12), (13), (14) and (15) pivot about centre (14). This will provide a yarn tension relief action as the loops are dragged off the loopers. The sideways shogging motion is derived from the standard barrel cam at the end of the rig (Fig. 4.12). The mass of the components to be shogged is minimised by providing two flexible struts (3) and (4), (Fig. 4.16). The flexible strut (3) is common to every looper and the flexible strut (4) is incorporated into each looper 4-bar as they are required to be manipulated independently.

4.4. Computer Aided Design

4.4.1. Mathematical Solution

The looper manipulation mechanism described in sub-section 4.3.6. was designed to fit in with the physical constraints imposed by the basic rig construction which was in turn determined by the dimensions of the commercial Locstitch machine. Having satisfied this requirement, the displacement curves of the primary and secondary looper cams were calculated. In order to obtain the correct looper orbital positions, as illustrated in Figs. 4.7. to 4.10., the whole of the mechanism was mathematically analysed from the chosen dimensions of the links such that the only variables were the cam displacements. Fig. 4.17. is a schematic diagram of the linkages showing the relevant dimensions used in these calculations. Appendix I contains the mathematical solution which was based on the instantaneous cartesian co-ordinates of the link centres with respect to the main shaft rotation. The mathematical solution of the total looper manipulation mechanism is not, in principle, a complicated derivation. However, to work through the whole calculation for every discrete main shaft angular position would have been an intensely time-consuming operation especially while making any modifications to the cam displacements in order to optimise the looper motion. Therefore the mathematical solution was rearranged so that the L.U.T. ICL 1904A computer could be programmed to print-out the looper co-ordinate positions relative to small main shaft rotational ordinates.

4.4.2. Cam Design

A desirable rise and fall motion for a high speed cam would be based on the cycloidal function\(^{16}\) and thus, both the primary and secondary cam displacements were initially designed as in Fig. 4.18 (a) and Fig. 4.19 (a) respectively. Using the computer the combined effects of these two displacement curves were calculated to produce the required orbit of the
Datum point at which needle pierces base fabric
looper elements, see Fig. 4.20. However, it may be observed from the acceleration curves of Fig. 4.18 (c) and Fig 4.19 (c) that there is a rather unfortunate rate of change (i.e. a pulse) at point 'X' in both curves, resulting from the contraflexure points in the velocity curves Fig. 4.18(b) and Fig. 4.19(b). It was desired that the cams should exhibit the most favourable dynamic characteristics possible in the circumstances because any pulses generated by them will be amplified through the linkage mechanism to the looper. Therefore a practical approach to cam design was devised to minimise any pulses produced by a cycloidal fall followed by a cycloidal rise, without appreciably affecting the displacement curves unfavourably. The computer was programmed to match the slope of the velocity curves in order to produce a new 'non-descript' curve in the region of likely pulses. This was achieved by also maintaining equal the integral of the new curve with that of the original velocity curve between the points of slope matching. Therefore the displacement curves remained virtually unchanged as in Fig. 4.21 (a) and Fig 4.22 (a) whilst the velocity and acceleration characteristics were theoretically improved as shown in Figs 4.21 (b) and (c) and Figs. 4.22 (b) and (c).

4.5. Implementation of the Mechanism

4.5.1. Production Problems

In the absence of precision cam manufacturing facilities, the computer was used to determine the polar co-ordinates of the primary and secondary disc cam profiles at 0.5° intervals. The cams were then machined in steps using precision milling techniques and finally hand-polished to form a smooth surface profile. It will be noted that in sub-section 4.4.2. considerable effort was concentrated on obtaining near optimum cam displacement curves, but in practice the accuracy might well be impaired by the manufacturing process used. However, final inspection of the cams revealed that their profiles were well within acceptable limits for the purposes of this research. The design of the looper 4-bar linkage was such that it suited the manufacturing skills and materials available. Fig. 4.23 shows all the small elements required for each pair of needles and at this stage jigs and fixtures were made in order that the dimensional accuracy of several components could be maintained within close tolerances. It may be observed from Fig. 4.16. that the sculpturing mechanism was to be situated within a confined space on the research rig, thus creating difficulties in measuring the alignments of the various linkages and pivots relative to the needle bar and cam module. Therefore a mounting fixture was constructed to reproduce the relevant sizes of the cam module housing and to
Fig. 4.18  INITIAL MOTION CHARACTERISTICS FOR PRIMARY CAM
Needle orbital positions

(a) Displacement of Cam Follower

(b) Velocity of Cam Follower

(c) Acceleration of Cam Follower

Fig. 4.19 Initial Motion Characteristics for Secondary Cam

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7' & 8' occur when the basic looper 4-bar linkage is held at the high pile height position.

Fig 4.20 LOOPER ORBIT PRODUCED BY PRIMARY AND SECONDARY CAMS
Needle orbital positions

(a) DISPLACEMENT OF CAM FOLLOWER

(b) VELOCITY OF CAM FOLLOWER AT 750 RPM

(c) ACCELERATION OF CAM FOLLOWER AT 750 RPM

Fig. 4.21  MODIFIED MOTION CHARACTERISTICS USED FOR PRIMARY CAM
Needle orbital positions

(a) DISPLACEMENT OF CAM FOLLOWER

(b) VELOCITY OF CAM FOLLOWER
AT 750 RPM

(c) ACCELERATION OF CAM FOLLOWER
AT 750 RPM

Fig. 4.22 MODIFIED MOTION CHARACTERISTICS USED FOR SECONDARY CAM
Actual Size Looper 4-Bar Links and Triggers

Assembly Fixture and Hardened
Master Components

Fig 4.23 LOOPER ELEMENTS
facilitate the setting up of the sculpturing mechanism prior to assembly within the research rig. Fig. 4.24 shows the needle bar cam module mounted on the fixture together with the sculpturing mechanism and one looper 4-bar linkage. In this condition the primary and secondary sculpturing looper cams were phased with the primary and secondary needle drive cams and the orbits of the looper checked with those of the needles. Fig. 4.25 is a 'rear' view of the sculpturing mechanism showing the physical relationship of one typical solenoid firing trigger (1) to the rest of the mechanism. The corresponding grouped pair of loopers can be seen at (2).

4.5.2. Single Looper Stitching

The sculpturing mechanism was installed in the research rig and the stitching performance of a single looper element (as in Fig. 4.25) was studied. A temporary yarn feed and tension device was included so that high speed operation could be achieved. The solenoid was wired such that the required 100 volt pulse and 24 volt holding load (sub-section 4.3.5.) could be applied manually. At slow stitching speeds (18 st/min.) the looper orbiting system performed exactly as predicted in sub-section 4.1.5. although when the solenoid was operated to produce a high pile-height loop the loop tended to be drawn slightly downwards when yarn slip-off occurred. This indicated that the loop yarn tension relieving motion of the looper (i.e. R.H.S. of Fig. 4.10 stations 14, 15, and 16) was not quite adequate. However, the loop formation system was, at this stage, suitable for producing a controlled sculptured stitch. At higher stitching speeds (750 st/min) the control performance of the single looper element remained unaffected and the pile fabric structure produced was actually more uniform than that produced at the slow stitching speed due to the reduced 'snarling' effects of yarn twist and lower base fabric deflection during stitching. These particular effects, due to inherent properties of the textile materials rather than to the mechanical motions of the elements, are more relevant to the commercial Locastitch process and will therefore be discussed in detail in section 9.4. The leaf spring arrangement (item 16 of Fig. 4.16) for moving the looper into the base fabric under the control of the nodding bar (item 7) performed satisfactorily for the single looper. However, when the looper moved towards the base fabric the yarn also exerted a force on the looper and the sum of the two forces was restrained by the nodding bar. These forces would be excessive when more looper 4-bar mechanisms are introduced (each with a leaf spring) and therefore experiments were conducted in order to determine whether the yarn force alone would be sufficient to pull the loopers into the base fabric. The physical space within the stitching

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Fig. 4.24 SCULPTURING MECHANISM MOUNTED ON THE ASSEMBLY FIXTURE
Fig. 4.25 REAR VIEW OF SCULPTURING MECHANISM SHOWING ONE TRIGGER ARRANGEMENT
zone of the process prohibited accurate calibration of the force requirements but it was established that, with a supply yarn tension of between 15 and 20 gf applied at a point in the needle cycle when the needle eye (plus the yarn) has pierced the base fabric, the looper operated satisfactorily without the leaf springing arrangement.

4.5.3. Increase of Maximum Pile Height

The maximum pile height that could be achieved with the sculpturing system was 5 mm (0.2") i.e. the maximum height that may be obtained on the commercial machine. This maximum height is governed by the distance between the base fabric and the needle point when the latter is withdrawn to allow the looper to shog. However, observation of the process in three dimensions revealed that full advantage was not taken of the needle/looper clearances. Considering Fig. 4.10 station 14, at this position needle NL is at minimum clearance from the looper 1L (approx. 0.076 mm, 0.003") in the vertical plane (y) but is well clear of the looper in the horizontal plane (x).

At station 1L (Fig. 4.9.) the needle/looper (NL,LL) clearance appears to be minimal, however, a study of the shogging displacement curves (Fig. 3.7c) indicates that the looper should not interfere with the needle tip until at least station 12. Therefore it is suggested that the basic specification for maximum pile height (5 mm, 0.2") on both the sculpturing system and the commercial Locstitch machine is unnecessarily restricted. To demonstrate that pile heights of up to 7.6 mm, 0.3", (representing a 50% increase on the specification) may be obtained a motion increasing linkage was added under the nodding bar of the sculpturing mechanism as in Fig. 4.26a which modified the looper orbit to that shown in Fig. 4.26b. Higher pile loops were produced under these conditions but because the displacements of the primary and secondary looper drive cams were not matched for direct increases in primary motion loop distortion occurred when slipping off the low pile height loops. However, the experiment served to show that the pile heights may be effectively varied between 1.8 mm to 7.6 mm (0.07" to 0.3") and Fig. 4.27 illustrates the differentials obtained.

4.5.4. General Appraisal

In general the principle of the sculpturing system developed performed effectively although three items arose that required further consideration. Firstly, an assessment was made of the anticipated reliability of using the yarn as a means of applying a force on the looper of sufficient magnitude that the mechanical springs on each looper could be removed. This would mean that, as the looper is pulled towards the base fabric by the loop formed, the yarn would slide, under tension, over the
Fig. 4.26 ARRANGEMENT FOR OBTAINING INCREASED PILE HEIGHT
Fig 4.27  NEW PILE HEIGHT RANGE
looper end. It was decided to accept this compromise and to attempt
minimisation of the sliding effects of the yarn over the looper by cyclic
control on the yarn tension (this is analysed in section 6.1). The second
consideration was whether to increase the amount of yarn tension relief
required when slipping off high pile-height loops. However, to do this
would involve moving the pivotal relationship of the looper 4-bar linkages
and thus necessitate the tedious manufacture of new looper drive cams; as
the effects were only of marginal consequence, it was decided that the
considerable time necessary for this alteration would be unjustified. The
third factor to be resolved at this stage is how much importance should be
given to increasing the maximum pile height to 7.6 mm (0.3") as described
in sub-section 4.5.3. The object of this research was primarily to
establish the basic principles required for producing sculpture patterned
fabric and although the pattern on the pile face would be more effective
with larger differentials between high and low loop heights the overall
principles remain unchanged. Therefore, it was considered to be sufficient
merely to observe that pile heights of up to 7.6 mm (0.3") can, and have
been obtained with the system but that the research rig mechanism remained
capable of up to 5 mm (0.2") maximum pile height in its operating state for
this particular research project.

The next stage in the development of the research apparatus was
to manufacture several looper 4-bar linkages so that a reasonable sewing
width of fabric could be produced for assessment purposes; at the same
time an automatic pattern information storage and retrieval system should
be included to remove the manual operation of the solenoid triggers and
this is discussed in Chapter 5.
5.1. Versatility of the System

The mechanical system for obtaining pile height variations, whose development was described in chapter 4, may be controlled by any pattern storage and retrieval means that provides a near instantaneous array of electrical pulse signals. These signals would be required to relay 100 volt firing loads and 24 volt holding loads, as described in sub-section 4.3.5., because commercially obtainable solenoids were used. If specially wound solenoids had been developed for this particular application, then the arrangement could possibly be optimised, resulting in lower voltage ratings. However a means of synchronizing the pulse signals with the cyclic position of the needles, either mechanically or electrically, must be provided no matter what solenoids are used. Final appraisal of the versatility of the sculpturing system with respect to pattern storage must therefore depend upon the mechanical constraints that have been introduced. At the maximum commercial machine stitching speed of 750 cycles/minute, the needle cycle time is 80 ms, and the cams provide the primary looper motion with a dwell of 35 ms at the reset or select position. Experimentation in solenoid response times (sub-section 4.3.5.) showed that 20 ms was required for actual mechanical movement of the solenoid core and triggers from the time of receiving a signal, therefore 15 ms remained for the signals to be transmitted from the retrieval system through the control circuitry to the solenoids. A 15 ms transmission time imposes no restriction on the type of solid state electronic circuit logic (or equivalent) that might be employed, as time scales for such devices are a matter of a few microseconds. Thus the sculpturing system may be considered sufficiently versatile to suit most of the modern pattern storage and retrieval methods currently available. Fig. 5.1. is a block diagram illustration of the electronic requirements where the pattern input signals 'A' may be obtained from for example:–

(a) A pre-programmed digital computer or magnetic tape where the pattern signal converter 'B' becomes a wave-form shift register. A scan of say 1000 bits could be made in a few milliseconds and stored in the register until the synchronizing pulse releases the signals to the solenoid drivers 'C' which in turn fire the solenoid triggers 'D'. This would be followed by a re-scan, involving the storage of a further 1000 bits, thereby facilitating independent solenoid control.
Fig 5.1 PRINCIPLE OF PATTERN CONTROL CIRCUIT
(b) The pattern input signals may be in the form of light (or the absence of light) as in graphical scanning systems (sub-section 2.1.8.). In this case the pattern signal converter 'B' becomes a light sensitive diode which produces electrical signals for the solenoid drivers 'C'.

(c) The graphical presentation may be displayed on a television screen which provides the input signals 'A'. The pattern signal converter 'B' would then read the 625 or 405 transmission lines from the display to operate the solenoid drivers 'C' or be used in conjunction with example (a) for pre-programming a computer.

The three examples above are not the only methods of storing pattern information; they have been listed here merely to emphasize the versatility of the pattern control methods for the locked-loop sculpturing system described in chapter 4.

5.2. Electronic Requirements

The commercially obtained solenoids used in the research apparatus necessitated a specially designed driving circuit rated at the 100 volt pulse load and 24 volt holding load. Therefore in order to demonstrate that the sculpturing system was capable of producing patterned fabric at high speed the solenoid driving circuitry had to be developed in relation to a synchronizing pulse signal phased with the stitching cycle. This was achieved, as described in sub-sections 5.4.2. and 5.4.3., together with a special purpose power supply system (sub-section 5.4.4.). Thus the electronic requirements of the research rig were satisfied since all the other control functions necessary for the operation of such a system had already been developed commercially.

5.3. Research Rig Requirements

As previously mentioned (section 5.1.) the pattern input device may be derived from any means that provides a near instantaneous array of electrical signals. Financial resources excluded the use of a digital computer or a commercially available graphical scanning system (e.g. Singer remote pattern drum) because of the ancillary equipment required to prepare the pattern drum. Therefore it was decided to design and build a pattern information storage and retrieval system specially for the research rig within the following terms of reference:-

(a) Comparatively simple and cheap to manufacture,
(b) Simple pattern preparation means,
and
(c) Rapid pattern changing.
These criteria only exist on current patterning systems to a limited extent, and therefore any improvements could well benefit patterning on other processes as well as the locked-loop process.

