Investigation of the electrical and mechanical requirements for the automation of a process in flexible material manufacture

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by

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Abstract

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This thesis describes a successful attempt to automate a manual process in footwear industry. The process is called *skiving of leather components* and it is one of the early processes necessary for the assembly of shoe uppers. Skiving is the localised thinning of leather components, mainly at some of their edge regions. The purpose of skiving is to produce quality decorative edges or more importantly to enable attaching and joining components without forming thick, discomforting and weak joints. Although other processes in footwear manufacturing have been subject to partial or full automation, skiving has been performed for decades now with a standard mechanism that requires 3-dimensional manipulation of the components by a human operator.

This research work was directed towards two main aims. One was to establish a novel method on the basis of which skiving may be performed without the need of human assistance. The developed method is called *dynamic matrix skiving* and it is capable of performing skiving on leather components by generating and actuating skive patterns as sets of finite elements of skived area to a given resolution. Following derivation and study of the method for skiving, the second phase was aimed at implementing a fully automatic skiving system.

The main requirement from the system was to be an intelligent, component oriented, flow through, processing device. This required the capability to receive input components at any orientation and position along its transport mechanism, to recognise them as to their identity and relative position, and to perform skiving upon them without moving them or disturb their continuous flow throughout the entire operation.

Individual chapters in this thesis describe the study and experimentation with regards to dynamic matrix skiving, and all logical steps taken to identify the necessary elements and implement their integration to produce the automated skiving system. The concluding part of this work includes presentation of the results obtained from the automated system, and it identifies the areas where further research and development is needed in order to improve the quality of its output.

Declaration

The work contained in this thesis has not been submitted elsewhere for any other degree or qualification and unless otherwise referenced it is the author's own work.

Statement of copyright

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the late *Mr. N. Dunning* and *Mr. M.O. Newton*, members of our research team,
Mr. P. Friend and Mr. M. Wilson, technicians from the electronics workshop,
Mr. B. Blackburn, Mr. H. Kelly and *Mr S. Watson*, technicians from the mechanics workshop.

CONTENTS

I dedicate this work to

My parents
Kiriakos and Eleni

my brother Dimitrios

my wife Sondja

and also to

the day when

the terms

"European News Media", "lies" and "brain-washing"

will become three distinct notions.

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ABBREVIATIONS

BUSM	The collaborating company (British United Shoe Machinery Co).
C	Name of computer programming language.
CIB	Central interface board, linking electrically modules of the skiving system.
DOTCLK	Dot clock signal, transfer rate for skive pattern pixels.
E-R	Electro-rheological fluid.
FrSwitch	Frequency switching signal for the TMS data transfer rate.
HSYNC	Horizontal synchronisation pulse.
ID	Identification
Int_ID	Interrupt identifier or signature.
LHS	Left hand side
M68000	Motorola 68000 series computer system.
PVC	Poly vinil chloride.
PVCF	PVC coated non woven fabric, used for the upper conveyor.
RAM	Random access (read/write) memory.
RCLCK	Return clock signal, bit latching pulse for skive pattern data transfer.
RHS	Right hand side.
SDATA	Serial skive pattern data.
SDB	TMS34010 Software Development Board, used alternatively for TMS.
TMS34010	Texas Instruments graphics system processor.
VRAM	Video RAM
VSYNC	Vertical synchronisation pulse.
XL	Standard symbol defining pitch size for timing belts.
Z8000	Zilog 16-bit microprocessor.
FORTRAN	Name of computer programming language.
EPROM	Erasable/programmable ROM (read only memory).
PC	Personal computer.
P-E	Piezo-electric actuator (or ceramic)
SPerLn	Motor steps per x-line of skiving.
UNIX	Computer operating system.
VDU	Video display unit, i.e. a monitor.

SYMBOLS

D	Thickness of substrate sheet.
D'	Diameter of front roller, located in the skiving process area.
d	Horizontal distance between the front side face of the pin and the band knife edge.
d_b	Horizontal between the back face of the front roller and the backstop.
d_c	"Dead" space in pin movement (in mm)
d_{co}	Thickness of leather component.
d_h	Vertical distance between the knife plane and the centre of the front conveyor roller.
d_k	Horizontal distance between the backstop and the band knife edge.
d_n	Horizontal distance between the front roller centre and the band knife edge.
d_p	Horizontal distance between the backstop and the front side face of the pin.
d_s	Depth of skiving.
d_{sk}	Direct distance between the knife edge and the conveyor's surface.
$d..._R$	The related distance (...) from the RHS of the skiving mechanism.
$d..._L$	The related distance (...) from the LHS of the skiving mechanism.
D_v	Deviation in averaging d_p sample values.
D_x	Increment of the x coordinate of component point due to translation.
D_y	Increment of the y coordinate of component point due to translation.
F	the input pin frequency
F_e	Force element causing local leather recovery, after pin impression is terminated.
F_p	Force of friction between pin and leather component.
F_s	Force of friction between substrate and leather component, at a particular point.
F_{sc}	Force equal to the sum of all Fs force elements.
F_u	Force equal to the sum of all F_e elements.
h_d, h_r	Hysteresis due to time elapse for full leather depression and recovery.
l_p	Length of eventual skiving.
l_s	Length of intended skiving (i.e. the intended length of a y-skive line).
L_t	Length of skiving defined by the "component teaching" software, in the database.
q	Angle of component rotation

R	Effective operating resolution of skiving.
R_k	Knife forward position adjustment (in mm of forward movement per revolution).
S	Pin travel (in mm)
T	the period of the input pulse.
T_c	The minimum value of T_i at corresponding to the time when T_{d2} becomes constant.
T_{dl}	the time between applying the input pulse and the pin reaching full stroke.
t_{d1}	Time response for actuation depression.
T_{d2}	the time between seizing the input pulse and the pin having returned to its datum.
T_f	the time between seizing the input pulse and the pin starting to retract.
t_i	Time taken for instruction for pin insertion.
T_i	duration of the input pulse (input to the solenoid)
T_i^*	The minimum value of T_i at which $S = 2$ mm is reached.
t_k	Knife drag on the leather (force value).
T_{l1}	the time between applying the input pulse and the instant when the pin starts to move.
t_n	The non active pin time during T.
t_p	Time duration of eventual skiving.
t_r	Time taken for instruction for pin retraction
t_s	Time duration of intended skiving (i.e. the intended length of a y-skive line).
t_{s*}	Effective skive time
t_w	Time from starting cutting until reaching valid skiving line depth.
V	Linear velocity of the conveyor belt.
V_i	The input voltage to the solenoid.
x,y	Cartesian coordinates of points of component silhouette.
x',y'	Cartesian coordinates of point of component silhouette after translation or rotation.

CHAPTER 1

Introduction

1.1 Main theme

The main theme of the research project described in this thesis has been to investigate all basic aspects involved in converting a manual industrial process into a fully automatic one.

The candidate process for automation is called *skiving* on leather components. The process involves machining of pre-cut leather components and belongs to the world of footwear manufacturing. During manufacture of almost any type of footwear, there are a large number of individual processes which take place, before the complete product reaches the warehouse. In some cases this number can be as large as 30 [6][8], and it depends upon the type and quality of the intended product.

These processes are usually divided into two main task streams. One is the manufacture of the shoe upper and the other making the shoe sole. Each case involves completely different machinery, as different as the natures of two tasks, and they usually involve separate shop floor areas. When the two main components are complete, then they are brought together and the overall shoe assembly is carried out, before entering the final stage, i.e. the finishing line. Skiving is one of the early processes involved in manufacture of shoe uppers.

Even today, with all the availability of high technology, a large number of the above processes are carried out manually or in some form of semi-automation [6][31]. The latter refers to cases where specialised machines may perform the main process, but still require manual guidance. The reason for this is first of all that some of the processes involved are too intricate to be performed by machines alone .

The second and very common reason is due to the difficulty of replicating the physical manipulation of the floppy components, necessary to perform the operation [1]. It must be highlighted that most of the components used in shoe making are made from floppy sheet material, and during many processes they require three-dimensional manipulations. In general terms, automation is usually met in systems involved with manufacture of soles and attachment of uppers to soles, and use of computer systems relatively higher in footware design [24].

The process of skiving is still carried out manually. Due to its repetitive nature and monotonous manual operation involved upon small or medium component batches daily, it has been considered that it would be a potential breakthrough if it was successfully automated.

1.2 Introduction to the skiving process

Leather shoe uppers are assembled from a number of individual pre-cut leather components. The first stage in shoe upper manufacture is to cut the hide to pre-defined shapes, which are necessary for its assembly. The shapes of the components relate not only to their relative position in assembly, but also to the mechanical function within the shoe during its use. For this purpose, different shapes are cut from particular regions of the hide, possessing specific properties to higher degree than other regions[2][5]. For this purpose, specific components of a particular footwear may be cut from different leather types and /or colours.

Cutting is performed manually or semi-automatically, in both cases using especially shaped dies. Also, cutting is carried out in medium sized batches, but this does not mean that identical components are cut sequentially. The reason is that a single hide is a source of a large number of individually shaped components. Hence it would be impractical to keep on switching hides for the purpose of accumulating and storing similar components together.

Therefore the pre-cut components exit the cutting area of the shop floor needing separation depending on identification and temporary storage. This is done manually, although some research has been done for the automation of this task using robot arms [4][23]. After cutting, the components are usually split to contain uniform thickness. Different thicknesses are required for different parts of the shoe upper, depending upon its function within the overall shoe construction. The extend to which splitting takes place for shoe upper components, depends also in the quality intended for the final product.

In order to assemble the shoe upper, it is necessary to cement and stitch leather components together. When two component edges are brought together for assembly, it is obvious that the adjoining region will contain the sum of the thicknesses of the two components involved. This feature is considered as an unwanted characteristic, and it is usually tolerated only in some regions in the construction of trainers. The reason is the resulting poor visual effect, but also the quality of the joint itself.

Therefore, as shown in figure 1.1, it is necessary to thin the adjoining regions of the components, to eliminate the above feature. The process necessary to achieve this is called skiving. Hence *skiving is the localised thinning of leather components,* and it is usually implemented to 50 % of component thickness. One may assume that by thinning the leather component its durability is reduced and its strength weakened. In reality this is not the case, because the plane of main strength of the leather component is located at 0.1 to 0.3 mm below its upper surface [25] (i.e the outside surface of the shoe). Furthermore the resulting joint is considered more rigid and more tolerable to fatigue. The above fact for leather strength is also an important criterion according to which skiving is never carried out at the lower surface of the leather components.

Apart of the above case, skiving is required for other reasons, such as decorative folding, joints using folding, and almost always, for the attachment of the shoe upper to the sole, where any projection due to thickness of the upper would result in discomfort in use. These cases are also illustrated in figure 1.1. Furthermore to achieve a reliable joints of leather workpieces, it is sometimes necessary that the edges of the components go through a roughing process [23]. If the edges are skived, they

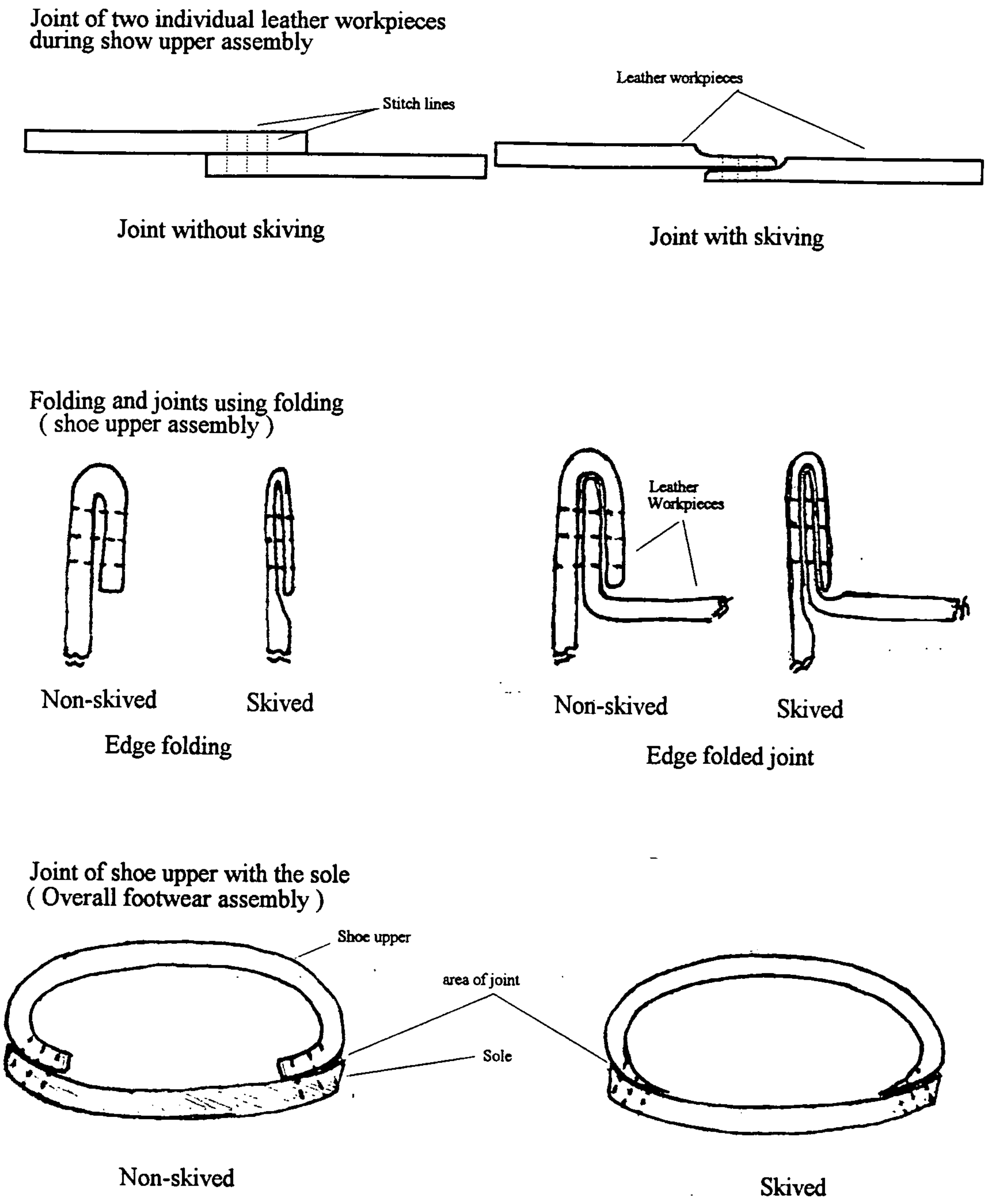


Fig. 1.1 The necessity for skiving in footwear upper assembly.

are automatically roughened for this purpose, because skiving inevitably intervenes in the structure of fibres at multiple levels within the component's thickness. Finally, skiving is sometimes carried out in the interior of leather components (i.e. not at the edges) for reasons of decoration, thought this is required much more rarely.

1.3 The research backround of the process of skiving

Automation of the process of skiving has never been implemented, according to industrial information sources. A study relevant to the process of skiving has been carried out only once before, by M. Saadat [5].

This research was undertaken in the University of Durham in collaboration with the company BUSM (British United Shoe Machinery) part of the multinational USM, and international leader in its field. This company specialises in designing and manufacturing machines used by the footwear industry. This formed the first major stage of a long term research programme organised by the university and BUSM.

During the previous research stage the emphasis was given into identifying the operational characteristics and material properties related to machining leather. The initial idea was that it may be possible to use the process of milling to perform skiving. Therefore the research was targeted towards the effects of milling upon both leather and the tools involved, as well as the properties of leather in general. The final part of this phase of research included considerations and experimentation for the automation of skiving, and concentrated into investigating the suitability of *face milling* of leather.

The current research programme is in effect a continuation of the overall effort to enable automation of the process of skiving. However it may also be considered as a stand-alone programme because it is focused into achieving automation using the method of *pin matrix* or *dynamic matrix* skiving. This method, although suggested during the previous research phase, it had never been researched in depth. Furthermore, according to availability of information, the subject of skiving in general, has never been the subject of industrial or academic research in the past. For this reason the existing research background in this field is relatively narrow.

This research project has also been carried out in collaboration with the company BUSM. During this research period, BUSM has provided the necessary industrial expertise, as well as material necessary for experimentation. They are also expected to exploit commercially the outcome of this research in the future.

1.4 The existing technology for skiving

The machines used for skiving nowadays are all based on the same basic mechanism. This consists of a continuously rotating sharp disk/knife and a suitable metallic guide, as shown in figures 1.2 and 1.3. Figure 1.4 illustrates a variety of skived leather workpieces, and figure 1.5 indicates how the skived components are assembled together to produce a typical shoe upper.

The operator manipulates the components by hand through the guide and knife, so that they are skived along the edges, where intended. The edges of the component passing through the guide are effectively put through a *localised splitting operation*. This is achieved by adjusting the gap between the knife and the guide to accommodate only a portion of the full thickness of the component. In this way, as the edge of the leather component is guided through, the excess thickness is skived off, thus producing a thinned edge.

In such machines there are adjustments as to how deep skiving should be, how wide and even what particular skive profile to produce (in more modern ones). It is thus clear that components should be carefully selected prior to skiving in groups, to minimise tool change and machine settings. Skiving machines have become more simplified over the years, with respect to tool change and settings. This is done by introducing electronic controls for rapid changes. It is also at this field, where industrial development on skiving machines has been concentrated.

The only example of skiving machine which does not use the mechanism described above is a novel system that uses a splitting machine as a component of the overall mechanism [27]. This type of skiving machine is used for skiving the edges of leather belts. The splitting machine is used in conjunction with adjustable metallic jigs which press the edges of the belt against the knife of the splitter, thus causing skiving. The

Fig. 1.2 The basic disk knife based mechanism, in all existing skiving machines (by permission BUSM Ltd).

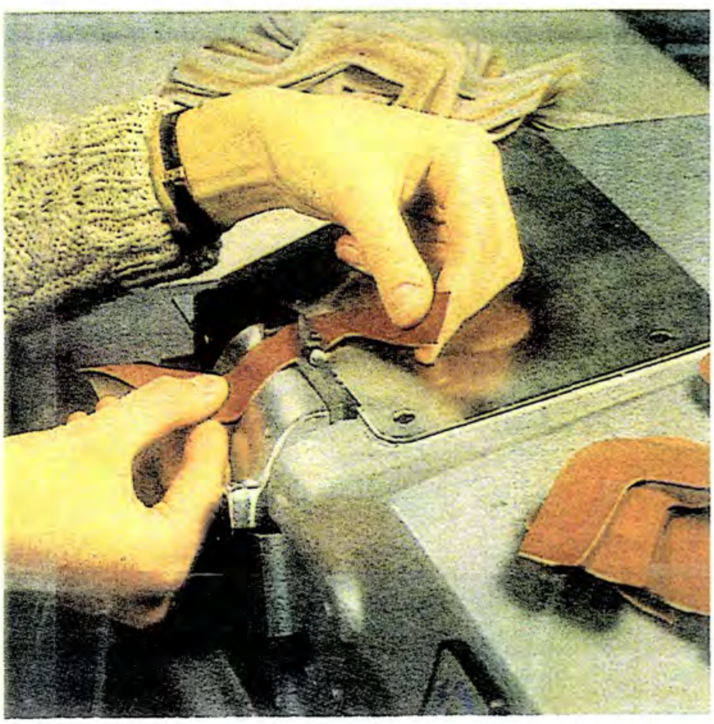


Fig. 1.3 The manual skiving operation (by permission BUSM Ltd).

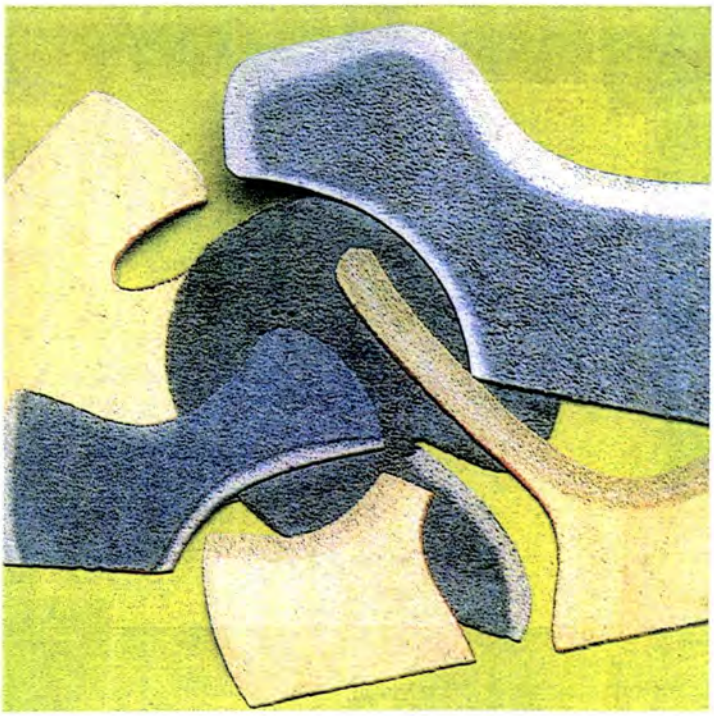


Fig 1.4 A typical example of skived components (by permission BUSM Ltd).

Fig 1.5 The assembly of a shoe upper, comprising a number of skived components (by permission BUSM Ltd).

novelty of this type of machine is its flexibility in easily re-forming the jigs to perform different skive profiles. However it is a dedicated device for skiving belts, and could not perform skiving as required on shoe components. Furthermore the belts have to be input to the machine at a particular orientation and even though the length of the skive stripe is not adjustable.

Manual disk-knife skiving is a semi-skilled operation and requires patience and the ability to work in an extensively repetitive and monotonous rhythm. To substantiate this argument, it is perhaps enough to mention, that at any time in a medium company there are 10,000 to 15,000 individual components present for processing. This number is not only generated by the amount of components per shoe upper or due to different footwear models, but also because of the large number of individual sizes per model, which introduces a global multiple of 20 or more.

1.5 The necessity for automation.

From the issues pointed out in 1.2 and 1.3 it can be easily concluded that full automation of the skiving process would immediately introduce the following benefits :

- *Elimination of the need for component grouping prior to skiving.*
- *Elimination of the laborious and sometimes dangerous manual operation.*
- *Reduction in costs due to potential increase in skiving throughput. Reduction in component operation cycle, system setting and retooling overheads.*
- *Reduction in the number of individual skiving machines required.*
- *Introduction of a novel, highly competitive and profitable industrial product.*
- *The possibility of linking automatic skiving with other automated processes to provide a versatile and intelligent multiple-operation station.*

With respect to the last statement, it is worthwhile mentioning that due to the outcome of previous research projects, BUSM has successfully automated other tasks, such as stitchmarking. This is the automatic printing of lines on leather components, where these should be stitched at a later stage. If skiving is fully automated this process could easily be embedded into the output stage of skiving, thus forming a two stage fully automated station. This philosophy is very much within the longer term research planning of BUSM, and involves, at least theoretically to this stage, a number of individual fully automated sub-tasks.

1.6 The research methodology adopted

Although the process of skiving is a very specialised process, belonging to a very specific section of the manufacturing industry, the logical method followed may be undertaken into automating a number of different processes. The two main aspects which characterise the automation of skiving are described by two key-concepts :

- "flexible materials"

and

- "physical intervention on the shape of a pre-defined component"

These two subjects are important enough to characterise the research methodology because, firstly, they immediately identify that the process will relate to a specialised section of component materials with distinct properties. Furthermore, by identifying the key operation "physical intervention" a range of processes, suitable to the above material properties are identified, and a vast range of others are immediately excluded. Finally, the term "pre-defined" identifies the circumstances where the identity of the operated component and its geometric properties are known before the operation. The latter indicates availability of data for component identification.

To resolve such an issue of process conversion into an automated one, the suitable principle of operation must first be conceived and established. Initially, enough evidence should be given as to why the manual process may not be automated by simple development, and/or why it is necessary to invent a novel approach.

If automation means unavoidably designing a novel approach to the process, then this novel principle of operation should be validated. It should be identified how successful it may be before the overall automatic system is implemented. Also, before this stage, it is essential to identify the variables and limitations of this novel principle. In other words, it should become clear what are the implications towards the overall automation. Furthermore it is essential to identify in an early stage, to what degree the result of the research would be a "down to earth" system, with real prospects of future commercial exploitation. For the latter, it is necessary to closely and methodically consult with experts of the related industry.

The second major research stage is to embed the novel principle process into the automation method considered, thus forming the full automatic system. The implementation of the overall system should finally prove the validity of all hypotheses, and also to indicate the aspects of the system performance that need to be investigated or modified in the development stage. Having arrived at this stage the main academic research program is concluded and industrial development stage commences, unless some aspect of the integrated system requires a separate specialised further research programme.

Upon the principles described above, this research programme has been focused into investigating the possibility in automating the process of skiving, and converting it into a potential stand-alone industrial unit.

1.7 Setting the specification for this research programme.

In the initial stage of this project the relevant academic and industrial bodies established a framework upon which the expectations are laid. This procedure involved setting targets relating to system behaviour, capabilities and performance. The main principle was to prove the viability of the main idea, and also the academic project should be of research value rather than developmental. For these two reasons the system specification was defined to limits which could prove that by further development, such a system could actually become a commercial product. In any case if the specification was to be defined to the standard of a commercial product, it would be unrealistic to attempt achieving it within a three year research programme. Hence, the main aim of this research project has been to prove that :

i. There is valid a method on the basis of which skiving may be automated

ii. Hard evidence of automatically generated skiving can be obtained.

In more detail the system under investigation should contain the following features :

- *Component oriented process.* The process should not involve manipulation of leather components in any way, but to accept them at any orientation and position. In other words the process should be versatile to adapt to the way the components are input to it.

- *Flow through process.* The system should operate while the components flow through it at a constant uninterrupted rate.

- *Intelligent process.* The system should be able to accommodate different components arriving in unspecified order. There should be a means of identifying incoming components and act accordingly.

- *Dynamic output generation.* The output of the process, i.e. skiving should be generated and implemented dynamically without interrupting the overall process or needing to use preset mechanisms or data structures at the final stage. A single flexible mechanism should be capable of performing skiving at any time and position on the processed components.

A lower level specification to the system can be summarised in the following statements :

- *Maximum component flow velocity (linear) : 185 mm/sec.* This is the speed at which components are transferred through the system and at which they are also skived.

- *Variable control of depth skiving : manually adjusted.* The depth of skiving is not expected to be adjusted automatically, as this is a minor developmental issue.

- *Variability of skive depth within a skive operation on a single component.* For reasons of complexity that become apparent further on in this thesis, this issue is left as a future research directive.

- *Capability of skiving any shape of skive pattern*

- *Capability of skiving at any possible position upon the components.* This includes skiving at the very leading edge of an incoming component.

- *The process should not in any way result in permanent alteration of the physical properties of the input components* (e.g. damage of the upper surface of the components, or colour deterioration etc.)

Based upon the specification given above, the automatic skiving process was to be researched and produce the required answers. Finally it would be expected to provide some alternative theories or considerations for overcoming particular problems of the behaviour of the automatic system. These alternatives would form basis of further research and/or development.

CHAPTER 2

METHODS FOR AUTOMATING THE PROCESS

2.1 Introduction

This research work led to the development of a fully automatic skiving system which is based upon the principle of a method called *dynamic matrix skiving*. Matrix skiving is an existing shop floor term and defines a manual laborious technique of interior skiving. This technique is applied on leather components with the aid of splitting machines.

The method adopted here to automate skiving, relied upon two basic elements. The first was to simulate by a novel system design, the mechanical action that causes skiving in the manual process. The second element was to invent an electro-mechanical means to generate skiving patterns as sets of successive skive lines. Skive silhouettes were thus formed and actuated on the components in real time, in a raster scan fashion. However before concluding that this particular method was the most suitable to produce a practical system, other ideas had been considered. This chapter briefly describes the alternatives and explains in some detail the method adopted.

2.2 Methods considered for automating skiving

The initial choice in deciding what method would be appropriate for the automation of skiving, is concerned with the very heart of the process, i.e. what type of operation will be used to reduce the thickness of the leather, in the appropriate areas of the component.

The obvious starting point would be to examine whether the existing manual skiving method can be automated. The manual disk-knife based method was described in chapter 1. Automating the skiving process on this principle would imply keeping the existing mechanism used, and automating the component feeding process. This is the reason from which it is concluded that this process cannot be modified to become a component oriented one. This method relies upon an external independent source to manipulate the leather component around the cutting edge.

If automation was to take place, some form of mechanism should be provided to perform component manipulation in the same way that the operator does. It could be assumed that handling and manipulating components is done by one or more robot arms. However the manual function performed by the human operator, although it may seem fast and easy, it is in fact a very complicated one.

Using complex robot grippers to simulate the movement of all human fingers used, to manipulate the component, is not practical. This is because manipulation for each individual component, depends upon sensing how the component deforms during the manipulation. Furthermore such deformations vary between components of the same shape but different leather type, hence they are virtually unpredictable for software simulation. Another requirement for such a system would be vision, possibly three dimensional. This would be essential to track in real time the position and orientation of the component, relative to the datum on the skiving mechanism. In any case, even if mechanical manipulation was viable, the overall system speed would be extremely low and it becomes very hard to imagine the system functioning as a flow through system, at industrial expectations (0.5 - 3 components/sec).

Therefore it immediately becomes apparent that due to complexity, direct development of the manual process for automation is an unrealistic solution, in terms of both component manipulation and speed of performance.

There are two main approaches towards the implementation of the skiving process. One is to employ the milling operation with the aid of a router and the other to use splitting of leather components. Both operations imply a direct machining process on the leather but use totally different tools. The problem of creating a dynamic output to enable automation for the method chosen is a later consideration and is highly dependent upon the nature of the mechanism used.

2.2.1 Face milling of leather

This approach [5] involves a router armed with an appropriate milling tool, which can thin down the areas of the leather components that have to be skived. The router itself is driven in X,Y and Z directions by a suitable mechanism based on stepper motors. The component area that is to be processed is defined as a set of points with Cartesian coordinates in X and Y directions. These points represent finite amounts of area the size of which define the operating resolution of the system, and are dependent upon the magnitude of the stepping angle of the motors, and the geometry of the cutting tool used. The Z direction is vertical to the X,Y plane and it is along this direction that the depth of skiving is determined.

This method was investigated by M. Saadat in the University of Durham, prior to the present research work, and the necessary rig was developed for experimentation. The resulting conclusions were positive, as far as the implementation of the skiving process was concerned, but presented reservations for developing a continuous flow through process based on this principle. The main obstacles were that the component had to be temporarily mounted on a table, where it would be processed, thus causing an interruption on the desired overall flow of components. Furthermore the throughput of such a system would be considerably low, if compared with the manual process. This work led also to the conclusion that if a flow -through, fully automatic system was to be developed, such a system should contain an input and output feed mechanism which could be easily integrated with other processes.

2.2.2 Localised splitting of leather

This method was the second candidate for automating skiving and formed the main subject of this research. The operation of splitting leather is not new. Suitable machines for this purpose are available in the market for decades. They are used for thinning leather components down to the required thickness for various purposes in footwear manufacture.

Such machines, even the most modern ones, have always been based upon the same principle. This principle consists of a band knife running at a constant speed (refer to figure 2.1). A simple feed-in arrangement based on rollers deliver the component through a preset gap. This gap is formed by the knife in the lower end and by a roller at the top. This gap is adjustable by vertical movement of the roller position and it defines the resulting thickness of the component. Therefore as it is shown in figure 2.1, the component is fed through this gap and any excess thickness is simply split by the knife. All leather waste follows the route underneath the band knife and towards the waste extractor. The processed component is guided out of the process area by the rollers which are driven by electric motors.

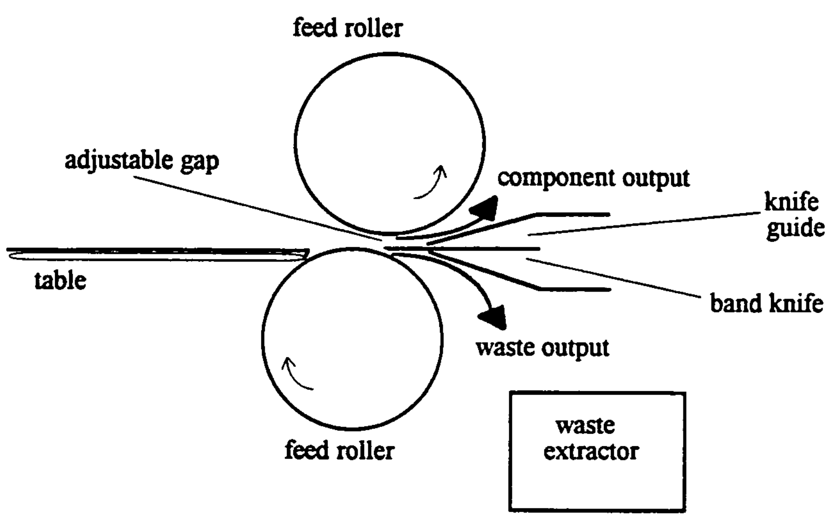


Fig. 2.1 The principle of the splitting mechanism

The latest splitting machines, are supplied with very accurate adjustment mechanisms that operate at very high resolution and one can specify leather thicknesses accurately down to tenths of a millimetre. Nevertheless they all still require an operator to initiate component feed-in and removal. The photograph in fig 2.2 shows the mechanism of a typical splitting machine.