5.4. Electronic Circuits

5.4.1. Pattern Read Signal

In order to provide a direct pattern reading system it was decided to use a method of graphical scanning. Existing commercial systems incorporate a transparent drum with a light source mounted internally and light sensor externally. This means that, when changing the pattern, the drum must be physically removed and replaced with another specially prepared drum. This undesirable feature was removed on the research apparatus by using the reflection of light from a polished metal drum surface and therefore, by interrupting the reflection with a painted transparent film, a pattern may be read. Fig. 5.2. shows the complete pattern reading head used on the research rig (the unit is inverted when installed).

Items 1 are commercially obtainable light emitting and light sensitive diode units with a predetermined focal range band which operate with infrared light out of the visible spectrum, thereby minimising the effects of changes in ambient light. One emitter/sensor was required for each solenoid together with the small printed circuit components (Fig. 5.2. item 2) which regulate the voltage outputs and square the wave-forms produced. The circuit diagram for the pattern read signal system is given in Appendix II.

5.4.2. Synchronizing Pulse

Fig. 5.3. illustrates the derivation of the synchronizing pulse. The disc with the slot (1) was driven mechanically, with a 1:1 speed ratio, from the cam module drive shafts. When the slot in the disc is rotated past the light source/sensor unit (2) a signal is transmitted to three power transistors (used as a switch) which divert a 100 volt pulse for 12 ms to the solenoid drivers. The length of the slot in the disc (1) provides a certain time period at maximum stitching speed for various capacitors to recharge. The circuit diagram for the synchronizing pulse unit is given in Appendix II. By adjusting the phasing of the pulse disc with the needle cycle, the solenoids are fired at a precise point in the cycle; this is at the beginning of the looper dwell, i.e. at the select period described in sub-section 4.1.5.

5.4.3. Solenoid Drivers

The principle of the solenoid driver circuits was based on the fact that the solenoids would not operate against the trigger return spring (Fig. 4. 16 item 22) under their normal continuous rated voltage of 24 volts.
Fig. 5.2 PATTERN READING HEAD
Fig 5.3 SYNCHRONIZING PULSE DISC
Thus, when the pattern read signals were received, miniature reed relays transmitted 24 volts straight to the solenoids but the triggers did not operate until the synchronizing pulse switched on the 100 volt firing load. When the pattern read signals were removed, the 24 volt holding load on the solenoids was retained until the next synchronizing pulse de-energised the reed relays via a switching transistor. Fig. 5.4. shows the main pattern control unit, housing the solenoid driving circuits. The front cover has been removed to reveal the printed circuit boards (1) one of which is being hand-held to show its construction. Each printed circuit board has six solenoid driving circuits mounted on it, the circuit diagram being given in Appendix II. The cycles of events are illustrated in graphical form in Fig. 5.5. for one solenoid trigger only where:

Graph (a) shows the signals transmitted by the pattern sensor and is dependent upon the pattern painted on the transparent film;

Graph (b) shows the relative positions of the synchronizing pulse which is common to all solenoid circuits;

Graph (c) shows the 100 volt firing pulse load; notice that it is only transmitted when the pattern sensor (graph a) is turned 'on';

Graph (d) shows the 24 volt load which is applied to the solenoids. It occurs immediately the pattern sensor is turned 'on' but is not removed until a synchronizing pulse is received with the pattern sensor turned 'off'; and

Graph (e) represents the mechanical movement of the trigger which moves in and out at a precise moment within the needle cycle time.

5.4.4. General Appraisal

The pattern read and synchronizing circuits were in principle simple to develop. However, the solenoid driving circuits provided several problems. Sub-section 5.4.3. describes the principles of the circuit functions but the practical solution was hindered by the availability of certain electronic components. Two or three circuit diagrams were designed using such components as silicon controlled rectifiers which are basically solid state latching relays. When a pulse is applied to a silicon controlled rectifier it 'makes' a circuit and holds it when the pulse is removed; a second reverse direction pulse in the main line 'opens' the circuit. This system could have provided a simpler solution for the solenoid driving circuits but, because of purchasing difficulties at that particular time in the research programme, miniature reed relays were used instead. Further complications then arose when the synchronizing pulse was applied with no pattern read signal because the reed relay opened at this instant with 100 volts across the contacts. This high voltage caused arcing, which welded the
Fig 5.4 MAIN PATTERN CONTROL UNIT
Fig 5.5 REPRESENTATION OF PATTERN CONTROL SEQUENCES
contacts and therefore the 100 volts remained across the solenoids for longer than the prescribed time of 12 ms so breaking down the coil insulation. To avoid this a 2 ms time delay was introduced between the synchronizing pulse and the 100v pulse such that the reed relay contacts opened 2 ms before the 100v pulse was applied and no arcing occurred. Problems also occurred in stabilizing the power supply circuit for the control system due to varying voltage drops in the 240v mains supply during national emergency measures appertaining at the time. The circuit diagram that was eventually developed to overcome these problems is given in Appendix II. Many other difficulties occurred in the development of a satisfactory electronic circuit but they are not detailed here. Mention of some of them has been made to justify the practical approach to the system which consisted of constructing a basic circuit and studying its performance in relation to what was required i.e. the outputs illustrated in Fig. 5.5. Then, by additions to the basic circuit, a workable solution evolved and this gave rise to the necessity for the pulse-sharpener and mono-stable circuits also given in Appendix II. Although a successful system was produced it was by no means an optimum solution. Therefore it is suggested that, in any further development of the system, the electronics should be re-appraised and redesigned in the light of the experience gained in this research.

5.5. The Complete System

The remaining requirement of the pattern information storage and retrieval system was a pattern drum drive mechanism and pattern preparation equipment.

5.5.1. Pattern Drum

Fig. 5.6. is a side view of the research rig showing the drive to the pattern drum. The main needle drive shaft drives the pulley (1) mounted on the layshaft (2); this layshaft drives the yarn feed system (see subsection 6.2.3.), the synchronizing pulse disc (see sub-section 5.4.2.) and a 40:1 reduction gear box (3). The gear box is connected to the shaft (4) via the electro-magnetic, 40 tooth, dog clutch (5) (see section 7.5.). The shaft (4) drives a spur gear which rotates the pattern drum with a further 2:1 speed reduction. Therefore the angular speed ratio of the pattern drum to the main needle drive shaft was 80:1. The pattern drum (Fig. 5.7. item 1) consisted of a chromium plated cylinder with 40 tooth film drive sprockets at each end and, as it rotated at constant speed, two lines of pattern were read per sprocket tooth spacing. The drum was phased cyclically with the
synchronizing pulse disc so that the pattern reading head (Fig. 5.7, item 2) responded to the central region only of a square area on the pattern film and this removed the necessity for precision when painting the pattern onto the transparent film. The roller (Fig. 5.7, item 3) allowed films of various lengths to be used as the pattern repeat length in the warp stitching direction was dependent on the film length. For research rig purposes the pattern repeat length was restricted to a maximum of 130 stitches although it should be observed that the addition of jockey pulleys etc. could facilitate extremely long film lengths.

5.5.2. Pattern Preparation

Fig. 5.7 shows the pattern film punch unit (4). The film material was 0.13 mm (0.005") thick acetate sheet and the manually-operated punch unit punched holes in the film to suit the sprockets on the pattern drum. Having punched the film the pattern could be painted to suit the matrix prepared on the punch unit (5). The function of preparing the pattern film was to interrupt the light reflection from the pattern drum as required. Several materials were experimented with in order to achieve this, e.g. indian ink, matt black paint, masking tape, chinagraph pencil etc., and all proved successful showing that the pattern reading head was extremely reliable. Item 6, Fig. 5.7, is the film bonding and cropping fixture. Having cut the film to the required length, acetone was used to bond the film into a continuous loop and the fixture ensured that the sprocket hole pitch was maintained. In section 5.3 certain criteria were mentioned regarding the suitability of a patterning system for the research rig. The system developed met these in that simple pattern preparation equipment was used, pattern changing could be done manually in a matter of seconds and precision in laying out the pattern was not necessary. Therefore it was regarded as a successful system and particularly suitable for this research.
Fig 5.7 PATTERN PREPARATION EQUIPMENT
CHAPTER 6
YARN CONTROL

The looper manipulation mechanism and the pattern information storage system described in chapters 4 and 5 respectively are not, in themselves, capable of producing patterned fabrics unless provision for appropriate yarn control systems are incorporated. Therefore before sculpture-patterned locked-loop fabrics could be produced at speed on the research apparatus, the problems of yarn feed and tension had to be analysed and a solution devised.

6.1. Stitching Zone Yarn Tension

6.1.1. System Employed on the Commercial Machine

The method of controlling the yarn tension on the commercial 'Locstitch' machine was assessed in order to establish whether adaptations of such a system, at present capable of producing only constant pile heights, could be incorporated in the research rig for producing sculptured fabrics. The system comprises a spring-loaded control bar in the stitching zone of the machine operating in conjunction with a set of constant speed yarn feed rolls. It was established in sub-section 4.1.1. that, for the correct formation of the locked-loop stitch, the yarn must be pulled tightly over the loop forming element at the same time drawing the necessary extra yarn from the supply. Fig. 6.1.(a) illustrates the basic layout of the commercial system for achieving this function. The yarn feed rolls (1) supply yarn at a constant rate and as the needles move to their full penetration position (Fig. 6.1.b) yarn is demanded at twice the needle penetration rate. This is compensated for by moving the spring-loaded bar (2), attached to the needle bar (3), in relation to a fixed bar (4) (i.e. in principle the 'dancing' roller system used on many textile machines). Therefore by presetting the relationship of the fixed bar to the spring-loaded bar, and adjusting the yarn feed rate accordingly, the spring (5) carrying the bar (2) serves to provide a near constant tension in the yarn throughout the needle cycle.

In practice, however, it was found that the amount of yarn required per stitch varied slightly due to the particular tensions developed in the locking loop and over the looper element. Therefore the yarn was slightly undersfed such that when needle retraction occurred those stitches formed with more yarn were pulled tighter by the bar (2) than those stitches using slightly lesser amounts of yarn, so removing the possibility of...
Fig 6.1 YARN CONTROL SYSTEM USED ON COMMERCIAL LOCSTITCH MACHINE
accumulative yarn feed effects caused by the inconsistencies in stitch formation. This type of system could not be adapted for sculptured fabrics because of the difference in yarn quantities required for high and low pile heights (i.e. 16 mm to 12 mm per stitch respectively, see sub-section 6.2.1.). The 4 mm difference could not be compensated for merely by the tension in the locking loop. As a preliminary measure, it was decided to consider yarn tension control independently from yarn feed devices; it was assumed that one would not be affected primarily by the other but it was realised that final practical trials might prove their interdependency.

6.1.2. Tension System on the Research Rig

It was considered undesirable to use the spring-loaded bar for yarn tensioning on the research rig for two reasons; firstly, the effects of a spring-loaded bar on a small number of yarns would be different than the effects when a greater number of yarns are threaded, and secondly, it was possible that the stitching speed might be varied periodically for observation and measurements etc., and thus the inertia effects of a spring-loaded bar on the yarn tension could change. Therefore, the system illustrated in Fig. 6.2.(a) was installed on the research rig as an initial trial of yarn tension control. A dancing bar (1) was attached to the reciprocating needle bar (2) but without the spring-loaded feature used on the commercial machine. The fixed bar (3) was set in such a manner that, as the needle bar (2) moved forward, yarn was provided by the movement of bar (1) in relation to bar (3), to allow for the appropriate feed rate. One aspect of the locked-loop stitching cycle was that, as the needles were retracted, there was excess yarn in the cycle caused by the difference between the depth of penetration of the needle eye into the base fabric and the actual amount of yarn used for the locking or prone loop. This excess yarn could be conveniently removed by the movement of bar (1) in relation to bar (3) on the return stroke of the needle bar (2), drawing some yarn from the supply at the same time. The array of bars (4) provided a friction system through which the yarn was threaded. It was found by experimentation that a yarn tension of between 10 to 20 gf was required at point 'A' in the yarn at certain stages in the cycle for the proper formation of the locked-loop stitch. However, it was desirable that the yarn tension at point 'B' in the yarn should be zero for yarn feed purposes (see section 6.2.). This method of zig-zagging yarns through an array of bars is not uncommon in single yarn textile machines as a means of controlling tension. In this particular application of multi-yarn ends, it was
[T_A, T_B, & T_C represent yarn tension values at particular points]

Fig 6.2 YARN TENSION SYSTEMS
found to function reasonably well but the initial threading of the yarns was cumbersome and the yarn tension produced at the needles could not be varied appreciably without the addition of extra bars; this made yarn threading even more difficult in the confined space available. Mathematically the system may be represented by:

\[ T_A = T_B \cdot \mu \Sigma \Theta \]

where \( \mu \) = the coefficient of friction between the yarn and the steel bars (which was found experimentally to be approximately 0.18) and \( \Sigma \Theta \) = the sum of the angles of wrap.

Therefore with say 5 bars having a total angle of wrap of \( 5\pi \) radians, and \( T_A \) required to be 20gf, \( T_B \) would be 1.18gf which is too high for a near slack yarn input. An alternative system, using a cymbal or disc type arrangement in series, was also tested as shown in Fig. 6.2 (b) and found to be more satisfactory. Two disc banks were used, each with 30 yarn ends and a spring and screw adjustment (5) at each end. This system proved to be reliable and gave adequate variation of yarn tension. Mathematically this system may be represented by:

\[ T_B = T_C + 2 \cdot \mu P_n \]

where \( \mu \) = the coefficient of friction between the yarn and the disc material; and \( P_n \) = the pressure normal to the axis of the yarn.

Here it may be seen that \( T_C \) can be at zero tension and \( T_B \) can be at 20gf maintained purely by the \( 2 \cdot \mu P_n \) term. The dancing bar (1) and fixed bar (3) were still required with this system for tension 'let-off' when the needles move through the base fabric and for excess yarn removal on needle retraction as previously described.

6.1.3. Looper Control

One design feature of the looper manipulation mechanism remained unresolved. The leaf spring arrangement (item 16 Fig. 4.16) for moving the looper into the base fabric under the control of the nodding bar (item 7) was removed with the intention of using the forces exerted by the loop yarn alone to pull the loopers into the base fabric. The object was to remove the combined yarn and spring forces on the nodding bar as previously discussed in sub-section 4.5.2. This would mean that, as the looper is pulled towards the base fabric by the loop formed, the yarn would slide, under tension, over the looper end. It was decided, in sub-section 4.5.4., to accept this compromise and attempt to minimise the sliding effects of the yarn over the looper by cyclic control of the yarn tension. However, experimentation with yarn tensions on 60 yarn ends
indicated that this method of looper control was unreliable due to differences in individual sliding effects in the looper guide slots. Therefore another method of moving the loopers into the base fabric was devised such that only the yarn exerted an upward force on the nodding bar while the spring action on the individual loopers tended to exert a downward force. The modification is illustrated in Fig. 6.3. The springs (1) were attached to the nodding bar (2) and therefore only exerted a force on it when the latch (3) was engaged, arresting the movement of the rocking segment (4). This force on the nodding bar was, to some extent, balanced by the force exerted on the looper (6) by the yarn loop (5). This proved to be a satisfactory solution to the problem, requiring less yarn tension in the stitching zone and resulted in a better consistency of pile heights and a more reliable stitching process.