The basic idea for performing skiving based on splitting of leather components, was to use the already existing technology of splitting, but also to find a practical way of determining the areas of the leather components which are not meant to be altered. This can be stated also in the reverse logic order as : *to be able to control splitting, so that it only occurs in those areas of an incoming component, where that particular component should be skived.*

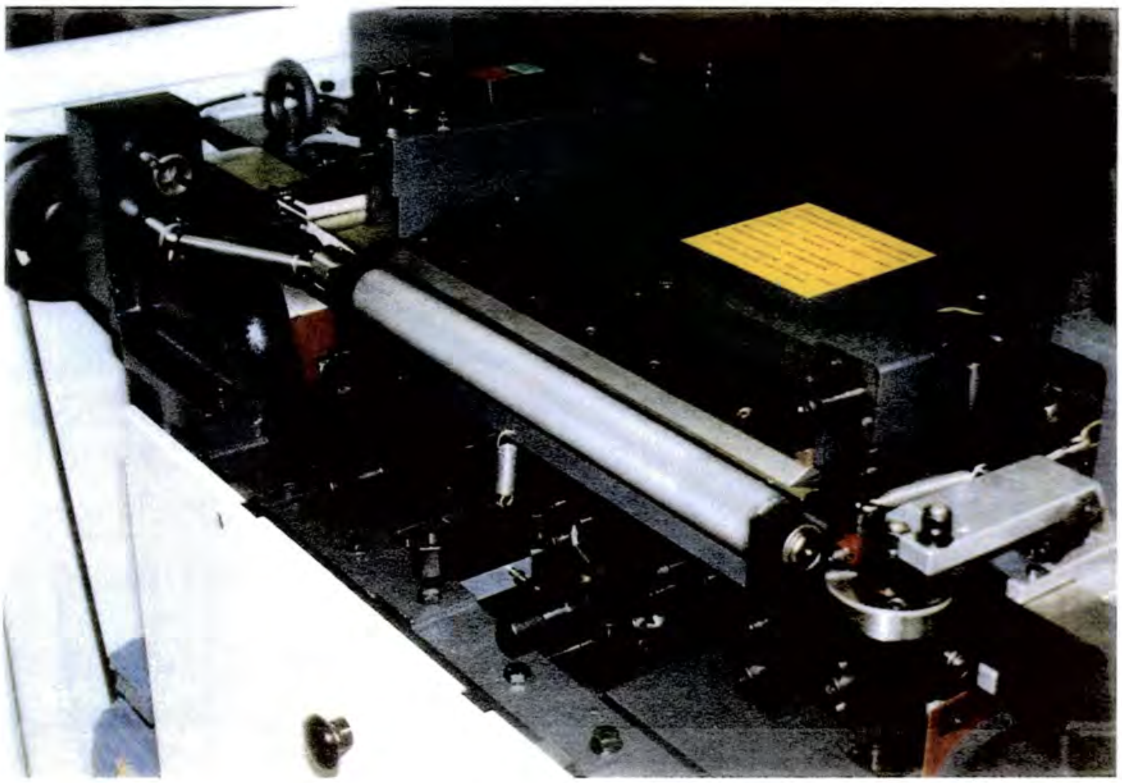


Fig. 2.2 The mechanism of a modern splitting machine (by permission of BUSM)

Splitting machines are occasionally used for skiving in shoe industries. In some cases where components have to be skived internally, the operator of the splitting machine deposits an adhesive backed piece of flexible material on the top surface of the leather [6]. This material is pre-cut to a required silhouette and to a specified thickness, equal to the thickness that has to be removed from the leather component (refer to figure 2.3). It is deposited on the reverse face of the leather component and

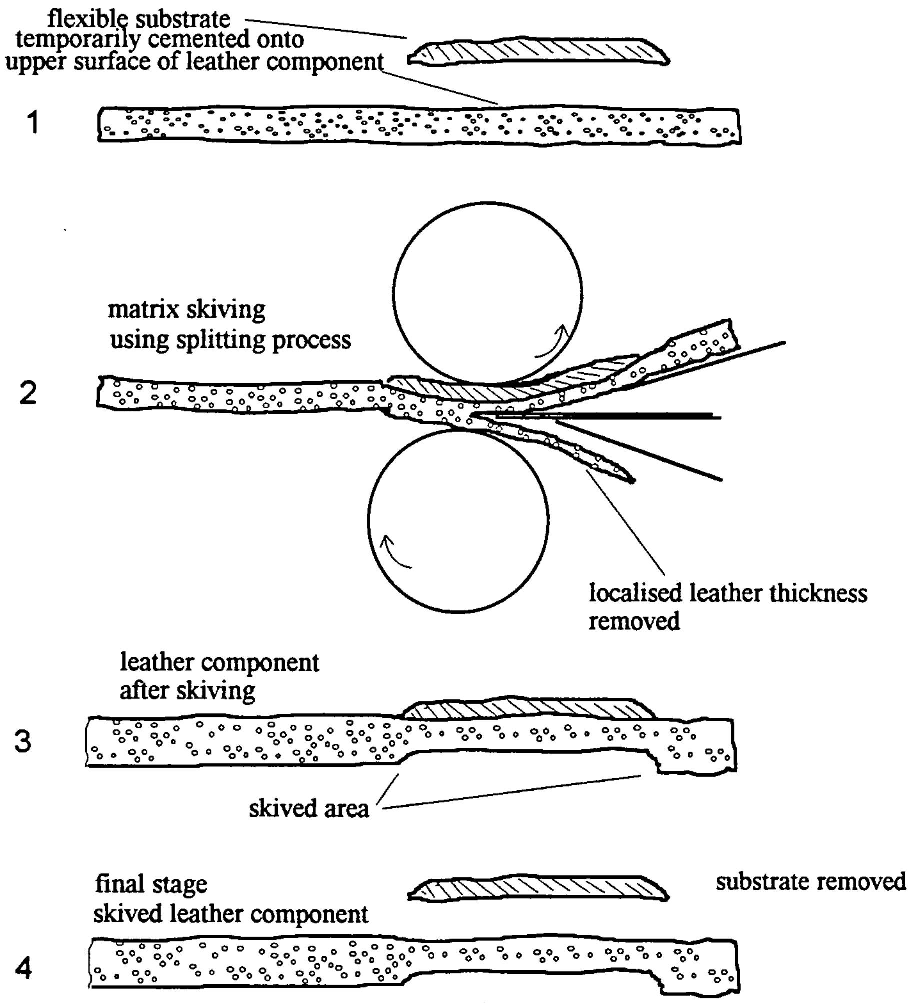


Fig. 2.3 The four stages of manual matrix skiving using a splitting machine

on the exact location, where the other side of the leather should be skived. Therefore the leather component is effectively subject to "additional thickness" in a specified area which can be removed by the splitting machine if the component is now simply fed through the splitter. After processing the added material is removed by the operator. This operation is called *matrix skiving* and it is the only solution for interior skiving. Let us remember that the existing skiving machines described in chapter 1, may produce skiving only upon the edges of leather components.

Due to the necessity of existing pre-cut adhesive backed silhouettes and due to the additional time consumption required, matrix skiving is avoided where possible. It is usually employed in the production of more expensive footwear. The idea of using a form of dynamically generated localised splitting to perform skiving, is supposed to take care of interior skiving too, eliminating the need of this expensive process described above.

2.3 Generating dynamic localised splitting

When considering how localised splitting of leather is achieved, it becomes apparent that if skiving was to be automated on this principle, then the role of the flexible substrate used in matrix skiving has to be undertaken by a dynamic process. Such a process should be able to generate and actuate the appropriate pattern (silhouette) that has to be skived on a particular component, while this component is moving through the splitting process area. This dynamic generation of output should also contain the property of flexibility, in the sense that different silhouettes may be required to be produced in sequence, depending on the identity of the incoming leather components.

It may now be apparent that using the splitting process to implement skiving can easily produce a non stop flow-through system. This is because components do not need to be moved at all from their original orientation to perform the operation. Hence this method could allow for continuous and uninterrupted input and output flow of components, provided it is supplied with a suitable component transfer mechanism. If this is considered together with the idea of a process generating a dynamic and flexible output, it may be concluded that a fully automatic skiving system could be developed on those two foundations.

Therefore the following two questions are :

- how to implement the flow through system

and

- how to design such a dynamic process.

The answer to the first question is that a suitable conveyor system in continuous operation could satisfy both the roles of the input and output paths of the flow through process. The answer to the second question has been the subject to considerations and alternative solutions and these are described in the following sections.

2.4 Simulation of matrix skiving

There are three possibilities of simulating the manual matrix skiving operation. They all rely upon successful generation of the effect of the flexible substrate deposited upon the leather to perform matrix skiving. These alternatives are described in the following three sections.

2.4.1 Dynamic production of flexible substrates

This idea is based on the method applied to implement manual matrix skiving. According to this idea, the point of intervention for automation is at the generation, i.e. production and location of the flexible substrates on the leather components. It assumes that the above may be done in a dynamic way.

The hypothetical system would be able to produce the substrate in the shape and thickness required, while applying it onto the upper surface of the leather. This dual function would of course have to be implemented in real time without interruption of the component flow. Such a hypothetical system would require the existence of a material that may have the following properties :

- being in malleable form at temperatures higher than room temperature but lower than those damaging leather
- solidifying a short time after placement onto the leather surface
- maintaining its original location upon the leather (self adhesion)
- being easily removable after the process by mean s of automation
- being directly reusable
- being of non corrosive nature towards leather

If such a hypothetical material was produced then the matrix skiving process may be used without any alteration as the intermediate stage of the overall process. The first stage would include component recognition and substrate generation and adhesion. The last stage would simply be the removal of the substrate patterns. The logic of this operation is illustrated by means of a diagram in figure 2.4.

The main attraction of this solution for automation of the skiving process is that an already existing device, i.e. splitter, could be used simply as a system component. In this case the main engineering issue would be the automatic generation and deposition

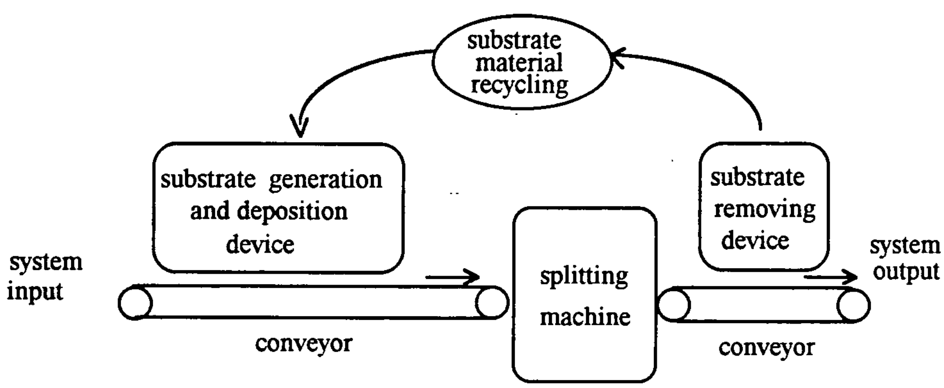


Fig 2.4 The function of a hypothetical system based on dynamic production of flexible substrates

of the flexible silhouettes. The development of a material with properties such as described above could be a subject of research in its own. However this method could be an alternative route for future research. The reason for which this method was not selected in this research programme is simply because it was the least favourable, by comparison of initial expectations from the three options.

2.4.2 Generation of 3-dimensional skive patterns

Another idea in simulating the effect of the flexible substrate would be to develop a mechanism which could be dynamically adjusted to form a 3 dimensional surface. In practical terms this could be done as a silhouette formed by finite extension of individual area units, with respect to a plane. According to one hypothesis, the plane could be formed by the tips of an x,y array of small spring loaded metal pins. All such pins could be aligned and mounted on a platform. To form the skive silhouette, the appropriate pins (= area units) of the pin array would be pressed to extend from the plane by a standard displacement. The projected pins would then create an extended silhouette. If this silhouette was then impressed upon the incoming component and followed it through to the splitting device, skiving would be performed in exactly the same way as in manual matrix skiving.

The height position of individual pins could be set with the aid of a row of solenoids (=X) moving across all successive pin columns (=Y). When the pins of a row are set, they could be mechanically locked into their "off" (resting) or "on" (extended) position. Finally an elastic layer mounted on the face of the platform and deformed locally by impressed pins, would ensure practical simulation of a 3-dimensional skiving pattern. It is this surface which would come in contact with the upper surface of the leather. The drawings in figures A-2.1 to A-2.3 in Appendix A-2 illustrate some of the futures of such a hypothetical system.

After processing a leather component the dynamic pin platform would return for the next incoming component. During the course of its return the new skive pattern would be formed by the pins. This new pattern would be the one appropriate for the new incoming component. Of course it could prove to be necessary timewise to have two such pin platforms, so that one is being set for the next component while the other is processing the current one.

The additional requirement would be that the design of the knife mechanism should allow a horizontal component movement throughout the process without the interference of the knife guide as seen in figure 2.1. This implies necessary modification of the band knife mechanism.

After considering this alternative it was concluded that although the ability of the system to form 3-dimensional patterns would be ideal, there is no existing mechanism available. The pin based mechanism would contain a vast amount of individual bits and could prove to be both expensive and difficult to maintain. Finally the need for introducing a different knife and guide mechanism implies virtual design of a novel splitting machine. For those reasons it was concluded that unless a simple (i.e. revolutionary) way of forming 3-d patterns was invented, the overall idea could lead to a dead end. Nevertheless researching into this approach identified a crucial point. All existing splitting machines are based upon the same design of the knife and guide mechanism. Therefore no matter how the method of skiving is to be implemented, it will have to adopt to the particular geometry of the knife guide.

2.5 Dynamic skiving generated as a raster scan

This method also uses the splitting machine to perform skiving. However it differs from the ones presented earlier in this chapter in one basic element. According to this method the skive pattern is formed in real time with the splitting process. The image forming the silhouette that has to be skived, is transformed into a mechanically actuated pattern in successive lines, as the component moves through the process area. This is explained graphically in figure 2.5.

A skive image consists of a certain amount of lines, being perpendicular to the direction of component travel and parallel to the splitter's knife axis. These lines are of finite width, equal to the practical resolution of the process. As the component arrives at the process area each line of the skive silhouette is imposed upon it, and only one line of the image is actuated at any point in time. This function carries on until the

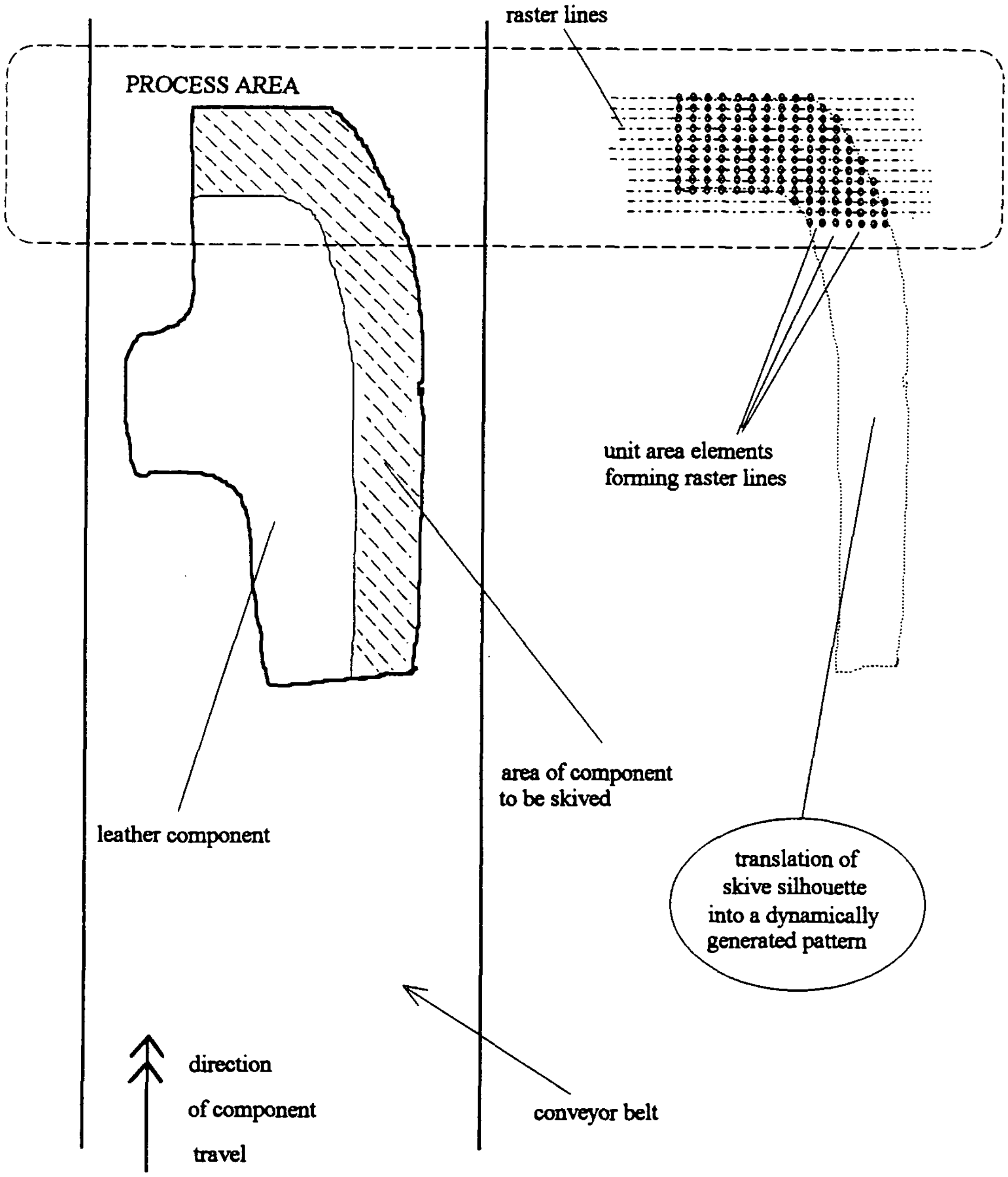


Fig 2.5 The raster scan principle in skiving

whole leather component has passed through the splitter. This method can be compared with a printer writing successive lines on a page to draw a shape. The only difference is that in the case of skiving all points contained within a single line are output concurrently. The principle of this idea also compares to the method used for the automation of the stitch marking process on components of shoe uppers by N. R. Tout [3], although the means of implementation differ.

To implement this idea with the use of a splitting machine, it was decided to design a mechanism which would take advantage of the principal feature of manual matrix skiving. This feature is translated as : if an external source (= flexible substrate deposit) causes the leather component to slightly buckle when delivered across the knife edge, then the buckled area will be thinned. Thinning, in this case skiving, will occur to a thickness equal to the distance between the knife plane and the lower surface of the leather at the buckled area. This of course assumes that the lower surface of the leather has been pushed below the plane of the knife. Also, skiving will stop then the external source seizes to apply force, i.e. when there is no further buckling (= substrate edge reached).

To bring this into practical terms, a metallic pin with a rounded smooth surface can play the role that the flexible substrate deposit did, in the case of manual matrix skiving. As seen in figure 2.6, the splitting mechanism has now been supplied with a spring loaded pin. This pin is vertical to the planes of the conveyor and knife. The pin is located at a small distance away from the knife edge. Its tip lies at a height above the knife plane, roughly equal to the thickness of the incoming component.

When the leather component passes under the pin and above the knife plane, any vertical movement of the pin will cause the leather to locally buckle and to bring its lower surface below the plane of the knife. Provided that this movement is smaller than the thickness of the leather, the excess thickness of the leather (as "seen by the knife") will be removed. This will continue to happen for as long as the pin is pressed and the overall effect will be a *"skive line"* on the leather component.

After experimentation with the first such mechanical arrangement it was concluded that it was necessary to embed the conveyor with a soft spongy material. From this point onwards, this will be referred to as the *conveyor substrate* or simply the *substrate*. The reason is that when the pin is pressed the substrate gives way and allows the

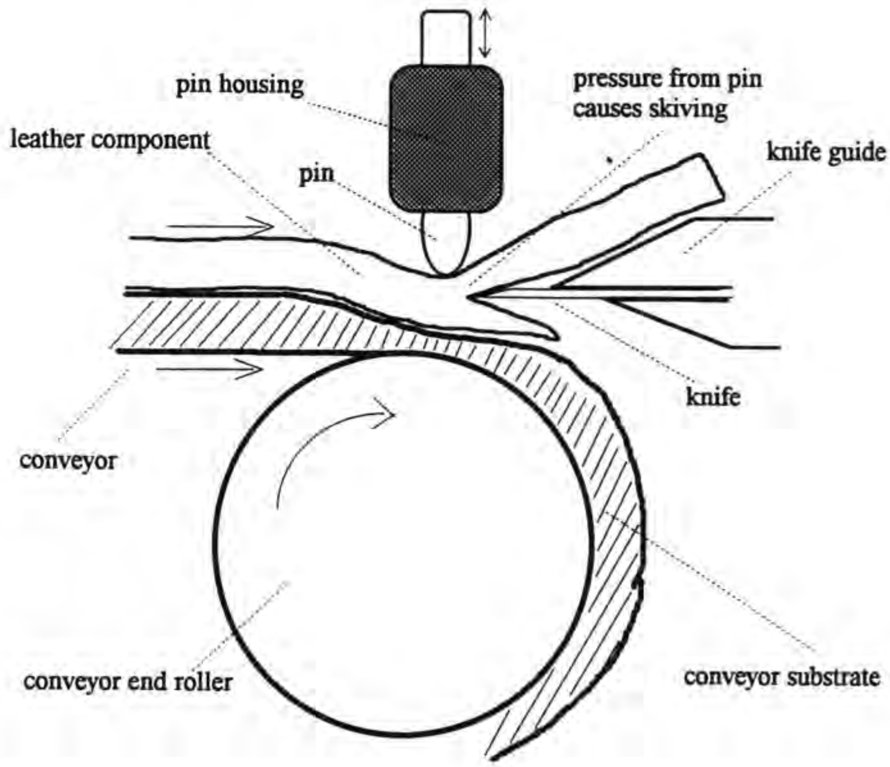


Fig. 2.6 The basic initial pin based skiving mechanism

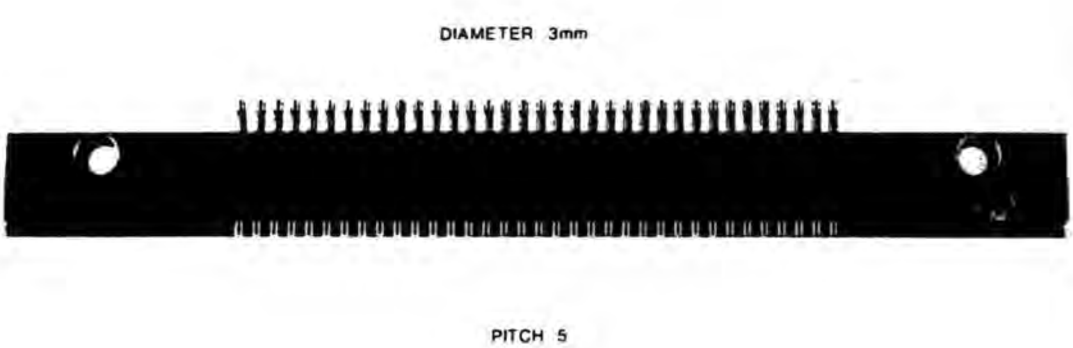


Figure 2.7 Photograph of the pin row used for skiving

leather to buckle. Otherwise if pressing against a solid conveyor surface, the pin simply presses the leather "against itself" making the process impossible. The role of the conveyor substrate is very important for the process from different points of view and this will be explained in chapter 4.

The effect of a single pin, as described above, is to cause a skive line (parallel to the direction of travel), for as long as it is pressed. To implement the line scan principle the system has to be able to produce skive lines perpendicular to the direction of component travel. To potentially achieve this, it is necessary to replace the single pin with a row of pins, the axis of which is parallel to the knife axis. A row of pins made for the purpose of this research is shown in the photograph of figure 2.7. In a similar way, if at any instant a number of pins are pressed against the passing leather component, this causes a skive line of the above specification. Such line will have width directly related to the time that the pins were kept pressed and to the velocity of the conveyor.

Therefore it becomes apparent that in this way, a two-dimensional skive pattern of any desired shape, can be generated upon the leather component, simply by pressing the appropriate pins at the appropriate instances and for the relevant time durations. Thus any two-dimensional skive pattern can be generated dynamically in the form of successive skive lines, each one generated and imposed at different instances upon the processed component. Theoretically, the overall effect of this function should be an uninterrupted smooth skive silhouette.

Using the mechanism described above, the graphic detail of skive patterns is directly related to the width of the pins. If we define as "X" axis the knife axis and as "Y" axis the direction of travel then :

- *Y-resolution* of the system is defined as the thinnest possible X - skive line.

- *X-resolution* of the system is defined as the thinnest possible Y - skive line

- *X,Y resolution* of the system is defined as the smallest possible area of skiving, performed by a single pin. Such an area will be of width equal to X mm and length equal to Y mm.

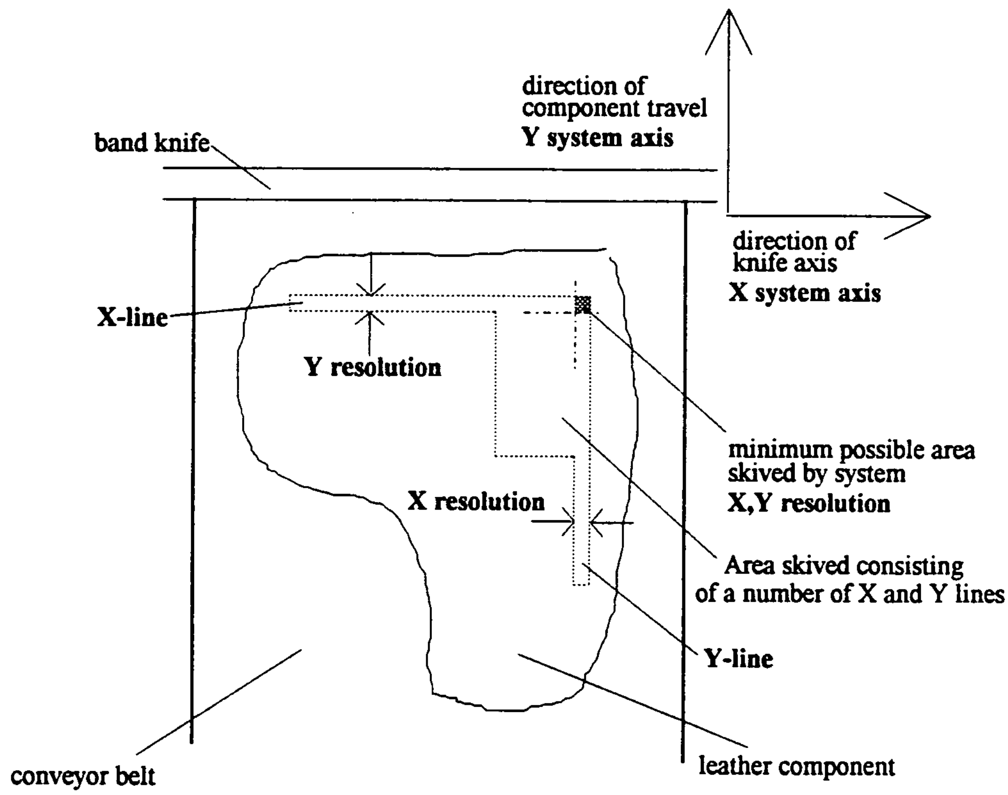


Fig. 2.8 Representation of the system definitions relating to skiving resolution

The physical representation of the above definitions are shown in figure 2.8. The problem of the system resolution and its influences are analysed later in chapters 4 and 5.

2.6 Actuation for pin based skiving

The basic skiving system, as described in the previous section, functions with local leather deformation caused by metallic pins. The pins themselves have to be driven by some form of actuating system. The responsibilities of such actuating system would be :

i. To provide enough force to manage leather and substrate deformation.

ii. To be able to operate at high speeds. A reminder here is that the component while being processed is continuously moving with certain velocity. Thus the speed of actuation is directly related to the resulting Y-resolution of the system (refer to figure 2.5).

iii. To consist of units small enough to be packed within a relatively low volume. The number of such actuating units would be equal to the number of pins used to form the pin row.

Actuators that could fulfil these requirements to some degree could be a choice between, pneumatic, hydraulic, solenoids or piezo-electric devices. Considerations for alternative actuation are briefly explained in chapter 9. Most alternatives for the choice of actuators were eliminated, on the basis of a combination of practicality, suitability and non sustainable hardware overheads to the system.

Initially, the most practical solution seemed to be the use of solenoids. Small, cylindrical, single acting, dc driven solenoids were thus mounted on a platform and were linked with levers, which introduced to the system mechanical advantage of 4:1. This amplification was necessary to enhance the output power of the actuators.

The choice of solenoid size was a compromise between volume, output power and operating stroke. The solenoids chosen were able to produce an output of amplitude 9 Newtons at full stroke and via the amplification gave an a force of 36 Newtons. Static tests had shown that this force value was large enough to cause the desired deflection on leather and substrate.

The main assembly of an actuator for an individual pin, is shown in figure 2.9. A number of such mechanisms were assembled one aside the other to produce a single actuator device, able to drive a row of solenoids. The first such mechanism built contained 32 individual actuators spaced at 5 mm pitch. This pitch of course is the same for the pin matrix, which contained 3 mm wide pins, separated by 1 mm.

The present actuating system is meant to operate in an on-off fashion, i.e. skiving either occurs to a specified thickness or it does occur not at all. This implies that the vertical pin-knife distance is initially preset via a manual adjusting mechanism. This in

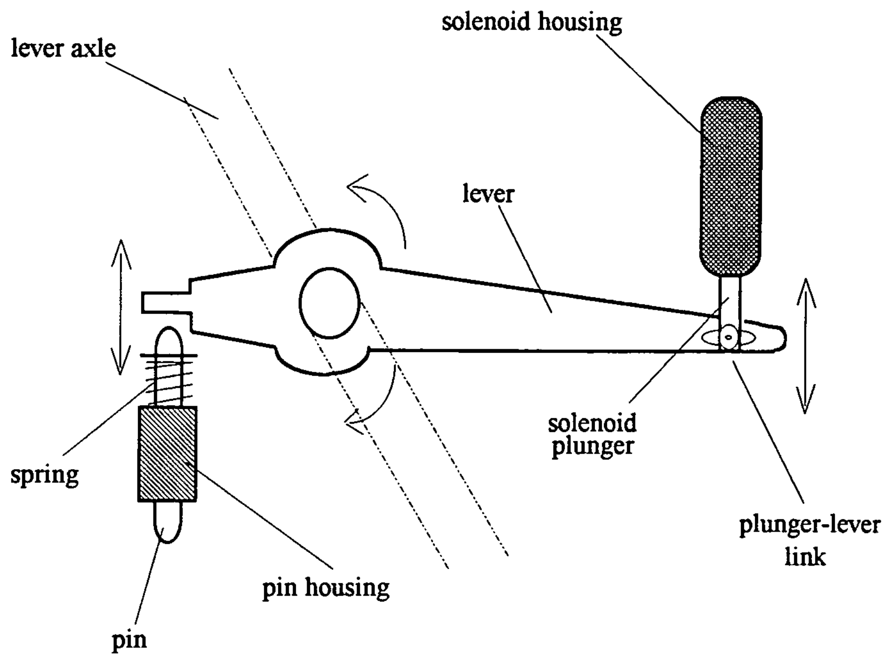


Fig. 2.9 The basic elements of pin actuation

turn means that the depth of skiving is initially preset. Therefore if leather components of different thicknesses are skived at the same skive depth adjustment, the remaining thickness of the skived areas will be common in all such components. The issue of dynamic skive depth adjustment is not a major concern in this research, and it is briefly discussed in chapters 3 and 5.

Finally, it is worthwhile noting that when solenoids are turned off, the pin springs are responsible for bringing back the lever/solenoid mechanism at its original position. Another alternative for this would be to use double acting solenoids, but this option will introduce additional cost and volume overhead, and it is clearly a decision to be considered at the future development stage of the skiving mechanism. The photographs in figures 2.10 and 2.11 illustrate the 5mm resolution pin based actuating mechanism, used in this research for skiving. The mechanism shown is separated from the pin matrix.

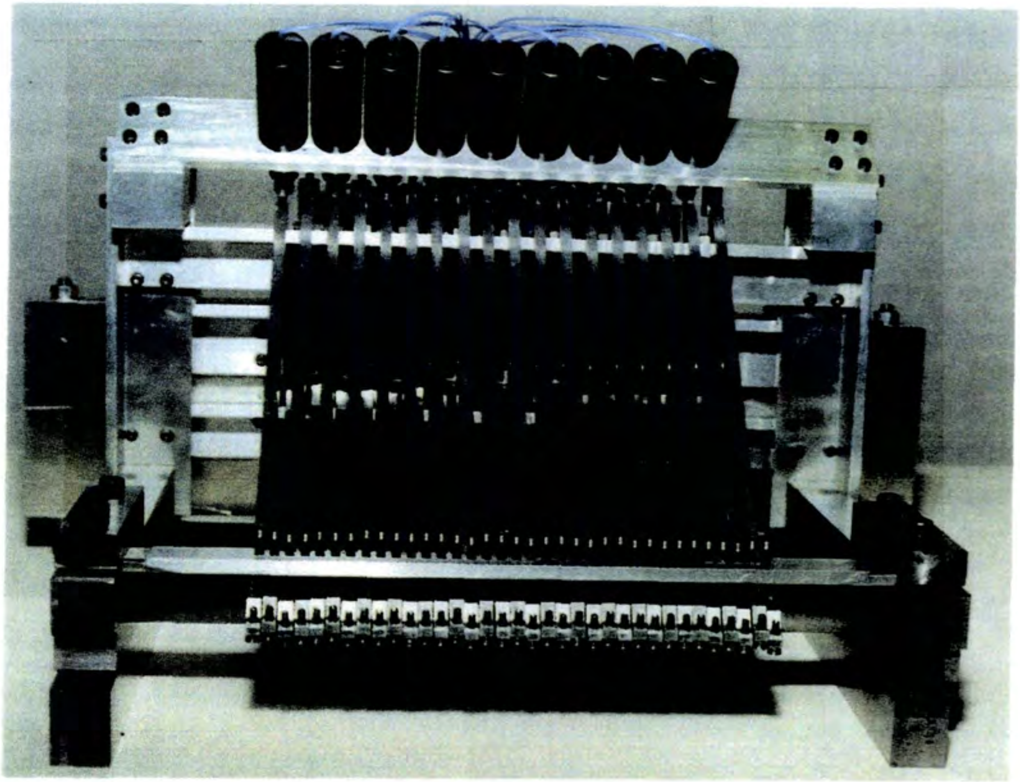


Fig 2.10 The 5 mm resolution actuating mechanism used for pin based skiving (front view)

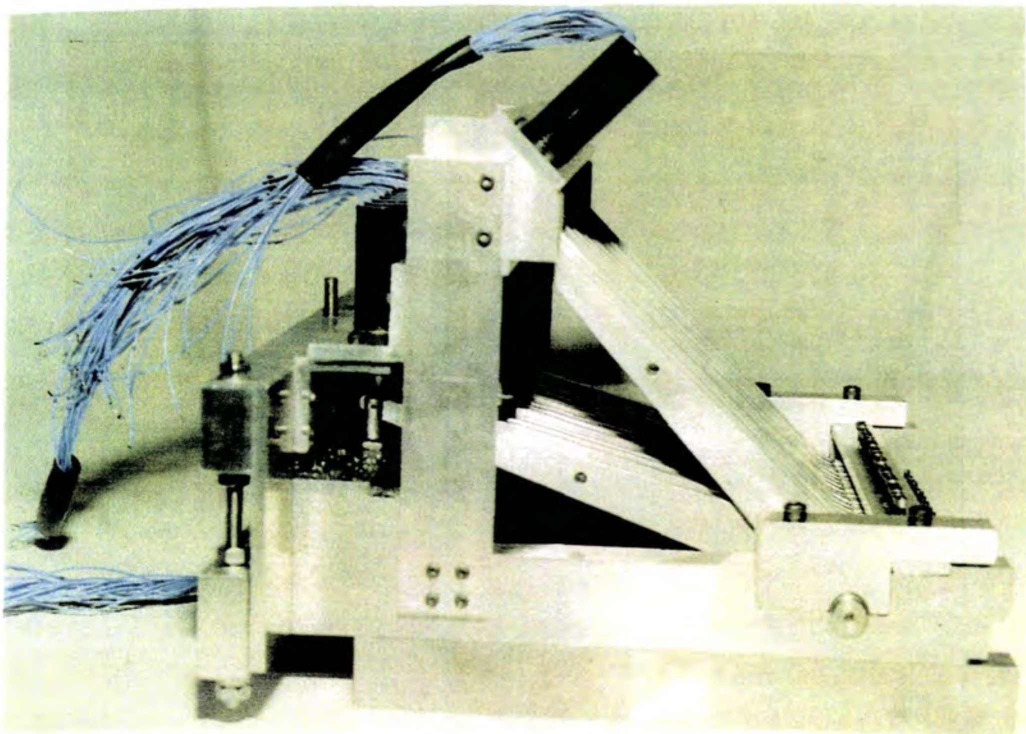


Fig 2.11 A side view of the actuating mechanism for pin based skiving

2.7 Skiving with a single pin

This idea was drawn from the way dot matrix printers operate. After having considered the main principle, i.e. pin based skiving, it was inevitable to consider the option of being able to skive using a single pin only. In this way the pin together with its actuating mechanism would be travelling along raster lines at high speeds (X-lines) forming them as a bit at a time. Such a mechanism would largely amplify the demand of speed of actuation but also it require large acceleration capabilities [26]. In the system above, for example, actuation would have to be faster by at least a factor of 32. This is because it would have to carry out the same amount of actuations of a single line (32) within the same time originally allowed for that line.

Therefore this solution would require high actuator capabilities and could easily divert the main aim and direction of this research. However another important unknown at this stage was the behaviour (response) of the leather/substrate system itself. This uncertainty introduced the question, how long should vertical displacement of leather be maintained for skiving to occur, at a given conveyor speed.

Originally, this idea was put aside and later some investigation was carried out to provide the answer to the above question. Assuming that the required actuator was invented, would skiving be possible at such pin speeds ? This would be an opening for future research into this particular area. This work is described in chapter 9.

2.8 Conclusion

In this chapter it was explained what is the principal method adopted to research into the automation of the skiving process. It has been concluded that direct automation of the manual method of *disk-knife based skiving* would not be practical. This is due to complexity and low throughput. The option of *face milling* has shown to be a viable solution but not a desirable one, due to its lack to perform in a flow through fashion and due to its low throughput.

The most promising method seemed to be one that would be based upon the principle of *localised splitting*. Localised splitting is occasionally used for decorative purposes in a manual form called *matrix skiving*. In this case the leather is locally deformed with the use of removable pre-shaped substrates. In the areas that have been temporarily deformed, the component is split while passing through a splitting machine. This method has the potential to perform both *interior* and *edge skiving*.

The effect of local leather deformation by substrates can be simulated with an actuated pin row and it is possible to define and split localised skive patterns. Such patterns may be generated remotely in the form of raster scan lines, and leather components may be skived while in motion through the system. This method is thus called *dynamically generated matrix skiving* or simply *dynamic matrix skiving* and it is expected to use the existing technology found in splitting machines as a part of its overall configuration.

CHAPTER 3

ANALYSIS OF SYSTEM REQUIREMENTS

3.1 Introduction

The first approach for the automation of the process of skiving, was to investigate into the issue of the principal method of component machining which would be employed. In chapter 2 it was explained that the method of localised splitting of leather, combined with dynamic generation of skive patterns, was a sufficiently promising candidate. The next stage in this research, was to look with some more detail into the overall set of requirements, for a fully automatic skiving system.

Before carrying out any analysis, it is necessary to define clearly the specific aims of the desired automation system. It is also essential that prior to further research and implementation of particular system modules, the expected limitations of these aims are identified. It is therefore necessary to come to a compromise between what is practically viable for the purpose of proving the main concern of this academic research, and the industrial expectations for a commercial product. This type of synthesis of commercial expectations and laboratory research aims is the guide rule, according to which the overall system requirements were laid down. This chapter faces the characteristics of all necessary individual modules and sub-tasks, which would compose a fully integrated skiving system.

3.2 System requirements.

The first stage in transforming the manual process of skiving into an automatic one, is to define the expectations of such a hypothetical system. To do this it was necessary to consult with BUSM[7] and decide what would be a realistic list of system properties and capabilities, that could define the automatic skiving machine in the industrial world. It was also essential to obtain some experience on the manual skiving process, but also on other processes in shoe manufacturing, within an industrial environment [6],[8].

The reason for this was to identify problems or issues confronted in automating other processes and/or influencing factors and constraints, common to many processes within a shoemaking industrial plant. Such issues, such as leather storage, cutting and selection for cutting and others, may not be directly linked with the issue of skiving, but they may indirectly dictate particular system properties. It was also necessary to learn what may or may not be acceptable to shoe manufacturers, from the quality point of view. Issues such as the the ones explained above can be identified as design criteria for reasoning in further system analysis.

Table 3.1 contains the system requirements/properties as seen from a high level point of view, before any . This is a summary of all requirements as confronted before any logical organisation of system tasks takes place. The third column of the table indicates with an asterisk, those requirements which were considered appropriate for a future research project or for attention during the system development stage. The object list contains the hypothetical system modules to which each system feature may be allocated.

Having decided upon the set of requirements for the automated skiving process, there are two logical stages of analysis that have to be carried out. One is to construct a function tree structure. This contains a high level description of the process sub-tasks, which will fulfil the requirements already defined. In this case the process sub-tasks have been organised in a logical manner. The second stage is to identify the technical implications derived from the function structure.

REQUIREMENT	OBJECT	
No component manipulation	Overall system	
Component transport	Transport mechanism	
No other permanent alteration on component surfaces	Overall system	
Thickness identification	Thickness sensing module	*
Component recognition	Recognition module & database	
Position and orientation recognition	Recognition module	
Availability of "known component" data	System database	
Maintenance of orientation and position	Transport mechanism	
Definition of component skive pattern	System database	
Timing of transport recognition and processing	System transport controller	
Generation and manipulation of skive patterns	Image processing module	
Transmission and execution of skive data	Process controller module	
Component movement sensing during transport	Movement sensing module	*
Component rejection	Movement sensing module	*
Skiving process method	Leather component	
Resolution of skiving	Skiving mechanism	
Interior skiving	Skiving process	
Edge skiving	Skiving process	
Maintenance of position during skiving	Transport mechanism	
Waste extraction	Skiving mechanism	
Actuation of skiving mechanism	Method of skiving	
Control of actuation mechanism	Skiving process controller	
Variance of skive depth	Skiving mechanism	*
Splitting while skiving (dual function)	Skiving mechanism	*
Continuous process flow	System controller	
Input and output method to the system	System integration with other	*
System throughput = 0.5-3 components / sec	Skiving process method	
Maintenance of component surface quality	Transp. and skiving mechanism	

Table 3.1 A comprehensive set of features comprising the automatic skiving machine.

3.3 The "task-tree" forming the automated system

To perform analysis on any large project or system, it is necessary to break down the main problem or function into lower levels of tasks, each branching out to related sub-tasks and gradually stretching out to low level functions. Those low level functions may represent individual hardware or software modules. From this point onwards implementation of the solution for the system can be dealt in a bottom up fashion. In terms of research, the individual branches represent known or novel sub-processes, which need to be resolved one by one, before the main system is assembled.

Hence to analyse the problem of automating the given process, it was considered essential to construct a top down task tree. The graphical representation of this function complex is shown in figure 3.1. In this diagram the analysis stops at the level of the description of the main functions that a hypothetical system would be desired to contain. If the analysis continues to lower stages, it identifies the specific electromechanical structures which would perform these functions. Low level analysis is carried out in the following chapters.

As explained earlier, the main concept of an automated skive processing system is to accept in one end pre-cut leather workpieces in a random fashion, and to output them skived in the other end. In this case, by definition, random input means unspecified orientation and position. However, at this stage, it must be pointed out that the there is only one restriction to the interpretation of "random input".

Leather components have two distinct sides. One is the chemically processed and/or coloured side, usually refered to as the upper side (refering to the "upper" or "outer" surface of the hide). This side may also contain surface patterns or other added decorative feature, or it may simply be a very smooth surface. This surface is always meant to form the regions of the shoe which are seen. During all processes in shoe manufacture, this surface is be subject to careful handling, so that it is not permanently altered or damaged in any way. Thus this is not only the first requirement from the automation of skiving, but it also imposes the restriction that skiving on both sides is not a permitted alternative for automation.

The other side of leather components may also be processed, in cases, to reduce porosity or to improve smoothness or fibre density, but it is always the side on which skiving is performed. Therefore the constraint to the term "random input" will have to be that components have to be presented to the system with the same side.

The reasoning for this conclusion is as follows ; if the main objective is to implement a component oriented process, this implies that no component manipulations are allowed. This means that if components were to be accepted in the system at any side, then the design for the skiving mechanism would be left with two possible options

- the skiving mechanism should be versatile to adapt to circumstances. The mechanism should be able to turn its plane of operation by 180^{o}.

- the skiving mechanism should contain a number of duplicate sections, forming pairs fixed to operate in reverse planes.

Both of the above options introduce unnecessary complexity for the design and implementation of the skiving mechanism. Hence it was thought to be a necessary compromise [7] to assume that leather workpieces would be input to the system in only one orientation, with respect to sides. Once this restriction has been admitted, then it makes no difference as to what side the components are to be placed on. The decision here was to deliver the components with their "upper" surface facing upwards and the side to be machined downwards. This decision was simply subject to easing the design of the skiving mechanism, and to allowing a standard splitting machine to be used.

The next step in analysis is to define that a flow through skiving system would require some type of mechanism to deliver the components. This mechanism would be subject to the system input at one end, and it would transfer the components to the process area. The processed components would eventually be output from the skiving machine. The input to the delivery mechanism could be some form pick and place device or the output of another flow through process, preceding skiving. Similarly for the system output.

It is worthwhile noting that these two stages are irrelevant to the theme of this research. This is because they are concerned with the integration of the complete system within a larger multi processing environment. The following sections describe some technical aspects of individual tasks, when breaking down the two main functions (delivery and processing), into lower level tasks.

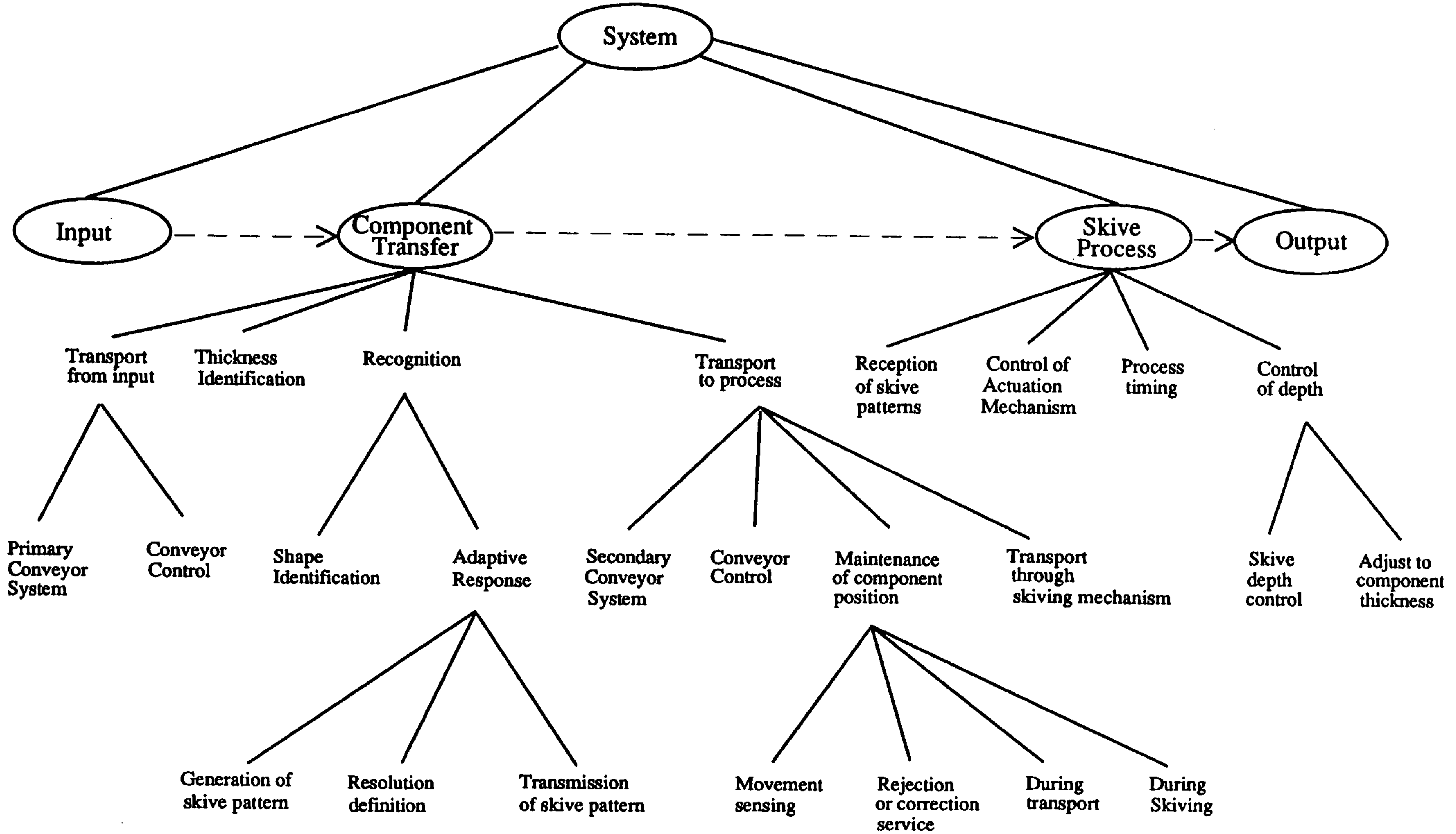


Fig. 3.2 Analytical representation of the basic system tasks

3.4 Component transfer

This is a major system function which includes all tasks involved, between accepting an incoming component and presenting it to the process area for machining. Within this stage a number of functions have to be carried out, so that the system is supplied with information, as to when and how the component is due to arrive to the process area. During this time the system should have developed the necessary conditions to process the component.

It is necessary that the component under processing is identified and distinguished between thousands of possible candidates. It has been assumed that one of the capabilities of an automatic skiving machine would be to accept leather components at any possible orientation and position when placed on the transport device. Hence, another important issue to be resolved is to identify the orientation and position that this component is being received by, and to translate this information to some meaningful format for the processing device. In other words the overall process should be able to modify and adapt to the conditions presented by the incoming component and manipulate its "known" response for a particular component, to satisfy the above conditions.

Another task delegated to the component transfer function is the mechanical means of achieving component transport. If a component oriented process is to be implemented, the components should be transported to the process area, by a means which ensures maintenance of the orientation and position of the component, to which it was received. The overall timing of the transport mechanism is also critical.

It has been explained that components can vary between thousands of possible shapes and sizes. Nevertheless this variability represents known data that may be stored and looked upon for reference. In other words the number of different possible shapes entering the system may be large, but all data is well defined and known. Therefore it may be stored in a software data bank. However there is another property that leather components possess and this is the leather thickness.

Unlike the other component properties mentioned above, this is an unpredictable one. The reason for this is that even with the most careful selection of leather type, hide size and age for cutting leather shapes, there is always variety in component thickness.

Component thickness may vary from 0.7 mm to 2.5 mm in some cases. This is a fact also for components cut out of the same hide, as hide thickness and quality varies from region to region. Hence it becomes apparent that there is the need for thickness identification of incoming components, so that the processing device may adapt to it.

The following 5 sections are concerned with further analysis of each of the requirements consisting the component transfer function.

3.4.1 Component transport from system input

The transportation of components may easily be handled by sets of conveyor belt mechanisms. Such mechanisms may be driven by stepping motors. This choice gives a hardware solution that may produce satisfactory timing with the overall process. Driving by stepping motors combines control by repeatable finite displacements of a given resolution, with the confidence of an error-free open loop system.

During component transportation to the process area, three processes are meant to happen. These are silhouette recognition, thickness identification and movement sensing. Because the latter two are considered to form future research areas, the design of the transport mechanism will be considered to host only the recognition process. Hence the specific design features of the conveyor mechanism are influenced by the method of recognition.

A recognition system that would suit the skiving process has been developed prior and during the research for the automation of the stitchmarking process[3] . In skiving, as in stitchmarking, the leather workpieces used are in the same major processing stage, within shoe upper manufacture. This means that no matter whether stitchmarking is applied before or after skiving, the shapes of the components are not altered in any way. This implies that not only the same recognition hardware may be used for both cases but also the same database, containing all shape information. It seems therefore practical to use existing technology for the task of the recognition, although some enhancements may be required to be implemented and modifications suitable for the process of skiving.

In this stage of analysis it is not necessary to go into a deeper description of the recognition module, as this is done further on in this thesis. However it is important to observe a particular feature of the recognition module which sets a demand in the design of the transport conveyor. Component recognition is implemented by using a line scan camera which forms a raster scan image of the passing component. This image is formed by successive lines of "shadow" (component's silhouette), as the component passes over a light source located opposite the camera. This principle is illustrated in figure 3.3.

It is therefore inevitable that the conveyor system has to contain a gap of a specific width [3] under the camera lens, through which light is available to the camera. This implies the constraint that the overall transport mechanism will consist of more that one conveyor. The primary conveyor will thus transfer component from the system input area to the vision area, and the secondary conveyor mechanism will deliver them to the skiving process.

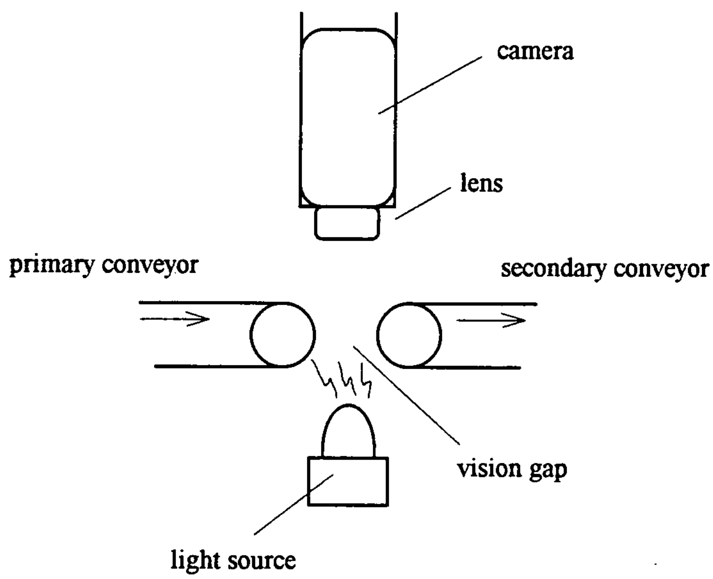


Fig 3.3 The principle of shape recognition

The requirements from the primary conveyor are reduced into simply carrying the components up to the vision area without allowing any movement, so that recognition may be implemented without distortion. Provided the transportation environment is not subject to major vibrations, a simple conveyor belt should be able to carry out this task. If the system is meant to employ a thickness identification mechanism, this may be located somewhere along the course of the primary conveyor. Again, this is not expected to introduce any additional requirements for the primary conveyor.

3.4.2 Shape recognition

Shape recognition is a system function containing more than one task. After having completed the formation of the image of the incoming leather component, the system refers to the data bank occurs for silhouette identification. The data bank contains all necessary information by which a particular component is distinguished amongst others. Together with the raw information there should be the means, i.e. a tool, via which this data is used to carry out the recognition process.

In addition to the above, the database should be accommodated with a mechanism for updating information. The latter includes deletion of non used components and addition of new ones. Addition (or teaching) of new components would be expected to be carried out using the same hardware which are used for the process of recognition. During the teaching process of a new component, apart of the geometrical properties of the component the database should be provided with all information concerning the regions in which components are supposed to be skived. It is inevitable that teaching new components and defining their skive regions may be done with reference to a particular orientation of the new component. Thus the stored component information will be referring to a certain component orientation, and this data should be successfully used to serve the recognition and action processes irrespective of the orientation of the incoming components.

When the system is aware of the identification of the input workpiece, it has to respond by generating data with the information of the skive pattern, to be applied to the component. Of course this skive pattern will be formed by manipulation of the original information for that component, contained in the data bank. This manipulation will be related to shape, orientation and position. These circumstances will apparently be different each time a component of the same shape is recognised. This is because it is highly unlikely that two identical components are at any time received by the system in the same position and/or orientation on the conveyor. This function is labelled as "adaptive response" in the structure tree in figure 3.2.

Image data manipulations will also occur to define the final working resolution of a skive pattern, suitable for the capabilities of the skiving mechanism. It is important to note that the working resolution of the vision system, as configured for the stitchmarking process (2,000 dots per inch) is significantly higher than for any likely skiving method. This is because the skiving method adopted here, or any imaginary alternative, would have to carry out displacements confined to a physical (practical) resolution. Let us note that this resolution is not only subject to actuator technology, but also to what the leather surface can sustain without surface damage to occur.

Hence the shape identification function, shown in the function tree structure of figure 3.2, can be broken down into the set of tasks shown in the diagram of figure 3.4. Apart of the components of the vision module, the overall shape recognition system contains hardware and software that are responsible for the task of the adaptive

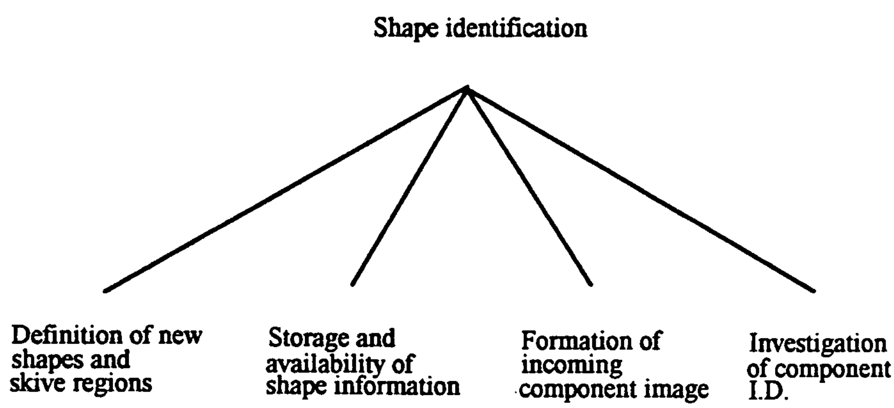


Fig 3.4 The components of the shape identification function

response. The suitability and need for modification of these sub-tasks for the skiving process, are subjects that fall into low level technical analysis. This is described in more detail in chapter 7.

3.4.3 Component transport to the process

This task is concerned with handling the components after having been processed by the vision system, and presenting them to the skiving process area. It is apparent that components at this stage should not be subject to any movement or rotation during transportation. As explained before, the system at this stage has adapted to the conditions that the component was received for recognition, and has (or is) developing its "intelligent" response. If the component has in any way moved between recognition and skiving, the system response will effectively be invalid.

Another constraint directed to the secondary conveyor mechanism, is that it must ensure that component handling is efficient, so that there is no movement during the skiving process. Also, another possible expectation is that the same mechanism should deliver components through the process, towards the output of the overall system.

Finally the last but not least requirement would be the allowance of a facility of "observing" the component's position, as near to the skiving mechanism as possible. This necessity is due to the possibility of adding-in a position maintenance sensing device, to ensure that movement has not actually occurred during transportation. Although the exact method of implementation has not yet been decided, it is obvious that there must be a point of access to the component on the conveyor system.

3.4.4 Conveyor control

Another task belonging to the component transport function is the overall control of the conveyors. However timing the two conveyor systems may not be an independent function. Skiving must occur at a particular time for each component and for different durations. This is directly linked with linear displacement of the conveyor surface, i.e. component movement. The same of course applies for the recognition module.

Hence it must be noted that the movement of components during transportation recognition and skiving should be in strict central timing. Therefore the timing of motors should be linked, within some defined relation, with the camera scan rate and with the actuation frequency(/ies) of the skiving mechanism.

Let us assume that, in principle, three independent electronic hardware sources are responsible for controlling each of the three processes. Let us also assume that all three processes are delegated to a central software control, which co-ordinates all part processes to implement the overall system function. Between these four modules there should be a common key-timing signal. It is only logical to assume that this signal should be derived from the function of the least versatile module. This module is the camera electronics which control the camera scan rate. This signal could then be taken directly or indirectly to perform the common timing source. In the diagram of figure 3.5 this critical timing link is shown.

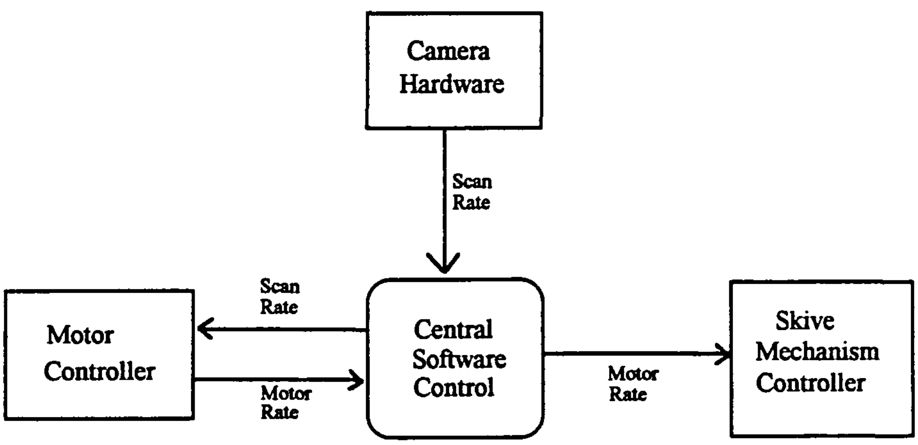


Fig. 3.5 Central timing control links

3.4.5 Movement sensing and component rejection

The need for this function is under question, as it will be highly dependent upon the performance of the handling mechanism. However, even if the repeatability of the conveyor system proves to be satisfactory, there may still be a need for such mechanism to prevent rare but possibly destructive events for the system. In other words it may be seen as a security device for mechanism malfunctions. For example if the conveyor mechanism produces a mechanical fault, this will appear in practice almost inevitably as some type of component dislocation.

Also, cases such as timing malfunctions or overlapping components fed through, or simply dislocated components, should be provided with a realistic exit from the system. It is obvious that leather components are too expensive to waste. Thus in the case of an error those components should be subject either to a mechanical exit from the system or a process-free flow through. Therefore position maintenance sensing and component rejection may prove to be necessary in the later development stage of the system.

3.5 Skiving process

The function of the skiving process itself is to physically intervene on the leather components fed to the process area, and perform the pre-defined localised thinning. With reference to the diagram of figure 3.2 it is seen how the skiving process can be sub-divided into the tasks that compose it. Those tasks are namely the reception of skive patterns (images), the control of the actuation system that drives the skiving mechanism, the process timing and the depth control.

3.5.1 Skive image reception and execution

In section 3.4.2 the generation of skive patterns was considered. These patterns, which may be more than one per component, have to be transmitted to the skiving process controller. The skiving process controller may be a hardware or software module or one containing both. No matter the nature of the controller, there has to be defined some method of transmitting this image information to the skive mechanism, and transforming it into sequences of actuation. These sequences of actuation will be responsible for forming the required skive pattern on the leather workpiece, based upon the principal method described in chapter 2.

Hence the requirement imposed upon the process controlling module is not only to communicate with the recognition module and to be able to receive the image data from it, but also to be fast enough to cope with the actuation of this image. Let us remember that both these tasks will have to be carried out in real time while the components are flowing through the system.

3.5.2 The relation between skive pattern data and skive resolution

The efficiency in speed is also related with the amount of data representing skive patterns. The more the data the more time it takes to be transmitted and executed. In turn, the amount of data defining a skive pattern is directly related to the resolution of the skiving action.

In chapter 2 it was concluded that skiving would be performed by the means of mechanical pins. The physical size of a pin and pin spacing define the x-resolution. If now it is assumed that x-resolution and y-resolution are equal, a square piece of area with side equal to pin spacing would define one unit of skive pattern data. Hence the higher the resolution in which skiving is performed the more the elements forming a skive pattern (in data terms).

The overall conclusion here is that the higher the operating skive resolution the heavier the image transmission and execution overhead for the skive controller, in terms of speed. Therefore a decision to alter the resolution of the system in the future may require a completely different hardware and software control module.

3.5.3 Actuation system control

Skive patterns have to be formed while components are flowing through the mechanism. This imposes the requirement of fast actuation. In the previous section it was explained how skive images require fast data transfer. Each element of the data forming a skive pattern will have to be actuated mechanically, at relatively high speeds. If for example it is assumed that an x-line is formed by 32 elements and a skive pattern is composed of 40 y-lines, this gives a total number of 1,280 actuations. If now it is assumed that the pattern has to be completed within 0.5 sec, this presents a speed requirement of 2,560 actuations per second.

To implement such a task will require not only actuators of demanding response characteristics, but also considerable computer processing power, possibly combined with low level programming.

3.5.4 Skiving process timing

The problem of timing the skiving process on a component is dependent upon the components position while moving, its linear velocity of travel and the response characteristic of the actuation mechanism of the skiving machine. These three elements have to be taken into account by the skive control module to perform the skiving process timing. This interaction is illustrated by means of a schematic diagram in figure 3.6. The influence of these three elements to timing control is explained as follows :

- *The component's position with respect to the process area.*

  The component is supposed to be flowing through the system at a speed requirement between 150 and 350 mm/sec[7]. If for argument sake commencement of the skive pattern actuation occurs 0.1 msec late , this would result in a shift of the pattern on the component by 1.5 to 3.5 mm. Such an event would be violate tolerances of quality control (set to +/- 0.5 mm [7]). These figures indicate the narrow limitations for accuracy in skiving control.

To comply with these limitations the skive controller has to keep track of the component's position reliably, while this is delivered from the recognition area to the skiving process area. To achieve this it is necessary to establish a reference point in time during component transport. At that particular instant the component's position, relative to the position of the skiving mechanism, should be clearly identified. Of course this has to happen without interrupting the overall process. This information may be provided to the skive controller by the recognition control, and the reference point in time may be the instant at which vision scanning has been completed.

- *The conveyor speed.*

Stepper motor drivers can provide the skive controller with their driving pulse train, which may in turn be related to the camera scan rate (fig 3.5). The stepping

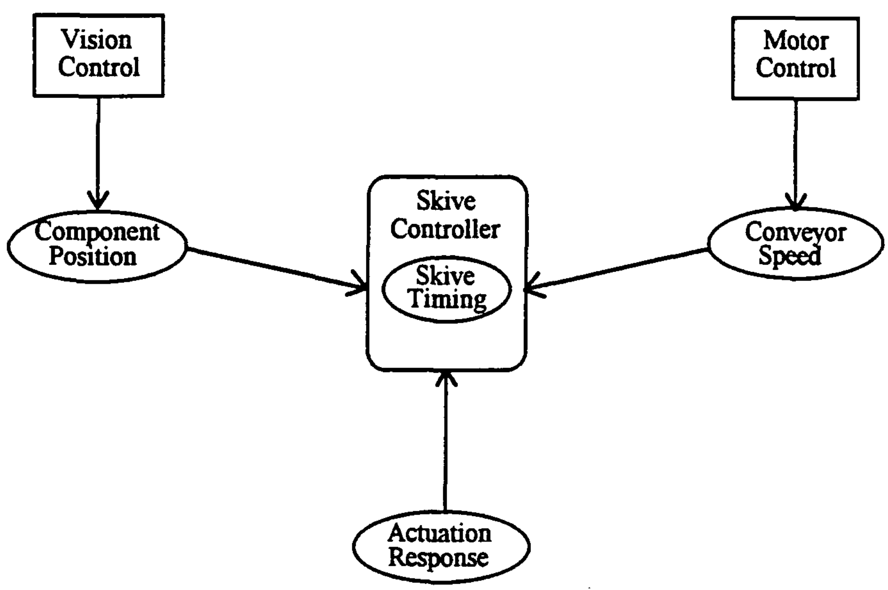


Fig. 3.6 Elements influencing the timing of the skive process

pulses may be the media by which the component's position is accurately monitored, in real time by the skive controller. The same pulses can also be a media by which length of skiving is determined. This can be done by the skive controller, by translating motor pulses to linear velocity of the conveyor, i.e. to the length of a skived stripe on the component. The amplitude of the period of stepping pulses is thus likely to indirectly define the system response, as this will be subject to the smallest possible movement of the component. This movement will be equal to the linear displacement of the component caused by a single motor step. Hence it is important that stepping motors employed are of low step angle. Also it is essential to provide the conveyor system with some type of mechanical gear reduction.

- *The response time of the actuation mechanism.*

  The actuation mechanism described in chapter 2 like all other such mechanisms it is expected to have a finite response time and a particular characteristic. If individual cells of a skive image are to occur at the right time and place upon the component, then this characteristic has to be taken into consideration in the control software of the skive controller.

3.5.5 Control of depth of skiving.

As it was explained in chapter 1 the leather components that are to be processed at any time within a factory, vary in size and thickness. Therefore another feature that would be desired in an automated skiving machine, would be the ability to determine dynamically the thickness to be removed from various components.

This problem has two aspects. One is to be able to adjust the skiving for thicker or thinner leather workpieces. The method and mechanism proposed for skiving (chapter 2) adjusting mechanism is added to the basic structure of the skiving mechanism. Such a mechanism would require information from the thickness identification module (mentioned in section 3.4.1), so that it may adjust the gap between the knife and the pin tips to a the required position to enable pin displacement within a new relative displacement band .

Obviously the argument here would be why should it not simply be allowed for the lever/pin mechanism to possess a longer stroke, so that there is not need for adjusting the whole mechanism. There are a number of reasons contributing to dropping this option. These will become apparent in chapter 4, where the features of the skiving mechanism are described in detail. However, one of the strongest arguments against this solution is that longer pin stroke means longer time of actuation and hence low system performance. This also implies greater actuator requirements. Detailed study into this particular issue is presented in chapter 5, where system actuation is examined in detail.

The other branch of the depth control problem is to be able to vary the depth of skiving, within a limited displacement band, during the processing of a single component. In other words, a further advantage would be to be able to determine different skive depths at different locations upon the same component.

Usually, components requiring more than one skive patterns are skived to the same specification in all areas. Nevertheless in some cases it is desirable to skive more than one pattern of different depths on the same component. In other cases it may be of advantage to skive a single pattern on a particular component, which has a varying crossection profile. This latter feature is an additional demand directed to the actuation system. One way for achieving this is to employ actuators with variable stroke. This idea however does present new obstacles to the overall system design. This problem in actuation is discussed in chapter 5 and some theoretical considerations for depth control are given in chapters 5 and 9. The mechanism developed during this research period does not contain the above capability. The subject of dynamically determined variable depth is considered to form an individual theme of future research.

3.6 Conclusion.

In this chapter it was explained how the automatic skiving system can be analysed, on the basis of expected system requirements. This has been a high level analysis and it does not cover a lower level of technical issues. So far it has been shown how the main skiving function required to be automated, may be dismantled to produce the main core of system requirements, which identify the type of technology which is necessary to be employed, so that the overall system may be implemented. Apart of this, there have been considerations presented for the relation between the individual sub-tasks. This in turn has produced a number of basic but necessary information links, via which these tasks may function in relation with each other, to produce the final goal, i.e. skiving an input component.

The last and concluding stage in this analysis is to assemble all the system components, and to produce a function structure containing the critical communication links already described. This may be considered to be the functional skeleton of the automatic skiving system, upon which detailed modular research and design may be based. Such a structure may be represented by means of a diagram, like the one shown in figure 3.7. This illustrates the basic functions of the system as events, presented in an order of task sequence with respect to time. It also contains the basic data paths between the functions. These data paths carry the vital information which is needed by some functions in order to operate in co-ordination with others, i.e. to perform the overall system function.

The type of data passing along the communication links is not of constant type. Some of this data types may present the receiving function with more than one possible solution. The "skive pattern" data link may be taken as an example, where skive patterns are likely to be different each time this link is accessed. Other data types, such as "component rejection" are of Boolean type and may only take one of two possible values "true" or "false".

In any case these data may be taken to represent the crucial system variables, whose compilation derives the outcome of the systems function for a single component. It is worthwhile noting that these variables are independent of particular hardware systems (processor types, electronic system architecture, or mechanical structures) used to perform these functions. It is considered that the function/variable structure presented will be a basis, upon which any future modification or development of the system by BUSM. will be carried out.

Finally as it may be deduced from this analysis, the automation of the skiving process undertaken in this research will produce an open loop system. This term is given with respect to inspecting the output of the overall process automatically, while it takes place. The necessity for employing the system with a feedback information path cannot be clear until the process method has been itself validated, and until performance evaluation is carried out based on a developed prototype system by BUSM.