6.2. Yarn Feed

6.2.1. The Problem

In sub-section 6.1.1. it was stated that in practice the yarn consumption varied from stitch to stitch. Therefore it was considered necessary to measure yarn consumption rates on the research rig in order to analyse the yarn feed problem. The rig was initially set to produce two pile heights at 14 stitches per inch, this stitching pitch being maintained throughout the experimentation and for calculation purposes, in order to remove one of the variables in the process, although the yarn feed system finally developed needs to be capable of supplying yarn for all the stitching pitches available. At 3.05mm pile height the yarn consumed averaged 12mm per stitch, and at 5.59mm pile height the yarn consumed averaged 16mm per stitch. It was interesting to note that the variation in yarn consumed measured ± 0.7mm per stitch irrespective of the pile height setting. This suggested that there was a lack of consistency in the quantity of yarn used for the locking loop rather than in the pile loop. Further investigation of this would be required in order to establish commercial yarn consumption rates if the positive yarn feed system at present used on the 'Locstitch' machine was not to be employed. Such measurements were thought to be irrelevant to this research and it was sufficient to note that the quantity of yarn consumed by the locked-loop process varied per stitch. The sculpturing effects were then superimposed onto this variation resulting in a total possible variation in yarn consumption per stitch of 11.3mm to 16.7mm at 14 stitches per inch. The sculpturing mechanism and pattern information system described in chapters
Fig 6.3 MODIFIED LOOPER RETURN SPRING
4 and 5 were capable of producing unlimited pattern repeat lengths in both warp and weft directions. Therefore the yarn feed problem resolved into providing a system of supplying yarn to the needles such that a random consumption rate of between 11.3mm and 16.7mm per stitch could ensue at a stitching pitch setting of 14 stitches per inch.

6.2.2. Possible Solutions

A possible basis for the yarn feed system could be to positively feed yarn into a mini-storage zone and allow the needles to draw yarn negatively from the store whilst monitoring the amount of each yarn in the zone and replenishing the storage as required. There are several feasible methods of achieving such a self-monitoring positive yarn feed system, two of which are discussed briefly below:

(i) Consider Fig. 6.4 (a) which illustrates a self-monitoring yarn feed system based on fluidic circuitry. The yarn (1) wraps over a friction roller (2) rotating at constant speed such that the \( T_D = T_C e^{\mu \Theta} \) relationship is sufficient to pull the yarn off the supply packages at a rate faster than the maximum consumed by the needles. Slack yarn (3) is then produced, but controlled by a light pivoted lever (4). When a certain quantity of yarn has been fed the lever (4) operates the fluidic switch (5) which signals the logic unit (6) and blows a simple air plunger (7) to trap the yarn. Thus \( T_D \) increases, the yarn slips on the roller (2) and the feeding stops. The stored yarn, being consumed by further stitching, causes the lever (4) to rise until the second fluidic switch (8) is contacted, which, via the logic unit (6), removes the yarn-trap air plunger (7) and allows the yarn feed to resume. Thus the cycle of events continues and self monitors the feed/consumption rate of each individual needle.

(ii) Fig. 6.4 (b) illustrates a possible self-monitoring yarn feed system based on the Singer-Cobble 'Universal Patterning Attachment'\(^29\). The system consists of a pair of yarn feed rolls (1 and 2) between which the ends of pile yarn (3) are threaded. The rolls are banded along their length with alternating rings of friction surface and smooth surface materials. They are driven such that the lower roll rotates at twice the speed of the upper roll and the bands of contrasting surface are so located that the rough surface bands on one roll coincide with the smooth surface bands on the second roll and vice-versa. Located just after the rolls are spring wires (4) which deflect if the yarn tension increases. The yarn takes a zig-zag path through the guides (5), the rolls, around the spring wires (4) and then through the second guides (6). Yarn is
Fig 6.4 POSSIBLE SELF-MONITORING YARN FEED SYSTEMS
normally fed on a friction band of roller (1) which supplies a quantity of yarn slightly less than the minimum amount consumed per stitch. Thus the tension $T_C$ gradually increases and deflects the wire (4) transversely, and the yarn moves with the wires and contacts an adjacent friction surface on roller (2). This feeds the yarn at twice its normal speed and relaxes the tension $T_C$, so causing the wire (4) to divert the yarn back onto the friction band of roller (1) as stitching continues.

Both of the above systems could, in principle, solve the yarn feed problems for the sculptured locked-loop stitch, but the mechanism evolved for sculpturing by looper manipulation is already relatively complex and it was thought undesirable to add to the complexity of the total process by including a self-monitoring yarn feed. Therefore it was decided to develop a random yarn feed system without monitoring each individual yarn by a separate mechanism.

6.2.3. A System for the Research Rig

The mechanism developed for yarn-feed on the research rig removed the intricacies inherent in the self-monitoring systems described in subsection 6.2.2. The principle was basically to create the same quantity of slack yarn at each needle cycle so that, if a high loop pile was produced more of this slack yarn would be used than with a low loop pile; because the same quantity of slack yarn was then regenerated at the next needle cycle no surplus accumulation of yarn should occur. Fig. 6.5 illustrates the main features of the system; the sheet of yarns (1) from the creel pass under a fixed bar (2) and then over the roller (3). The roller (3) is covered with a friction material (rubber) and driven at a constant angular velocity. The dancing bar (4) is driven by a bell crank (7) and eccentric (8) which rotates at the same speed as the needle drive shaft. The sheet of yarns then pass through the disc type yarn tension device (6) and the double bar tension compensator (9) (as described in sub-section 6.1.2) to the needle bar. The system is provided with several variable setting features to cope with different yarn types, cone-winding tensions, seam stitching pitches etc., and these include:

(i) The speed of the roller (3), adjusted by driving the shaft (5) from a variable-speed drive unit;
(ii) The stroke of the dancing bar (4), varied by a slotted arrangement in the bell crank driver;
(iii) The timing of the dancing bar (4), varied in relation to the cyclic position of the needles to give a 'pull-back' of yarn at a discrete position in the stitching cycle.
Fig 6.5 YARN FEED SYSTEM ON RESEARCH RIG
and (iv) The fixed bar (2), arranged to be preset to vary the angle of wrap of the yarn sheet around the roller (3).

Other changes in the system could be incorporated in order to modify the performance. The frictional characteristics of the roller (3) could be varied by using other surface materials. The bell crank does not necessarily have to pivot about the shaft (5) and thus the velocity of the dancing bar (4) in relation to the peripheral velocity of roller (3) could be changed. Perhaps the most significant variation would be to use a cam drive on the bell crank instead of an eccentric. This would make available very precise control of the cyclic feed and tension changes required for a particular application.

The mechanism operates such that, when the yarn tension at point 'C' in the system is zero then no yarn feed occurs because $T_D = T_C e^{\mu \Theta} = 0$. As the dancing bar (4) moves downwards so the yarn tension $T_C$ begins to increase until $T_D = T_C e^{\mu \Theta} = 1$ to $3 \sigma'$ (i.e. the measured tension to pull the yarn off a cone). At this stage the yarn grips the friction roller (3) the rotation of which drives the yarn off the cones. This movement of yarn has the effect of reducing the yarn tension $T_C$ until $T_D = T_C e^{\mu \Theta} = 0$ again and the yarn feed ceases. When the bar (4) is then raised slack yarn is created and the needle stitching action may use as much of this slack yarn as it requires for that particular stitch. Thus, when the bar (4) again moves downwards some yarns will receive a $T_C$ tension value and commence feeding before the others but the effect produces the same quantity of slack yarn irrespective of the amount consumed per stitch. It may be observed from the relationship $T_D = T_C e^{\mu \Theta}$ that $T_C$ should be a relatively small value compared to $T_D$ and therefore the disc type tension device (6) can be preset to give a substantially constant yarn tension $T_B$ to the needles with little effect from $T_C$ ($T_B = T_C + 2 \mu \rho n$ where $T_C \to 0$). The importance of the dancing bar (4) may not seem obvious because, as the needles move towards the base fabric, yarn is demanded which would cause an increase in $T_A$, $T_B$ and $T_C$ and the yarn would automatically feed over the rotating roller (3) without the bar (4). However, the time when the needles are demanding yarn is when the yarn passes through the base fabric, the needle eye, out of the base fabric and over the loopers. In order to allow the yarn to slide easily by the flank of the needle and through the eye at this stage, $T_A$ must be zero. This is achieved by the movement of the fixed bar compensator (9) previously described, but if $T_C$ were to reach any value at this point in the cycle $T_A$ would not be zero. Thus the dancing bar (4) ensured that yarn was fed over the roller (3) at some
other point in the cycle when yarn is not demanded by the needles. It was initially summarized that a suitable point in the needle cycle for applying a tension $T_C$, and thus feed yarn, was as the needle reached full penetration depth. At this point no yarn is demanded from the supply and an increase in $T_A$ may assist the spring returned loopers (item 6 Fig. 6.3) to reach their pile height setting, relieving the work done by the springs (Item 1 Fig. 6.3) especially when low pile heights are selected. In practice this was found to be necessary and in fact $T_A$ needed to be increased in the form of a pulse tension at this point because of the drag from the base fabric which affected the tension control on the looper. It may now be seen that the yarn tension and feed requirements for the locked-loop process are directly interdependent, but the yarn tension requires cyclic control with the slack generator yarn feed system. Therefore the cyclic yarn tension requirements were assessed and are illustrated in relation to the needle cycle in Fig. 6.6. Between points 15 to 5 $T_A$ should be at zero, achieved by the fixed bar compensator system on the needle bar and between points 8 to 14 $T_A$ should be at a nominal value of 5 to 10 gf achieved by the disc type tension device. The increased tension between points 10 and 12 is not really required but, as excess yarn is removed from the cycle by the retracting fixed bar compensator, the tension may rise slightly at this point. The pulse of 20 gf between points 6 and 8 would be required for the looper yarn tension previously discussed and to achieve this the motion of the dancing bar (item 4 Fig. 6.5) was studied in more detail. On the research rig the bell crank was driven by an eccentric and thus the dancing bar had a sinusoidal velocity function. At the beginning of the downward stroke the bar's velocity was matched approximately with the peripheral velocity of the roller (item 3 Fig. 6.5) creating the relationship $T_D = T_C \cdot e^{\mu \Theta} = 1 - 3$ gf, as before, but, as the velocity increased, at mid-stroke of the bar, it began to move faster than the peripheral velocity of the roller. This caused the yarn to slip over the roller in advance of rotation, changing the relationship to $T_C = T_D \cdot e^{\mu \Theta}$. The values were $\Theta = 200^\circ$, $T_D = 1 - 3$ gf, and $\mu = 0.57$ (found experimentally for yarn on rubber), which gave $T_C$ a value of approximately 15 gf momentarily until the velocity of the bar decreased and the equation reverted back to $T_D = T_C \cdot e^{\mu \Theta} = 1 - 3$ gf. The 15 gf pulse tension in $T_C$, created the 20 gf tension in $T_B$, from the $T_B = T_C + 2 \mu P_0$ relationship of the disc tensioner.

6.2.4. Performance of the Chosen Yarn Feed System

On most fabric-producing textile machinery the quality of fabric
Fig 6.6 ASSESSMENT OF CYCLIC YARN TENSION REQUIREMENTS
depends upon the accuracy of yarn feed and tension control. The mechanism described in sub-section 6.2.3. was therefore assessed by the quality of locked-loop fabric produced on the research rig. The pile heights, both high and low, were consistent no matter what stitching speed was used (from 1 to 750 stitches per minute) and uniformity of the locking loops was also observed. The yarn used on the research rig required 1 - 3 gf tension to draw it off the cones. However, a few of the 120 cones used had occasional 'tight' spots in them, so requiring up to 10 gf (T_D) yarn pull; if these tight spots happened to occur at the stage in the yarn feed cycle when \( T_C = T_D e^{\mu \theta} \), then \( T_B \) rose to about 60 gf which caused either distortion of a stitch or yarn breakage. This was considered an undesirable feature of the yarn feed device but it was thought that the quality of yarn and cone winding was suspect. In sub-section 6.2.3. a graphical assessment was made of the cyclic yarn tension requirements and therefore comparative measurements were made of the actual yarn tension produced with the yarn feed system. Because of the difficulty in applying the Rothschild tensiometer head close to the stitching zone, it was applied between the tension discs and the fixed bar compensator shown in Fig. 6.5, i.e. for a measurement of \( T_B \). 

Fig. 6.7 shows the recorder outputs for several needle cycles and it is seen that the general shape of the curves for various stitching speeds and pile height settings compare favourably with that assessed mathematically and illustrated in Fig. 6.6. However, at the high pile-height settings, Figs. 6.7 (b) and (d), the peak tensions in \( T_B \) were greater than at low pile-height settings (a) and (c). This was caused by the increased amount of yarn overfeeding the friction roller, i.e. the peripheral speed of the friction roller (item 3 Fig. 6.5) was matched to the bar (4) at low pile-height settings and, because the bar (4) was driven from an eccentric (8) the velocity matching could not be accurate for both yarn demands. This, of course, could be overcome by using a cam instead of an eccentric, as mentioned previously (sub-section 6.2.3). The high frequency disturbance at the peak tensions of Fig. 6.7 (b) may also be caused by excess yarn overfeeding but it was thought that the main reason was variations in the friction characteristics as surface fibres protruding from the yarn slip over the rubber-coated feed roller. Naturally this was not observed at high stitching speeds, Fig. 6.7. (d) because of the frequency resolution of the recording equipment used. The tension assessment (Fig. 6.6) shows that \( T_A \) should be zero for part of the needle cycle. However, this did not occur and the lowest tension at all speeds and pile height settings was 5 gf. This may have occurred because the measurements
LOOPER SET AT HIGH PILE HEIGHT (18 stitch/min)

LOOPER SET AT LOW PILE HEIGHT (18 stitch/min)

LOOPER SET AT LOW PILE HEIGHT (600 stitch/min)

LOOPER SET AT HIGH PILE HEIGHT (600 stitch/min)

Fig 6.7 RECORDINGS OF YARN TENSION ON RESEARCH RIG
recorded were of tension $T_B$ rather than $T_A$ for practical reasons and while, visually, $T_A$ appeared to have a slack period ($T_A = 0$) this was not recorded by the Rothschild head further away from the stitching zone, which was measuring $T_B$. The installation of the yarn-feed device completed the research apparatus such that sculpture patterned locked-loop fabric could be produced at high speed.
CHAPTER 7
FURTHER SCULPTURING SYSTEMS

The locked-loop sculpturing apparatus (chapter 4) produced a fabric to specification I (sub-section 2.2.4.) i.e. high loop heights and low loop heights. It is now necessary that other sculpturing mechanisms be discussed in order that fabrics to specification II may be provided for. This chapter considers these alternatives, together with adaptations that may be incorporated into the basic locked-loop process and sculpturing system in order to provide as wide a range of patterned fabrics as possible.

7.1. A Three Pile Height System

It was stated in sub-section 2.2.3. that a mechanism that could provide maximum, minimum and zero loop pile heights in-process would be the ideal sculpturing system for the locked-loop process. However, a more detailed analysis must now be considered to show the difficulties involved in providing such a system. The main difficulty would be to provide a looping element, with a single selection device, that in two modes of operation picks up the yarn loop while, in a third mode, purposely misses the yarn.

7.1.1. Hooked Loopers

Consider Fig. 7.1 (a) which represents three discrete positions of a hooked looper working similarly to those used on the first powered rig (see sub-section 3.1.2.). At position 'A' the looper could be arrested to maintain that position instead of moving down into the stitching zone to pick up the yarn, thus no pile loop would be formed. If the looper is not arrested it would move to position 'B' and shog to pick up the yarn and at the same time another selection could be made. Dependent upon this second selection the looper would then move either to position 'C' clear of the stitching zone to form a low pile loop, or back to position 'A' to form a high pile loop. A second shog of the looper must then be provided to ensure that all pile loops are positively dropped off the hooks to allow those loopers arrested at position 'C' to retract to the reset position 'A' before commencement of the next cycle. The function of the selection device at position 'A' would be to restrain a downward motion of the looper, while at position 'C' it would be to restrain an upward motion. Therefore a positive bidirectional latching system would be required rather than the undirectional system employed in sub-section 4.3.3. This would present no real mechanical problem but the physical size of the looper hook and its
Fig 7.1 HIGH, LOW, ZERO PILE HEIGHT SCULPTURING
interaction with the yarn would re-introduce the disadvantages already described in sub-section 4.1.2. Consider also one hooked looper shogging to pick up a yarn in position 'B' whilst an adjacent looper is retained in position 'A'; the shogging motion at 'B' would interfere with the adjacent undeflected yarn. For this reason, and the fact that it would be extremely difficult to gain access to the needles for threading, it was concluded that this three pile height sculpturing method with hooked loopers was not practical.