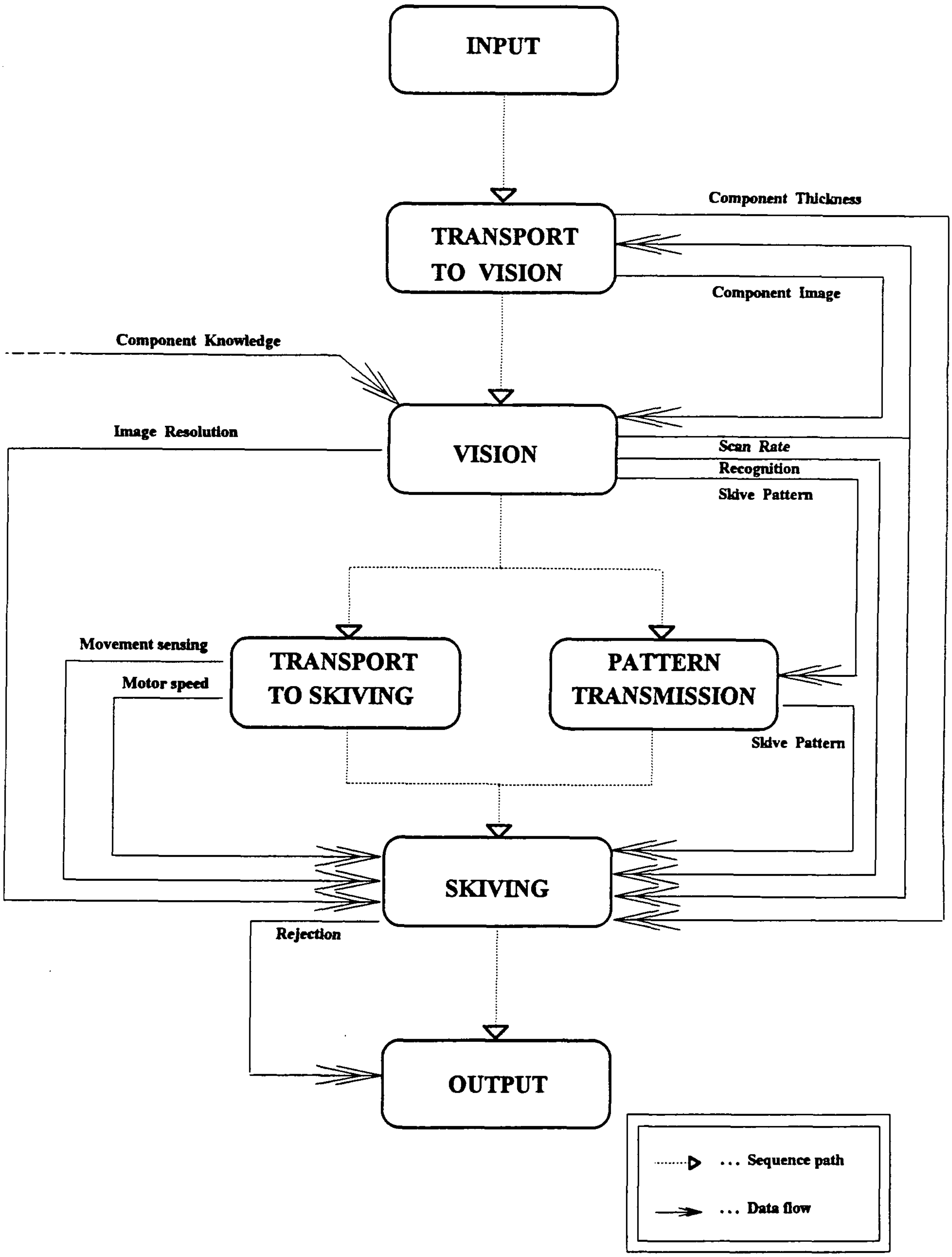


Figure 3.7 Diagram of the critical data flow paths and global variables of the automated skiving system

CHAPTER 4

THE FACTORS INFLUENCING SKIVING PERFORMANCE

4.1 Introduction

Initial trials of skiving on leather components indicated some problems to overcome. Due to lack of successful component handling during the process, components appeared to rotate and move during skiving. This in turn caused distortion of the intended skive patterns. Also, initially it seemed that by using the method of dynamic matrix skiving, it was not possible to produce leading edge skiving because of component jamming. To overcome such problems a series of investigations and experiments took place which led to the idea of the twin belt transfer and handling system. This chapter analyses these issues and describes an investigation in the process area, to identify all the variables influencing the performance of the skiving process. It also presents the successful results of skiving, after having implemented the necessary developments in the process area.

4.2 The mechanical features of the skiving mechanism

The initial structure of the skiving mechanism is shown in drawing 4.1. This drawing illustrates the three basic elements of the process area; the pin row, the band knife and the conveyor surface. All elements are drawn accurately to scale. A detailed drawing

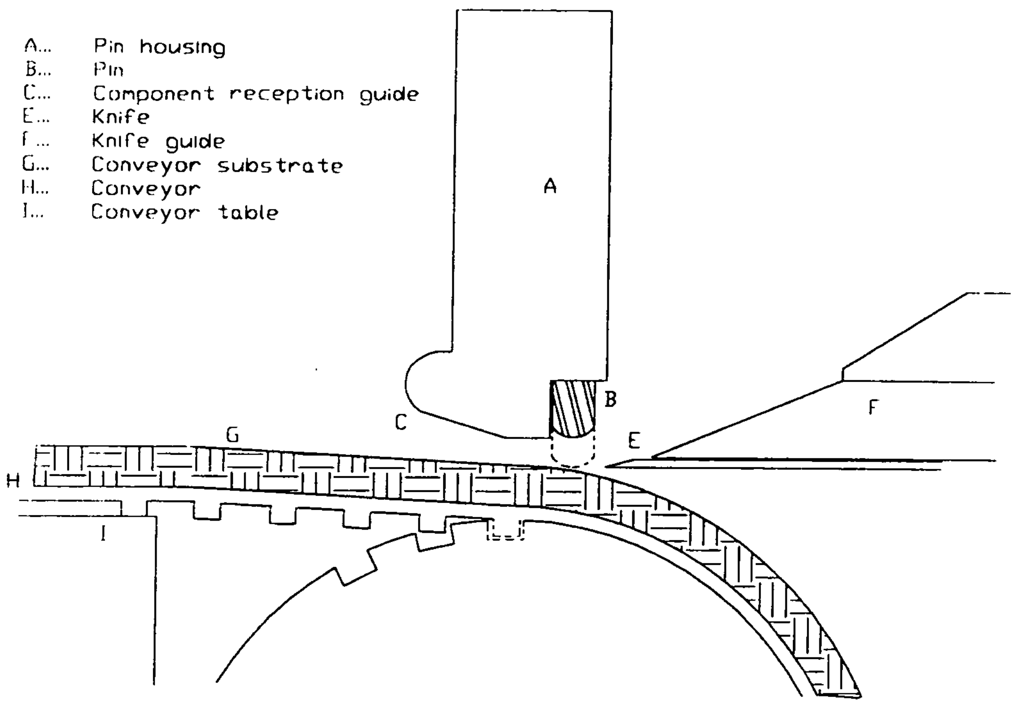


Fig. 4.1 The initial structure of the skiving mechanism

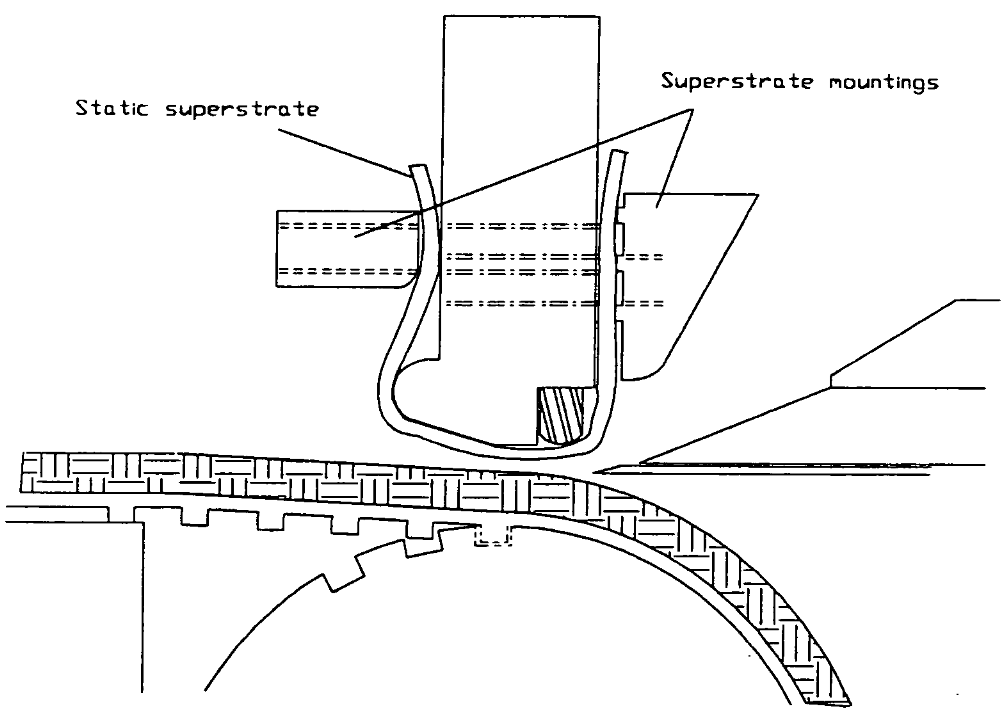


Fig. 4.2 Skiving with static superstrate/spline

of the mechanism, including all critical dimensions is provided in drawing A-4.1, appendix A-4.

One of the main constraints in this system is the slope imposed by the knife guide. Its presence, immediately behind the skive region, implies that the passing leather component has to bend and follow this path to exit the process area. Even the smallest real life components will have to be forced to bend as they approach this region, while they are being skived. The knife guide is a part of the band knife mechanism of the splitting machine. Its purpose is to guide the knife smoothly along its exposed area, and to stop it from moving in the vertical direction. Furthermore it has become apparent that all existing splitting machines have a similar mechanism and the only slight differences noticed were concerned with the length of the guide slope.

After specific investigation it was concluded that the knife guide is not possible to be modified to eliminate the slope. The only alternative would be to invent a novel knife mechanism which would be adapted to the splitting machine. This implies complete redesign of the splitting machine, and this option stood well beyond the scope of this research. Hence it was concluded that if the skiving machine was to adopt a splitting machine as one of its components, the presence of the knife guide would have to be assumed and allowed for.

Another feature of the mechanism, is the reception projection in the lower region of the pin housing. Because leather components are flexible and are not likely to be received at the skive area totally flat, it is necessary to ensure that the leading edge is not excessively curled, when arriving at the pin matrix. The purpose of this projection was to ensure that the leading edge of the component is gradually forced flat before it reaches the process area.

The mechanism is meant to accommodate leather components of different thicknesses. It is therefore necessary to have a facility to alter the gap between the substrate and the pin. This facility is present by means of a manual adjustment. This implies that for a particular adjustment of this gap the mechanism can skive a limited domain of different component thicknesses. If now it is considered that the operation of the pin movement is limited between two mechanical stops, i.e. no control of stroke, it becomes obvious that : *for a particular adjustment of the pin-conveyor gap the depth of skiving will differ, according to the thickness of the incoming component.*

The distance between the knife plane and the lower edge of the pin at full stroke, is fixed to a different value, for each pin-conveyor gap adjustment. Thus for a specific set gap, the amount of leather thickness skived off will be the excess thickness below the level of the knife plane. This principle is illustrated in figure 4.3. Although in the present mechanism there is lack of control for depth of pin stroke, there was still the facility to investigate the main objective, i.e. whether automatic skiving is viable.

Another critical adjustment in the skiving mechanism is the distance between the knife edge and the vertical pin axis. The splitting machine provides a manual adjusting mechanism for this purpose. It must be noted that the initial setting of this distance to its

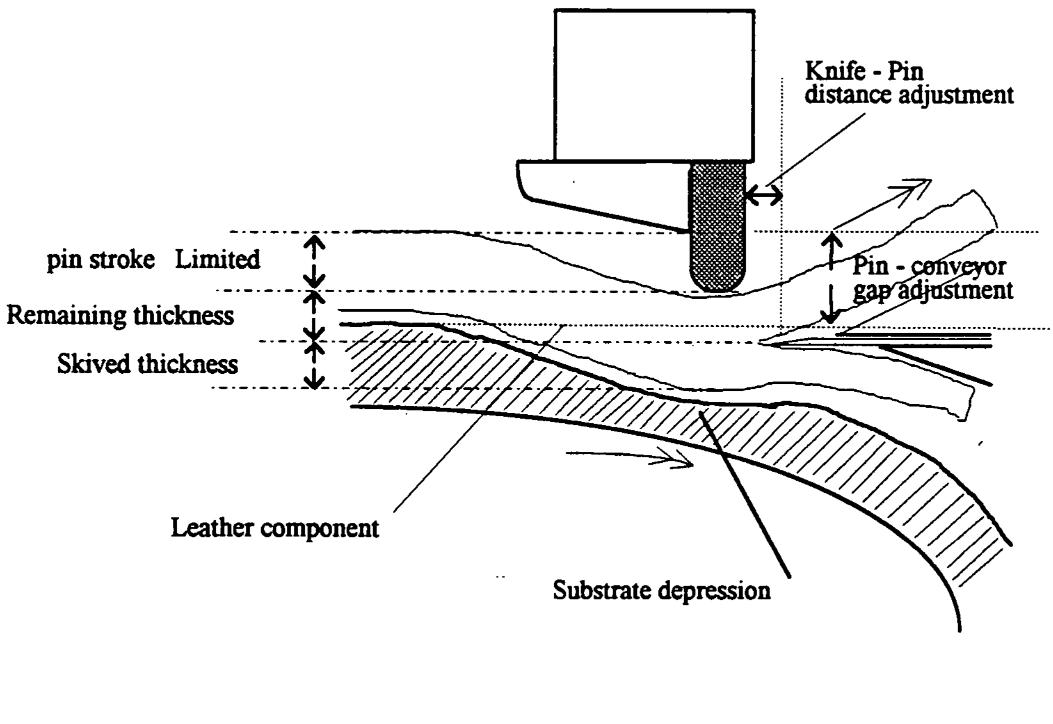


Fig. 4.3 Skived and remaining thickness in relation to pin stroke and leather component thickness.

critical value was done experimentally. However later in this chapter it is described how the variance of this distance influences the performance in skiving.

An important feature of the skiving mechanism is the presence of the conveyor substrate. As mentioned in chapter 2, the substrate layer allows for leather bending where pressed by pins, so that a certain amount of the component's thickness lies beneath the knife plane. However, there are another two separate roles for the substrate. The substrate is made from suitable material to provide friction, so that components do not slip during skiving. It must also provide fast response in recovery after release of applied pressure by the pins.

When skiving by a particular pin is meant to stop, the actuator of this pin is de-energised and the pin is subject to its spring return forces. It is to those forces that the substrate response contributes. However although disengagement between pin and leather may occur fast, at the instance of occurrence the leather is still being split. A certain amount of its thickness is still held under the level of the knife plane, and it may only gradually return free above the knife plane. The contribution of the substrate in this case is that it aids the leather to return, and thus skiving to terminate as early as possible.

4.3 Early attempts for skiving

The principle of the method of dynamic matrix skiving was explained in chapter 2 and is illustrated in fig 2.5. Initially, and prior to any further research into overall system integration, it was necessary to examine the behaviour of the skiving mechanism. The reason for this was that any possible modification in this mechanism, could alter dramatically the concept of the overall automatic skiving system.

The first step of investigation was to provisionally evaluate the ability of the basic mechanism to perform skiving. For this purpose the splitting machine was modified and supplied with a conveyor, on which components are transported to the skiving area. The control of actuation of the pin row was implemented by a Motorola 68000 computer. The M68000 produced a skive pattern and it was transmitted to the pin actuators as a set of successive X-lines of actuation. At this stage, due to the lack of system synchronisation, relatively large leather components were fed-in the skiving machine, to ensure that skiving occurred well within the boundaries of the component.

The first attempts to skive involved interior skiving. Interior skiving is the simplest and easiest form of skiving to implement. This is because the skive pattern has to be implemented in regions of the component which are away from its edges. The results on interior skiving were satisfactory in the sense that skiving did actually happen, but at the same time problems appeared, which had to be overcome. These are described below :

- ***Component rotation.*** During skiving, components tend to lose their original orientation, by which they were placed on the conveyor. This happened to a higher degree when skiving was attempted away from the centroid of the shape of the components.

- ***Component translation.*** Components appeared to slip along the conveyor while being skived.

- ***Poor skive pattern definition.*** The skive pattern that was supposed to be formed on the components was not contiguous. It appeared to be formed by a number of discrete Y-lines. The distance between those parallel skive lines was equal to the X-resolution of the skiving system. In addition, edges of skive patterns which were oriented at an angle with the direction of component movement, appeared stepped rather than smooth as expected.

- ***Permanent damage on the upper surface of the component.*** This appeared mostly on components made from the thinner and more sensitive types of leather.

In addition to those problems with interior skiving, when *edge skiving* was attempted, it seemed that in most cases *leading edge skiving* was impossible. This was because component jamming occurred, prior reaching the knife edge. At this stage it must be noted that *leading edge skiving* is the term describing the skiving operation on the edge of the component that is facing the pin row, as the components proceeds towards the skiving area. Also the term *trailing edge*, which is referred to further on in this chapter, refers to the edge exactly opposite to the leading one, i.e. the edge of the component last to leave the skive area. Leading and trailing edges may be any two opposite faces of the component's silhouette, and this depends solely upon component orientation on the conveyor belt.

The four issues explained above formed the body of the next stage of research, in developing a successful skiving mechanism. The investigation for the causes of these problems and the procedures undertaken to overcome them are described in the next few sections.

4.4 Component rotation and translation during skiving

As mentioned earlier leather components appeared to rotate during skiving. In some cases the component simply lost its grip against the conveyor's substrate surface and slipped while being skived. In other instances component dislocation appeared as a combination of rotation and translation. In all cases the result was to produce a distorted skive pattern on the component. This means that if the system was fully automated, the skive pattern would appear not only at the wrong orientation and position on the component, but also its shape would be distorted.

The drawings in figures 4.4 and 4.5 illustrate the forces that contribute to component rotation and slip. The reason for the occurrence of slipping is explained as follows. The pin when pressed against the leather introduces a friction force F_p between the pin and the upper surface of the leather. The direction of this force is opposite to the direction of conveyor movement. The force that is responsible for keeping the leather intact with the conveyor substrate is the friction between the two, shown as F_s. Depending upon the pin pressure and the texture of the surface of the particular leather type F_p may become greater than F_s. Component slip occurs when this condition is met.

Component rotation is effectively a form of slipping. Unlike simple slipping along a straight path, it occurs in a circular mode with respect to a fixed point, around which the component rotates. With reference to the drawing in figure 4.4 let us assume that a single pin is pressed against the component in a location A far from the centroid C of its shape. If at A the conditions for slipping are met then slipping occurs in the

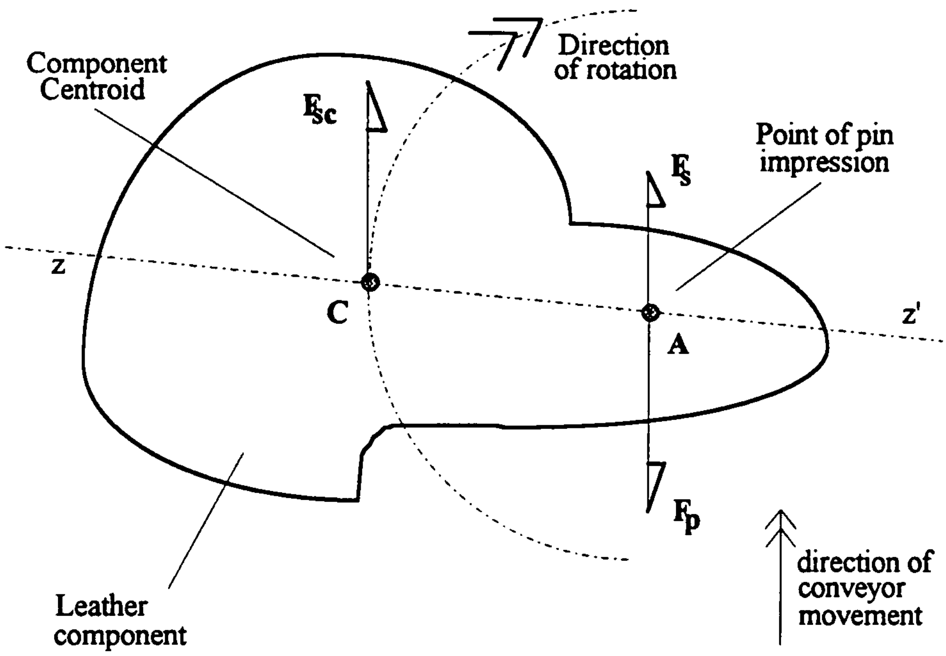


Fig. 4.4 The forces causing component rotation during skiving

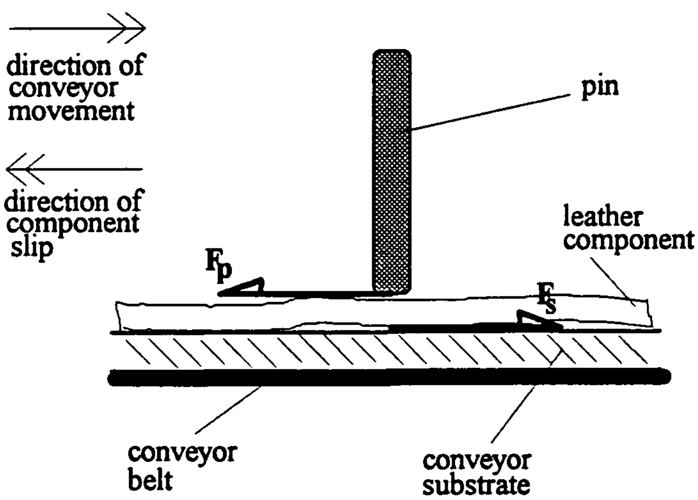


Fig. 4.5 The friction forces responsible for component drag
during skiving.

reverse direction to the one of the conveyor travel. Let us now also assume that F_{SC} represents the sum of all F_S force elements of the area on the L.H.S. of A. At the instance when $F_S - F_P$ takes a negative value (i.e., $F_S < F_P$ at A) there is a moment induced with components $F_S - F_P$ and F_{SC}. This moment causes component rotation, while at the same time the component is slipping backwards.

Another cause of component slipping is the receiving guide of the pin housing. Due to imperfections in consistency of component thickness, the guide tended to produce additional friction upon the upper surface of the leather. This is not considered to be a main cause for slipping but a contributing factor.

It was thus concluded that to eliminate component rotation and slip, it was necessary to introduce the following resolutions :

- reduction of the friction force F_P

or

- increase of the friction force F_S

- improvement of component guide,
  (elimination of static surfaces that come in contact with the moving component)

4.5 Poor definition of skive patterns

This issue is concerned with the resolution of the pin matrix. Although the problem of system resolution is analysed in chapter 5, poor skive definition may be resolved by modification of system features other than the actuation mechanism.

The drawing of figure 4.6 illustrates the crossection a typical sample of poor definition on a skive pattern. Instead of the intended cut the resulting pattern crossection is formed by hills and valleys. Of course results of this type occurred with this anomaly to different degrees, depending upon the type and thickness of the leather components. It was observed that the more flexible and elastic the leather type was, the more non-uniform the skive pattern.

The valleys (i.e. the areas of deeper cut) were located underneath the pins that caused them, with the lowest point of cut coinciding with the centre axis of the pin. It became thus clear that the problem of poor skive pattern definition was due to the resolution of the pin matrix, which was 5 mm (3 mm wide pins located at 5 mm centre distance).

Also, it may be assumed that the profile of the tip of the pins in relation to pin diameter and pin spacing is critical too. The tip of the pin should be curved and smooth to reduce friction between itself and the component. By reducing the tip curvature it was obvious that skiving would improve, but this would introduce greater risk for surface damage on the surface of the component by individual pins.

The logical solution for this obstacle, theoretically at least, would be to reduce pin spacing, and size. However this solution faced constraints in terms of practicality and research scope. In any case, there would always be a limit to which the technology involved to produce a high resolution pin matrix would cross the line carrying the serviceability and reliability of such a mechanism.

The conclusion resulting from such considerations was to investigate into a generic method of reducing the effect of poor skive definition using the existing resolution. Theoretically, this implies a method of improving the effects of poor matrix resolution, no matter what that resolution is. Such a generic method would involve perhaps additional features to the skiving action, to smoothen the discontinuity of skive patterns. The logic behind this approach is that if such a method was found, and skive patterns could improve at the existing resolution, then improving the skiving resolution would become a simple issue of commercial system development.

To solve the above problem it was considered to introduce an interface between the leather components and the pin matrix. The interface would be some type of flexible sheet material of suitable thickness which would have the following properties :

- *Elasticity.* It should be able to sustain deformations without permanent alteration of its structure.

- *Virtually no friction on at least one surface.* The surface coming in contact with the leather component should not cause component displacement due to friction.

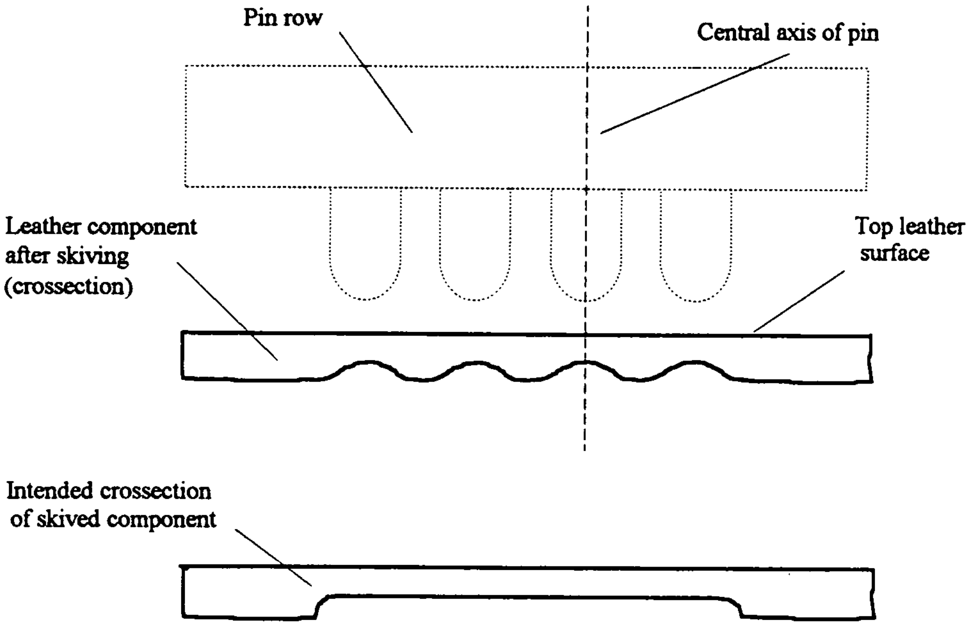


Fig. 4.6 The effect of poor skive image definition in skiving leather components
(the direction of component travel is perpendicular to the plane shown)

- *Non - compressible.* The material should not consume pin movement and/or force. It should act as a direct transfer of motion between the pin and the component. The theory behind this idea was that the impression of the individual pin on the leather during skiving, will be spread around it and that it will merge with neighbouring impressions giving an overall continuous skived pattern. The degree of continuity of the skive pattern will depend on the degree of widening of the valley caused by an individual pin. This idea is illustrated in figure 4.7.

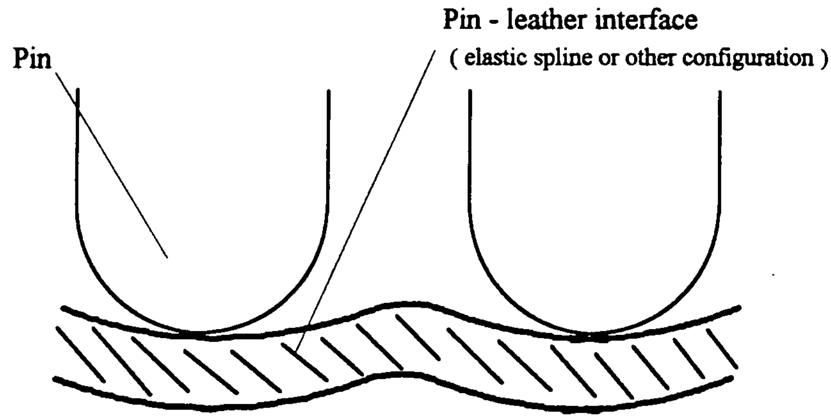
However it is obvious that this would introduce a negative feature. This is the reduction of the skiving resolution of a single pin. In other words, the larger the widening of a skive valley the wider a Y and X -skive line. Thus there is expected to be a limit to which the smoothing effect of the interface can be allowed for.

In the same way the pin - leather interface should improve the stepping effect on skive lines mentioned earlier. This is shown in the drawings of figure 4.8.

The first experiments that were carried out to prove the principle described above, involved various superstrates of sheet materials cemented on the upper surface of the leather. These tests were carried out for a variety of leather components in both thickness and leather type. The results of these experiments confirmed the assumptions of this idea. Skive pattern definition improved to the degree of perfection with some types of materials. However the smoothing of stepped lines was improved but not perfected. At this stage it was concluded that the use of an interface superstrate together with future increase of pin matrix resolution would contribute to the perfection of stepped lines. Also in all cases damage to the upper surface of the leather was not observed.

The tests described above involved superstrates which were cemented on the components. This of course did not represent a realistic approach to the problem because it introduced two additional operations for skiving, i.e. the deposition and removal of the superstrates. It was necessary to implement a single superstrate which would be used for all components and it would be stationery with respect to the pin row, rather than the components.

The next consideration was that the superstrate should form a static flexible spline, permanently positioned under the pin matrix. In this configuration the components were expected to slide under the superstrate during the operation. Also, in this case the frictionless side of the superstrate material should be facing the leather, so that sliding could take place without component dislocation. In the early tests, it appeared that the best material tried for superstrate, coincided to possess one side of virtually no friction. This material used is a PVC coated fabric (non woven), coated on one side. This will be referred to as the PVCF material fron this point onwards. The other side is fabric with some degree of friction. PVCF thus seemed the ideal candidate at least for the first trials. Figure 4.9 illustrates the principle in using a flexible spline, permanently housed at the lower end of the pin matrix. The drawing of figure 4.9 also combines this idea with an alternative design of the knife mechanism to provide a flat and continuous table of operation.



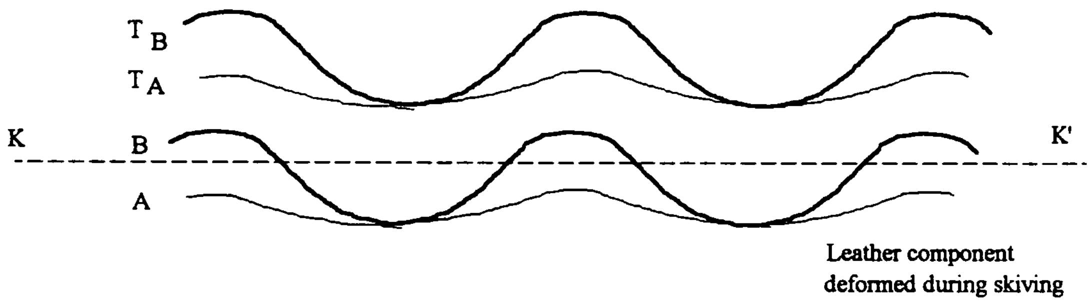
T_B ... Top surface as deformed without substrate

T_A ... Top surface as deformed with substrate

B ... Surface to be skived as deformed without substrate

A ... Surface to be skived as deformed due to substrate

K K' ... Knife axis - component thickness below axis level will be skived



T_{AB}.. Top surface after skiving (coincides for both cases)

B' ... Skived surface without the use of substrate

A' ... Skived surface due to substrate (improved skive definition

A,B ... Line defining original component thickness

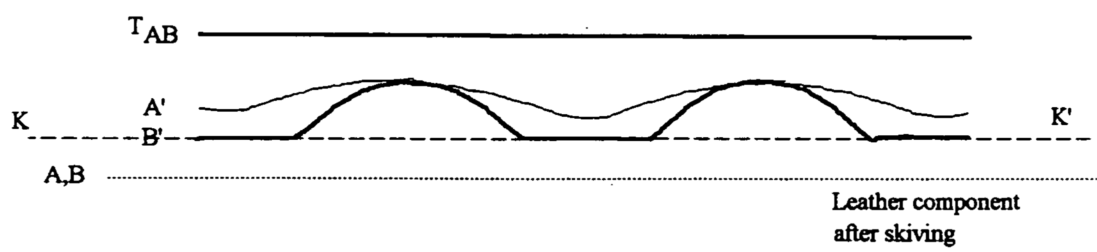


Fig. 4.7 The smoothing effect on poor image definition introduced by the use of superstrates

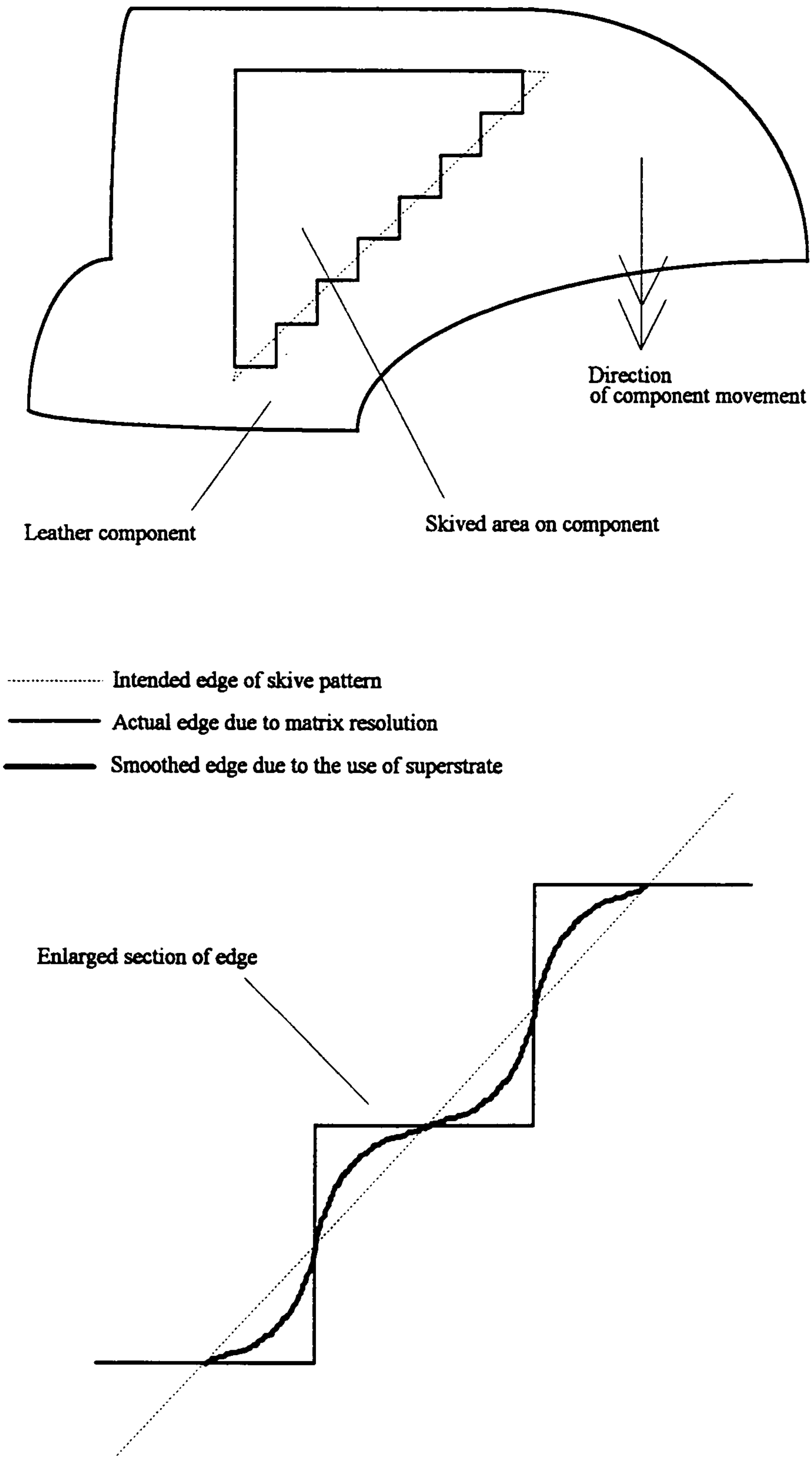


Fig. 4.8 Pin - leather interface improves aliasing on skive pattern edges.

Unlike the band knife used in the splitting machine, the S - type knife mechanism shown does not need an upper support for its guide, thus allowing component movement through skiving in a horizontal plane. This would overcome the constraints due to the guide slope (mentioned earlier in this chapter) but it may only be considered as a futuristic idea, for the reasons explained.

To test the idea of the flexible spline, a clamping mechanism was added to the skiving mechanism, at the lower end of the pin matrix, such as the one shown in the figure 4.2. This clamp holds the superstrate firmly against the pins at their relaxed position. The tension applied by the gripper is adjustable and it is should set to a suitable level, so that it does not increase the force requirement by the pin to overcome, but also that it is not too loose to cause interference with incoming components.

The results of the above experiment confirmed once more the theory of the advantage of the pin - leather interface. Nevertheless this configuration did not solve the problem of component dislocation during skiving, although it occurred less frequently. Leading edge skiving was obtained for the first time but not at a good repeatability, as component jamming was still occurring from time to time. However there was a noticeable difference in the quality of edge skiving in general. Without the superstrate, edge skiving was very frequently failing, in the sense that when the skive pattern was approaching the edge of the component, the component was cut through. In this case edge skiving produced a smooth profile up to the very edge of the component.

4.6 Leading edge skiving and maintenance of component orientation

The developments and ideas up to this stage had resolved a number of constraints in skiving, some of them partially. The necessity here was to assume that the superstrate could be in permanent contact with the component without any friction in-between. Theoretically this would solve the problem of component orientation. To implement such idea one could only assume that the superstrate travels together with the component, while at the same time it is not cemented to it. This led to the concept of an upper belt mechanism made from the superstrate material, which would be timed to the motion of the lower conveyors.

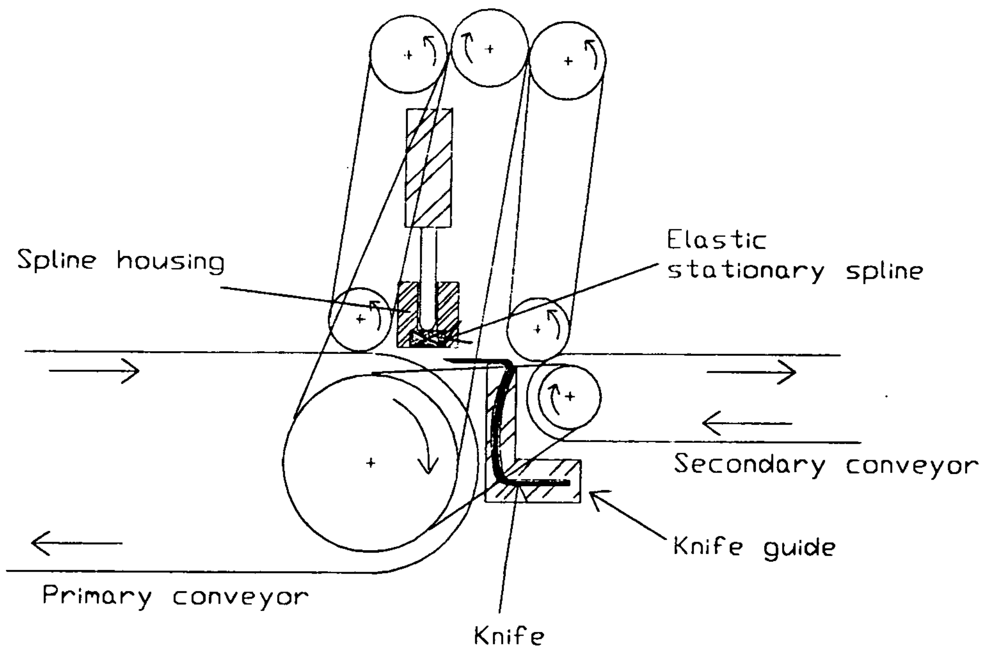


Fig. 4.9 Skiving mechanism based on S-type knife and a stationary leather - pin interface (elastic spline)

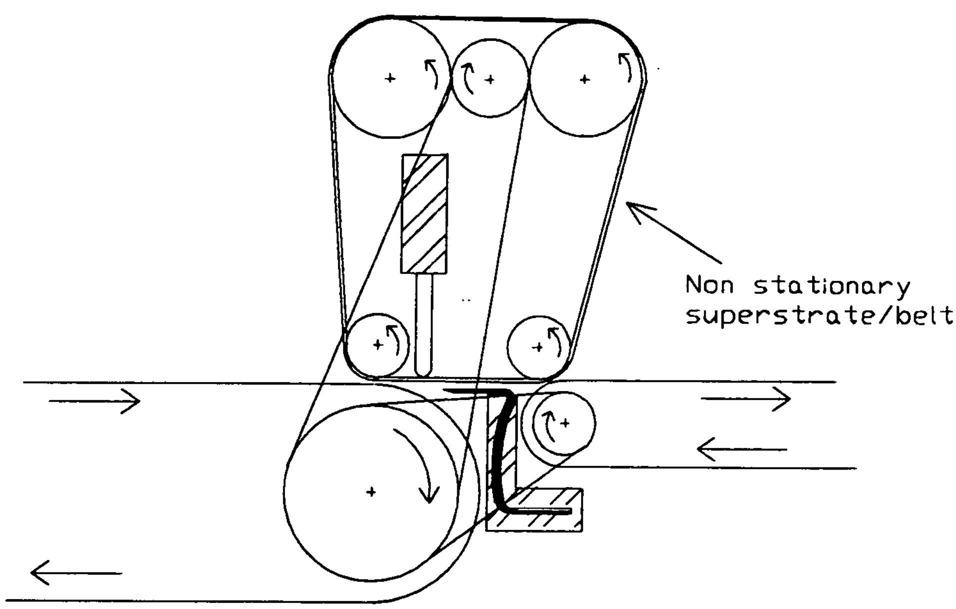


Fig. 4.10 Skiving mechanism based on S - type knife and moving leather - pin interface (superstrate/belt)

A suggestion for the ideal skiving mechanism, possessing this feature, is illustrated in the drawing of figure 4.10. This belt should possess the characteristics mentioned above for the superstrate material plus *durability*. This is because in this case, it is the superstrate belt that will be subject to deformation while it is running against the pins. For this purpose the belt should have its smooth surface facing the pins and the rough surface against the component.

The arrangement described above should also have beneficial attributes for the achievement of leading edge skiving. Figure 4.11 explains the circumstances causing the problem of component jamming, and thus the failure of leading edge skiving. To achieve leading edge skiving the pin should be pressed at the precise instance of arrival of the leading edge of the component. If the pin is in direct contact with the leather, often it occurs that the edge of the component is gripped by the pin and is not allowed to proceed. This causes curling of the rear of the leather component and jamming occurs. Also the same will occur if the pin is pressed immediately before the arrival of the component. It is also conceivable that if the edge is pressed by the rear half of the tip of the pin, it is likely to force it to slip backwards, due to its curved surface. These are the three cases which cause component jamming and are all due to direct contact between pin and component.

Let us now assume that a moving belt/substrate encloses the component, between itself and the lower conveyor surface. In this case, as shown in figure 4.12, the pin is not allowed to stop the leading edge of the component, and the latter is aided to proceed. In this case leading edge skiving may take place successfully.

For the problem of maintenance of component position during skiving, other alternatives had also been considered prior to the idea of the twin belt mechanism. Redesign and modification of the pin housing reception guide block had taken place assuming that a different angle could solve the problem. However this only improved things slightly.

Another idea was the addition of pressure idle rollers immediately before and after the skive area. These rollers would be mounted to a suspension which would effectively grip-roll the component while skiving takes place, and thus they would not allow it to move during operation. The primary roller would be awaiting the arrival of the component, at a vertical offset from the conveyor belt. Knowing the speed of the belt

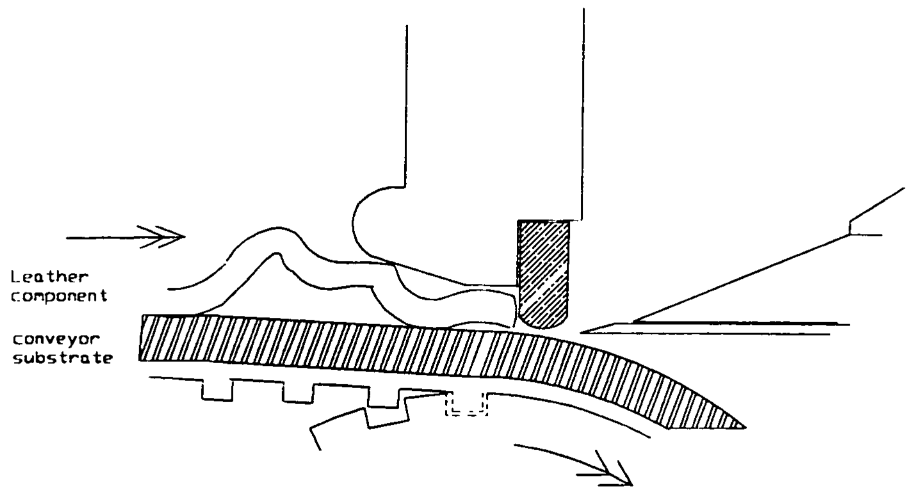


Fig. 4.11 The cause of component jamming and failure of leading edge skiving

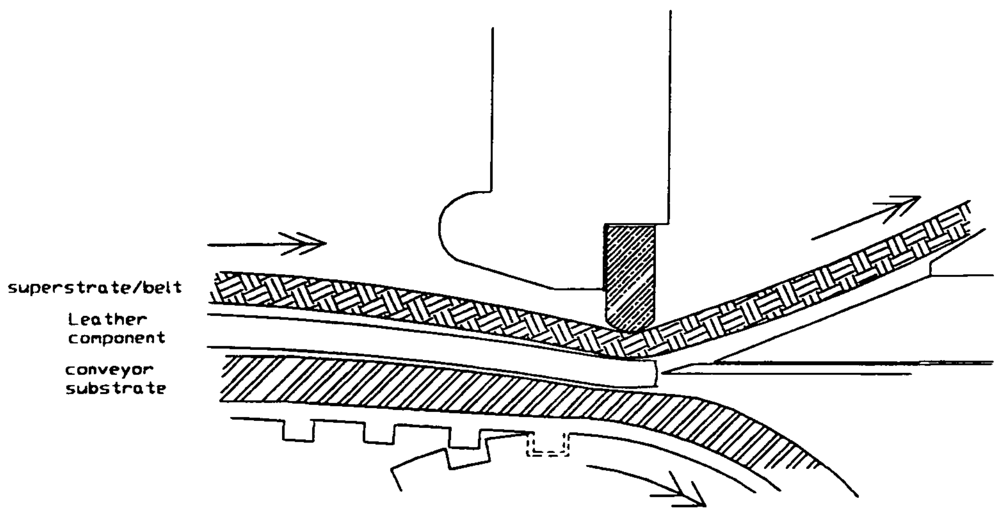


Fig. 4.12 Enhanced design of skiving mechanism.
The function of the additional upper belt (superstrate) enables leading edge skiving .

and the time that the travelling component leaves the vision system, it is possible to let the free roller "drop" on the incoming edge of the leather. The secondary roller would get hold of the component leading edge after it had passed the knife area.

The presence of two rollers obviously would not allow any component movement during skiving. However there would be two time intervals during which the component would be gripped only by one of the rollers. When the leading edge passes the under the pin matrix and when the trailing edge leaves the primary roller. It is conceivable that component dislocation could occur during both those intervals. This was the main disadvantage and reason for rejection of this suggestion. Nevertheless there has been another reason for being uncertain with ideas based on transfer of leather components by pressure rollers. It has been found [10] that due to the orientation of leather fibres components tend to gradually shift sideways during transfer by twin roller systems. The direction of shift relates to the direction of the fibres.

Another option examined was in principle to increase the friction force between the conveyor surface and lower surface of the leather component. It has been evident [9] that leather can be subject to electrostatic fields. This feature enables controllable friction between the leather and a surface that provides the electrostatic field. The most important and useful fact is that the forces that cause the friction are acting mostly parallel to the plane of the electrostatic surface. This may be translated as being able to apply force to the leather so that it may not slide along the conveyor surface in any event, but also at the same time to be able to remove the component from that surface easily. The University of Hull had already made prototype electrostatic surfaces, in the form of flexible sheet material which could be converted to conveyor belts.

The above idea had two basic disadvantages. One was that it was still impossible to grip leather components at all times, i.e. during skiving. The other was that if a conveyor belt was to be compliant with the sheet material that formed the electrostatic surface, then this material should play the role (or at least part of it) of he lower conveyor substrate. This material, although flexible, it was not elastic and did not possess any of the properties needed for the substrate layer.

From all considerations explained it was deduced that it was necessary to construct a mechanism of interface between the leather component and the pin matrix which would perform the following functions :

- *Deliver components to the process area without movement*
- *Deliver components through the process area without movement*
- *Protect the upper surface of the components*
- *Be a part of the skiving process too*

The only idea that met these requirements was the twin belt mechanism, the physical construction of which is described in chapter 6.

4.7 Evaluation of materials characteristics for the process area

As it has been studied earlier a certain amount of pin displacement is necessary to achieve skiving. This pin displacement is dependent upon the leather thickness and the mechanical settings on the skiving device. The pin displacement causes local deformation on the leather and it forces the relevant area to be skived against the band knife. To achieve this the lower conveyor substrate gives in, and allows for leather deformation.

Since the early stages a type of material had already been suggested for the purpose of substrate for the conveyor. This was the Nercoprene N11, a neoprene based sheet adhesive backed material, made by North Estern Rubber Co. Its friction and response characteristic is sufficient but the most important was its capability not to fatigue stretch or alter in any way its characteristics after continuous operations upon it.

However it was necessary to examine some alternative types of materials to compare between them the force requirement for pin impression to a certain stroke. The reason for this is the necessity to reduce this force overhead as much as possible, because it has direct influence in the choice for the type and size of actuators needed to drive the pins.

Having concluded on the choice of best material for substrate, it was also desired to examine how the force required by the pin (during impression) varied for different substrate thickness. This would identify what the ideal thickness would be for the substrate layer to be laid on the conveyor belt.

The third issue to be resolved was to decide upon different options for the choice of material for the upper substrate/belt. It must be noted that the intention was not to obtain the best possible solutions for the above questions as this was considered to be a task of commercial development. The intention here was to decide upon a set of materials and thicknesses which could perform skiving satisfactorily, so that it would be possible to proceed to the next critical stage, i.e. to integrate the various sections of the system to an automatic skiving machine.

To obtain the necessary answers static test were performed. In this case, static implies that the tests were carried out away from the skiving machine. Although these tests were static, the results may be taken as a reference when examining the suitability of other candidate substrate materials. In other words this forms a method of comparison between force/displacement characteristics of alternative materials and indicates their suitability for forming the substrate and superstrate layers. The choice for static tests eliminates the need for the laborious and time consuming operation of cementing different materials on the lower and upper belts for dynamic testing.

Leather components could be made from a large variety of leather types, in both thickness and stiffness. The final issue to be resolved was to obtain a realistic force domain, which would be required from the actuators to successfully depress leather components of all possible types. In reverse logic this information could provide the evidence of the limitations of a particular actuation mechanism, and of what specific leather types the system could not possibly accommodate.

4.7.1. The tri-layer system under investigation

The system examined consists of three elements. The superstrate, i.e. the material which forms the upper conveyor belt, the leather workpiece itself and the substrate, i.e. the layer cemented upon the lower conveyor.

The superstrate is not meant to hold any compression characteristics, i.e. it is not meant to reduce its thickness when the pin applies force upon it. Its only function is to provide the appropriate interface between the passing leather component and the metal pin. The requirements for the superstrate are five :

- Stiffness along its plane
- Elasticity across its plane (without permanent deformation)
- A rough surface
- A frictionless surface
- Minimum sheet thickness

Nevertheless the superstrate does introduce an additional force overhead for the actuation mechanism, no matter what material it is made from. Its participation in the force requirement is considered to be a constant force value, and therefore it may not influence in any way the variance of leather types or substrate thicknesses in this experiment.

The leather workpiece, enclosed between the superstrate and substrate may be one of a wide variety of types. In the experiment it was necessary to examine the behaviour of the system for such a variety, limited between extreme cases of very thick and stiff and very flexible and thin types. Only in this case it would be possible to achieve a more realistic force range required for the actuation mechanism of the skiving machine. The substrate is meant to hold five basic properties :

- Friction on its upper surface
- Sponginess. High reliability and durability in presenting no permanent deformation.
- A critically constant response time during pin retraction, regardless the frequency and time of use.
- Critically uniform sheet thickness.
- Resistance to fatigue

4.7.2. Description of the experiment

As shown in figure 4.13, in the experiment the tri-layer system was simulated in a static fashion. Sections of the materials of the superstrate and substrate where clamped enclosing a piece of leather. The holders a and b were at a distance from the testing area enough not to influence the test, but also not far enough to cause local airstrips between the three components. The test area comprises of a single spring loaded pin of diameter 3 mm with its housing bar. This arrangement was identical to the existing pin mechanism on the skiving machine.

The pin was linked to a linear displacement transducer (dc, potentiometer type) so that pin displacement could be measured accurately. Above the pin, a mechanical fixture allowed the placement of metal weights to simulate static force. It is important to notice that, each individual measurement was performed at a different location across the layer plane. This ensured that temporary local material deformation did not affect the validity of the results.

It is equally important to mention that the time duration for which the pin force was applied, was kept equal for all attempts. This was possible with the aid of a digital storage oscilloscope, in which the motion of the transducer (= pin) against time was captured and stored during each trial. This ensured that the displacement reading was taken within the same interval of time since the instant of force application. This time interval was set at 0.75 sec after application of the weight, enough to allow any pin overshoot to relax, but not long enough to allow progressive "digging-in" to the materials. The latter would produce an illusive displacement as far as skiving is concerned.

The pin, as mentioned earlier, is spring loaded as in the real system. For the purpose of this experiment the pin mechanism was initially calibrated and the spring characteristic was derived. This is shown in chart 4.14. Because it was desired to derive force/displacement characteristics of the system, free of any external influence, the spring characteristic has been subtracted from all material characteristics shown. Thus all the characteristics shown represent purely the tri-layer system. The accuracy of the results presented are subject to the error band of +/- 2.5 % , which is the calculated combined error of the digital storage oscilloscope and that of the displacement transducer.

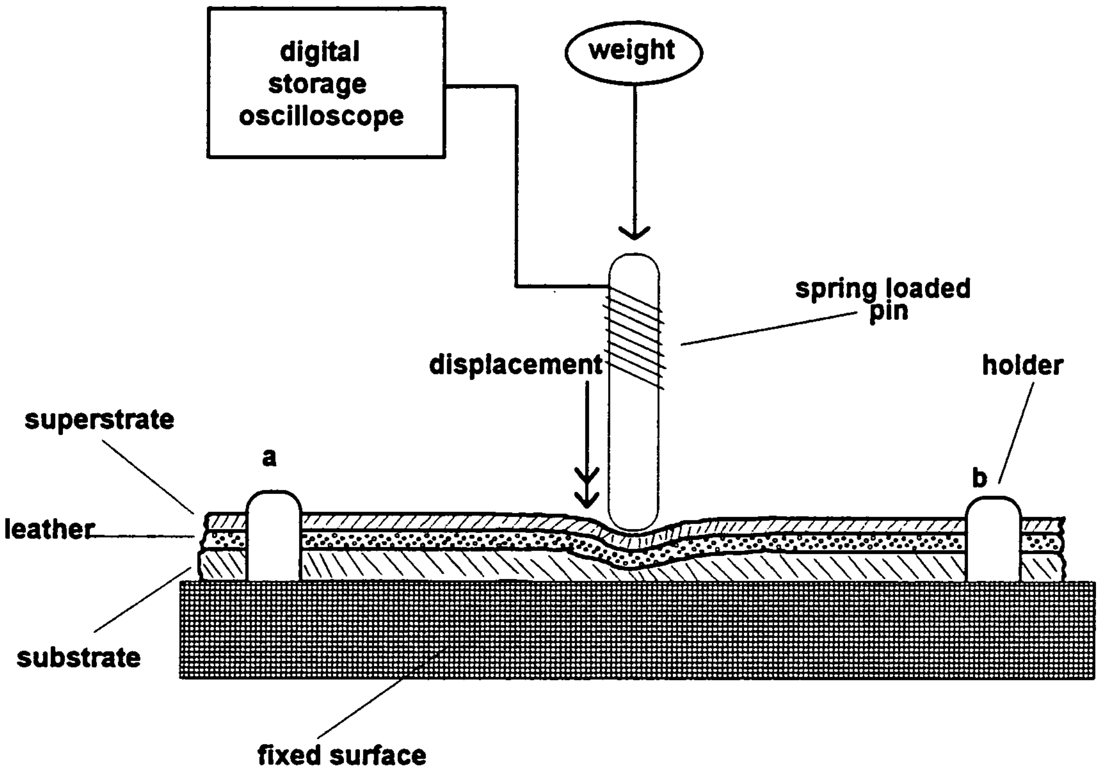


Fig 4.13 Illustration of the method of the static tests on the s/l/s system.

4.7.3 Pin force requirement for varying superstrate material type

As mentioned in section 4.5, the material PVCF appeared to be satisfactory, when used as a superstrate, during the early trials with static superstrates. Later, when the upper belt mechanism was constructed, this material was used to form the upper belt. During following experimentation, this material appeared to behave in a most promising way, in both maintenance of component orientation prior and during skiving and quality of skive pattern definition. Nevertheless, there was a disadvantage, and this was the incapability of the material to withstand wear.

This material proved to be satisfactory for the purpose of this research, the durability of a single upper belt was sufficient to skive 100-200 components, before surface wear becomes apparent. The reason for the wear was the direct contact of the pin tips with the upper surface of the superstrate, which caused progressive "digging in" of the impressed pins. However this record is far from suitable for a commercial product, through which tens of thousands of components would be expected to be process every month.

Although the target of this research was not to identify the ideal material for this purpose, it was considered common sense to at least provide an opening into this field. This is to identify at least the type or structure of sheet materials that may be considered suitable.

Research was carried out to identify materials suitable for the upper belt of the skiving mechanism. The outcome of this was that most rubber based or silicon based sheet materials [11] were not suitable for three reasons. The first was that those materials containing elasticity in the vertical (to the sheet) plane, were not stiff enough along their plane, and vice versa. Also there were no materials available that possessed a slippery surface, to the degree required. Of course there was always the assumption that the surfaces of such materials could be chemically treated and/or coated to provide slip and friction where necessary, but once more this option would take this research far from its scope. Finally the thickness of such materials was not small enough, to suit skiving (< 2 mm). The manufacturer claimed that, attempting to produce rubber sheet materials of this type at smaller thickness, would not guarantee uniformity of thickness.

Following the above results, PTFE based sheet materials were examined. The behaviour of pure PTFE sheet seemed also unsatisfactory. This was because 1.5 mm to 0.8 mm thick sheets appeared too stiff to allow for any deflection buy the pins. In the other hand, thinner sheets 0.7 mm to 0.1 mm, although allowed some deflection, this caused permanent deformation in their structure.

At this stage it was concluded that for a material to be suitable, it must be of composite structure. It should perhaps be made of two (or more) attached sheets, each contributing some of the features required. This concept led to the assumption that the suitable material would contain a layer of fabric, to produce durability, and perhaps some type of glass or sand based layer to produce the slip and friction surfaces required.

To examine this assumption a range of such materials were assessed [12] . The most promising option was the Tygaflor 116A/05T, at 0.13 mm thickness. This material is made for the purpose of constructing specialised conveyor belts. It is consisted of two layers of PTFE, enclosing a layer of fabric mesh. The presence of PTFE has always been considered to be an advantage, because it is the most frictionless material available. Furthermore the manufacturer of this material could produce it etched at one side. In this case etching was an additional process, carried out after manufacture of the original material. During this process, one of the surfaces of the Tygaflor is chemically treated to cause microscopic cracks on the PTFE surface. This provides a surface that although looking extremely smooth, it produces considerable friction to leather components, if it is attempted to rub them along this surface.

Later experiments with this superstrate material, proved that it was possible to achieve skiving. However the X-resolution was increased by almost 2 mm. This was because the Tygaflor material is stiffer if compared with the PVCF and its capability to buckle smaller. Hence the smoothing effect of this substrate on skiving patterns was greater. Also, another disadvantage was that material was to rigid to follow the path around the arcs of the small drive rollers of the upper conveyor mechanism. Furthermore it could not follow the path imposed due to the band knife guide of the splitting machine. The latter introduced a higher force requirement for the pins to cause skiving. Nevertheless the obstacles mentioned are due to the present mechanical design of the skiving machine and may be overcome with suitable modifications in the development stage.

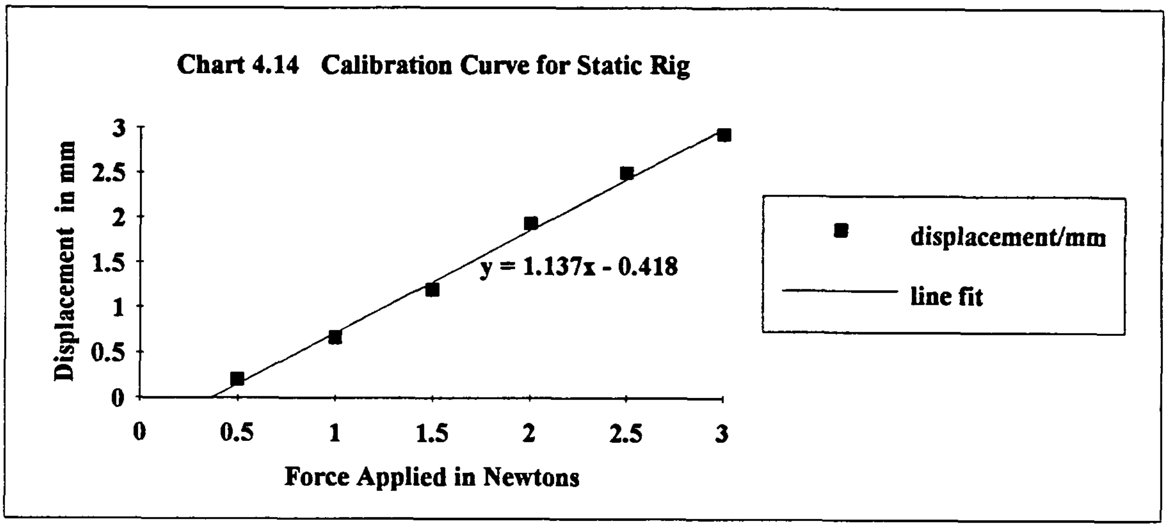
A different approach to the construction of the upper belt, is one that uses a combination of two independent materials. The idea behind this was that the Tygaflor material could be used at a static interface (in the form of a gripped spline) between the pins and the moving superstrate made out of PVCF. This idea uses the static Tygaflor substrate to protect the upper surface of the PVCF while the latter moves.

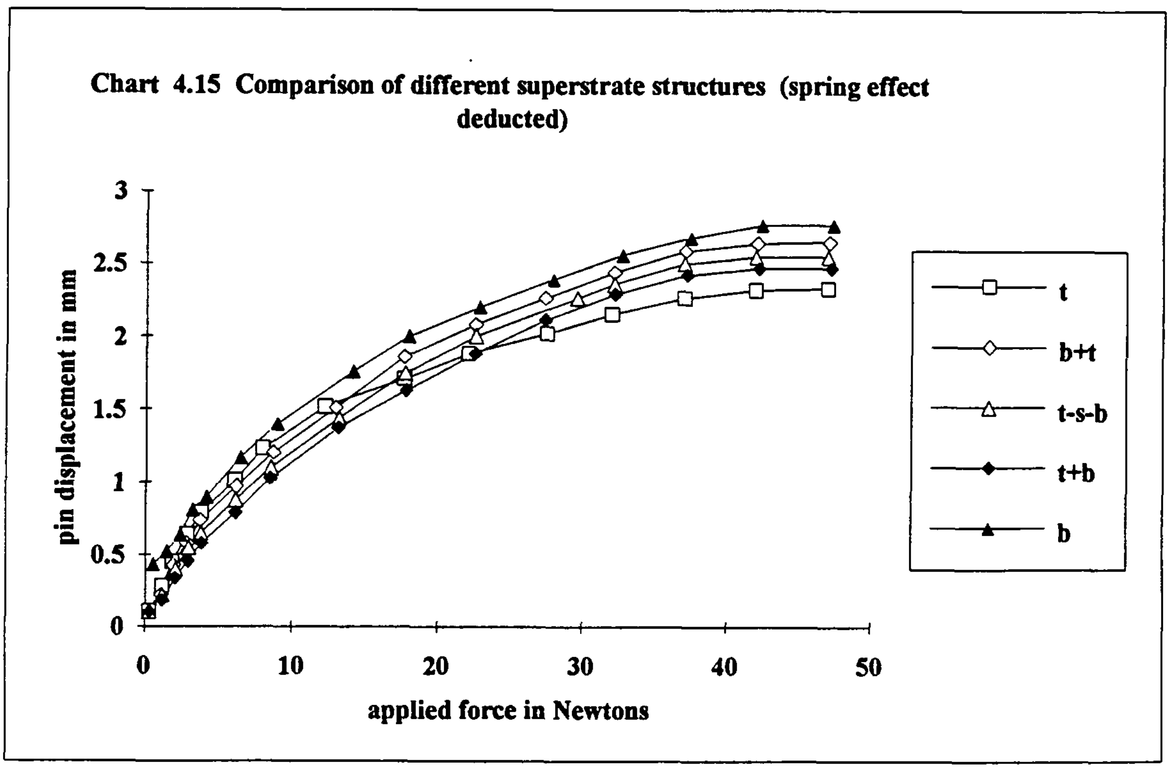
The two superstrate materials can rub against each other without any wear while the upper is taking away the burden of damage due to pin impressions on the PVCF. This principle may certainly be applied in the reverse order. However the first order would be preferred because of the documented behaviour of the Tygaflor when forming a belt. This idea was implemented and skiving was successful without apparent signs of belt wear. However the drawback with this option was that the smoothing effect on skive patterns was exaggerated, resulting in a substantial increase of X-resolution by 2 mm. This is explained as a result due to the extra thickness of the overall substrate plus the extra stiffness of the Tygaflor.

Another option for superstrate material was the use of Tygaflor 208AP/06T at 0.08 mm thickness. This one is similar to the Tygaflor material mentioned earlier with the only difference that it consists of only two layers. A PTFE layer and a fabric mesh layer, the side of which is adhesive backed. This material could not be tried on its own due to its fragile thickness, but it could be cemented on to the PVCF material.

This option is based on the assumption that the additional layer on the PVCF material would contribute to its durability, which was proved to be the only benefit. The PTFE surface could be directed to play the role of a reliable and slippery interface between the PVCF and the pins. This option seemed to be the most promising because the desired properties of the PVCF could be preserved due to the small thickness of the Tygaflor material while the former becoming more resistant to wear. Also, due to the small increase in total substrate thickness (+0.08 mm) the X-resolution was not expected to increase noticeably.

The static force characteristics of different structures for the upper belt are shown in chart 4.15. The results of this experiment are a reference, for the difference of pin force required between the material PVCF alone and other interface structures using Tygaflor material. From this it may be deducted that the presence of the Tygaflor, either on its own (t), or as a belt component (e.g. t+b), increase the force requirement at various pin displacement regions, by up to 5 Newtons, if compared with the material PVCF alone (b). It is worthwhile noting that the curve of t falls below the other curves from a certain force region onwards. This may be explained as follows : The other three composite superstrates contain PVCF. This in its own allows some compression after a certain force value onwards. Thus the appearance of being easier to compress the composites after a certain force value is actually an illusion and does not correspond to 100% pure leather displacement. Nevertheless in the case of t-s-b it was expected to obtain a higher curve (= easier pin impression)





t : material t on its own
b+t : layer of material t on top of layer of b
t+b : layer of b on layer of t
t-s-b : material t (adhesive backed) cemented upon b
b : material b on its own

because the cemented Tygaflor is of reduced thickness to b+t, t+b and t.

Finally, an overall conclusion is that the difference in force requirement for the above material combinations is not substantial to form a criterion for selection. This fact is intensified in the case that a future skiving mechanism is achieved to work with smaller pin stroke, i.e. < 1.5 mm (refer to chart 4.15). It must be noted that the substrate layer present in the above tests was made from Nercoprene N11. It must also be explained that the cases of b+t and t+b are the static force characteristics, corresponding to belt structures using Tygaflor and PVCF as "spline + belt".

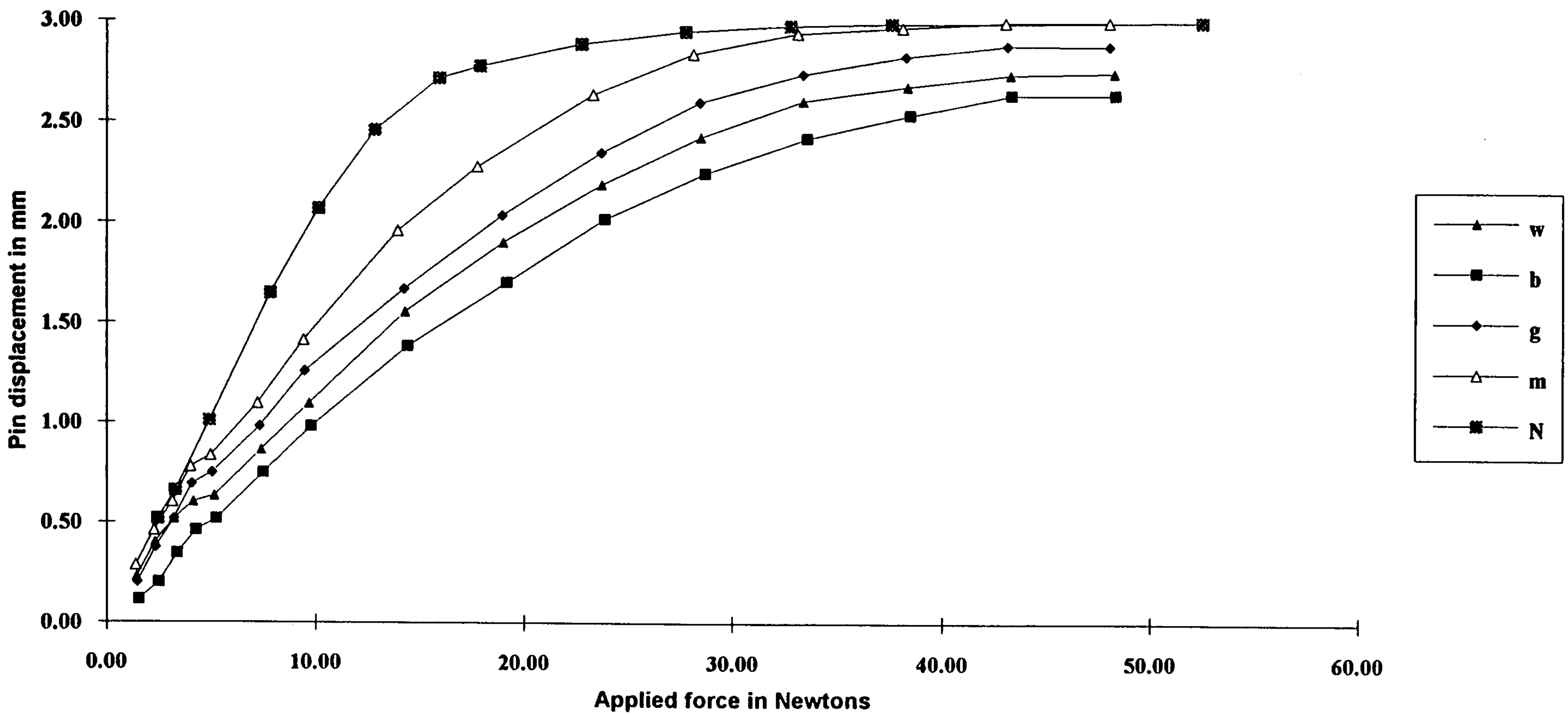
4.7.4 Pin force requirement for varying substrate material type

Static tests similar to those described in 4.7.3, were carried out for a range of different materials for the purpose of the substrate layer. In all cases the superstrate was common, and it was made out of PVCF. Also the thickness for all materials was kept equal (3 mm) so that the results could be used as future reference.

In this case four different materials supplied by BUSM [13] were tested, for the purpose of comparing their pin force requirement with the Nercoprene. These samples were selected by BUSM due to their compressibility and friction features, and were initially considered as possible options for the role of the substrate. The results of the experiments are illustrated in chart 4.16.

The conclusion is that all these materials (w, b, g ,m) would be less satisfactory than Nercoprene (N), because of their higher pin force requirement. The difference in force required varied substantially (by 100% + for w, b and 200% + for g), in the regions of pin displacement greater or equal to 2 mm. Thus it may be assumed that w, b and g would be unsuitable, given that the pin displacement of 2 mm has been the pre-set stroke of the current skiving machine.

Chart 4.16 Comparison of different substrates (spring effect deducted)



4.7.5. Pin force requirement for varying substrate thickness

The chart 4.17 illustrates the characteristics of the five different thicknesses of Nercoprene tested. This material is purchased in adhesive backed sheet form at 3 mm thickness. Although the interior of the material is porous (spongy), the upper surface is treated to be smooth. To take advantage of the friction capabilities of the material for skiving, this surface is always skimmed off using the skiving machine as a splitter. This was also done in the samples used for the static tests. In this case a series of samples were skimmed to different thicknesses. This is the reason that the material thicknesses shown in chart 4.17 are only approximations to the values 3, 2.5, 2, 1.5 and 1 mm respectively. Also, in these tests, the leather type present was kept the same, and the superstrate was a single PVCF belt.