7.1.2. Reed Type Loopers

Consider Fig. 7.1 (b) which represents a reed type looper with a similar motion to that discussed in sub-section 4.1.5. Positions 'X' and 'Y' would operate in much the same way as on the present research apparatus forming high and low pile heights respectively. In order to miss the loop and produce zero pile height the looper must move from 'X' to 'Z' whilst an adjacent looper may be selected to move from 'X' to 'Y'. A looper in position 'Y' must return to position 'X' via position 'Z' in order to cast-off low pile height loops. Thus the selections to be made are, 'X' maintained or 'X' to 'Y' to 'Z' to 'X', or 'X' to 'Z' to 'X' producing high, low and zero pile heights respectively. The writer was unable to devise a mechanism with only one electro-magnetic selector that would not only select positions, but also select orbits. It could be achieved with two electro-magnetic latching devices by de-commonising the looper secondary motion existent on the research apparatus. However, the complexity of the resultant mechanism would be such that it could not be utilized at the existing seam pitches and would be very impractical.

7.1.3. Adaptation of Developed Mechanism

It may be concluded from sub-sections 7.1.1 and 2 that the production of locked-loop sculptured pile fabric with maximum, minimum and zero pile heights does not appear to be a feasible proposition. However, a three pile height system can be produced quite simply by adapting the existing research apparatus to produce maximum, medium and minimum pile heights. The present pile height differential of 5 mm (0.2") maximum, to 1.8 mm (0.07") minimum may not tolerate an intermediate pile height of, say, 3.3 mm (0.13") and still produce a visually discernable sculptured pattern. This problem, caused by the stitching density in warp and weft directions, was discussed with examples in sub-section 2.2.3. However, research into the stitching zone clearances revealed in sub-section 4.5.3. that proper use of needle/looper interactions would produce, without modifications to the basic process, maximum pile heights of 7.6
This situation provides possibilities for a sculptured fabric with 7.6 mm (0.3") maximum, 4.6 mm (0.18") medium and 1.8 mm (0.07") minimum pile heights (see Fig. 4.27), differences which are likely to be clearly visible in the finished fabric. The previously mentioned simple adaptation of the existing research rig (see Fig. 4.16) would involve the use of a different looper primary motion cam and, as Fig. 7.2 shows, a modified catchment area on the rocking segment (1). This rocking segment would incorporate two latching points forming a double-toothed ratchet (2,6). The nodding bar (3) moves down and dwells in the reset or select position in the normal manner holding the looper end (4) at the increased position of 7.6 mm (0.3") indicated. At this point the trigger (5) might be fired into the first of the two catches (6) such that as the nodding bar is raised the looper is maintained in this highest pile position. The raising motion of the nodding bar (3) then goes through a second dwell position and, if the trigger had not been fired at the first dwell, it could be fired at this second dwell stage into the second of the two catches (2) and thus hold the looper at the medium pile position of 4.6 mm (0.18"). If the trigger is not fired at either of the two dwell stages, further raising of the nodding bar allows the looper to move to the minimum pile height of 1.8 mm (0.07"). Fig. 7.3 (a) shows the existing primary looper cam displacement curve previously illustrated in Fig. 4.21 which may now be compared with Fig. 7.3 (b) showing the cam displacement curve required for the double-dwell motion of a sculptured three pile-height system. Notice that the time period allowed for firing the solenoid triggers will now be greatly reduced; in fact, instead of 35 ms it would be 15 ms in either of the dwell positions at maximum stitching speed of 750 stitches/min. This means that consideration must be given to the solenoid response time which was measured as 20 ms on the existing research apparatus. This response time, measured from initial application of voltage to final movement of the trigger, (see sub-section 4.3.5.) may be divided into two components: the time for magnetic flux growth in the solenoid coil, and the time for actual mechanical motion; these have not been independently quantified. However, the magnetic flux growth is dependent upon the time constant for current growth which has already been boosted with the 100 volt pulse and therefore any improvements would require the development of a more efficient solenoid for this particular application, e.g. reduced magnetic flux losses etc. Considering the mechanical motion, the acceleration of the trigger for a given force is inversely proportional to the mass of the trigger and therefore the response time could be reduced by reducing the
Fig 7.2 THREE PILE HEIGHT
SCULPTURING MECHANISM
Fig 7.3 COMPARISON OF LOOPER PRIMARY CAM DISPLACEMENT CURVES
mass. Furthermore, the time taken is proportional to the square root of the distance travelled by the trigger for a given acceleration rate. In sub-section 4.3.5. the distance travelled by the trigger was set at 1 mm (0.040") this was divided into 0.62 mm (0.025") catchment length and 0.38 mm (0.015") clearance when the solenoid was de-energized. However, 0.62 mm (0.025") proved to be a more than adequate length of engagement even with individually hand-made components; 0.25 mm (0.010") ought to be a sufficient amount of trigger engagement and this could be maintained with appropriate production methods. By the same argument, the amount of clearance could be reduced to 0.12 mm (0.005") when the trigger is in the de-energized position. With the total displacement reduced by 62% and assuming that the effective mass of the trigger can be reduced by 10% the resultant theoretical reduction in mechanical response time would be 26%. Therefore in order to obtain a latching time of 15 ms or less the system must be made mechanically dependent only by removing the electro-magnetic and pattern reading delays. This may be done by applying the synchronizing pulses slightly in advance of the position when actual mechanical movement is required. The amount of advance synchronization required will depend upon the machine stitching speed at any instant and thus the synchronizing pulse initiator should be mounted on a speed-sensitive automatic advancing unit. Such a unit is envisaged to be a centrifugal device similar in principle to that commonly used for distributing voltage in a motor car ignition system. Having obtained a satisfactory response time of the trigger for the three pile height system the pattern information storage and retrieval system must be considered. Its function must be to provide one of three selected signals, a main firing signal, a time delayed firing signal and an off position. The two firing signals should be phased with the cyclic position of the double dwell looper primary cam and this could be conveniently achieved by providing two synchronizing pulses derived from a common auto-advancing unit. Pattern reading of three signals from a single graphical display would require a certain amount of development work. However, it is envisaged that the system would operate as follows:

(i) The transparent film is painted to form a pattern with black non-reflective areas for low pile heights; grey semi-reflective areas for medium pile heights; and clear, full reflective areas for high pile heights.

(ii) The circuitry for the light sensitive diodes could be modified to output 0v, 1.5v, or 3v, depending upon the intensity of light received.
(iii) When a black area is picked up by the sensors the reed relays in the solenoid driving circuits do not energize; neither the 24v nor the 100v pulse are transmitted to the solenoids thereby facilitating low pile heights.

(iv) When a clear area is picked up by the sensors the reed relays immediately transmit 24v to the solenoids but due to pulse delay they do not operate until the first synchronizing switches the 100v firing load. The second synchronizing pulse also switches another 100v load which, of course, will have no effect because the trigger has already been moved, and therefore high pile heights are produced.

(v) When a grey area is picked up by the sensors the reed relays again immediately transmit 24v to the solenoids but also open circuits the 100v pulse line. The first synchronizing pulse then re-closes this 100v pulse line such that the second synchronizing pulse is clear to transmit the second 100v pulse to the solenoids in phase with the second latching position, and therefore medium pile heights are produced.

In case (v) above, with the trigger (5) engaged in latching tooth (2) (Fig. 7.2), it will be appreciated that as the nodding bar (3) moves downwards again to reset all the looping elements, the latching tooth (6) will force the trigger (5) out of engagement. Therefore only when medium pile height is selected the 24v holding load should be removed from the solenoid when the nodding bar is moving downwards to allow easy escapement of the trigger (5) which must then be re-fired every subsequent cycle if the medium pile height setting is maintained. The uncertain aspect of this suggested system for pattern information storage and retrieval is that, to obtain three signals from one light sensitive diode, by varying the light intensity only, requires very 'sensitive' circuitry making it vulnerable to any spurious pulses in the system. However, the mechanical proposals are sound and, as a last resort, two pattern drums and two solenoid driving circuits could be used. One pattern drum would read high and minimum pile heights and the second drum would read medium and minimum pile heights, which is a similar function to that of commercially available systems for creating three pile heights in the tufting processes. Therefore it may be concluded that, with further development work, the locked-loop sculpturing system described in chapter 4 may be adapted to produce a three pile height sculptured fabric.
7.2. **Back-Robbing**

In sub-section 4.1.3 investigations into sculpturing by the system of back-robbing previously formed pile loops was postponed until the research rig was at a suitable stage in development for practical trials to be carried out. However, having reached this stage in development, it was found that the required negative yarn feeding and tension control could not be maintained over the sewing width of the rig in order to sustain consistently even back-robbing. Furthermore, the yarn tensions required were near to the limiting tensile strength of the yarns used, as was the case with the manually-operated rig (see sub-section 4.1.3). Therefore it may be finally concluded that the locked-loop pile fabric process cannot be successfully sculptured by the technique of back-robbing.

7.3. **Looper Motion (Specification II)**

Specification II fabrics have been defined in sub-section 2.2.4 as two pile height sculpture patterned fabrics having pile loops of both zero height and any suitable predetermined pile height. In order to achieve this, the reed type looping element must either allow a loop to be formed in the normal manner, or it must move to such a position that a loop fails to be formed. Consider Fig. 7.4 with needles A & B interacting as normal. While needle B moves from position 3 to position 6 the looper C may be shogged to pick up the yarn D. Meanwhile, needle A is travelling underneath the shogging looper and, when needle A reaches position 8 in its orbit, clearance is provided for further motion of looper C. Therefore needle B partially forms a loop of yarn D around the looper but before this loop is fully formed the looper drops down to position E and dwells there while needle B moves from position 12 to 15 (i.e. to bottom dead centre). At approximately needle position 11 the partially formed loop will drop off the looper and be pulled down to zero height. As needle B then travels from position 15 to position 2 the looper moves back from position E to position C, the select or reset position. Obviously if the looper is permanently held at position C during a needle cycle the pile loop will be formed. Notice also that, as in the case of the sculpturing system described in chapter 4, the three elements, (needles A, B and looper C) are never simultaneously side by side, thereby making maximum use of the clearances available. The task remained to design a suitable mechanism to obtain the above needle/looper interactions incorporating a trigger system.
Fig 7.4 SPECIFICATION II LOOPER MOTIONS
7.3.1 Complete Mechanism

The period during which the looper is required to dwell at the reset or select position is 35 ms at the maximum machine speed of 750 stitches/min. This time period is well outside the 20 ms required for firing the trigger components previously used (see sub-section 4.3.5). Therefore similar triggering components may be used for the specification II mechanism. Fig. 7.5 is a cross-sectional view through one half of the research rig, showing the proposed mechanism. The looper end (1) is again paired to produce manipulation of two adjacent seams as described in sub-section 2.2.4. These paired loopers are mounted on the plate like member (2)(3)(4) of which plate (2) is pivoted at (10) and also connected to plate (4) via a flexible member (5) similar to that described in sub-section 4.3.6. Pivot (10) is supported by the shogging plate (12) and this in turn is supported by the flexible struts (9) which are exactly the same as those used in sub-section 4.3.6. The solenoids (8) operate the triggers (7) under the action of the return leaf spring (14) and the whole assembly is mounted on a plate (13) which may be manually preset in order to obtain different pile heights (when formed). The nodding bar (5) reciprocates on the plate (4) and, when pile is required, the trigger (7) is fired into the catchment area (11) holding the looper (1) in position C (Fig. 7.4) when the nodding bar is subsequently raised. If the trigger (7) is not fired, the raising of the nodding bar causes the looper plate (2)(3)(4) to pivot about (10) under the action of the control leaf spring (6). Thus the mass of the components to be shogged is again minimised by using the flexible members (3) and (9); the nodding bar action may be considered as a proven device in view of its performance on specification I type sculpturing. Fig. 7.6 illustrates the system as it would be installed on either the research rig or a commercial machine. Two cams (15) are situated each side of the needle drive module (17) and are mounted on the main drive shaft (16). The cams reciprocate the two swan necked arms (18) which support the nodding bar (5) and are pivoted about (19). Either some form of cam follower spring or cam conjugation would be required but these features are not indicated in Fig. 7.6 for clarity reasons. Pattern information storage and retrieval may be identical to the systems described in chapter 5.

7.3.2 Cam Design

The looper motion illustrated in Fig. 7.4 involves a dwell period from needle positions 2 to 9, a fall from positions 9 to 12, a dwell from positions 12 to 15, and a rise from positions 15 to 2. Therefore, for
Fig 7.5 SPECIFICATION II LOOPER
DRIVE MECHANISM
Fig 7.6  INSTALLATION OF SPECIFICATION Ⅱ MECHANISM
the configuration shown in Fig. 7.6, the cam displacement curve (in linear form) is illustrated in Fig. 7.7 and, for the most favourable dynamic characteristics, it is suggested that cycloidal rise and fall motions should be used.

7.4. In-process Shog Cancellation

It would considerably increase the versatility of locked-loop pile fabrics if plain borders in the weftwise direction could be provided. This would facilitate the production of, for example, towels with a uniformly zero pile height section leading into the main pile area (either plain or sculptured) followed by a second uniformly zero pile height section to finish off the product. When the fabric is subsequently cut into product sections, such zero pile height edges could be conveniently hemmed. In order to achieve these weftwise strips of zero pile height, the operation must be such that no yarn is formed over any of the loopers in the total weftwise direction. This could be done on either plain or sculptured fabrics by cancellation of the looper shogging motion. Shogging the loopers causes the yarn, extending from the base fabric to the needle eyes, to be wrapped around the looper end; by not shogging the looper, the yarn would fail to wrap around it and the yarn would be pulled down to zero pile height. The critical consideration for the design of a shog cancellation mechanism is that shogging must not only cease at a particular stage in the needle cycle but it must also be re-engaged at a further particular stage. If for any reason this should not occur in practice, then the loopers may interfere with the needle motion causing possible damage to both needles and loopers, and therefore the mechanism must be reasonably fail-safe. Fig. 7.8 is an illustration of a proposed shog cancellation mechanism showing the standard barrel cam (1) mounted on the layshaft (2). This layshaft is driven as on the existing commercial machine by the spur gear (3) and is driven at half the speed of the main needle drive shafts (see sub-section 3.3.3). Provision has now been made for an eccentric boss (4) on the gear (3); onto this boss is secured a bearing (5) which is housed by one end of the connecting rod (6). This connecting rod is pivoted at (7) to a lever (8) rigidly secured to shaft (9). Shaft (9) is free to pivot in the bearings (10) and carries a second rigidly fixed lever (11) on the other end. This lever is provided with an abutment (12) such that the second lever (13), free to pivot on shaft (9), may be held against the abutment by the spring (14). Therefore as the layshaft (2) is driven, the arrangement so far described causes
This dimension will be dependent upon the ratio of centre distances between the cam follower and nodding bar.