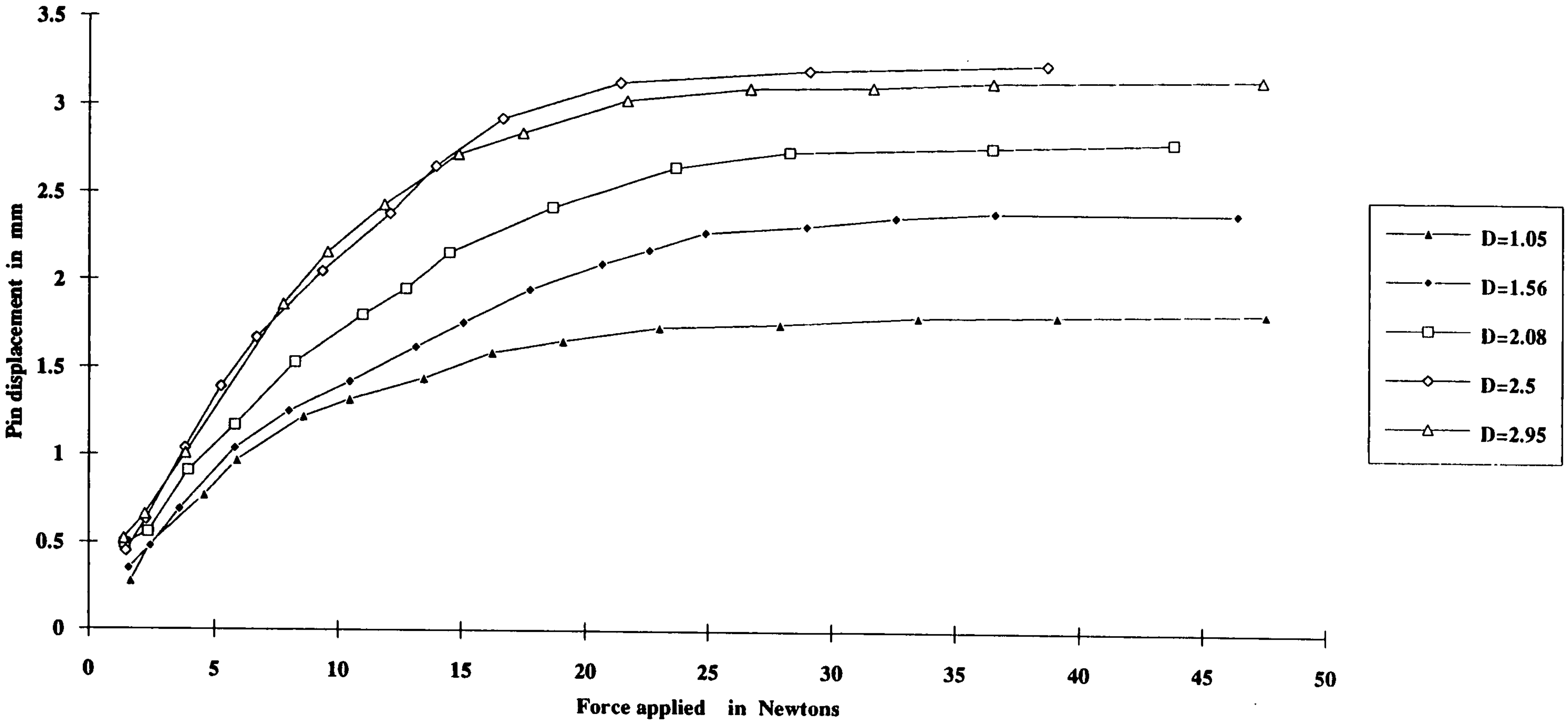
From the results shown, it can be deducted that as substrate thickness increases, the force required for pin displacement decreases. However there is a point at which no matter how much the substrate thickness increases the force amount required for equal displacements is effectively the same.

It is worthwhile mentioning that, the substrate thickness applied to the conveyor in early tests, is approximately 2 mm, and the pin force used 35 Newtons. If now the force requirement in static conditions is examined, it may be observed that a force of approximately 13 Newtons is required to achieve a 2 mm pin displacement. This of course is not equal to the real force used in the skiving machine.

The static value is smaller, as expected, because it does not meet the requirements of friction forces of the pin against its guide (due to shear forces applied by the continuously sliding superstrate). The force requirement in real operation would also be greater, due to the fact that virtually at any instant, the pin is pressing against a "fresh" area, as the conveyors continuously move underneath it. Furthermore the pin spring force has been subtracted from these values as mentioned earlier. This would impose another force overhead in the dynamic case.

It must be noted that another factor that adds to the pin force requirement, in real terms, is the slope of the knife guide which forces the leather to bend while skiving, and also forces the superstrate/belt to follow a curved path. This in turn forces the belt to rub hard against the pins thus making their descent more difficult. In reverse, the

Chart 4.17 Plot of force applied against substrate thickness for a single leather type



static tests simulate a straight path of component flow, which inevitably decreases pin force requirement. Nevertheless the static values obtained are useful for comparison of suitability of different superstrate materials that may be considered in the future.

Another observation on the test results is that as the pin displacement approaches the value of substrate thickness, the force required for further displacement is disproportionately large. This may be explained as the substrate not having any further the ability to give-in to pin displacement, and the leather and superstrate materials starting being compressed.

The general conclusion from these results is that the substrate thickness has a vital influence to the force required by the actuation mechanism to perform skiving. This may be illustrated as the difference between for example the second and fourth curve (D=1.56 and D=2.5 in figure 3.1), where for an equal displacement of 1.5 mm forces of 13.5 N and 5 N approx. are required respectively.

The final decision for the ideal substrate material it is expected to be taken during future system development by B.U.S.M., and there is one important issue that has to be considered. It is a fact that the substrate thickness and type requiring the smallest amount of force will be the best solution for the selection of cheaper and more compact pin actuators. However easier depression of the substrate means slower recovery and consequently, increased delay in leather exit from skiving conditions. Therefore the ideal solution is expected to be a suitable compromise between the substrate response time and its compressibility.

4.7.6 Tests with varying leather types.

Similarly the characteristics derived from this test are shown in 4.18. The types of leather tried varied within extreme limits of stiffness and flexibility. Eight different leather types were tried altogether and their thicknesses varied from 3 mm to 0.5 mm. This is apparent from difference in pin force values obtained. In these tests the substrate was Nercoprene at 3 mm thickness, and a single PVCF superstrate belt was used.

However for the middle range of leather types, which in real life is by far the dominant range in skiving, it may be concluded that the force range necessary is limited between 10 and 17 Newtons (for a pin displacement of 2 mm). It is important to note that type '6' was the leather type used for the experiment with variable substrate thickness. Substrate thickness was used in this experiment.

It must also be noted that with the very thick and stiff leather types, it was noticed that pin displacement was partially achieved by local leather compression. Because of their incapability to form narrow arcs, they started compressing even before the substrate had the chance to give way for pin displacement.

One of the intentions behind this particular experiment was to find a working force range for skiving of components made of different leather types. As mentioned earlier these results may only taken as a reference because they are taken under static conditions. However they do present a fact that may be accepted without concern about the static environment. This is the width of the range of forces required to perform skiving. This value of course varies depending on the amount of pin displacement. Nevertheless the width of a force range for a specific pin displacement value is expected to be the same in dynamic conditions too.

With reference to chart 4.18 it is seen that for pin displacement of 2 mm the force range is limited between 7 and 25 Newtons. Similarly for pin displacement of 1 mm the range is limited between 2 and 7.5 Newtons. This gives force range widths of 18 and 6.5 Newtons respectively. In other words if the pin working stroke is 2 mm , the extra force required to skive the stiffest components is almost 2.5 times that required for 1 mm pin stroke. This comparison is illustrated in chart 4.19. In this chart it is shown how the force range width for all leather types increases with increasing skiving pin stroke.

4.8 The effect of the "knife - pin" distance as a process variable

One of the variables in the skiving process is the distance between the band knife edge and the pin row. The vertical axis passing from the nearest (to the knife) point of a pin , is considered as pin reference axis for this measurement. The ideal distance

Chart 4.18 Plot of force against pin displacement for varying leather types

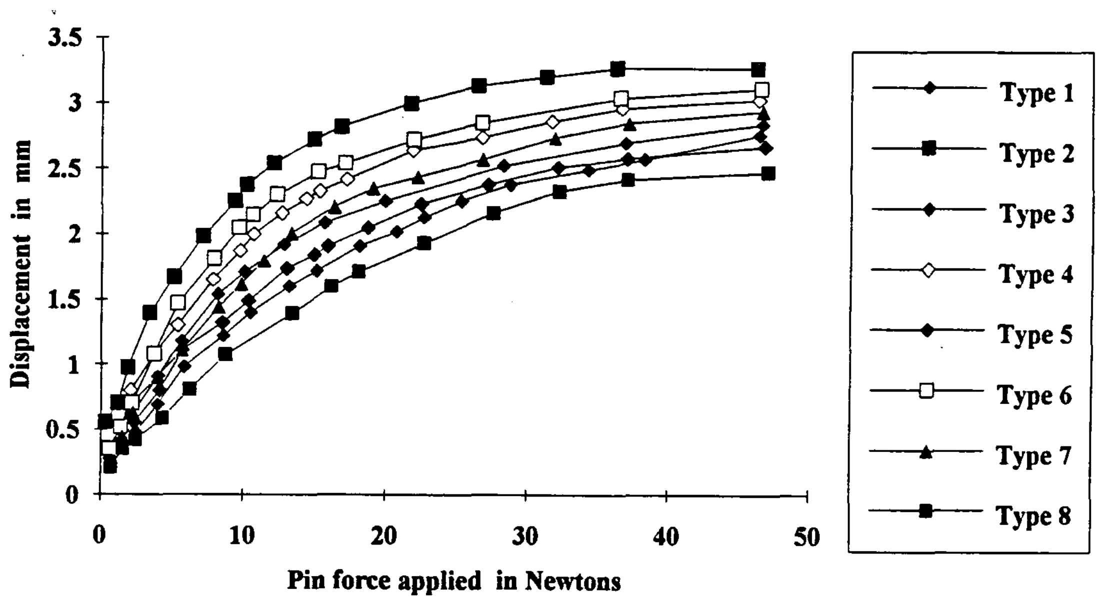
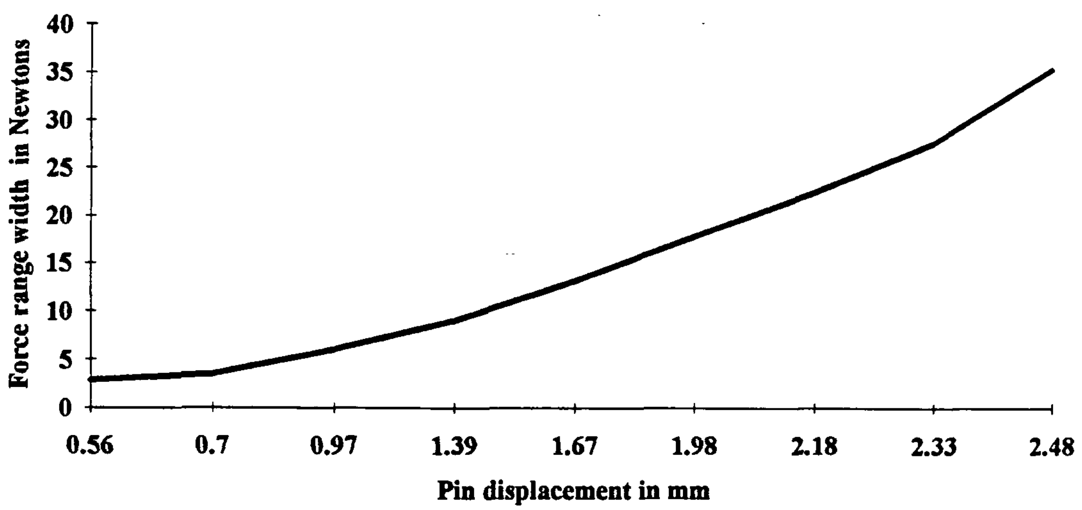


Chart 4.19 Force range width (for all leather types) against pin displacement



between the band knife and the pins is the one at which skiving is performed at its best. It had been suspected that skiving would occur within a range of distances, and that outside this range quality would deteriorate. It seemed thus necessary to investigate into this issue and observe how skiving varies as the pin matrix is progressively moved away from the knife edge.

As it is explained further on, there was a limit as to how close the pin matrix could be brought to the knife edge, due to physical restrictions of the system. To resolve this, one could assume to move the band knife nearer to the pins, using the manual adjustment for horizontal movement of the band knife. This was not feasible because the knife may not be progressed nearer to conveyor. If attempted to do so, it would skim the substrate further and thus alter system the substrate thickness (refer to figure 4.20).

To make this more clear, a detail of the mechanism should be emphasised. As shown in figure 4.20, the knife edge is not placed at point A as perhaps assumed. Point A is a conveyor surface point from which the vertical centre roller axis passes. The knife is located away from point A by 6.7 mm horizontally and 1 mm vertically. This is done

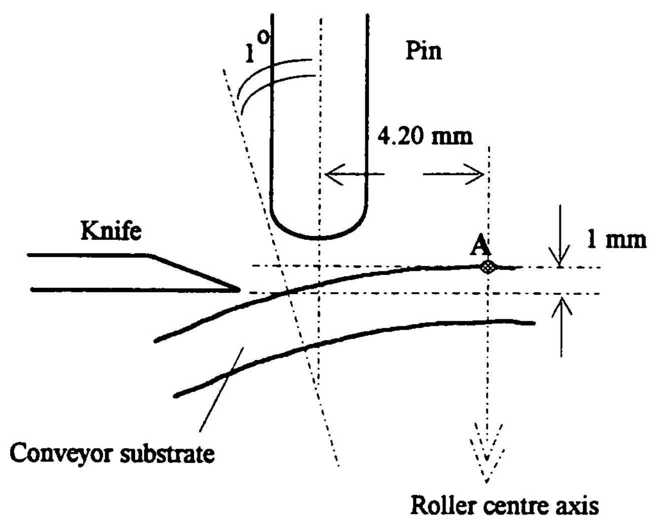


Figure 4.20 Vertical knife offset from conveyor surface

to ease the passing of the rejected skived thicknesses under the band knife. Hence an attempt to reduce pin - knife distance by moving the knife closer, would simply result in skimming the conveyor's substrate.

However in this experiment the closest starting point for the pin was a region at which skiving was performed at its best, according to the experience from this research. From this point onwards it was expected that skiving would continue to occur successfully for a certain range, and afterwards it would start to deteriorate. To observe this it was necessary not only to assess the quality of skiving visually, but to systematically take readings of depth of skiving for successive increments of the pin - knife distance. This of course assumes that the intended depth of skiving would be adjusted to a constant value for all trials. The following sections describe the results of relevant experimentation, in which this distance was successively increased and the behaviour of skiving observed.

4.8.1 Experiment set-up

The module containing the actuators, levers and pin row (referred to as the "skiving head" or "actuator module") is mounted on to the splitting machine at a fixed position. Thus it is not provided with a means of position adjustment horizontally. This position was determined in the start of this project as a best estimate to what would be a successful pin position relevant to the knife edge.

During evaluation of the behaviour of the skiving mechanism it became necessary to determine the critical distance band within which skiving continued to be performed at its best. For this purpose the actuator module was enhanced with the additional feature of an adjusting mechanism. This mechanism provided the ability to position the actuator module nearer or further away from the knife edge, without altering the vertical distance between pin and conveyor. Figure 4.21 illustrates the directions of the adjustments.

However there was a limitation as to how close to the knife the actuator module could be shifted. This was determined by a physical backstop on the splitting machine.

Because this backstop was the main body of the splitting machine (casting) there was no means by which this could be overcome.

4.8.2 Measurements prior to experimentation

Before any attempt was made to examine the effect of varying the knife - pin distance, it essential to record all relevant distances and adjustments within the skiving process area, as they were at the time. This would form a reference geometry for the forthcoming process evaluation. This involved accurate measurement of all dimensions labelled in figure 4.22. A secondary reason for these measurements was to identify any misalignments within the process area, and to compensate for them before the experiment. To implement this, the following steps were taken.

4.8.3 Measurement of distance between knife and roller centre.

With reference to figure. 4.22 this distance is defined as $d_n = d_b + d_k - \frac{D'}{2}$

To ensure correct alignment d_k was measured for both LHS and RHS of the skiving machine. Left and right are defined as if facing the splitting machine. Thus in following quotes any subscripts "L" and "R" refer to left and right accordingly. The values measured were :

$d_{kL} = 4.45$ mm $d_{kR} = 4.0$ mm
$d_{bL} = 15.25$ mm $d_{bR} = 15.45$ mm

$\frac{D'}{2} = 10.30$ mm
$d_{nL} = 9.40$ mm $d_{nR} = 9.15$ mm

This indicates a slight misalignment between knife and roller centre. However the present conveyor/splitter interface did not allow adjustment for this. The measurement was taken with a potentiometer based digital vernier with accuracy +/-0.2 mm.

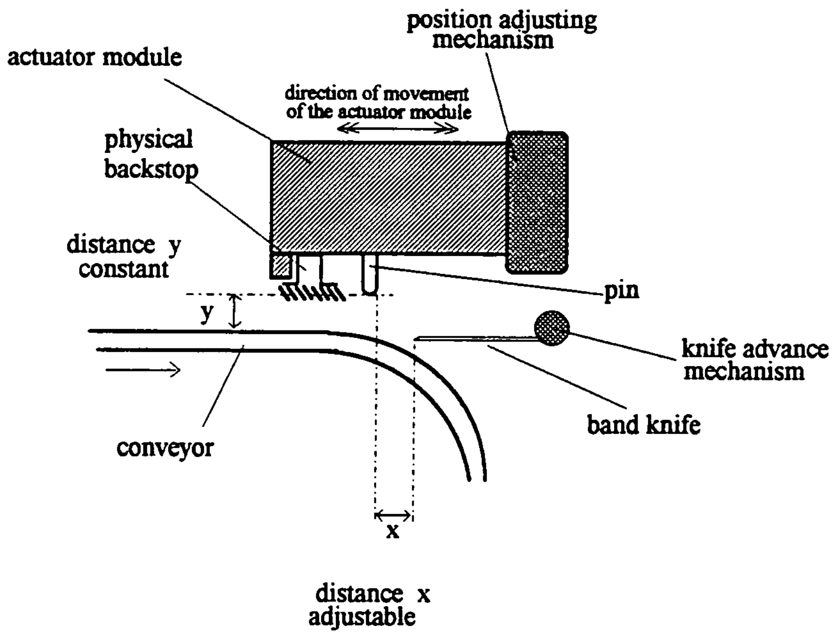


Fig. 4.21 Illustration of the principle of the adjustable distance between knife and pin.

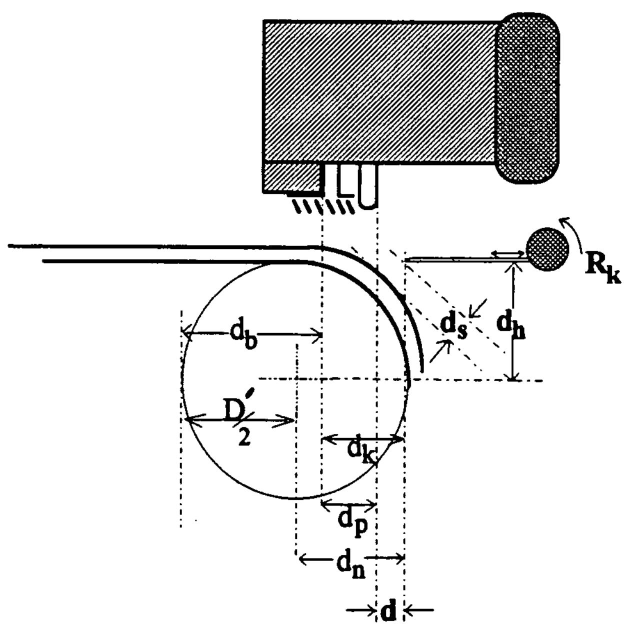


Fig. 4.22 The distances forming the reference geometry of the skiving process area. (Note : actual geometrical shapes and proportions have been altered for illustration purposes.)

4.8.4 Measurement of gap between knife and substrate

This was done with feeler gauges and was $d_s = 1.0$ mm with accuracy +/-0.05 mm.

4.8.5 Measurement of vertical distance between knife and roller centre

This was implemented with relative measurement from a single reference point, using a micrometer. The distance was found to be $d_h = 26.40$ mm with instrument accuracy +/- 0.02 mm.

4.8.6 Measurement of resolution of knife advance mechanism

For this measurement again feeler gauges were used as the only option. The measurement was taken with reference to the backstop, as the gap between a slip gauge (clamped on the backstop) and the knife edge. One full resolution of the advancing knob produces 0.366 mm advance of the knife edge, i.e. $R_k = 0.36 \frac{mm}{rev}$. This measurement was repeated for a number of times and for different numbers of turns. It was calculated that the combined accuracy of measurement was +-0.05 mm.

It has been suspected that the knife may "snake" whilst in operation. This means that the edge of the knife may not maintain its position horizontally during operation, but instead it may be waving backwards and forwards (with respect to the pins). This effect was visually apparent to a certain degree as a periodical fluctuation of edge position and it seemed necessary to be investigated by measurement.

To measure the suspected knife snaking, the knife drive mechanism was turned on and off for a number of times and for duration of randomly selected time intervals. Hence each time the band knife was exposing a different area of its edge around the measurement area. At each instance measurements were taken as described above. The gap was found in all cases equal to 4.05 mm (on the RHS backstop). This implies that the knife "snaking" observed was only a visual effect (varying shadow width due to imperfect knife sharpening) or that the snaking was smaller to the measurement's error band of +/-0.05 mm.

4.8.7 Measurement of the reference distance between knife and pin

With reference to figure 4.22 the knife - pin distance d is given as : $d = d_k - d_p$
The reason for having to evaluate the other two distances first, was that it was not possible to measure d directly. d_k was recorded with the method described in section 4.8.6 for both LHS and RHS of the exposed section of the knife. The gap between the knife edge and each of the two backstops was found to be different :

d_{kL} = 4.45 mm d_{kR} = 4.05 mm

To evaluate d_p it was necessary to record it as the distance between the pin row and the two edges that face the backstops on the splitter casting. This would give the minimum knife - pin distance, as far as this experiment is concerned, because of the presence of the backstops. Figure 4.2.3 illustrates the method used to obtain an accurate measurement of d_p.

Table 4.24 contains the initial values of d_p. Table 4.25 contains the means and deviations of the values in 4.24. These sets of values represent measurements for d_p from three different areas of the pin row, the two ends and the middle section of the pin row. These areas are labelled as A, E and M in figure 4.25 and do not represent a single pin in each case, in the contrary they represent neighbouring pins for each region. The reason for this was to avoid error in measurement due to a possibly bend or worn pin. Furthermore each measurement of d_p was formed as a subtraction of $d_p = d_1 - d_{ref}$ as shown in table 4.25. This was done using a micrometer with error band +/- 0.02 mm.

The deviation noted as D_V = 0.396 mm was explained when it was found that d_{refL} and d_{refR} differed by 0.38 mm, i.e. d_{refR} - d_{refL} = 0.38 mm. Because of this the values of table 4.25 become as in table 4.26. Therefore it is now possible to take means for M, A and B regions with confidence. The relevant values are shown in table 4.27. The final outcome of the above measurements and calculations are shown in figure 4.28 where finally the values for d (the distance between knife and pin row) are concluded. The difference of 0.64 mm between d_L and d_R was compensated for, prior to the forthcoming experiment. This was done by aligning the position adjusting mechanism accordingly and with the insertion of a 0.65 mm thick simm between the RHS backstop and actuator module. Thus it is correct to assume that after this adjustment the knife edge and the pin row axies remained parallel.

4.8.8. Experimental method

To identify the role of the distance **d** as a variable in the skiving process, three sample series were used (labelled A, B and C), i.e. two distinct skive silhouettes were attempted for a number of components, each one as treated as an individual experiment. The series A silhouette was simply a straight 2-pin-wide line skived all along the component (including leading and trailing edges). This line was parallel to the direction of motion of the component. The series B silhouette was a Γ shape and comprised of leading edge skiving across the whole leading edge of the component and one side of it. Series C silhouette was a simple line thickness perpendicular to the direction of motion, at the leading edge of the component. The leading edge of the component was always perpendicular to the direction of component travel.

During each experiment the actuator module was adjusted initially at its backstop position, i.e. adjusted to the minimum possible **d** = 2.15 mm. From this position, increments of 0.10 mm were taken for **d,** each time using the adjusting mechanism. This was measured with a micrometer of accuracy +/- 0.02 mm which was permanently fitted onto the actuator module, for the purpose of this experiment. These measurements were taken with reference to the same fixed point, i.e. a ground surface fitted permanently onto the cast body of the splitting machine. At each increment adjustment of the actuator module a number of leather components were placed onto the conveyor system and were skived.

Another important fact in this experiment was that for each of the three series of leather components, a different initial skive depth was set. At completion of skived leather pieces were measured for their remaining thickness within skived areas.

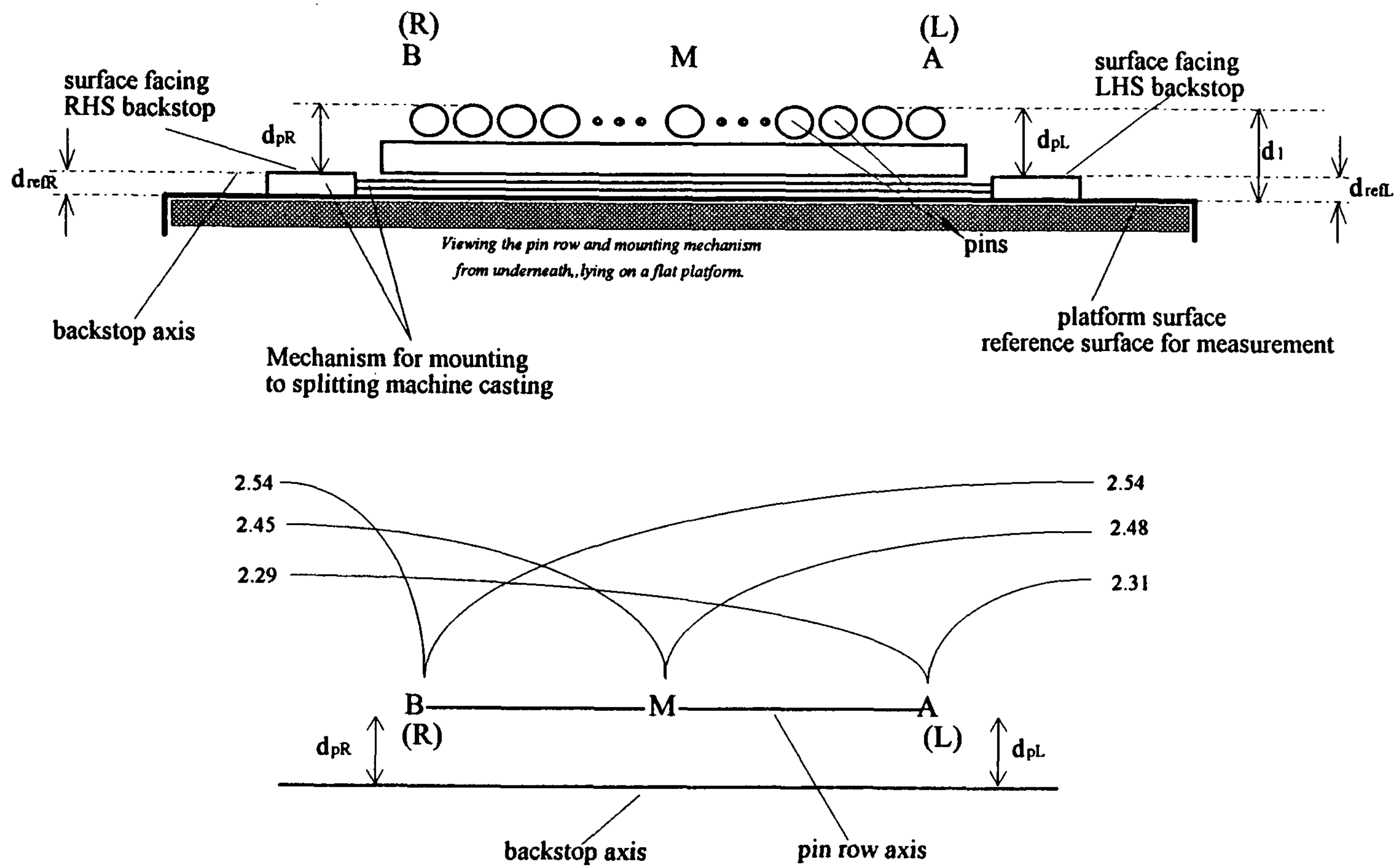


Fig. 4.23 The method for measurement of distance and alignment between backstop axis and pin row axis.

	d_{pR}	d_{pL}
M	2.08	2.49
M	2.07	2.49
M	2.09	2.50
M	2.08	2.49
M	2.06	2.46
M	2.06	2.46
M	2.04	2.45
M	2.06	2.46
M	2.08	2.49
A	1.90	2.31
A	1.92	2.31
A	1.91	2.30
A	1.91	2.32
B	2.15	2.54
B	2.18	2.55
B	2.15	2.55
B	2.18	2.54

Table 4.24 : initial measurements of d_{pR} and d_{pL}. M, A and B indicate the regions from where the measurements were taken. All values in mm.

	average d_{pR}	average d_{pL}	Deviation D_v
M	2.07	2.48	0.41
A	1.91	2.31	0.40
B	2.16	2.54	0.38

Average D_V = 0.396 mm

Table 4.25 : mean values of table 1.2.1. All values in mm.

New	average d_{pR}	average d_{pL}	Deviation D_v
M	2.45	2.48	0.03
A	2.29	2.31	0.02
B	2.54	2.54	0.00

Average D_V = 0.016 mm i.e. within instrumentation error band

Table 4.26 : New mean values of table (ref. to table 1.2.2), after compensation for misalignment of d_{ref}'s. All values in mm.

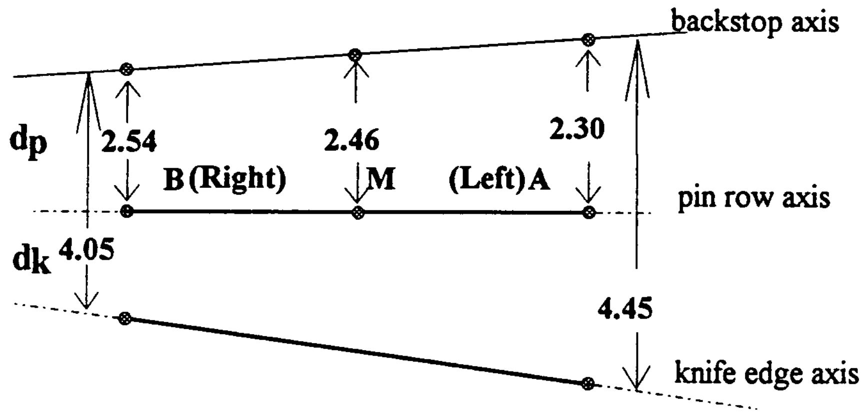
New	average d_p
M	2.46
A	2.30
B	2.54

Average D_V = 0.016 mm i.e. within instrumentation error band

Table 4.27 : New mean values of table (ref. to table 1.2.2), after compensation for misalignment of d_{ref}'s. All values in mm.

Measurements were performed by using a micrometer (error 0.02 mm) pointing against the leather component, which was lying flat against a metal slip gauge.

The return spring of the micrometer pointer was effectively a small damping force against any misleading readings due to leather compressibility (surface hairs). This feature was important for the measurement especially when measuring the original component thickness. Because all leather pieces were of similar leather type, variations of compressibility have been kept low. However a number of measurements



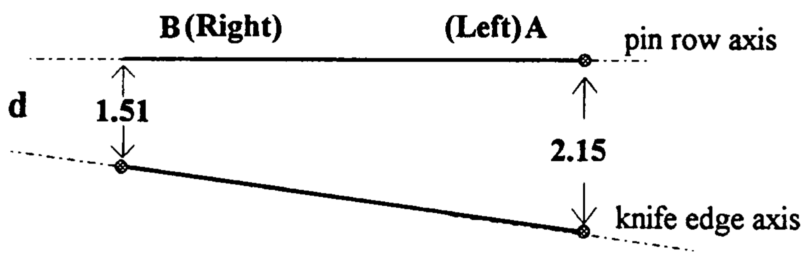


Fig 4.28 An illustration of the arrangement of the the pin, backstop and knife edge axies according to measured.
All values shown are in mm.

were performed on the same component and within the same neighbouring area (1 cm^2) to evaluate the error in measurement due to the very feature of leather described above. This error appeared to be +/- 0.05 mm.

The initial assumption was that after a certain amount of increments for **d**, the amount of skived thickness would start decreasing and later, signs of skiving would disappear altogether.

4.8.9 Conclusions drawn for the effect of pin - knife distance.

Charts 4.29, 4.30 and 4.31 illustrate the curves obtained for component series A, B and C respectively, from the data of the experiment described. These curves are derived from the mean values of all sets of trials at each increment.

The first unavoidable observation upon the resulting figures was that a process repeatability band was present. This means that for a number of attempts to skive the same type of silhouette and for the same adjustment position of **d** there was a variant amount of skived leather thickness of as much as 0.55 mm in the worst case (series B). Also this seemed to increase (poorer repeatability in series B) as the upper belt was slowly wearing out. This is clearly due to the structure of the upper conveyor belt as it was explained earlier.

The problem of repeatability in the above experiment is smoothened down, by calculating a mean value of skiving thickness for each adjustment of **d.** Also it is important to mention that the original leather thickness and type was kept constant (as much as practically possible). Theoretically, if two leather pieces were of different thicknesses and the same amount of skiving thickness was attempted upon them, then the remaining thicknesses would be equal, provided that the thickness of the substrate was enough to compensate for large variations of leather thickness.

Series C consisted of thinner leather pieces, with average difference of 0.6 mm if compared with B series. This of course does not alter the validity of the experiment, as explained above, but it makes impractical the construction of a comparison chart such as chart 4.32. The comparison attempted here was with purpose to observe the behaviour of the process at different settings of **d** but also at different skive depths. Ideally, to be able to obtain a meaningful conclusion from such a comparison, all series and all components should be of exactly the same thickness. Thus it was necessary to simulate this feature.

This was done by adjusting all the "original thickness" values of all series to a common one. This was followed by adjustment for the values of "remaining thickness" . The actual skiving depth, on each individual leather piece, was not actually altered, but its remaining thickness was compensated for as if : the skiving machine was adjusted to perform three (=series) different skiving depths on components of absolutely equal thickness. These new values were also averaged, for the number of trials at each adjustment of **d**. Hence chart 4.32 contains a comparison of the three different cutting depths with the assumption of absolute thickness equality.

When observing the characteristics provided in chart 4.32, the overall effect of varying **d** is still apparent. If the repeatability issue is set aside, maintenance of constant depth of skiving is apparent for an additional increment for **d** of at least 0.25 mm. This conclusion is based upon allowance for the total error of experimentation (+/- 0.07 mm). Of course in this case, "maintenance of skiving depth" is a meaning that can be altered by changing the setting of the "acceptable minimum skiving depth variance". If for example this value is defined as 0.2 mm then according to chart 4.32, the band of **d** for constant skiving is about 0.35 mm (from 2.15 to 2.455). If now the error of the method of measurement is taken into the last consideration too (total allowance +/-0.17 mm), then the two critical band values above become 0.25 mm and 0.55 mm respectively.

Another interesting observation is one concerning the different initial pre-set depths of skiving. The three components series A, B and C differ in initial depth of skiving by approx. 0.45 mm between them (common original thickness = 2.06 mm). The result, as expected, is that series B would reach non skiving conditions earlier than series A and similarly C earlier than B.