Fig 7.7 SPECIFICATION II CAM DISPLACEMENT CURVE
Fig 7.8 SHOG CANCELLATION MECHANISM
levers (11) and (13) to oscillate in unison. Attached to the main structure of the machine is a pivot (15) carrying two levers (16) and (17) which are free to move independently of each other. These levers are pulled together against an abutment (18) by the spring (19) and because lever (16) is driven, via link (20a), by the existing barrel cam (1), the levers (16) and (17) oscillate in unison. Connected to lever (17) is the looper shogging bar (22) via link (20b) and thus, as the barrel cam rotates the bar (22) is shogged to and fro. Lever (13) is provided with a catchment area (23) such that a trigger (24) pivoted at (25) may be operated by a solenoid (26) and thereby arrest the lever (13) in the down position and allowing lever (11) to continue oscillating. The displacement curve of shogging bar (22) has been illustrated previously in Fig. 3.7 (c) and the eccentric boss (4) should be phased with this displacement such that as the shogging bar is dwelling at maximum displacement from the barrel cam, the lever (13) is allowed to move unrestricted between the lever (17) and a location pad (27). However, if the solenoid is energized the lever (13) will stop the motion of lever (17) by arresting the catchment area between lever (17) and pad (27) but will allow levers (11) and (16) to continue oscillating, thereby cancelling the motion of the shogging bar. If the solenoid is not energized lever (13) will move out of the path of lever (17) before the end of its dwell period. If the shog is cancelled it cannot be restarted even if the solenoid de-energizes out of phase with the cycle because catchment (23) will hold the trigger (24) against its return spring until lever (11) slightly moves lever (13) allowing the trigger to release. This fail-safe aspect is duplicated in similar manner by the lever (17) clamping the catchment area (23) of lever (13). It may be observed that the shog cancellation mechanism described above is controlled electrically by the action of the solenoid trigger in a similar manner to that of the looper element control triggers (sub-section 4.3.3). Therefore signalling instructions for shog cancellation may be achieved by similar equipment to that used for sculpture pattern information storage and retrieval as described in chapter 5.

7.5 In-Process Pattern Stop Device

An in-process pattern stop/start device was designed and manufactured for the research rig in order to demonstrate certain versatilities of the pattern reading system. The drive to the pattern drum was described in sub-section 5.5.1 and, referring to the illustration Fig. 5.6, an electro-mechanical clutch, item 5, may be observed connecting the out-
put shaft of the reduction gear box (3) to the pattern drum drive shaft (4). The clutch took the form of a unidirectional 40 tooth dog clutch which may be dis-engaged by energizing the solenoid (6) and re-engaged by the return springs (7) when the solenoid is de-energized. Therefore energizing the solenoid stops the pattern drum rotation and de-energizing the solenoid restarts the pattern drum; the 40 tooth unidirectional principle ensures that the pattern drum can never run out of phase with the stitching cycle (see sub-section 5.5.1). Stopping and starting the pattern drum has been resolved into an electrical control function and one extra source/sensor unit (item 1 Fig. 5.2) was provided on the pattern reading head to read signals and operate the clutch solenoid. Fig. 5.4 shows part of the pattern control panel with a manually operated button (2) to stop and start the pattern drum. Also shown are the automatic stop/start controls (3) such that the pattern drum can be preprogrammed to run, then stop for a preset number of stitches, and restart. This may be done continuously causing a semi-intermittent rotation of the pattern drum where the amount of intermittency can be predetermined by a standard preselectable logic counter. On the research rig the system operated as follows:

(i) The pattern film was painted with an appropriate design in the normal manner including black non-reflective dots (control signals) in line with the extra control source/sensor unit.

(ii) The auto-stitch count selector was preprogrammed to stop the drum in accordance with the control signals for a certain number of stitches. On the research rig any number of stitches could be programmed, in binary form between 0 and 255.

(iii) The pattern film was loaded on the pattern drum and run to produce the required patterned fabric.

(iv) When a control signal was picked up a pulse was sent to the auto-stitch programmer circuit (see Appendix II) and, in order to ensure that the pattern drum stopped in the centre of a particular reading band, the circuit did not function until a synchronizing pulse was received. The two pulses together switched through an 'AND' gate starting the stitch counter and energizing the clutch solenoid. Thus the pattern drum stopped on a particular line while stitching commenced forming warpwise elongation of that pattern line.

(v) The preprogrammed number of stitches was counted by monitoring the subsequent synchronizing pulses.
When the count was complete the output signal from the programmer de-energized the clutch and started the pattern drum rotation. Naturally the control signal dot then moved from under the control source/sensor unit which stopped the signal to the 'AND' gate such that the counter reset itself ready for subsequent control signals.

The pattern stop device increased the versatility of the pattern reading system by providing the effects of pattern elongation, i.e. for a particular painted pattern film, the corresponding pattern produced on the fabric could be expanded in the warpwise direction. Fig. 7.9 illustrates the fabric effects obtainable with the corresponding pattern films used.

7.6 General Adaptations

It may be observed from the discussion so far in this chapter that there are at least three sculpturing systems to choose from if one is considering further research or even the possibilities of commercial applications. These are a specification I system; a specification II system; and a three pile height system. The shog cancellation and pattern stop devices could, of course, be additions to any of these sculpturing systems, thereby widening the range of possibilities. However, there are several other electronic and mechanical adaptations that could be made available even with the relatively simple graphical pattern scanning system used on the research rig. The details of these other adaptations were not finalised in this research programme but there is every justification for mentioning some of their functions and versatilities in this section.

7.6.1 Electronic Adaptations

(a) Polarity change: If the circuitry of the pattern read sensors was to be equipped with a voltage inverter which could be brought into operation by control signals painted onto the pattern film, then the relationship of the reflective and non-reflective areas to the sculptured pile produced would be reversed. The pattern could commence with the reflective areas producing low pile and the non-reflective areas producing high pile but, on receiving a control signal the same pattern would proceed with the reflective areas producing high pile and the non-reflective areas producing low pile. The advantage of such a facility would give extra scope for textile fabric design.

(b) Auto-scrambler: On the research apparatus one particular source/sensor unit controlled a corresponding solenoid trigger. However,
Fig 7.9 EFFECT OF AUTO-PATTERN STOP DEVICE
an auto-scrambling unit could be installed between the solenoid driving circuits and the solenoids. This may be programmed on a stitch count basis in order to change control of the source/sensor units to different solenoids. Thus for a given pattern film, the pattern produced on the fabric could be, say, automatically mirrored in the weftwise direction, or displaced generally as production progressed.

(c) Auto-shog cancellation: The pattern stop signal described in section 7.5 could be used to signal shog cancellation simultaneously. Thus when making borders of zero pile height the pattern film would stop and not be wasted while a length of border was being stitched at zero pile under the control of a preprogrammed auto-stitch count selector.

(d) Auto-pattern reverser: The pattern drum could be driven through an electrically controlled mechanically reversing gear box. Electrical signals to the gear box would automatically reverse the direction of rotation of the pattern drum. Therefore, geometric pattern repeats in the warp direction could be produced with only half the pattern needing to be painted on the film. Also the number of reversals could be preset so that after a given period the pattern continues to a new geometric array producing extremely versatile pattern repeat possibilities.

7.6.2 Mechanical Adaptations

(a) Superimposed standard loopers: All the looper manipulation mechanisms postulated so far for producing sculptured fabrics were designed in module form. This means that for, say a 3 metre stitching width machine only certain areas of the width need to be provided with a sculpturing module, the rest of the width being made up with either no loopers or standard looper banks. Thus on one fabric face there could be possibilities for simultaneously producing areas of specification I and specification II sculpturing together with adjacent regions of zero height pile and preset standard plain pile heights.

(b) Looper removal: Loopers could be removed, as desired, from the sculpturing mechanisms in order to produce borders or stripes of zero pile height in the warp direction. The advantage of the fabrics thereby produced would be the same as those when shog cancellation is used for weftwise borders (section 7.4).

(c) Double-sided sculpturing: Because the sculpturing systems designed operate independently from the stitching on the other side of the base fabric, the possibilities exist for completely independent double-sided sculpturing. This includes using different mechanisms on either side which may or may not be controlled by a common pattern drum.
7.6.3 Possibilities for Commercial Development

Having outlined briefly the adaptations of the basic sculpturing systems it was thought necessary to discuss some of the wider commercial implications. This discussion, in chapter 8, therefore also includes references to other pile-fabric processes which might benefit from this research.
CHAPTER 8

COMMERCIAL IMPLICATIONS

8.1. Commercial Production of the Sculpturing Mechanisms

The nature of this research was, of necessity, very closely linked with the commercial aspects of producing high-speed patterned locked-loop fabrics and thus it is important that the information obtained, together with the apparatus constructed is of real practical value. Therefore one method for assessing the degree of commercial success achieved would be to consider the convenience of manufacturing and installing the sculpturing systems into a commercial Locstitch machine and in consequence the redesign that may be necessary.

8.1.1. Specification I

The specification I sculpturing mechanism described in chapter 4 produces fabrics with high and low pile height loops. The cross-sectional view and a photograph of the general construction of the mechanism may be found in Figs. 4.16 and 4.24 respectively. It may be observed from these illustrations that, in order to adapt the apparatus for use on a full stitching width machine a considerable amount of redesign and development would be necessary. However, there are certain concepts that may be discussed at this stage. The swan-necked arm (Fig 4.16 item 2) which provides the vertical motion of the loopers was connected to the pivot link (22) via link (23). Two such links (23) on the research apparatus were positioned externally to the stitching width of the rig, thereby allowing them to pass by what would be a continuous member on a full-width machine. Obviously this link would have to be removed to allow the looper 4-bar and trigger firing mechanisms to have an uninterrupted span across a full-width machine. Fig. 8.1 is a perspective sketch of half a typical arrangement which may have a continuous stitching width and incorporates the sculpturing mechanism for producing specification I fabrics. The major change from the research rig design is that the vertical looper motion is derived directly from the secondary cam (1) via the link (2) which protrudes through a cored hole, sealed for lubrication purposes with a rubber gaiter, in the main "trough-shaped" beam carrying the needle drive cam modules. This would mean that the looper shogging bar and trigger firing mechanisms could extend to the full width of a machine whilst still being supported and driven at several discrete positions along their length, in the same manner as the needle bar is supported on the standard commercial Locstitch machine.
Fig 8.1 SPECIFICATION I FULL WIDTH MECHANISM
The individual looper 4-bar linkages used on the research rig consisted of five components (see Fig 4.23), the flexing looper link, the front link, the rocking segment link, and two pivot pins. These elements were convenient to manufacture in this form with the workshop equipment available. However, mass production of, for example, the bifurcated front and rocking segment links would be expensive, as would the riveting on of the flexing member in the looper link. Therefore for production purposes it would be more desirable for all the links to be flat stampings as illustrated in Fig. 8.2. This reduces the number of components to three as the pivotal motions would be obtained via 'jig-saw puzzle' joints. The flexing part of the looper link would then be achieved by a simple grinding operation to locally thin out the link in a position where flexing is required. This principle would have the added advantage that if loopers, for any reason, were damaged in the machine they could be conveniently replaced by prising them out and 'snapping' in new ones over the jig-saw puzzle joints.

8.1.2. Specification II

The mechanism for producing specification II sculptured pile fabrics (pile loops and zero height loops) was described in section 7.3. This particular mechanism, being considerably simpler than the specification I mechanism, has few of the complications described in sub-section 8.1.1, and therefore adaptation of the design to suit a full sewing width machine would be more convenient. Fig. 8.3 is a perspective sketch of half a typical arrangement which would allow the specification II mechanism to have a continuous looper bar. It may be observed from this illustration that there is little difference in design from that shown in Fig. 7.6 which is a research rig design.

8.1.3. General Design Possibilities

There are several design concepts that are applicable to both the Specification I and II sculpturing mechanisms that may also be considered from the commercial viewpoint. In sub-section 7.1.3 ideas were postulated for improving the response time of the solenoid firing triggers. However these ideas were based on the use of the commercially obtained solenoids which were not perhaps ideal for the application. It would be desirable to design a special purpose solenoid for firing the triggers since large quantities would be required for each machine. By designing a special solenoid the air-gap losses could be minimised and the general efficiency may be up-rated for this particular application. However, before such a design undertaking there would need to be considerable research into the electro-magnetic characteristics required and into testing of long-term
Fig. 8.2  LOOPER 4-BAR
LINKAGE WITH JIG-SAW
PUZZLE JOINTS
Fig 8.3 SPECIFICATION II FULL WIDTH MECHANISM
reliability. Nevertheless the prospect of making the trigger and solenoid core an integral component as illustrated in Fig. 8.4 seems, even at this stage, worth pursuing. The curved windings would remove the necessity of a slotted end in the trigger whilst the rectangular cross-section of the windings would help to ease problems of staggering arrangements (see sub-section 4.3.5) i.e. the factor governing the physical size and weight of the triggers. Thus the triggers become relatively simple stamped components.

Other changes in the design of the mechanisms for use on a commercial machine would include the use of casting instead of fabrications, better bearing arrangements and generally more suitable materials etc.

8.2. Fabric Specifications Available

An important aspect when assessing the commercial viability of a textile process is to consider the range of fabrics that the process is capable of producing. In the case of sculptured locked-loop pile fabrics the following fabric specifications form the limit of the developed process.

(i) The pattern on the fabric surface may be independent on either side of the fabric but it must be created by either high loops and low loops (specification I) or loops and zero height loops (specification II).

(ii) The pattern on the fabric may consist of combinations of specification I and II but only as discrete areas across the stitching width (see sub-section 7.6.2).

(iii) The pile loops may have a preset maximum height of 7.6 mm (0.3", see sub-section 4.5.3) and a preset minimum height of 1.8 mm (0.07") but may be infinitely variable between this range.

Apart from the above limitations there are no further constraints governing the range of patterned fabrics that may be produced because the selection system developed provides a full jacquard pattern in the complete warp and weft directions.

8.2.1. Colour Patterns

In sub-section 2.2.1 the possible techniques for producing colour patterned locked-loop fabrics were discussed and it was concluded that the process did not readily lend itself to such techniques. However, this research has revealed the possibilities of producing pile heights of 7.6 mm (0.3") together with zero pile heights. Therefore, using an improvised hand-assisted version of the specification I mechanism, already installed
Fig 8.4  SPECIAL PURPOSE SOLENOID TRIGGERS
in the research rig, with looper maximum height preset at 7.6 mm (0.3") and threading the needles alternately with two different coloured yarns a colour patterned fabric was simulated. The technique was identical to that of traditional tufting i.e. by bringing the required colour to the foreground in one seam of the fabric and allowing the other colour to sink to the background in adjacent seams and be hidden. Time did not permit a specification II mechanism to be actually manufactured but by adapting the specification I mechanism and running at extremely low speed it was possible to test this colour patterning technique on the research rig. The fabric produced by this method is illustrated in Fig. 8.5 and appears to be very encouraging at this stage. The yarn used was a 6's cotton count 'Courtelle' but a false-twisted and set bulked polyester filament type of yarn may well produce even better results; the increased face coverage resulting from such yarns would conceal the background yarns to a greater extent. Further work in this area, which is probably more appropriate to the Textile Technologist rather than to the Mechanical Engineer, would be necessary before making any judgements regarding the commercial acceptability of such fabrics.

8.3. Applications to other Pile Fabric Processes

The system developed for sculpturing the locked-loop fabric may be defined as a 'high-speed multi-end Jacquard process'. Therefore the principle of the system may have possible applications on the other high-speed multi-end processes that have not, as yet, incorporated Jacquard patterning equipment. The response time of the actuation triggers was found to be 20 ms (see sub-section 4.3.5) but with the automatic pulse advancing system postulated in sub-section 7.1.3 it would be possible to reduce this response time to 15 ms. If this represents, say, half the cycle time of a process then it would be possible to make individual selections of elements on processes capable of speeds up to 2000 cycles/minute. In fact, when the response of the solenoid triggers were tested, they were found to operate under simulated speeds of up to 2300 operations/minute. Apart from non-Jacquard needle insertion narrow-fabric looms and the very simplest warp-knitting machinery the author knows of no other multi-end fabric producing processes capable of such speeds. Therefore the developed selection system could be adapted for use on other textile machinery. Such adaptations would be dependent upon the interface between the mechanical elements for manipulating the yarns in a particular process, and the electronic firing devices. Therefore the possibilities are briefly discussed below for some
Fig 8.5  COLOUR PATTERNED LOCKED-LOOP FABRIC
of the known multi-end pile fabric processes.

8.3.1. *Kraftamatic*

Fig. 8.6(a) is a diagrammatic illustration of a machine using the Kraftamatic principle (see sub-section 2.1.3). The base fabric (1) is fed in the direction indicated by the feed rollers (2). The needle banks (3) push the threads through the base fabric and on retraction loops of thread are retained by the latch needles (4). The latch needles are mounted individually on rocking segments (5) pivoted at (6). They are steadied against the prime mover (7) by a spring (8). The pivot (6) is mounted on the needle bar (9) which also carries a looper latch (10) and an operating solenoid (11). The latch catches the shoulder (12) on the rocking segment when the latter is displaced by the prime mover (7) for the production of longer loops. Fig. 8.6(b) illustrates the loop stitch formation and the variation of loop length possible by the latch needle displacement. The individually mounted upper loopers (13) are arranged to pivot at (14) on the looper bar (15) under the control of the prime mover (16) and spring (17) which biases the loopers to the lower position shown. Fig. 8.6(c) illustrates the alternative positions of the loopers, i.e. for short loop lengths the solenoid (18) does not engage the latch (19) and for long loop lengths the latch is engaged. Hence a double-sided sculptured Kraftamatic fabric could be produced.

8.3.2. *Malipol and Araloop*

The Malipol and Araloop processes are very similar and use almost the same stitching elements as illustrated in Fig. 8.7. In Fig. 8.7(a) the compound needle (1) penetrates the fabric and interacts with the thread guides (2) to catch the thread and form a loop over the looper (3). The looper has a stepped profile at the free end to provide high and low pile height loops when the looper is in either the forward or backward position. The looper is actuated by a prime mover (4) and includes a latch portion which is engaged by the latch (5) operated by a solenoid. Thus the looper can be held back by the latch (low loops) or can be allowed to move forward (high loops) in a preselected manner. Zero and pile loops could be achieved by arranging for the looper to be latched in the back position clear of the stitching zone. An alternative system is illustrated in Fig. 8.7(b). Here the looper (6) is pivoted at (7) and biased to a low pile height position by the spring (8). The prime mover (9) acts to move the looper to a high pile height position where it may be held by the latch (10) or allowed to fall back to the low pile height position depending upon the actuation of the solenoid (11).
Fig 8.6 KRAFTAMATIC SCULPTURING
Fig 8.7 MALIPOL AND ARALOOP SCULPTURING
8.3.3. Tufting

Fig. 8.8 is a diagrammatic illustration of a possible adaptation of the conventional tufting process for producing high and low loops without the necessity for back-robbing (see sub-section 2.1.8). The needle (1) interacts with individually mounted looping elements (2) which are pivoted at (3) to a rocking segment (4) which is itself pivoted at (5). The prime mover (6) causes an up and down motion of the looper which is either held in the high pile height position by the latch (7) or allowed to fall to the low position, depending upon the actuation of the solenoid (8). The looper would pick up the yarn from the flank of the needle in the normal manner via the action of the second prime mover (9).

8.3.4. Warp Knitting

Conventional warp-knitted pile fabrics are usually produced on a twin bed raschel machine where one needle bank has been replaced by a set of 'plush' points (see sub-section 2.1.6). The sculptured pattern possibilities are limited by the number of thread guide bars used on the machine and the warp threading. Fig. 8.9 illustrates the possibility of using the standard needle motion of the raschel machine for causing the lever (1) to actuate individual plates (2) which carry the plush points. The latch (3) is operated by the solenoid (4) to engage or miss the catch (5). If it engages, the points (6) are prevented from entering the knitting zone and no pile would be produced. Alternatively, if the latch is not engaged, the points would be raised into the knitting zone by the action of the spring (7) and a pile loop would be formed when the thread guides wrap the yarn around the protruding plush points. Thus in continuous operation a warp-knitted pile fabric could be Jacquard sculpture-patterned.
Fig 8.8  TWO PILE HEIGHT
 TUFTING
Fig 8.9 WARP KNITTED SCULPTURING
CHAPTER 9

DESIGN APPRAISAL OF THE COMMERCIAL MACHINE

The sculpturing mechanism described in chapter 4 was designed to be used in conjunction with, and without modification to, the existing needles and needle orbits as used on the commercially produced Locstitch machine. Indeed, close examination of the cyclic interactions between the needles and loopers (Figs. 4.7 to 4.10) revealed that the loopers perform no function in the production of the basic locked-loop stitch. The basic stitch is produced by the interactions of the needles (see section 1.1) and the loopers merely prevent a portion of the yarn from lying flat against the base fabric. However, on the research rig which included the sculpturing mechanism, the reliability of the process was initially inadequate and resulted in frequent yarn breakages and 'dropped' stitches. At first it was thought that the sculpturing mechanism was causing these problems but when it was removed so that basic, unpatterned, locked-loop fabric could be produced the same degree of unreliability was exhibited. Such inefficiencies would normally lead to a detailed analysis of the stitch formation process in order to remove the malfunction. However, an investigation of this nature did not come within the terms of reference for this research project. The dilemma of demonstrating to industry an otherwise reliable patterning system on a research rig with inherent unreliability influenced the decision to make a brief appraisal of the basic locked-loop process. Investigations led to the modification of certain stitching elements which resulted in a research rig with a greatly improved fabric production reliability; although this reliability was still somewhat imperfect, the investigations did reveal possibilities for further improvements. These improvements could not be undertaken because time and financial resources did not permit. Nevertheless it was thought that such information might be useful for future researches and should be reported in this chapter together with a general appraisal of the commercial machine and process.

9.1. Needle Motions

9.1.1. Primary Motion

The primary motion of the needles was previously described and illustrated in sub-section 3.3.2 and Fig. 3.7 (a) respectively. The primary displacement curve corresponding to the needles moving into the base fabric is a parabolic function whilst the displacement curve corresponding to the
needles' retractive motion is a cycloidal function. The combined effect of these two motions produces a quick-return action for the needles, but also generate an infinite third derivative or pulse at the points of zero velocity. Therefore these curves do not offer the most favourable dynamic conditions for high-speed cam design. In sub-section 4.4.2 a procedure was described for removing third derivative pulses that would have been generated by the sculpturing mechanism cams; using such a procedure on the primary needle cams might well improve the needle dynamics and hence the operational life of the conjugate cams. The suggested improvements to the velocity and acceleration curves are compared with the existing curves in Figs 9.1 (b) and (c) respectively. It will also be noticed in Fig. 9.1 (a) that an increased displacement of the needle retraction is suggested which would allow a further increase in the maximum pile height i.e. in excess of the 7.6 mm (0.3") already produced. In sub-section 4.5.3 it was argued that needle station 12 (Fig. 4.9) was the critical stage for needle/looper clearances and if station 12 were to be increased to 10.4 mm (0.410") as shown in Fig. 9.1 (a) then maximum pile heights of 10 mm (0.4") may be achieved. This would still leave 0.4 mm (0.010") clearance between the needles and loopers whilst increasing the pile height specification quoted for the commercial machine (sub-section 3.3.1) by 100 per cent.

9.1.2. Secondary Motion

The suggested modifications in sub-section 9.1.1 for primary motion are sound but they would have little effect on the reliability of the stitch formation process, since proper and consistent formation of the locked-loop stitch is thought to be primarily dependent on the secondary displacement of the needles. Fig. 9.2 is a reproduction from Fig. 4.10 of certain needle stations which affect the correct formation of the locked-loop stitch. At station 11 it will be noticed that the needle point is above the yarn extending from the base fabric to the needle eye. At station 13 the yarn and needle point are coincident until, at station 14, the looper shogging has partially occurred with the yarn now above the needle point. These functions are required so that the yarn is correctly positioned as shown at station 16 i.e. through the eye and over the top flank of the needle. However what has been observed to occur occasionally in practice is illustrated in Fig. 9.3. At station 14 the yarn is sometimes pierced by the needle point (Fig. 9.3 a) or, more frequently, the yarn is caught underneath the needle flank (Fig. 9.3 b). In either case the yarn is incorrectly positioned at station 16 and when the needle pierces the base fabric, under these conditions, the complimentary needle often fails to pick up the yarn.
Fig 9.1 CHARACTERISTICS OF NEEDLE PRIMARY MOTION
Fig 9.2 CRITICAL NEEDLE POSITIONS
(a) YARN FIBRE PIERCING

(b) YARN WRAPPED BELOW NEEDLE POINT

Fig 9.3 INCORRECT YARN POSITIONING
to form the locking loop. The cause of this problem is obviously a result of the needle secondary displacement. There is no reason why the needle point should ever be taken above the yarn as occurs at the existing station 11. Thus if the yarn is never below the needle point it can never be caught and held there. The criteria for achieving this would be to reduce the secondary displacement when the needles leave the base fabric, as shown in Fig. 9.4 (b).

From the shape of the existing secondary displacement curve (Fig. 9.4 a) it is obvious that the cam design was based on the maximum stitching pitch positions because of the straight-line portion, which produces a constant velocity equal to the base fabric speed. When stitching pitch adjustment is made the secondary displacement becomes distorted in the part of the cycle where a straight-line is ideally required. This deviation has been measured to be 0.71 mm (0.028") and in practice this is compensated for by a combination of both vertical needle deflections and base fabric weft thread displacements. Any motions that cause deflections ought to be optimised in order to minimise such deflections. The sizes of the stitching pitches possible by adjusting the standard cam modules are 6, 8, 10, 12 and 14 stitches per inch (see sub-section 3.3.1). Therefore it is suggested that the constant velocity secondary displacement should be based on the 10 stitches per inch setting which would create a reduced distortion at 14 and 6 stitches per inch of approximately 0.35 mm (0.014"). This would produce the more desirable displacements illustrated in Fig. 9.4 (b).

The combination of the suggested new primary and secondary needle point motions are illustrated in Fig. 9.5. From the trajectory of the yarn at stations 11 and 12 together with the increased pile heights possible it will be appreciated that there would be a marked improvement over the existing motion illustrated previously in Fig. 3.8.

9.2. The Looper System

In sub-section 4.1.4 the commercially used reed type looper was discussed. It was concluded that a short length tip with pile height adjustment perpendicular to the base fabric should be used for the sculpturing mechanism. The advantages of such modifications also apply to the standard non-patterning looper i.e. the fewest loops retained on the looper at any one time creates the smallest transverse force on the looper during shogging. The shogging member, on which the looper reeds are mounted, is constrained by a slideway lined with a low friction material. This slideway poses certain alignment problems which could be alleviated by using the flexible
Fig 9.4 SECONDARY NEEDLE DISPLACEMENTS
Fig 9.5  A MODIFIED NEEDLE ORBIT
strut system developed for the sculpturing mechanism and described in sub-section 4.3.6. By such means the shogging member would be able to move essentially in the transverse direction only and be relatively friction free without the need for further constraints, lubrication or exacting alignment (see Appendix III section A). The displacement curve (Fig. 9.6 a) of the loopers should also be reviewed in this critical appraisal. It will be noticed in Fig. 9.6 (a) that, when the loopers are shogged in one particular direction, they move 0.46 mm (0.018") dwell, and then move a further 1.54 mm (0.060") to complete the displacement required. This characteristic was intended so as to delay the passage of the loopers in front of the retracting needle points until the last possible moment without collision occurring, in an attempt to ensure that the yarn trajectory lies above the needle flank, for the reasons detailed in sub-section 9.1.2 (see also Fig. 9.2 stations 13 and 14). Failure of the stitch formation has been attributed to the needle's secondary displacement rather than to the looper motion, but shogging could still be delayed to the last possible moment by using the displacement curve shown in Fig. 9.6 (b); this removes the necessity for a dwell portion thereby eliminating a double acceleration and retardation function which causes wear of both cam and follower.

9.3. Yarn Feed

The mechanisms for yarn tension and feed control on the commercial machine were discussed in sub-section 6.1.1 and basically function as a positive yarn feed system. However, it was shown experimentally (sub-section 6.2.1) that if the locked-loop stitching process is allowed to consume only the amount of yarn required per stitch under constant cyclic tension conditions then up to 0.7 mm variation in length of yarn consumed per stitch resulted. Therefore it may be assumed that, with the preset quantity of yarn feeding into each stitch on the commercially used system, there must be different cyclic variations in the yarn tension per stitch. Further experimentation would be required in order to determine whether such tension variations have any effect on the efficiency of the process and whether the process would be better serviced with a negative type yarn feed system similar to that described in sub-section 6.2.3. A more significant factor influencing the choice of yarn feed systems occurs when a stitch is mispicked i.e. when a needle fails to pick up the yarn from the flank of its complimentary needle. The frequency of this occurring is dependent upon the efficiency of the process which, in turns is dependent upon several factors such as the quality of yarn, production speed, environment,
Needle Point Positions

(a) EXISTING SHOG DISPLACEMENT CURVE

(b) MODIFIED SHOG DISPLACEMENT CURVE

Fig 9.6  LOOPER SHOG DISPLACEMENT CURVES
type of base fabric used etc. In the locked-loop process the occasional missed stitch does not necessarily mean a reject fabric provided that the correct stitch formation is resumed immediately after the failure in a particular seam, so that the fault may not be noticeable. However, when stitches are missed the unformed locking-loop causes excess yarn in that particular stitching seam and if the yarn is fed positively into the stitching zone then several needle cycles may be required to consume this excess. This is satisfactory provided that the slack yarn around the needle eye under these conditions does not interfere with adjacent yarns; unfortunately such interference does occasionally occur in practice. The negative yarn feed system described in sub section 6.2.3. 'resets' the quantity of yarn to be fed each cycle and therefore immediately compensates for slack yarn generated by missed stitches. This may be a more desirable mechanism than that currently used on the commercial machine.

9.4. The Basic Stitching System

The investigations that were carried out in order to provide a reasonably reliable stitching process involved about six months of research time but were not relevant to the 'Development of Patterning Systems' and therefore are not detailed in this thesis. However, the results of these investigations revealed certain phenomena that have apparently not been experienced with any other textile process. Theories have been postulated to explain these phenomena but further work is necessary for verification. Therefore the investigations will be briefly mentioned in this section in the hope that further research will be stimulated.

There are two fundamental requirements for the production of a locked-loop fabric. The first factor is that a row of needles, with offset points, simultaneously pierces a preconstructed matrix of threads (i.e. the woven base fabric). The second factor is that, at any point in time, at least one row of needles is always penetrating the base fabric.

Research has been carried out on the conventional tufting process which involved a study of needle deflections when they pierce a preconstructed woven base material; but, while the problem is acknowledged, no solution has yet been offered. Therefore needle deflections in the locked-loop process must be expected and these will affect the needle closure (i.e. the relative needle positions when the yarn is being picked-up) especially when the deflections occur in the weftwise direction. These weftwise needle deflections were considered to be the major factor influencing the reliability of the locked-loop process and therefore an understanding of
the causes of deflection propagation would provide useful information for future researches.

9.4.1. Experimental Constraints
In order to establish reasonable experimental conditions certain features of the process remained constant, as follows:

(i) The needles used were those commercially employed on the Locstitch process and, although part of the experimentation involved modifying the needle point shape and shank length, the basic needle cross-sectional size and shape remained constant.

(ii) The needles were mounted on the research rig which incorporated the standard drive cam modules and as the needle orbital motion remained constant so did the depth of needle penetration into the base fabric.

(iii) The deflections of the needles and other components were measured in one plane only i.e. the weftwise direction.

(iv) Unless specifically stated all experimentation was conducted without pile yarns threaded through the needles. This was done in order to obtain maximum clarity in the stitching zone.

(v) The actual measuring instrument used was a travelling microscope equipped with a lens target having a magnification dictated by the space available for mounting the instrument. Calibration tests revealed that the instrument's vernier scale and target positioning means combined to give a reading accuracy of \( \pm 0.025 \text{ mm (0.001")} \).

(vi) The weftwise deflections of the needles relate to measurements of their points at a particular stage in the needle cycle, this being at the full penetration position, i.e. B.D.C. (bottom dead centre).

(vii) All measurements of needle deflection were from a datum undeflected position. This was achieved by cutting a hole in the base fabric large enough to ensure that no forces were imposed on the needle; the microscope target was then zeroed on the needle point at the B.D.C. position.