Theoretically this is explained as follows. Let us assume the comparison A-B. Because the pins were set higher (in case B) to produce shorter stroke and thus less initial skiving depth, the process was bound to reach non skiving conditions earlier because the *critical direct distance* between pin edge and knife edge is reached earlier. This is because, in this case, the pin tip at full stroke is further away from the knife. Direct distance, in this case, is not d (the distance between relevant vertical axies), but the direct imaginary line joining pin edge and knife edge (the two being at different heights). This direct distance is equal to d only when the pin tip is at the same height with the knife. The above comparison may be done also in a different way. With reference to chart 4.32 it is observed that curves for series B and C are in effect the two latter portions of the curve for A, assuming different skive depth offsets. This fact alone confirms the validity of the overall experiment.

The main overall conclusion from this data obtained is that the present (and minimum

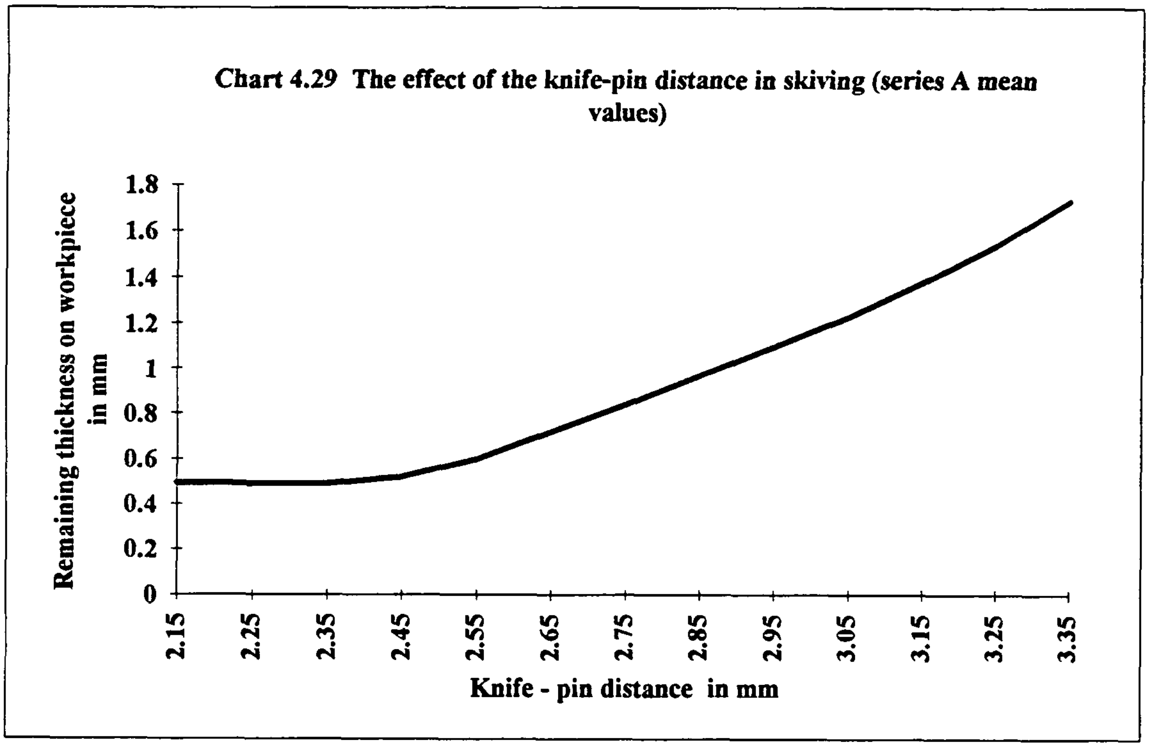


Chart 4.29 The effect of the knife-pin distance in skiving (series A mean values)
Remaining thickness on workpiece in mm
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2.15
2.25
2.35
2.45
2.55
2.65
2.75
2.85
2.95
3.05
3.15
3.25
3.35
Knife - pin distance in mm

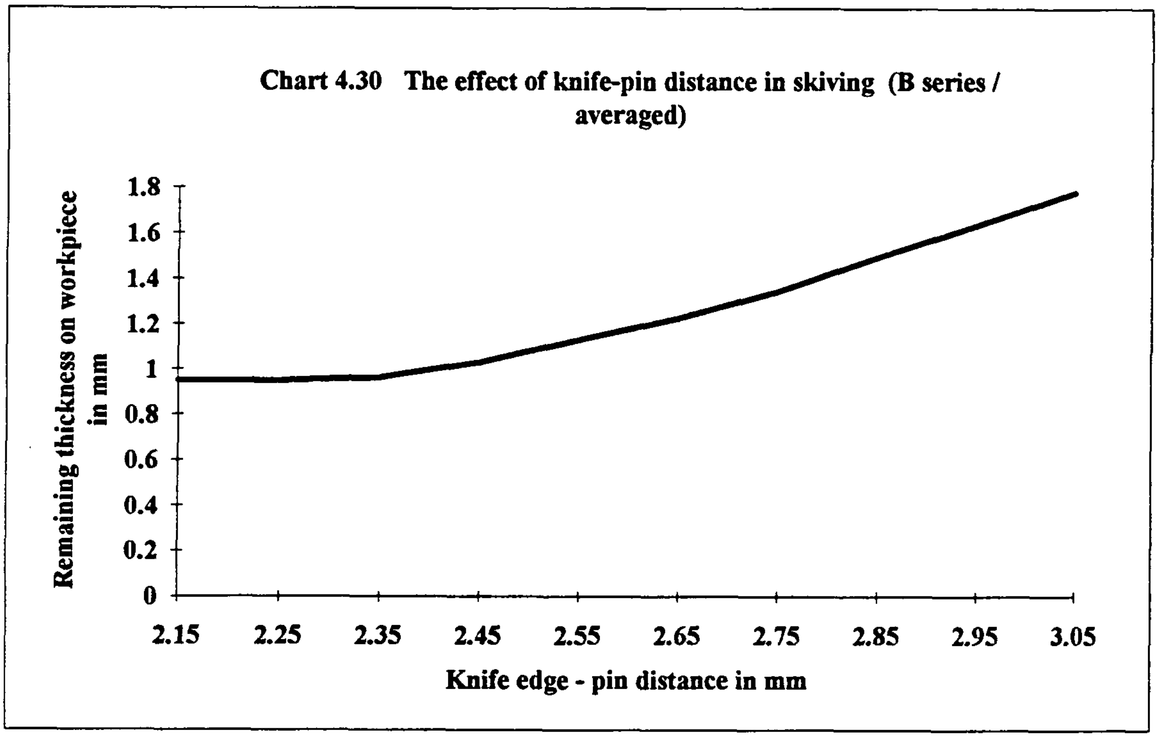


Chart 4.30 The effect of knife-pin distance in skiving (B series / averaged)
Remaining thickness on workpiece in mm
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2.15
2.25
2.35
2.45
2.55
2.65
2.75
2.85
2.95
3.05
Knife edge - pin distance in mm

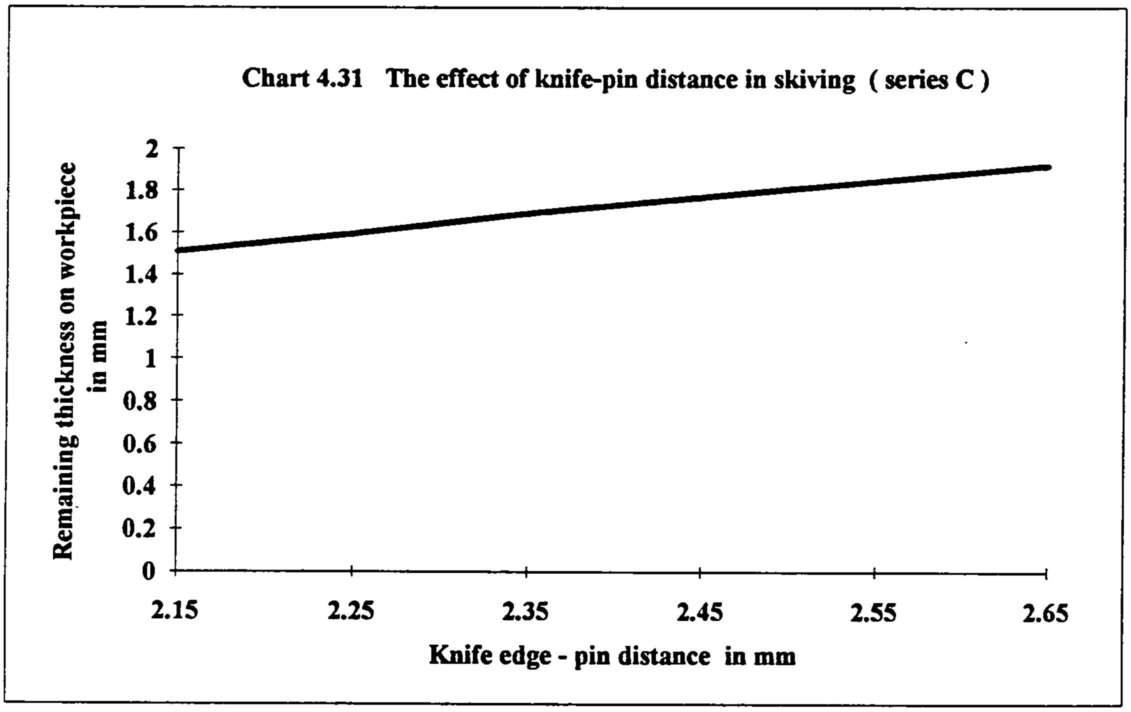


Chart 4.31 The effect of knife-pin distance in skiving (series C)
Remaining thickness on workpiece in mm
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2.15
2.25
2.35
2.45
2.55
2.65
Knife edge - pin distance in mm

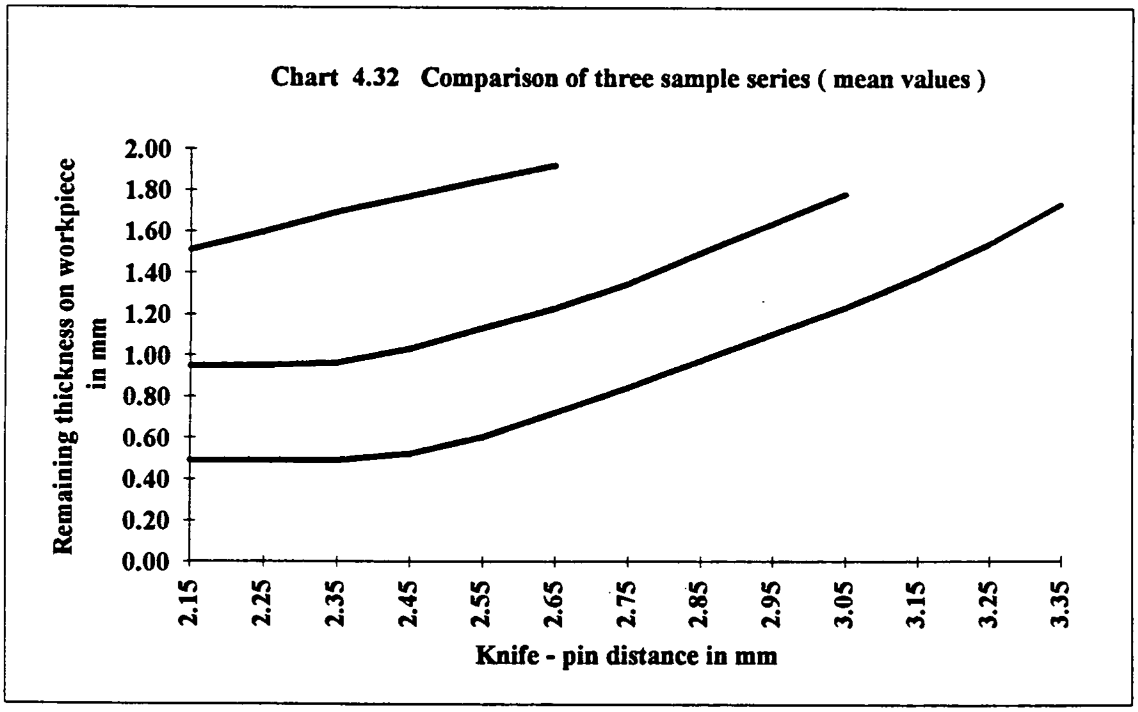


Chart 4.32 Comparison of three sample series (mean values)
Remaining thickness on workpiece in mm
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
2.15
2.25
2.35
2.45
2.55
2.65
2.75
2.85
2.95
3.05
3.15
3.25
3.35
Knife - pin distance in mm

possible) adjustment of d lies at a small distance (0.35 mm) before the end of the band, within which variance of **d** does not influence the process. After this barrier the depth of skiving gradually reduces, and the quality of skiving deteriorates. Hence the maximum distance for d, for successful skiving, is 2.50 mm.

What happens "behind" the 2.15 mm barrier, i.e. in the region not reached due to the cast backstop, is yet unknown but the following is assumed : the process will continue with static behaviour for a certain displacement, until d will be small enough to cause interference between knife and pin and machine damage will occur. However it is expected that before reaching this point, there will be a displacement region within which components will be cut instead of skived.

It is also very important to note that the limiting **d** (smallest) for safety is heavily dependant upon the shape of the pin tip. If for example a conical shaped, ball ended pin tip is employed, the critical safety value of **d** would be variable, determined by the position of the pin within its stroke range, at any point in time. The study in the behaviour of the process within this region of **d** (<2.15 mm) could form the subject of a future investigation, when there is a mechanical structure that allows further decrement of **d**.

4.9 Conclusion

In this chapter it was explained how the various elements and factors within the process area contribute to the success of the skiving action. This was done by methodical reasoning to explain the influential factors behind each part of the unwanted behaviour of the mechanism. The major development in this stage has been the identification of the need for an interface between the pin matrix and the leather components.

It has been concluded that only if this interface plays an active role in the process itself, it is possible to achieve all three targets : leading edge skiving, skiving quality and skiving without component dislocation. The former, may be considered the most important achievement during this stage of research, because it had been the main question mark for the success of dynamic matrix skiving. The photograph in figure

4.34 illustrate samples of successful leading edge skiving. One of the samples demonstrates skiving in one of its most difficult areas, i.e. around a leading corner of the component. Notice that the arrow indicates the direction of component movement. The photograph of figure 4.33 demonstrates a typical sample of poor skiving quality due to lack of interface between the component and the pin matrix. By comparing the samples shown in 4.34 with the one shown in 4.33 it can be identified how the introduction of the superstrate layer clearly improved skiving.

During evaluation of the influences for successful skiving, a range of data was obtained. This data was useful for study of suitability of actuation mechanisms for skiving and may be used as a reference, for future industrial system development. However it must be pointed out that skiving is not expected to be viable for all possible leather types, because of the extra forces required to skive the thicker ones.

The solutions to the above problem are two. One is to determine a range of leather types to be handled by a particular skiving system. The other is to take advantage of the reduction in force required for shorter pin strokes. The latter idea suggests redesign of the knife mechanism (i.e. splitting machine) to allow straight horizontal movement of components.

Another important issue was identified to be the presence and properties of the conveyor substrate material. The substrate is important because it allows skiving to occur in the first place. Finally the basic adjustments of the mechanism, necessary to perform skiving, were evaluated. These may be taken as a datum, for a skiving mechanism based on pin skiving against a band knife.

This study and experimentation proved that dynamic matrix skiving is possible, given certain conditions. The next major phase of research thus was directed towards the integration of this system, to perform skiving as a stand-alone automatic industrial unit. This phase is analysed in chapters 6, 7 and 8.

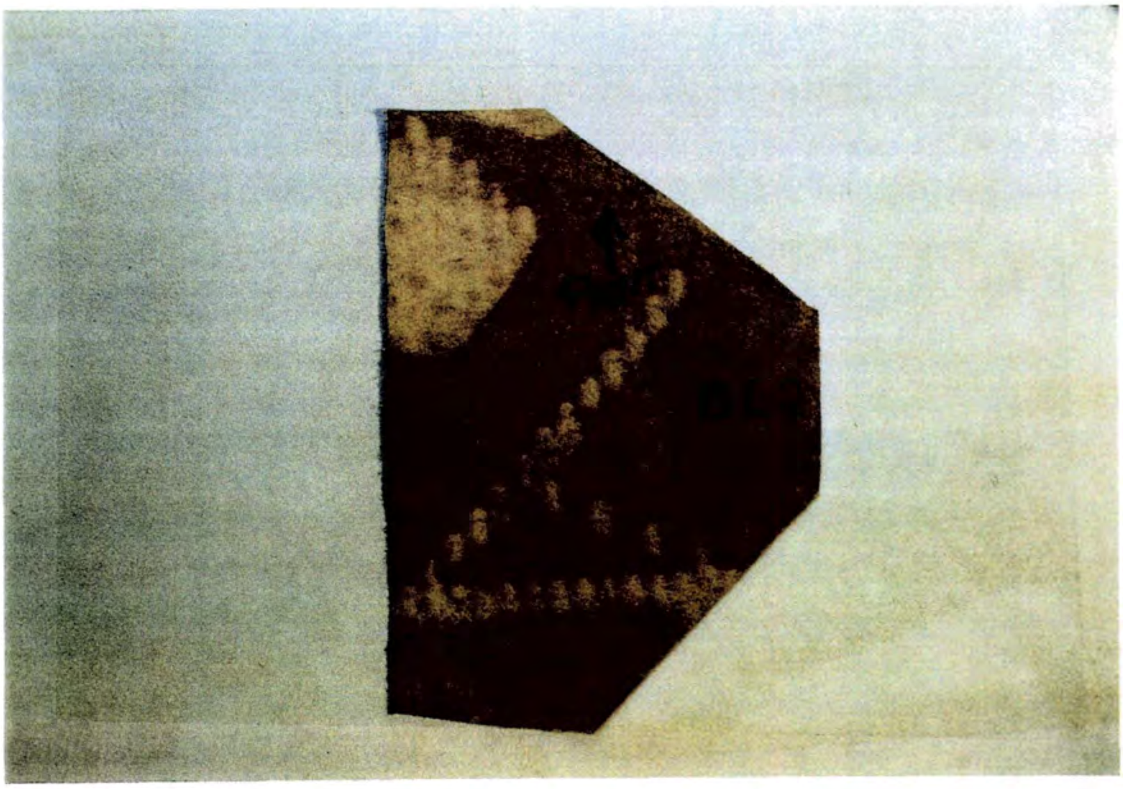


Fig. 4.33 Sample of skiving without the use of superstrates.

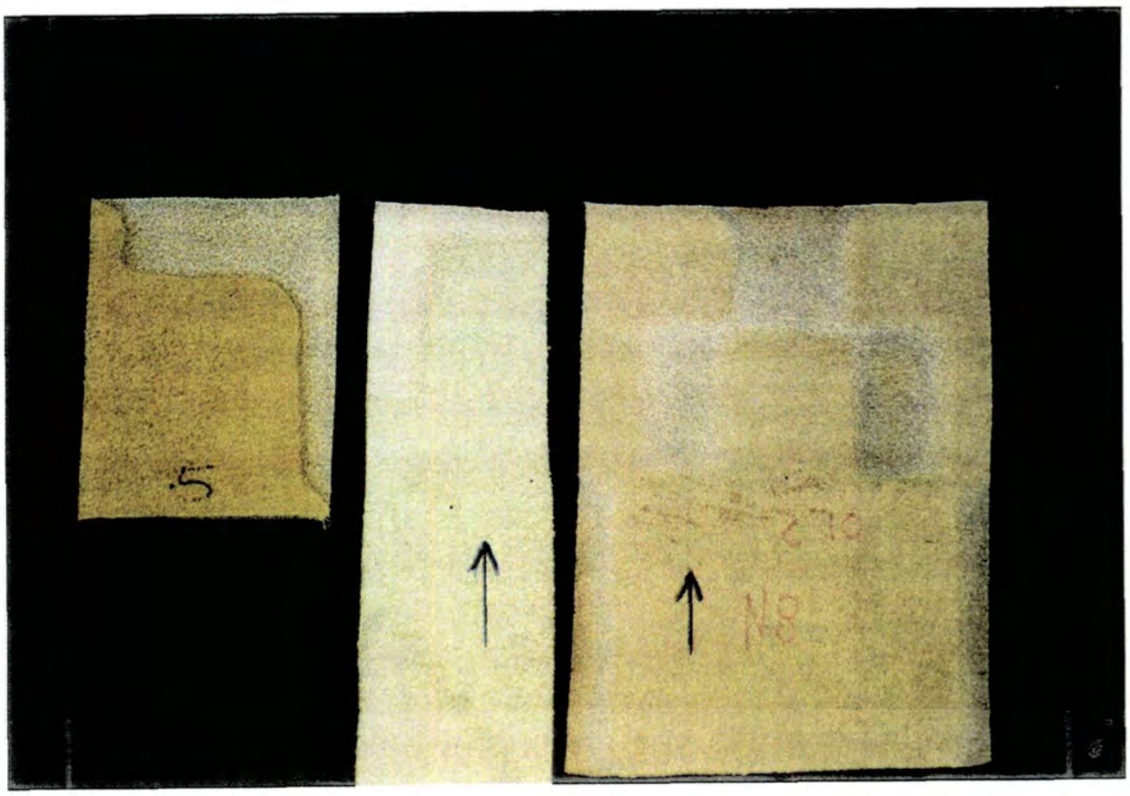


Fig. 4.34 Samples of successful skiving using the twin belt feed mechanism.

CHAPTER 5

SYSTEM ACTUATION AND RESOLUTION

5.1 Introduction

Skiving has been proved to be feasible, using the pin matrix based mechanism. However there were some aspects related to the quality of skive patterns, which had to be investigated. Some of these aspects are related to more than one system variables.

As it was mentioned in chapter 4, the resolution of the skiving mechanism is responsible for two unwanted features. The first is poor skive pattern definition. The other obstacle has been the aliasing effect in some skive pattern edges. The presence of superstrates although improved skive pattern edges, it did not eliminate this problem. This issue alone, led to the observation of the difference between the profiles of trailing and leading skive edges.

Another feature was that the intended y-length of skive patterns was different to the factual one. The controllability of the y-length of skiving was suspected to be dependent on more than one factors the response of actuation and the knife drag. Also, the x-resolution of skiving was too low to approach industrial expectations for the skiving process.

Some of the above issues are influenced by factors described in chapter 4. However the same issues relate directly to the operating skive resolution, i.e. to the size and spacing of the pins in the pin matrix. In turn, the issue of the resolution is indirectly, but decisively, linked with the design of the actuation mechanism. Any intention to modify the mechanism for improving resolution, has implications in the technology used and the expense of manufacture. Another influence towards these features is the behaviour of the actuating mechanism due to the type of actuators used.

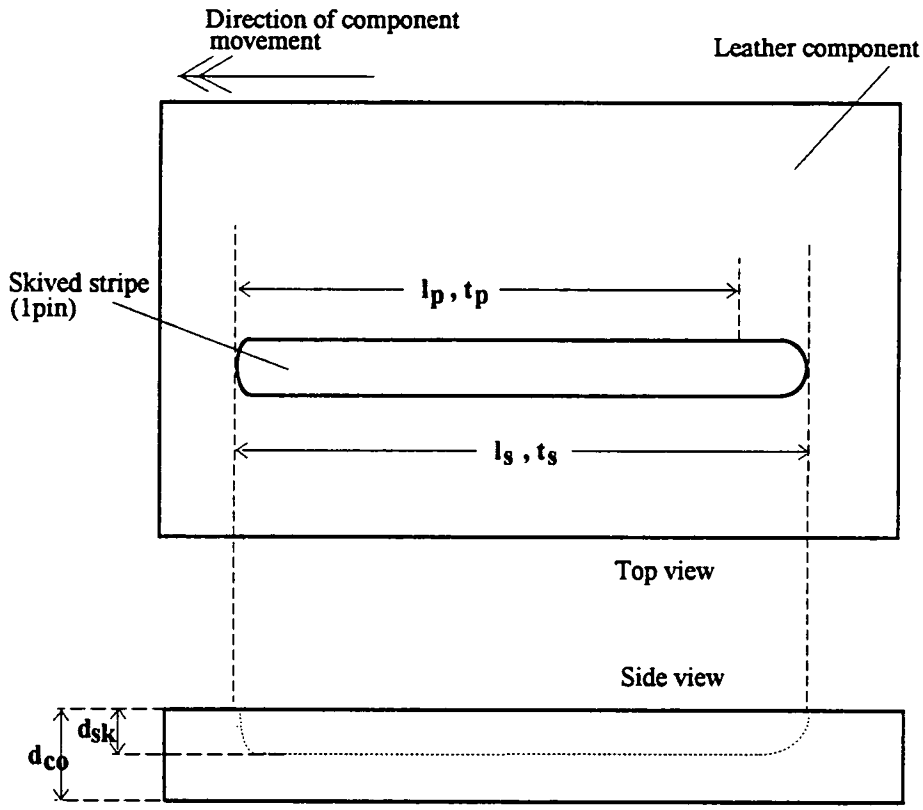
It was thus necessary to examine the behaviour of the actuation mechanism, to identify in more detail its influences in skiving. This also generated ideas for alternative actuation methods and mechanism, which are presented in chapter 9, System enhancements. This chapter is an attempt to distinguish between the relations of the above features and to indicate those due to the actuating mechanism and its resolution.

5.2 Definition of length of skiving

This issue was suspected to be related to two different constants. One is the response of the actuating mechanism and the other the knife drag. Both of these elements constitute the response of the skiving mechanism. The response of the skiving mechanism has two values; the time taken for commencement; and the time taken for termination of skiving. This is measured as the time duration between the presence of the corresponding signals and the actual execution of the above two functions.

To examine the response of the skiving mechanism it is necessary to define the concept of length of skiving. This is the length in mm of a skive stripe, oriented in the direction of conveyor movement. This is illustrated in figure 5.1.

Since early skiving trials it had been suspected that there may be an overshoot in skiving length. In other words the eventual skive stripe is longer than the intended one. By intended skive length it is meant the skive length that should occur between the signals for pin insertion and retraction. As with any electro-mechanical structure, it has been expected that the actuating mechanism would produce some delay in executing the above functions. It was thus necessary to evaluate this delay(s) and to



l_s : Length of intended skiving , t_s : the time involved
l_p : Length of eventual skiving , t_p : the time involved
t_i : Time of instruction for pin insertion
t_r : Time of instruction for pin recovery
d_{sk}: Depth of skiving
d_{co}: Component thickness

Fig. 5.1 An illustration of the definition of lengh of skiving

deduct it, if necessary, from the overall system lag. This operation would separate the role of the actuating mechanism in system response, from the role of other factors.

Such possible factors are delays caused by the return forces of the substrate, leather component, and superstrate. Another independent factor, which could take advantage of slow tri-layer response, is the downward drag of the component due to the knife. The latter is explained as follows : during skiving, the knife is "dug" into the leather as shown in figure 4.3. When the pin that sustains skiving is retracted, the leather component is in effect held down by the knife. Due to the tri-layer system return forces, the leather will come back above the knife plane. However this may not happen instantaneously, but it will appear as a gradual return of the knife, "cutting its way out". This of course happens in the reverse way during pin insertion, i.e. skiving commencement.

Therefore if such an overshoot exists, it may be caused by slow system response, to exit the component out of skiving conditions. This response characteristic could be due to the response of actuation, due to knife drag, or due to both.

5.3 Forces during entering and exiting skiving conditions.

With reference to the skive profile, shown in fig 5.1, it can be observed how the sections of pin insertion and retraction differ. The entering profile is distinctly steeper, in contrast to the exiting one which is much more gradual. This feature, just like skive overshoot, was suspected to be related with exactly the same two factors described in the previous section. This means that the profile of an skive edge is related to the response time and force/displacement characteristics of the actuating mechanism. During pin insertion, the solenoid responsible for driving the lever / pin mechanism faces three obstacles :

- The inertia of the pin / lever mechanism
- Return forces due to return spring and tri-layer system
- Hysteresis due to time for electromagnetic build up, in the solenoid itself.

The most influential of the three above features, for the skive profiles, is the third one. This is because it relates to the force/displacement characteristic of the solenoid. It is important to mention here that the force of the solenoid (35 N) required for skiving cannot be reached instantaneously. The force is gradually increased depending on the amount of surface area the solenoid core being within the coil boundaries. This gradual production of pin force, if considered in parallel to component movement, is responsible for forming a slowly progressing entering skive profile. Nevertheless in comparison, the resulting entering skive profile is certainly sharper than the exiting one.

This feature is common to all solenoids and thus it is expected to be present if solenoids are used as actuators. The only possibility of improving performance, i.e. achieving a steeper entering skive profile is to substantially increase the pin force. This in turn implies larger solenoids, a choice that faces not only the problem of cost, but the solenoid space allocation for a certain pin resolution. At this stage, it must be stated as a conclusion, that absolute square skive profiles are impossible with the pin matrix skiving mechanism.

Similarly, the exiting skive profile would be expected to be more gradual. After the signal for pin retraction takes place, the three influencing factors presented above, operate in assistance to exiting the component out of skiving conditions. However the pin cannot return to its datum instantly. As it progressively returns, the conveyor is still moving and skiving continues, and the leather may only gradually exit skiving conditions.

In any case, because the forces during pin insertion are much greater than those during retraction, it is logical to assume that the pin will be inserted faster than retracted. This is expected to cause a faster component entry into skiving conditions and a much slower exit. This assumption justifies the difference in the corresponding skive profiles observed.

The other force in opposition to exiting skive conditions is the knife drag. This could be expected to contribute towards the slow component recovery. This contribution could be substantiated, only if skiving continued after the instant that the pin has been retracted far enough not to cause skiving.

The above explanations for the cause of entering and exiting skive profiles are related to the linear velocity of the conveyor. In high conveyor speeds, such as 180 mm/sec, which is the lower limit for industrial expectations, the situation should be aggravated, at least theoretically. In high conveyor speeds, the circumstances relating to system forces are exactly the same. However there is a difference in the relation between the response of these forces and the motion of the component. In this case, the relative return of the pin is even slower. The effect of the knife drag is also expected to relax later, in terms of skive length, if compared with the situation at lower conveyor speeds.

Thus skiving overshoot is likely to be proportional to the speed of the conveyor. Finally, time during which the knife (alone) holds the leather in skiving conditions is expected to be related to the width of the skive pattern at the time of pin release. This means that the more leather length (X-direction) is engaged under the knife, the more difficult it will be for it to return above the knife plane. Also, the overshoot due to knife drag, should be longer in the middle regions of the skive pattern width. This is because those regions would be the last ones to be released from the knife.

With reference to fig. 5.2, it can be explained why should this happen, by taking two extreme cases. Let us assume the minimum possible width of a skive pattern under skiving conditions, i.e. that caused by a single pin. Let us also assume the case of a 10 pin wide skiving pattern.

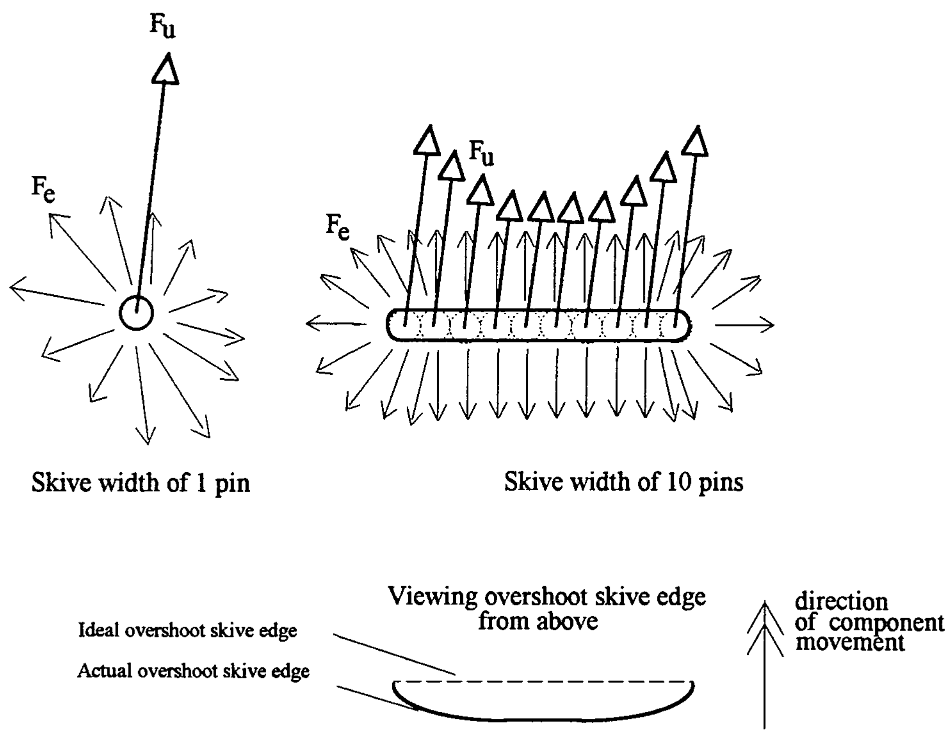


Fig 5.2 Leather surface force elements overcoming knife drag

It can be argued that in the first case, the force elements contributing to the return of this area, are many more per unit of area, than in the second case. The force elements shown are assumed to be in the plane of the leather component (surface tension forces), present due to the rigidity of the leather. In both cases those force elements F_e would result in force F_u, which is vertical to the plane of the component, and responsible for the return of the area under skiving. However in the second case, because of the lesser available free surrounding area (per unit of skiving area), the F_e unit forces of skive areas will be smaller.

Furthermore, for the same reason, the central area units will be subject to even smaller forces. This will result in that the central areas will exit skiving conditions later, and thus the skiving overshoot will vary along the ten-pin width. The overshoot skive edge shown in figure 5.2. explains this. It is worthwhile noting that there are no justifiable reasons due to which alteration in the pin matrix resolution should change the above situation.

The effects described so far and the reasons behind them are also directly related to the phenomenon of the stepped lines, described in chapter 4. It was explained that stepped lines were due to the problem of poor resolution. It seemed that stepped lines occurred in much higher intensity on *leading edges of skive patterns* (this term is not to be confused with the term *leading edge skiving*). In contrast diagonal lines of trailing edges were smoother. With the introduction of superstrates, this effect was generally improved but the above difference was intensified. This very difference is in line with the argument of slow leather recovery during pin retraction.

The explanation for the above is as follows : because of the slow recovery of leather regions during termination of skiving, a smoothing effect takes place between sequentially recovering adjacent skive stripes (y-lines). A real life example of this contrast of diagonal skive edges is shown in the photographs of figures 4.33 and 4.34. It may be observed how the skiving mechanism behaves differently at leading and trailing diagonal edges of the skive pattern. Another example is the one shown in figure 5.3. This photograph illustrates two skived leather components, one with an interior skive pattern. In this example it is observed how starting the leading edge of a skive pattern is more gradual if compared with the more sharp exit from skiving conditions. In the photographs, this is distinguished by observing the change of colour along the skive pattern. The darker the colour the shallower the skive pattern. All observations should be done by taking in account the direction of movement of the component, denoted by an arrow. To examine the degree of influence of the actuation response and knife drag dynamic and static experiments were carried out. Those are described in the following sections of this chapter.