(viii) The base fabric used for piercing was a 100% Vincel 52 x 40, 20/20's cotton count woven structure and, although the piercing of a matrix structure is shown to be a contributing factor to the needle deflections, its use was
maintained throughout the experimentation. Other base fabric structures were not readily available and, in any case, time did not permit a repeat of the measurements under new conditions. The justification for experimenting with only the one base fabric was that it was typical of fabrics required as a backing for towelling and similar Lcostitch products and therefore such a fabric forms a criteria for the process reliability.

9.4.2. Single Needle Deflections

As the needle's offset point pierces the base fabric, a transverse force is applied which deflects the needle. This force is caused by the needle's point of entry being at a different position to the principal cross-sectional axis of the needle shank. In order to quantify the deflections caused purely by this offset needle point, one such standard length needle was attached to the needle bar and its deflections measured when it repeatedly pierced the base fabric. Naturally it was expected that the amount of deflection would vary according to the exact point of entry of the needle in relation to the warp thread positions of the base fabric, as illustrated in Fig. 9.7(a). For this reason a sample size of 100 consecutive penetrations were measured in order to construct a probability curve for further comparisons. As only one needle was used the deflections due to the offset point were expected to occur in one direction only and this will be defined as the positive direction as shown in Fig. 9.7(b).

The deflection measurements were recorded in graphical form as in Fig. 9.8(a) and it may be seen that the variations in the amount of deflection were so great that a good statistical distribution was not produced with a sample size of 100, although the general needle movement tendency could be assessed. The length of the non-active needle shank was then reduced, all other experimental conditions remaining constant. The results are shown in Fig. 9.8(b) and as expected the amount of deflection was reduced. This is because deflection is proportional to the cube of the length for a given force, and the improved needle stiffness produces an increase in base fabric warp thread distortion. Similar results were also obtained when the needle shank length was further reduced as illustrated in Fig. 9.8(c). It is interesting to note from the three distribution curves that the increased stiffness of the needle not only reduces the average deflection value but also reduces the range of deviation. This suggests that the deflections of stiffer needles with offset points are less dependent upon the needle's point of entry between two adjacent warp threads (i.e. as in Fig. 9.7 a)
Needle A will be deflected more than needle B due to the position of the warp thread X

(a)

Deflections always in this direction relative to the needle's offset point

(b)

Fig 9.7 DEFLECTION DIRECTION OF OF A SINGLE NEEDLE
Fig 9.8 DEFLECTION OF NEEDLES WITH MODIFIED LENGTHS
than more flexible needles. From the three curves the average deflection values for needles (a), (b) and (c) were determined as 0.26, 0.17 and 0.09 mm respectively. A simple static deflection rig was then constructed in order to plot the bending characteristics of each length needle previously tested. A static load was applied at a distance from the needle point equal to that of the base fabric position when deflections were measured. Thus having calibrated the needle deflection/force characteristics (see Fig. 9.9) it should be possible to determine the actual force that the base fabric applies to the needle. One would expect this force to be the same irrespective of the stiffness of the various needles since the geometry of the penetrating point remained unaltered. However, the resulting line through the average deflection values is not the expected vertical line at constant force (see Fig. 9.9) but indicates that the transverse force exerted by the fabric decreases as a function of increased needle stiffness (i.e. decreased needle length). The amount of experimental data is limited and therefore further research is required to determine whether this phenomena is a characteristic of an offset pointed needle piercing process or whether a fault existed in the experimental procedure.

As stated above, needle deflections in the weftwise direction affect the needle closure conditions and it has been demonstrated that the use of short length needles reduces such deflections. Therefore a second experiment was carried out on the short length (15 mm) single needle in an attempt to further reduce the deflections. Fig. 9.10 is a detail drawing of the standard needle dimensions which were measured optically with a travelling microscope because no manufacturers drawing could be obtained. It will be noticed that the point of the standard needle does not lie exactly along the flank, in fact, there is a 0.2 mm difference. The offset point contributes to the needle deflections and yet such an offset point is essential for the formation of the locked-loop stitch. Therefore the amount of offset was reduced to a minimum requirement, i.e. so that needle point and flank are coincident. Fig. 9.11 illustrates the deflections recorded for 100 penetrations of each of three needle point shapes and, as expected, the average deflections were reduced with smaller offset points.

The experiments with the single needle show that using a 15 mm long needle with its point lying exactly on the flank reduces the average deflections from 0.26 mm to 0.05 mm. However, what is more important is the reduction in range of deviation from 0.25 mm to 0.08 mm which is a far more favourable range for assessing the needle closure tolerances required for the process.
Fig 9.9 NEEDLE LOAD/DEFLECTION CURVES
Fig 9.10 STANDARD NEEDLE DIMENSIONS
Fig 9.11 DEFLECTION OF NEEDLES WITH MODIFIED POINTS
9.4.3. Needle Bank Piercing

Sub-section 9.4.2 gave some indication of the deflections of a single needle, but when several such needles were arranged at 1.98 mm (0.078") pitch to form a bank (see Fig. 3.9 d) and passed through the base fabric simultaneously different characteristics were observed. The increased area of base fabric distortion, caused by the needle bank, tightly packed the warp threads between each needle and thereby tended to hold the individual needles in rigidly set positions. The constrained needles (60 in the particular bank tested) now offered resistance to the transverse forces which previously deflected the single needle. This resistance resulted in a complete weftwise displacement of the base fabric. Fig. 9.12 illustrates the complete weftwise displacement of the base fabric at two discrete static positions, i.e. with the needle fully penetrated and with it fully withdrawn from the base fabric. The measurements were made by fixing the microscope target on a particular warp thread and monitoring its movements in the stitching zone. It will be noted from Fig. 9.12 that the warp threads in the base fabric made a serpentine path through the stitching zone, the effects of which were more significant when both needle banks, each side of the base fabric were considered (see sub-section 9.4.4). From Fig. 9.12 the amount of weftwise base fabric displacement was found to be 0.4 mm when the bank of offset pointed needles was inserted. This value is actually half the width of the needle (see Fig. 9.10) and, because the needle point lies essentially along one flank, the theoretical needle deflections should be zero under these conditions. To verify this, one particular needle within the bank was selected and its weftwise deflections were measured in the same manner as previously described (sub-section 9.4.3). However, instead of plotting the deflection distribution curves, the results were recorded as consecutive points on a linear scale as in Fig. 9.13. It may be observed from this graph that the deflections of the particular needle measured are far from zero and also several of the deflections were negative (unlike the solely positive deflections of the single needle). When the pierced holes in the base fabric were inspected it was found that none of the needles separated the fibres within the warps, the needle points preferred to pierce the gaps between complete adjacent warp threads. The base fabric used contained 52 warps per inch and the bank of 60 needles were pitched at 0.078" (1.98 mm) therefore within the needle bank's total length of 4.602" (116.89 mm) there were 239 warp threads. The number of complete warp threads between any two adjacent needles was then determined and found to be 4 warps between 56 needle pairs and 5 warps between 3 needle pairs. However, because of the serpentine motion of the
Fig 9.12  BASE FABRIC DISPLACEMENTS
Fig 9.13  CONSECUTIVE DEFLECTIONS OF A NEEDLE
base fabric (Fig. 9.12) the 5 warps were not always between the same 3 pairs of needles. This would seem to explain the steps in the results recorded in Fig. 9.13 at, for instance, points A, B and C, with the severe deflections occurring at a stage when the needle pierces an alternative warp gap and is then forced through an extra 0.4 mm displacement due to the total base fabric movement. Because only one bank was used for this experiment both the needles and base fabric reset to their relative equilibrium positions each time the needles were withdrawn such that one set of deflection conditions did not affect subsequent deflections.

9.4.4. Twin Needle Bank Piercing

Two needle banks were mounted on the research rig, one each side of the base fabric, and their relative motions were in accordance with the proper formation of the locked-loop stitch. Under these conditions there is always one set of needles piercing the base fabric at any one stage in the cycle. In normal operation the needle interactions require the offset point of one needle to pass by the flank of its complimentary needle in close proximity to obtain satisfactory needle closure. However if the complimentary needle has been appreciably deflected it is held in such a deflected condition by the compacted warp threads in the base fabric. The point of the interacting needle then mispicks the stitch when the needle closure is increased or, for needle deflections in the other direction (+ve), the interacting needle collides with the top edge of the complimentary needle and is severely deflected to the extent that it passes the wrong flank of the complimentary needle. This latter condition has been defined as the 'crossed-needle effect' and, unlike a mispicked stitch, the effect is not self-correcting. In the next half cycle the new incoming needle is presented with a severely deflected needle which is held by the base fabric so that the incoming needle also severely deflects and passes the wrong flank. This continues until the process is stopped and the offending pair of crossed-needles are manually manipulated into their proper relative positions. The necessity for stopping the process in order to correct a crossed-needle effect was not acceptable even for a research rig and solving this problem became a priority.

In sub-section 9.4.3 one needle bank displaced the base fabric 0.4 mm, i.e. half the needle width, and the same result was measured when both needle banks were used. The reason for this may be explained with the aid of Fig. 9.14 where 'A' and 'B' are points on the base fabric not on the needles. When needle N1 has pierced the base fabric the point 'A' displaces 0.4 mm from its datum X-X position (Fig. 9.14 a). As needle N2
Fig 9.14  BASE FABRIC MOTION
WHEN PIERCED BY
TWO NEEDLES
approaches the base fabric its point pierces at position 'B' which is 0.4 mm from *A* (Fig. 9.14 b). As needle N1 withdraws from the base fabric and needle N2 fully penetrates (Fig. 9.14 c) point 'B' moves 0.4 mm in the opposite direction. Thus points 'A' and 'B' on the base fabric still only move 0.4 mm as was the case for a single needle bank. The feature that must also be recognised from this is that the point of entry of needle N2 into the base fabric is affected by the position of needle N1 and visa versa. Therefore it was necessary to study the points of needle entry with respect to the warp thread distortion caused by the other needle being present in the fabric. It was found by examining the seams of holes produced in the base fabric by both sets of needles that there was one warp thread spacing between the holes. Although this particular warp thread zig-zagged around each hole position, there was never a case found where two warp threads or no warp threads spaced the holes. This was highlighted by threading the needles with pile yarns adjacent to the seam being considered and photographing the holes produced with a microscope attachment; the result is illustrated in Fig. 9.15. This phenomena, together with the fact that there is always a needle piercing the base fabric at any stage in the cycle and considering that across the sewing width some needles were spaced by 4 warps and some by 5 warps, indicates that the process may be critically dependent upon the alignment of the base fabric feeding into the stitching zone. To test this aspect the base fabric was deliberately fed into the stitching zone at an angle of 2° relative to the theoretical warp direction and after several successive stitches approximately 50% of the needles of one bank on one side of the fabric attempted to pass the wrong flanks of their complimentary needles (i.e. the crossed-needle effect). This test was repeated with the 2° base fabric angle biassed in the other direction relative to the warps and the same result was obtained but the failure occurred in the other needle bank from that previously observed. However, even under normal base fabric alignment conditions, such that the path of a particular warp thread makes a serpentine motion rather than a continuous diagonal motion, the accumulation of effects may result in crossed-needle failures. This would mainly occur on seams that are spaced by 5 warp threads rather than by 4 warp threads because the latter condition would not exert such a high needle deflection force as the former condition. To observe the seams in which the needle deflections accumulate to the point of stitch failure the needles were threaded with pile yarns so that the seam spacings were more visually discernable. The research rig was then run until the crossed-needle effect resulted in a particular seam, this was manually
Fig 9.15 PIERCED FABRIC CHARACTERISTIC
corrected and the process restarted. Fig. 9.16 is a photograph of a typical result and it may be observed that the seam spacing 'A' before the failure is different from the spacing 'B' after correction. It is not sufficient to say that the crossed-needle effect occurs because the needles cannot 'jump' a warp thread in the base fabric resulting in an accumulation of needle deflections. What must be discovered is the precise mechanism controlling the point of entry of a needle and why this point is always at one warp thread spacing from the complimentary needle. One possible theory is the relationship of the needle closure condition just prior to the stage where the needles pierce the base fabric. If the needles make contact with each other at this stage the in-going needles may be pre-deflected to a given point in the base fabric's matrix structure. An intensive research programme would be required just to establish the facts relating to this particular phenomena alone and such research was considered too diversified to be covered in this thesis.

9.4.5. Yarn Puckering

In section 1.1, the basic locked-loop process was described and with reference to Fig. 1.0 (F) it was stated that 'the yarn on needle N2 slightly puckers to allow needle N1 to pick up the stitch'. However, it was observed on the research rig that when the row of sewing needles pierce the base fabric the latter locally bulges due to the frictional drag along the flanks of the needles. Thus when the needles initially start to retract from the base fabric there is no relative movement between the base fabric and the needle shank (the bulge is allowed to decrease instead) and so no yarn puckering occurs. This problem was alleviated, to some extent, on the research rig by creating a very high base fabric tension to minimise the initial size of the bulge. However, the side effects of this increased tension were, firstly, approximately 2 per cent fabric extension occurred during the process and secondly, the transverse movement of the fabric met with greater resistance. Therefore a compromise existed between sufficient base fabric tension to cause the yarn to pucker but not enough to affect the needle closure condition.

9.4.6. General Solution

The experimentations described in section 9.4 relating to the reliability of the basic locked-loop process were only incidental to the main objectives of the research and were probably insufficient for adequate conclusions or recommendations to be offered. However, the results did indicate two areas where modifications could be made to improve the reliability of the research rig. Firstly, the needles were shortened as much as possible
Fig 9.16 SEAM SPACINGS
to increase their stiffness and reduce the deflections resulting from the transverse forces applied by the base fabric; and secondly the needle points were sharpened to such an extent that a slight chisel-point was formed. This was done in an attempt to cut through some of the weft threads and so relieve some of the binding forces on the warp threads in order to reduce the constraining forces imposed on the needles. These modifications to the needle design totally removed the crossed-needle effect and although a few stitches were still mispicked the research rig could be run continuously with reasonable reliability for the main objective of sculpture patterning to be realised.
CHAPTER 10

CONCLUSION

10.1. The Degree of Success Achieved

The apparatus developed during the course of this research project demonstrated that sculpture-patterned locked-loop pile fabrics could be produced at the same high production rate as the plain locked-loop fabric. Appendix IV contains photographs of a small selection of patterned fabrics that have been produced on the research rig. However, this does not mean that the terms of reference have been satisfied. The research was biased towards the practical aspects of developing a patterning system that would be commercially acceptable to the textile industry and economically viable for machine manufacturers and fabric producers alike. Therefore the degree of success achieved by this work is dependent upon whether the system is adopted commercially. The Science Research Council were the sponsors of this research and consequently the research supervisor and his collaborator (Prof. G.R. Wray and R. Vitols) were obliged to consult the National Research and Development Corporation regarding commercial exploitation. Consultation with N.R.D.C. resulted in patent cover for three aspects of the research; the flexible support means for the shogging looper members; the sculpture patterning mechanism and its variations; and the yarn feed device. These inventions have been assigned to N.R.D.C. and extracts relating to some of the more important statements within the patents may be found in Appendix III. The Pickering Locstitch Company (manufacturers of the basic locked-loop pile fabric machine) are currently studying the commercial feasibility of the sculpturing system, and should they or other companies decide to exploit the inventions via licensing agreements with N.R.D.C., then this research work may be regarded as successful.

10.2. Suggestions for Further Work

The locked-loop pile fabric production system is still in its infancy when compared with weaving, warp-knitting, weft-knitting, tufting, and other commercially accepted processes. It is suggested that there is still an appreciable amount of basic research needed before this fabric, and method of producing it, can establish a realistic share of the pile-fabric market. Certain aspects of new research requirements have been high-lighted previously (section 8.1 and chapter 9) but, because this project was based upon patterning techniques, the suggestions for further work will be confined accordingly.
10.2.1. Fabric Production Rate

The production rate of the sculpture patterned pile fabrics was dictated, to some extent, by the production rate quoted for the commercial machine (sub-section 3.3.1) i.e. 750 double stitches per minute. Having achieved this, why not increase the speed? It has been demonstrated that the pattern selection system has the capability for this (section 8.3). When the research rig speed was increased (850 double stitches per minute) the lack of cam module balancing was apparent and the amount of 'dropped' stitches and yarn breakages increased disproportionately. However, even with a superior dynamic balancing system, the speed limitation factors remain unknown. An eyed needle used on an industrial sewing machine is capable of taking thread through a base fabric 3000 times per minute. Therefore, is the locked-loop production speed limited by: (i) the quality and strength of the inserted pile yarns? (ii) the forces exerted when a row of needles and yarns pierce a base fabric at high speed? or (iii) the pulse tensions in the yarn, created by the yarn feed device, being susceptible to a phase lag between their point of origin and the stitching zone? Further research into these areas could well remove such speculation and provide a faster and/or more efficient sculpture-patterned locked-loop process.

10.2.2. Needle Drive Mechanism

Suggestions were made in section 9.1 regarding possible modifications to the needle orbital motions that would ultimately improve the specification of the sculpture patterned fabrics. It would be useful to examine the requirements of a linkage mechanism for producing such needle orbits, especially in the context of the research work by R.N. Parry\(^\text{12}\) and in view of the cost of producing precision conjugate cams.

10.2.3. Colour Patterns

Judging from the results of preliminary experiments described in sub-section 8.2.1 (with particular reference to Fig. 8.5), it would be a valuable exercise to manufacture a specification II sculpturing mechanism. Then the potential of colour patterned locked-loop pile fabrics could be realised. With 10 mm (0.4") pile heights and specially selected yarns the author is confident that the textile technologist could provide a commercially acceptable product.

10.2.4. Other Processes

The application of the element selection system on other textile processes are only given as possibilities in section 8.3. Feasibility studies of such adaptations are essential before any further work in that...
area could be considered. However, as a first stage of such studies, high-speed processes with a limited number of warp ends e.g. narrow fabric looms, could be examined.

10.3. A Product for the Textile Industry

This research has resulted in the development of a technique for individually manipulating and selecting the movements of small elements on a multi-end textile process. To date, high-speed jacquard multi-end selection systems have never been attempted commercially. The reason could be either that the cost of such sophisticated textile machinery is commercially prohibitive or that the demand for jacquard-patterned fabrics is diminishing. In the case of machinery capital-costs it must be conceded that an electro-mechanical selection device on each warp line will be relatively expensive to manufacture. On the other hand, if the demand for jacquard-patterned fabrics is diminishing because they cannot be produced fast enough to compete with, say, printed patterns then this research may provide the basis for reversing this preference. However, the textile industry is largely motivated by fashion, and fashions change, so even if the technique developed in this research is of no immediate use to the industry it could well meet the requirements for future demands.
REFERENCES


21. F. Uriger - "Experience in the Production of Pile Fabrics by the Malipol Process" Deutsche Textiltechnik 1971, 21, No. 11, p.689-96 (in German).
34. USP. 3,625,260 - "Fabrics with intricate pile arrangements"  


36. E.R. Brooke - "Textile Machinery mechanisms - Tensioning Devices"  


38. B.P. 01516/75 - Complete Specification - "Improvement in or relating to Apparatus for producing pile fabrics and the like."  

39. B.P. 45777/75 - Provisional Specification - "Improvements in and relating to feed apparatus for yarn and like filamentary materials"  

The mathematical solution of the mechanism described in chapter 4 is not complex, but it is included in this thesis in order that any modifications to the looper orbit that may be thought desirable for future research can be conveniently undertaken. The cams designed for the sculpturing mechanism drive the looper element via a linkage system. This linkage system was mathematically solved so that the path of the looper element could be predicted for given cam displacement curves.Conventionally the path or orbit of the element would provide the criteria for the cam design but in this case the displacement curve of the cam was used as data for the reasons stated in sub-section 4.4.2. Thus by altering the cam displacement curves until an optimum element path was obtained, more favourable dynamic characteristics were produced at the motion source. The link lengths and centre distances that make up the mechanism also formed data for the calculations because they were determined merely by the physical constraints of the research rig construction (see section 4.2).

For machine shop purposes all dimensions are in inches.
The starting point is determined when the centre of the nodding bar is at the \( k_{\text{datum}} \), \( l_{\text{datum}} \) position, i.e. when the looper is at a minimum distance from the base fabric.

\[
\theta_p = 2 \cdot \sin^{-1} \left( \frac{h_p}{2 \cdot c} \right)
\]

\[
l = a - d - J \cdot \sin (\phi - \theta_p)
\]

\[
k = b + c - J \cdot \cos (\phi - \theta_p)
\]

\[
\beta_{\text{datum}} = 1.309 \text{ rad.}
\]
\[
P = 1.4375
\]
\[
n = 2.84375
\]
\[
m = 0.375
\]

**Fig IB**

Detailed dimensions of nodding bar primary cam drive

**Fig IC**

Detailed dimensions of nodding bar action on the rocking segment

\[
q_{\text{datum}} = \sqrt{(P - l_{\text{datum}})^2 + (k_{\text{datum}} - n)^2} \ldots \text{ constant}
\]

\[
\delta_{\text{datum}} = \sin^{-1} \left( \frac{P - l_{\text{datum}}}{q_{\text{datum}}} \right) - \sin^{-1} \left( \frac{m}{2 \cdot q_{\text{datum}}} \right) \ldots \text{ constant}
\]

\[
q = \sqrt{(P - l)^2 + (k - n)^2}
\]

\[
\delta = \sin^{-1} \left( \frac{P - l}{q} \right) - \sin^{-1} \left( \frac{m}{2 \cdot q} \right)
\]

\[
\beta = \beta_{\text{datum}} + \delta_{\text{datum}} - \delta
\]
The starting point is determined by link R being horizontal when the cam radius is at its maximum position.

\[ U = \sqrt{(b + c - x)^2 + (V - a + d)^2} \quad \text{constant} \]

\[ \psi_2 = \pi - \sin^{-1}\left(\frac{V - a + d}{U}\right) \quad \text{constant} \]

\[ y = \sqrt{R^2 + U^2 - 2.U.R\cos \psi_2} \quad \text{constant} \]

\[ \zeta_{\text{datum}} = \cos^{-1}\left(\frac{y^2 + T^2 - S^2}{2y.T}\right) + \cos^{-1}\left(\frac{y^2 + U^2 - R^2}{2y.U}\right) \quad \text{constant} \]

\[ \theta_s = 2.\sin\left(\frac{h_s}{2.e_2}\right) \]

\[ \zeta = \zeta_{\text{datum}} - \theta_s \]

\[ \psi = \tan^{-1}\left(\frac{T \sin \zeta}{U - T \cos \zeta}\right) + \cos^{-1}\left(\frac{T^2 + U^2 - S^2 + R^2 - 2.T.U \cos \zeta}{2.R \sqrt{T^2 + U^2 - 2.T.U \cos \zeta}}\right) \]

\[ x_2 = R - R \cos(\psi - \psi_2) \]

\[ y_2 = R \sin(\psi - \psi_2) \]

Referring to Fig IA, because links R and R1 are of equal length, the values obtained for \(x_2\) and \(y_2\) apply to any point on link N.
\[ \theta_1 = \tan^{-1} \frac{x_2}{y_2} \]
\[ z = \sqrt{y_2^2 + x_2^2} \]
\[ q = \sqrt{z^2 + (n-A)^2 - 2z(n-A)\cos(\frac{\pi}{2} - \Theta_1)} \]
\[ \Theta_2 = \sin^{-1} \left( \frac{z \sin(\Theta_2)}{q} \right) \]
\[ \varphi = \tan^{-1} \left( \frac{H \sin(\Theta_2)}{Q - H \cos(\Theta_2)} \right) + \cos^{-1} \left( \frac{H^2 + Q^2 - B^2 - 2HQ \cos(\beta + \Theta_2)}{2B \sqrt{H^2 + Q^2 - 2HQ \cos(\beta + \Theta_2)}} \right) \]
\[ \psi_1 = \pi - \Theta_2 - \varphi \]
\[ y_4 = P + y_2 - B \sin \psi_1 \]
\[ x_4 = A + x_2 - B \cos \psi_1 \]
\[ y_5 = P - H \sin \beta \]
\[ x_5 = n - H \cos \beta \]
\[ \psi_3 = \tan^{-1} \left( \frac{y_5 - y_3}{x_5 - x_3} \right) \]
\[ \psi_4 = \tan^{-1} \left( \frac{F}{E - D} \right) \quad \text{constant} \]
\[ g = \sqrt{(E + D)^2 + F^2} \quad \text{constant} \]
\[ x_3 = x_5 - g \cos(\psi_3 + \psi_4) \]
\[ y_3 = g \sin(\psi_3 + \psi_4) - y_5 \]

\( x_3 \) and \( y_3 \) are thus the coordinates of the looper tip with respect to the datum point of penetration of the needles.
APPENDIX II

ELECTRONIC CIRCUITS FOR PATTERN RETRIEVAL

List of Circuits

IA  Pattern Reading and Synchronizing Pulse Circuits.
IIB  Solenoid Drive Circuits.
IIC  Power Supply.
IID  Pulse Sharpener and Mono-Stable Circuit.
IIE  Auto-stitch Programmer Circuit.
Fig IIA  PATTERN READING AND SYNCHRONIZING PULSE CIRCUITS
Fig II B
SOLENOID DRIVE CIRCUITS

COURTESY OF M. QUELCH
Fig IIC  POWER SUPPLY

COURTESY OF M. QUELCH
Fig IID PULSE-SHARPENER AND MONO-STABLE CIRCUIT

COURTESY OF M. QUELCH
Fig II.E: AUTO-STITCH PROGRAMMER CIRCUIT

COURTESY OF M. QUELCH
APPENDIX III

EXTRACTS FROM PATENT SPECIFICATIONS

Section 10.1 stated that N.R.D.C. have taken patent protection of certain features that have arisen from this research. Extracts from the specifications are given below to indicate their contents:-

A. "Improvements in and Relating to Textile Apparatus"

This invention relates to the support for the shogging bar which carries the loop forming elements, as described in sub-section 4.3.6, and removes the slideway alignment and friction problems described in section 9.2. There are 11 claims covering this invention:-

1. Mounting means for a body which in operation is required to be capable of substantially linear movement back and forth to take up selected predetermined positions in turn, comprising at least two spaced apart, resilient mounting members to which the said body is fixed, the said mounting members being fixed to a base, and the mounting members being such as in combination to allow the said body freedom only for a substantially linear movement relative to the base.

2. Mounting means according to Claim 1 in which the resilient mounting members comprise two or more elongated members positioned parallel to each other and at right angles to the intended direction of the said substantially linear motion of the body.

3. Mounting means according to Claim 1 in which each resilient mounting member comprises a sheet of thin flat resilient material constituting a strut between the body to be moved back and forth and the base, the sheets being arranged when at rest in an undeflected position to be parallel to each other and to be perpendicular to the said intended direction of movement of the body.

4. Mounting means according to Claim 3 in which each sheet is rectangular and is secured to the body along one edge region of the sheet and is secured to the said base along that other edge region of the sheet which is parallel to the first mentioned edge region.

7. Mounting means according to any preceding claim in which the resilient mounting members are arranged to exert a restoring force on the body towards a null position intermediate the extreme positions between which the body moves in operation.

8. Positioning apparatus comprising a body to be positioned, mounting means for the body according to any preceding claim, and programming means for effecting movement of the body between selected predetermined positions and for effecting dwell of the body in a selected predetermined position.

9. Positioning apparatus according to Claim 8 in which the programming means comprises a cam track mounted for rotation about an axis parallel to the general direction of said substantially linear movement of the body, and a coupling element coupling the body to a cam follower associated with the cam track, the cam track being adapted to induce in the cam follower, upon rotation of the cam track, the said substantially linear movement.

10. Positioning apparatus according to Claim 8 or 9, in which the said body comprises a bank of thread guides, loopers, sinkers, or needles for use in textile machinery.
This invention relates to the mechanism for producing high-speed sculpture-patterned pile fabrics. It therefore includes the descriptions and functions covered in chapters 4, 5, 7 and 8 of this thesis. The patent specification has 27 claims:

1. A stitching or knitting apparatus for providing warpwise lines of pile or plush loops extending from at least one face of a base fabric and comprising means for regulating the loop lengths, wherein means is provided in conjunction with the loop forming elements for at least selected lines of loops, to enable different loop heights to be set in each particular line during operation of the apparatus, whereby a sculptured effect may be obtained on at least the one face during continuous production of the fabric.

2. A stitching or knitting apparatus as claimed in Claim 1, wherein loop height selecting mechanism is provided for each of said selected lines of loops.

3. A stitching or knitting apparatus as claimed in Claim 2, comprising control means for actuating said selecting mechanisms during operation of the apparatus.

4. A stitching or knitting apparatus as claimed in Claim 3, wherein said control means comprises electromagnetic means.

5. A stitching or knitting apparatus as claimed in Claim 4, wherein said electromagnetic means is adapted for operation through automatic patterning means.

6. A stitching or knitting apparatus as claimed in any preceding claim, wherein said regulating means comprises trigger means arranged to prevent or restrict movement of the loop forming elements to determine loop height.

7. A stitching or knitting apparatus as claimed in Claim 7, wherein operating means for said trigger means is arranged to be actuated by pulse signal means.

8. A stitching or knitting apparatus as claimed in Claim 9 or 10, wherein said pulse signal means is derived from a pattern storage and retrieval system.

9. A stitching or knitting apparatus as claimed in Claim 11, wherein said pattern storage and retrieval system is a pre-prepared digital computer or magnetic tape.

10. A stitching or knitting apparatus as claimed in Claim 11, wherein said pattern storage and retrieval system comprises a graphical scanning circuit.

11. A stitching or knitting apparatus as claimed in any preceding claim wherein provision is made for loops to be formed of zero height whereby the sculpturing effect is produced from a loop/no loop configuration.

12. A stitching or knitting apparatus as claimed in any one of Claims 1 to 13, wherein arrangements are made for looping elements to be set to provide for loop formation of three different heights.

13. A stitching of knitting apparatus as claimed in any preceding claim wherein the apparatus is of module form adapted to be assembled with other modules and/or other apparatus to provide for production of fabric of any desired width.

14. Stitching or knitting apparatus as claimed in Claim 1 and substantially as hereinbefore described.
This invention relates to the yarn feed system developed for use on the research rig and described in chapter 6. At present the patent specification is only in provisional form and therefore the claims have not been finalised, but all the variants of the system described in subsection 6.2.3 have been included. The following are some of the more important statements made in the provisional specification:-

The present invention relates to an apparatus for feeding yarn and like filamentary materials.

The invention is pertinent to textile machinery for warp knitting, weaving, tufting and stitch bonding processes and has particular relevance in relation to machines demanding yarn at an uneven rate, for example carpet machines, some knitting machines and looms. Generally speaking however it will usually only be suitable for creel fed machines as opposed to beam fed ones ......

According to the present invention, a feed apparatus for a machine to be fed with yarn or like filamentary materials comprises a store for storing a predetermined amount of the material for use in a subsequent material-demanding operation by the machine, and supply means adapted to replace in the store any of the material taken from the store in said material-demanding operation.

 Preferably the amount of material held in the store is comfortably in excess of what is ever likely to be used in the subsequent machine operation so that there is no danger of insufficient material being available to the machine for any given operation ......

Although the Locstitch machine has not been described, reference may be made to the patent and patent application quoted above for details of the basic machine and of how this can be adapted for producing sculped Locstitch fabrics. Basically, any such machine so adapted will require yarn to be fed to it in differing amounts depending on whether the next stitch is to form part of the low loop pile or the high loop pile which together will give the fabric its sculped appearance ......
Several sculpture-patterned locked-loop fabrics have been illustrated with reference to the text of this thesis. The following illustrations are further sundry examples of patterned fabrics produced on the research rig.