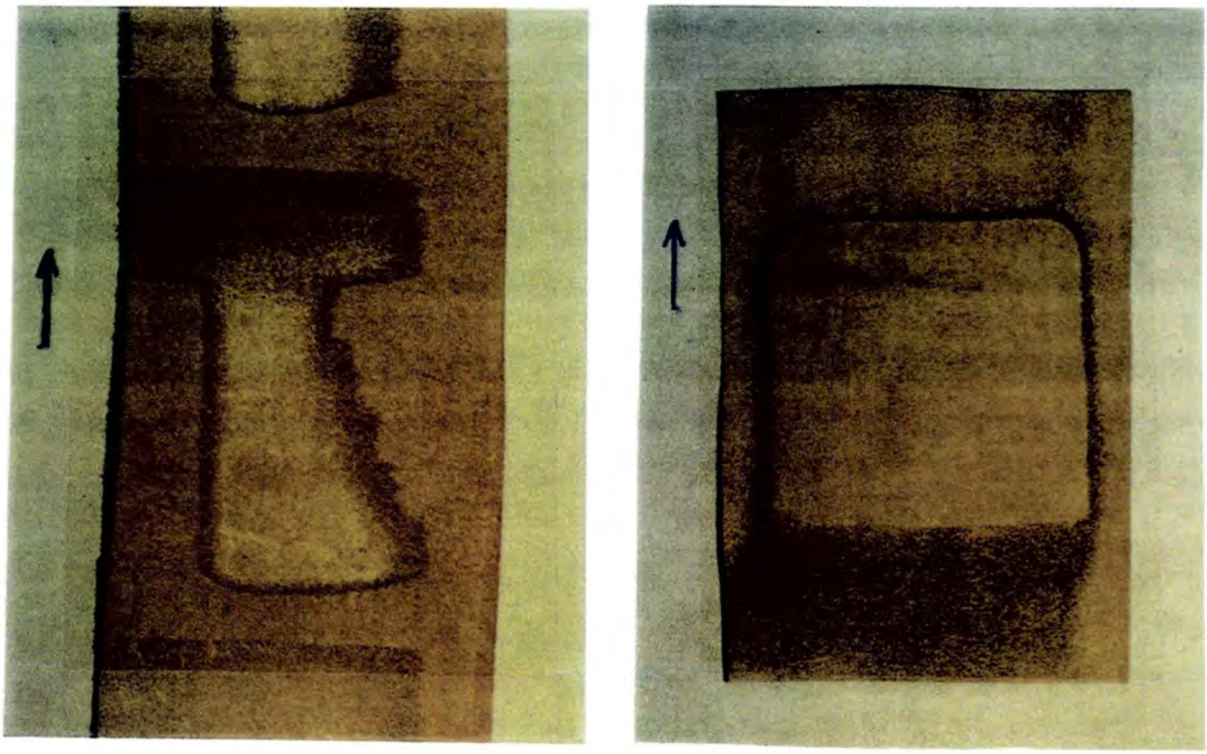


Fig. 5.3 An illustration for the difference between leading and trailing skive pattern edges.

5.4 Investigation for skiving overshoot.

To examine whether overshoot in skiving stripes really does take place, it was necessary to conduct experiments, based on comparison of l_s and l_p (fig. 5.1). Evaluation of the response characteristic of the solenoid based actuating mechanism should be the first step. Following this, a dynamic experiment should investigate the value of skive overshoot, and obtain a value for the above comparison. Finally, the contrast of the results of the two experiments should indicate the reasons causing the overshoot.

5.4.1 Method for evaluation of actuation response

Initially it was considered to be essential to obtain a static characteristic for the actuating mechanism. The term static in this case implies that the mechanism should be tested whilst not skiving. The main justification for this was that the data obtained could be used as a form of comparison, if a different type of mechanism or actuator would be considered in the future. Another reason was the difficulties present in attempting to measure the dynamic characteristic, i.e. while performing skiving on a component. In any case the dynamic characteristic could be calculated, as it will be seen at a later stage.

The static characteristic concerned with pin retraction is expected to represent the worst case scenario, where no external forces are influencing (contributing to) the return of the pin to its datum. In other words, in the case of dynamic operation the additional return forces provided by the tri-layer system, are expected to increase the overall system response. However it must be stated that while skiving the pins are subjected to forces of direction perpendicular to their vertical centre axis. These forces are caused due to the friction of the superstrate and the pin tips. It is only logical to hypothesise that due to the above forces the friction may be caused between the pins and their housing guides. In any case the latter forces are expected to be negligible due to the smooth finish of the pin surfaces and interior housing walls.

Hence it is expected that the combination of the above forces will assist the return of the pin. Nevertheless the magnitude of this resulting force is always dependent upon the type and thickness of the leather, the substrate and the superstrate. Hence if a dynamic test was to be carried out it would identify a characteristic relevant to particular circumstances.

For the purpose of obtaining the response characteristic of the actuating mechanism a static experimental arrangement was set-up, such as the one shown in figure 5.4. The skiving mechanism was removed from the rig and was placed on a workbench at the same orientation as for skiving. As it is illustrated in figure 2.7 solenoid plunger and the lever are mechanically linked. However there is no mechanical link between the pin and the driving lever, as this was not practically viable due to the narrow pin spacing. The only return force of the mechanism is the return spring of the pin, which in turn forces the lever and the solenoid plunger back to their datum.

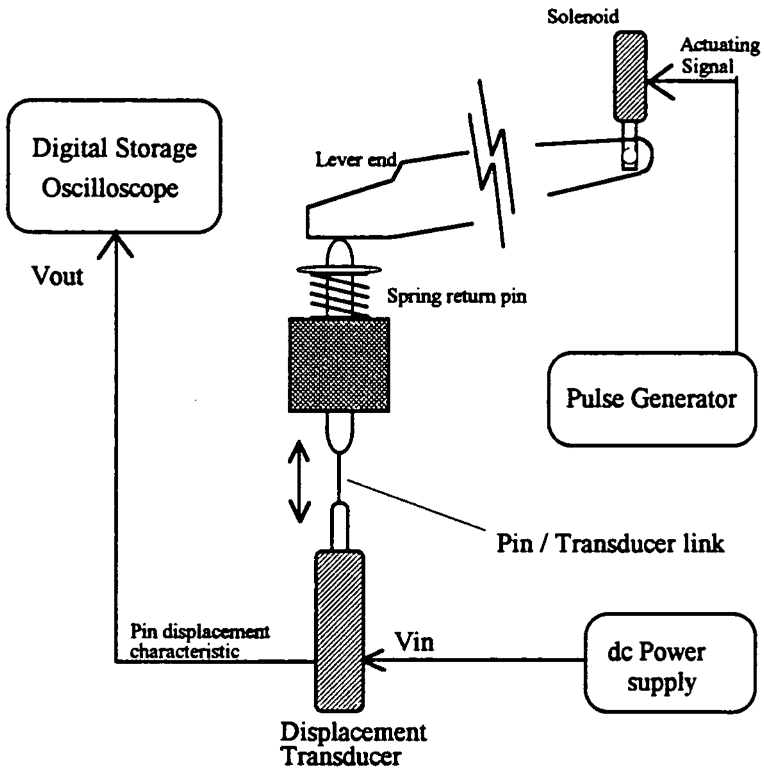


Fig. 5.4 The experimental set-up for evaluation of the static displacement characteristic of the skiving actuating mechanism

The return spring force is responsible to overcome the 1:4 ratio of mechanical advantage between the ends of the lever. However it is not known whether, at high actuation frequencies contact between the pin and the lever is maintained at all times during return. Therefore it was considered that it would be inappropriate to use the solenoid plunger, or the lever as reference points for measurement of displacement against time. Hence the only valid reference in measurement is the pin itself. Because the pin is not accessible from the above for attachment of some type of displacement transducer, the only solution was to access the tip of the pin. This was also a decisive criterion for dismissing the option of performing a dynamic test.

To track pin movement a displacement transducer was used. It was a linear displacement spring return transducer, which operates as a potentiometer (barrel/core type). The input to the device is 10 V dc and the output is a dc voltage that varies linearly with the displacement of the core with resolution 0.00075 mm/mv.

As shown in figure 5.4, the tip of the pin was cemented with a piece of steel spring to provide a reasonably flexible but not extendible joint. The other end of the spring was cemented to the plunger of a displacement transducer. In this arrangement the plunger of the transducer follows the motion of the pin at all times. Although the transducer contained a spring which aimed continuous contact with the pin tip it was necessary to link the transducer mechanically with the pin. The reason was to avoid possible transducer overshoot at higher operating frequencies.

The input to the transducer was via a DC variable power supply and the output of it (and all other readings) were observed and recorded on a digital storage oscilloscope. Using the time variable voltage from the displacement transducer, the oscilloscope displayed the displacement / time characteristic of the motion of the pin. The use of pulse generator was necessary to be able to vary easily the mark to space ratio and the frequency of the driving signal to the solenoid. Because of the storage capability of the oscilloscope it was possible to keep records of the characteristics observed for future study and reference.

During measurement, the effect of the spring of the transducer on the system was considered to be negligible because it is a low tension spring (0.1 N/mm). This assumptions is relative to the return force of the pin spring (4 N/mm). Also the mass of the core of the transducer was as little as 5 gram., so the additional inertia in the actuating system can be considered negligible. Thus it is acceptable to ignore the influence of the transducer in this measurement, for the above reasons, without risking calculable errors.

5.4.2 The static response characteristic of the actuating mechanism

A typical sample of the results obtained from the experiment described in section 5.4.1 is represented in figure 5.5. The top graph represents the input drive pulse to the solenoid, as a voltage against time characteristic. The amplitude of the pulse is 38 volts, as applied for skiving.

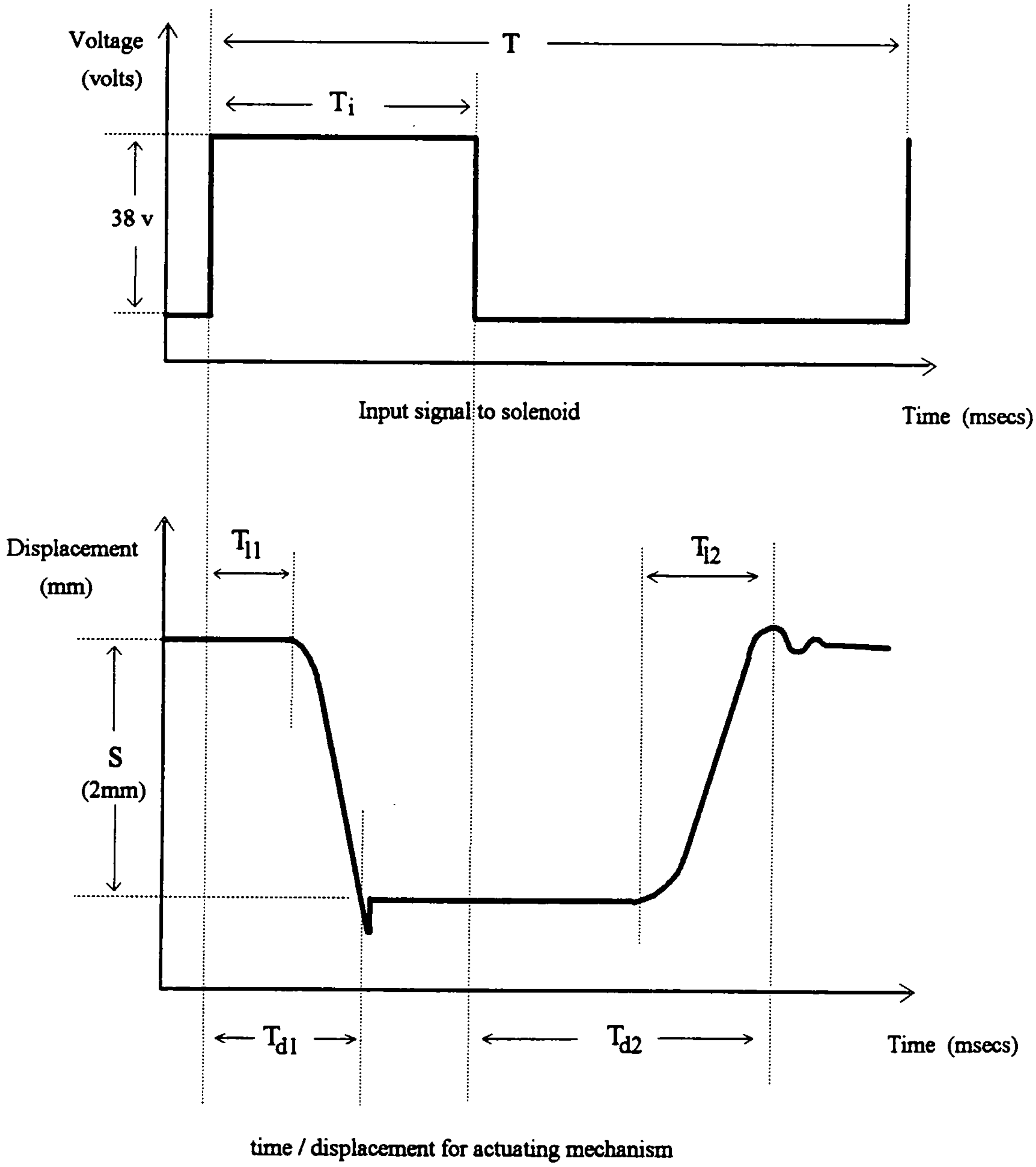


Fig. 5.5 The static time / displacement characteristic of the actuating mechanism in relation to the input signal pulseto the solenoid.

The second characteristic represents a typical image stored in the oscilloscope. Although in the oscilloscope the vertical axis represents voltage, it may converted to displacement in mm. The total voltage variation corresponds to the total pin movement (stroke) denoted with S. The following definitions apply to all symbols used :

- T_i : duration of the input pulse (input to the solenoid)
- T : the period of the input pulse
- F : the input frequency
- T_{l1} : the time interval between the instant that the input pulse is applied and the instant at which the pin starts to move.
- T_{dl} : the time interval between the instant that the input pulse is applied and the instant at which the pin has reached full stroke (2 mm)
- T_{d2} : the time interval between the instant that the input pulse is terminated and the instant at which the pin has returned to its datum
- T_f : the time interval between the instant that the input pulse is terminated and the instant at which the pin starts to retract
- S : Pin travel (in mm)
- T_i* : The minimum value of T_i at which S = 2 mm is reached.
- T_c : The minimum value of T_i at which the constant in pin retraction is established, i.e. the point at which T_{d2} becomes constant.

To obtain a valid conclusion about the behaviour of the actuating mechanism, it was necessary to observe its response characteristic at different input pulse durations T_i. This would indicate if there are any changes of the characteristic at particular frequencies. It would also indicate limits beyond which skiving should not be operated. Table 5.6 shows how the defined sections above varied with frequency. It is worth while noting that the overall experiment was repeated for two different actuating structures, to verify the validity of the results. The results shown are the mean values, derived from the two cases. The values shown are subject to a +/- 1.5 % total error tolerances. All values stated are in msec.

T_i	T_{l1}	T_{d1}	T_{l2}	T_{d2}	S
4.5				00.00	0.00
5.20				08.00	0.27
6.25				11.00	0.65
7.00				15.00	0.93
7.25				17.00	0.96
8.00				20.00	1.22
9.50				24.00	1.74
10.50				27.00	1.85
12.00				30.00	1.90
12.70	6.27	16.00	2.00	33.00	1.93
14.00	6.27	16.00	2.50	35.00	2.00
14.50	6.27	16.00	15.00	37.50	2.00
15.00	6.27	16.00	20.00	44.00	2.00
15.50	6.27	16.00	28.00	51.20	2.00
16.00	6.27	16.00	30.50	51.20	2.00
17.00	6.27	16.00	30.50	51.20	2.00
18.50	6.27	16.00	30.50	51.20	2.00
21.00	6.27	16.00	30.50	51.20	2.00
25.00	6.27	16.00	30.50	51.20	2.00
28.00	6.27	16.00	30.50	51.20	2.00
34.50	6.27	16.00	30.50	51.20	2.00
48.00	6.27	16.00	30.50	51.20	2.00
62.00	6.27	16.00	30.50	51.20	2.00
76.00	6.27	16.00	30.50	51.20	2.00
110.00	6.27	16.00	30.50	51.20	2.00

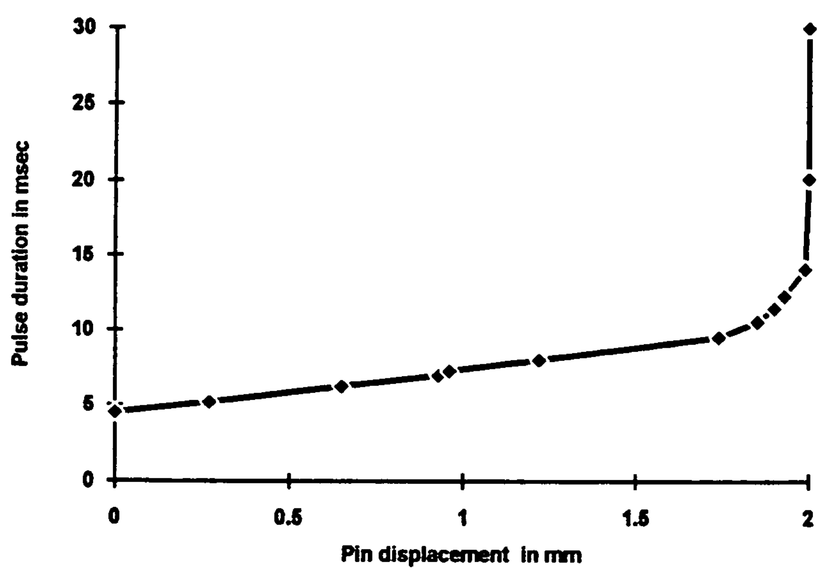
Table 5.6 The results obtained for the response of the actuating mechanism

5.4.3 Observations in the characteristic of the actuating mechanism

One of the first conclusions from the values shown in table 5.6 of measurements is that, if we examine the variation in pin displacement S against the pulse width T_i, there is a value below which full stroke cannot be achieved. That limit is Ti* =14 ms. Below this value for input pulse duration, the stroke of the pin falls rapidly, but gradually, to 0 at 4.5 msec. Of course this means that skiving may not be performed below this value, because skiving is at this stage operated without depth control, and thus the pin should always reach full stroke.

The above observation is important for the possibility of skiving with depth control. Chart 5.7 illustrates how pin stroke varies, by altering the pulse duration within the band of 4.5 to 14 msec. If now it is assumed that such an actuating mechanism would be operated with at selected pulse durations for particular pin depths, it may be possible to control skiving depth. In this case the minimum mark to space ratio would have to be the maximum appearing within this band, i.e. 14 : 35 (or 4 : 10). The purpose would be to allow coil discharge and avoid resonance conditions. This implies that every y-stripe of skiving should be actuated as an integer multiple of such mark to space ratios.

Chart 5.7 Variation of pin stroke with varying pulse duration



Another method to implement control of depth would be to simply vary the mark to space ratio at very high frequencies. In this case one simple descent of the pin would be the result of thousands of input pulses. Theoretically at least, by altering the mark to space ratio of the input signal the amount of input energy to the coil (per unit of time), would be proportional to the stroke reached by the core of the solenoid .

Another observation from the results is that there is a slight overshoot of the pin when it reaches full stroke. This happens because although the lever reaches its full stroke, relative to the solenoid plunger, the pin is allowed to continue its course slightly due to its momentum at that instant. This is allowed because the return spring of the pin is not fully depressed when the lever is at its full stroke. In other words in the present system there is no physical stop for the travel of the pin at 2 mm. In real operation this overshoot may be dumped out by the presence of the tri-layer system.

Some other observations from the characteristic and results shown are the following :

- T_c is reached at T_i = 15.5 msec. From this point onwards the constant delay Td2 - Tl2 becomes established. For this reason it may be stated that this should be the minimum T_i used for skiving, if the operation is intended to be based on constant actuation return response time.

- T_{d1} appears to be constant at all values of T_i provided that $T_i >= T_i^*$, otherwise T_{d1} has no meaning. The constant value is 16 msec. In other words it appears that at the present setting of 38 V dc to the solenoid, it takes 16 msec for the pin to travel 2 mm and thus to reach full stroke.

- T_{l1} also appears to be constant as expected for all values of T_i provided again that $T_i >= T_i^*$. This value is approx. 6 ms and it is also subject to the input voltage set at 38 V dc.

- T_{l2} rapidly increases from zero (for values of $T_i < T_i^*$, T_{l2} does not exist, refer to Photograph in figure 5.10) to its constant value of approx. 30 msec at $T_i = T_c$.

- T_{d2} simply represents the total time elapsed for the pin to return to its datum. Its minimum value 35 msec is at $T_i = T_i^*$ and gradually reaches its constant value of around 51 ms at $T_i = T_c$.

5.4.4 Skiving with resonance conditions in actuation

During the above experimentation, it became apparent that the actuating mechanism in some particular frequencies produced a longer stroke for the pin, than what it is conventionally expected. This means that in those particular frequencies of actuation the system behaved in a manner that did not agree with the data in table 5.6. It was observed at instances that for values of $T_i <= T_i^*$ (where S=2 mm should not be reached) the pins reached full 2 mm stroke or near it.

The characteristic shown in figure 5.11 is a record of a case where T_i = 8 msec and it is expected to produce a pin displacement of about 1.22 mm. However if a pulse train is applied at a particular frequency it is seen that the very first stroke is indeed around 1.22 mm but the following ones reach 2 mm. It seemed thus that the mechanism falls into resonance in various cases (and to a different degree) such as :

with	Ti = 8 ms	resonance at	F = 27.70	Hz
"	Ti = 6.2 ms	" "	F = 34.13	Hz
"	Ti = 5.1 ms	" "	F = 44.94	Hz

It is worthwhile noting that in all cases m/s ratio was around 1:3.4 .

This particular feature led to the idea that using pulse trains to bring the system into resonance, could be a way to perform skiving, while controlling the depth of cut. However for this to happen, the response of the leather component should be such that, the area under skiving would not return above the knife plane (or move at all) in between individual strokes like those illustrated in fig. 5.11. This implies that continuous stroke skiving would be simulated with application of very fast stroke sequences. To examine the possibility of this theory becoming practice it is necessary to evaluate the retraction response of the tri-layer system, and this is analysed in chapter 9. Nevertheless, this idea was considered, but was put aside as an alternative option for future development.

5.4.6 Limitations in skiving due to pin retraction response.

If it is assumed that an instant touch of the pin on the leather results in a skived circular area of diameter 3 mm (=pin width) and if, for argument sake, the minimum necessary T_i is T_c = 15.5 ms (for an effective result on the leather) then : if we are to allow the full constant delay of 51 msec to elapse the maximum operating speed of the skiving machine will be

3 mm / 67.2 msec = 44.6 mm/sec (where 66.5 = $T_{d1} + T_{d2}$)

In other words the above conveyor speed would eliminate any optical effects of the retraction delay for achieving the minimum possible y-resolution for the given pin thickness.

However the above conclusion would be illusive for the following reason. The T_{l2} part of the delay should not be considered responsible for skiving overshoot during its whole length. This is because during T_{l2} the pin is gradually returning and it is expected that from one point onwards, this delay will not be responsible for maintaining skiving conditions. Hence if it is assumed that a 0.7 mm skiving depth is implemented then, the delay T_{l2} should be responsible for maintaining skiving for 0.7 / 2 of its duration, i.e. for approx. 10 msec. This would define the *effective* part of the constant retraction delay (51 msec) as

[(51.20 - 30.5) + 10] = 30.7 msec.

Similarly, the T_{l1} part of T_{d2} is inactive, as the two thirds of the downward slope. Therefore the *active* part of T_{d1} for a skive depth of 0.7 mm will be

(16 - 6.27) ∗ (0.7 / 2) = 3.4 msec

Therefore in this case the maximum conveyor speed for maintaining the minimum y-resolution would be

3 mm / (30.7 + 3.4) = 87.9 mm/sec.

The above considerations indicate that due to the feature of the response characteristic, the duration of the active sections of the insertion and retraction delays are dependent upon the depth of skiving. Hence skive overshoot and optimum conveyor speed are dependent upon the depth of skiving too.

Let us now observe the same issue from the reverse point of view. A 30.7 msec delay in retraction (for 0.7 mm skive depth) , would cause overshoot proportional to the operating conveyor linear speed. If for example the speed was to be set at 180 mm / sec (lowest industrial expectation) this would result in skive overshoot of 5.5 mm. This overshoot may be taken care of by suitably offsetting the time of retraction of the pin. However, the minimum skiving y-strip (i.e. the y-resolution of the system) would be

34.1 * 180 = 6.1 mm long. (for the above conditions)

The above capability does not appear to be sufficient for commercial purposes and it seems necessary that the delay constants T_{d1} and T_{d2} (85% of total time, in minimum possible pulse duration) would have to be reduced somehow. Hence the overall conclusion is that a faster actuating system should be used in the development stage. However it must be remembered (section 5.3) that the above delay in retraction is expected to be improved partially, by other system forces, when in dynamic operation.

5.4.7 Analysis of the actuation system characteristic.

To be able to form a valid final conclusion, and perhaps a suggestion for improvement for the present actuation mechanism, it is essential to analyse the given characteristic. To do this the characteristic should be divided into its three distinct regions. With reference to the diagram in figure 5.8, the characteristic is broken down as follows :

- The insertion delay, earlier noted as T_{d1},
- the insertion time
- the retraction delay.

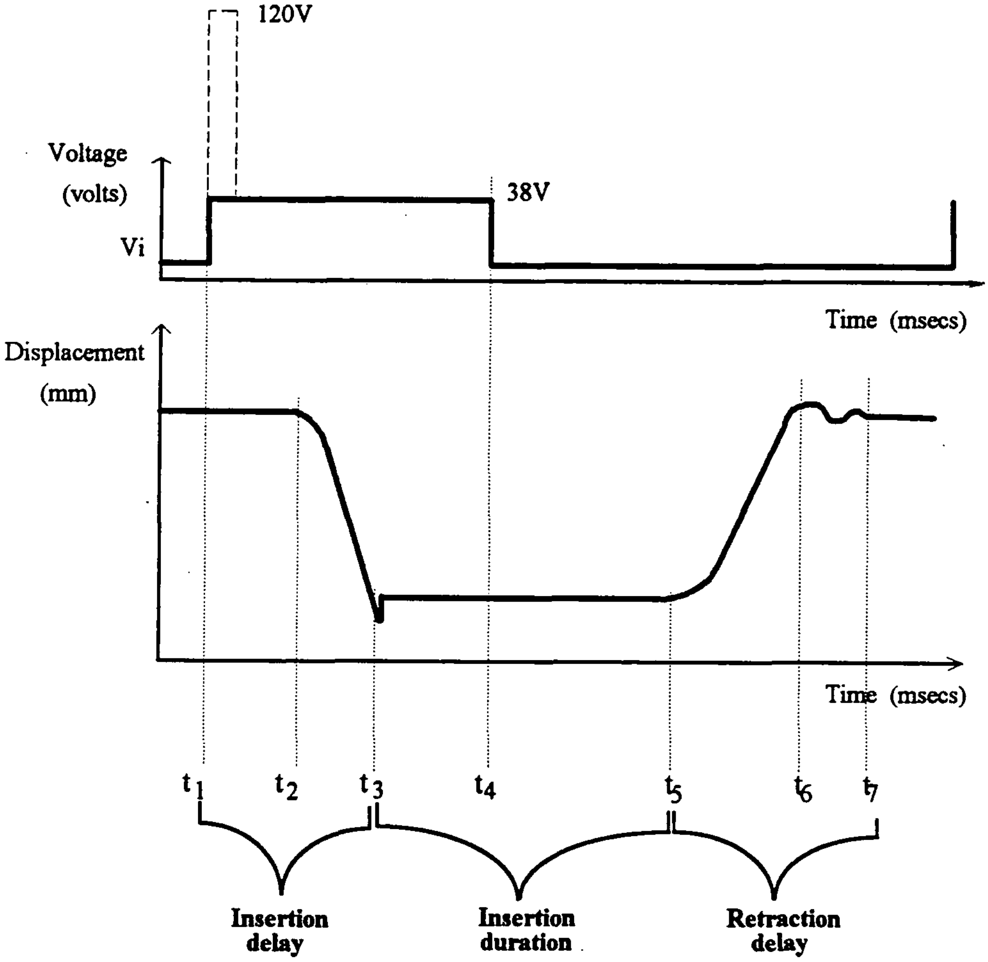


Fig. 5.8 The three major sections of the displacement characteristic of the actuating mechanism

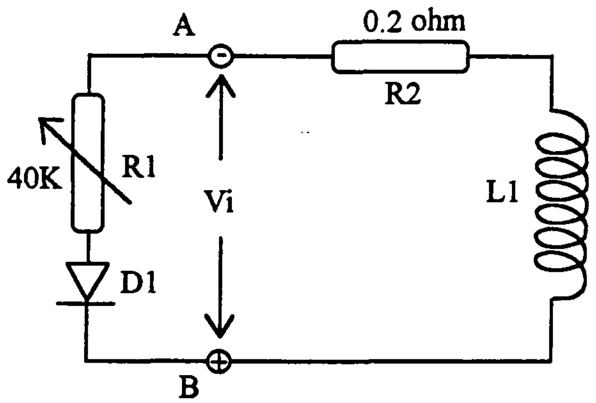


Fig. 5.9 Discharge circuit for fast actuator retraction

During the *insertion delay*, the input signal was given at t_1. The delay between t_1 and t_2 (T_{l1}) is due to the time needed for the solenoid to be energised. Therefore the pin is unable to start moving until t_2. This could be improved by introducing a relatively large voltage for a very short period in the beginning of the pulse, shown by the dashed line in the input signal. Thus this part of the delay is clearly due to the electrical nature of the system.

However the delay from t_2 to t_3 is due to a combination of the mechanical and electrical behaviour of the system. It is expected that the pin will actually start to move before the coil is energised fully and during this time (or part of it) it is expected that the coil's current keeps on increasing until reaching maximum value. Meanwhile the presence of opposing forces and the inertia of the lever/pin mechanism also influence the motion and contribute to the delay.

During the *insertion duration* (t_3 to t_5), the pin maintains its full stroke, and skiving takes place. However it was intended that full stroke was maintained only up to t_4, at which instance the input pulse Vi is removed. The following delay has proved to have a constant value, irrespective of the duration of Vi (if $T_i >= T_c$). This is also the largest individual delay of the system. The delay t_4 to t_5 can be present because of three reasons :

i. Lack of the coil to discharge quickly and thus to effectively release the mechanism.

ii. Purely because of the ability of the pin spring to overcome the inertia of the system. Let us not forget that the mechanical advantage of the lever (1:4) that aided insertion is reversed during pin retraction (4:1) and the only assisting force is the return spring of the pin.

iii. Due to a combination of i and ii.

At first case i. should be examined. For this purpose the circuit shown if figure 5.9 was connected to the solenoid. The intention here was to enable fast discharge of the coil once the pulse was removed. However this did not appear to influence the characteristic of pin displacement and the interval t_4-t_5 was not at all reduced. The resistance R1 was given values from 40 k down to 0 and the result was the same.

The units for the characteristics below are : time in msec for x (→) and Volts for y (↑)

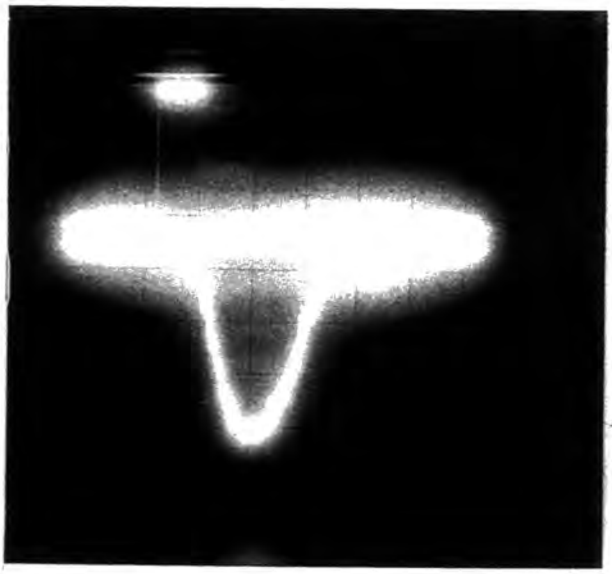


Figure 5.10 Controlling pin stroke with varying solenoid signal duration.

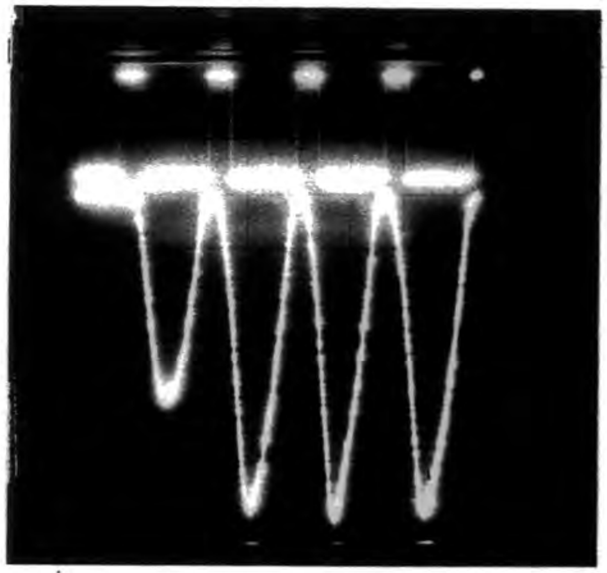


Fig. 5.11 Skiving at resonance conditions

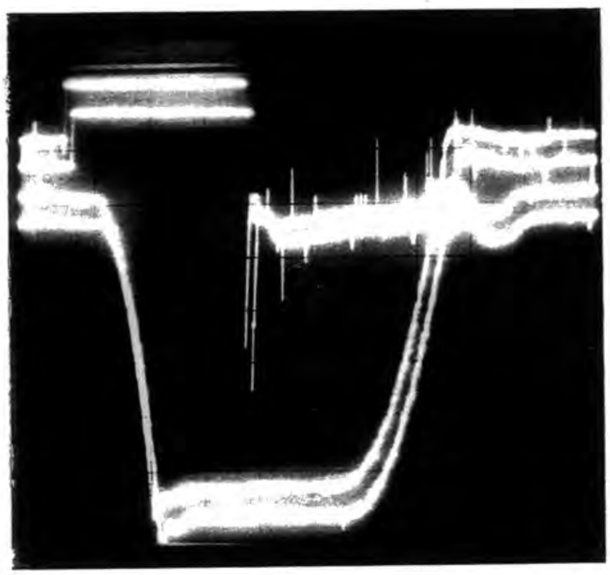


Figure 5.12 Comparison of actuator behaviour with and without discharge circuit.

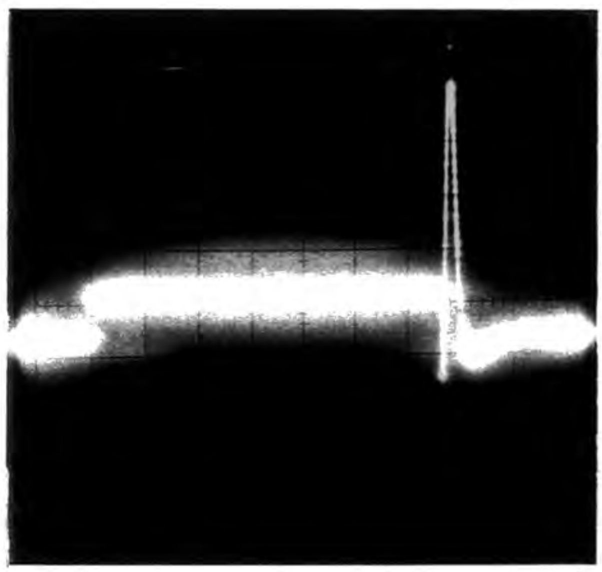


Figure 5.13 Solenoid discharge characteristic

The photograph in figure 5.12 compares the behaviour of the system including R1 and D1 and excluding them. In this case the voltage across A and B was measured in both cases. The upper characteristic in the photograph is the case including D1 and R1 ; the lower one excludes them. As a step further, the current across R2 was observed as in photograph 5.12. Here it may be identified that the time delay for discharging the solenoid is relatively short if compared with the duration of the pulse (33 msec). Note that the measurement shown in 5.12 involves the same circuit, but excluding R1 and D1.

The final stage was to examine the solenoid detached from the actuating mechanism, to see if there would be any change in the voltage characteristic. To do this the voltage across the solenoid (extracted from the system) was examined. In this experiment obviously there is not any force to retract the core of the solenoid after the pulse is terminated. However the characteristic seemed to be identical with the one shown in figure 5.12, although the system is free from all mechanical aspects.

The conclusion from these experiments was that the delay t_4 - t_5 cannot be justified with the argument of case i. This eliminates also case iii.

It is therefore expected that the delay t_4 - t_5 is due to the argument of case ii. described above. During experimentation, it was also noted that after Vi has seized to be applied to the solenoid, the core of the solenoid remained held in the shell. To retract the core from the shell it was necessary to exert a certain amount of force. As soon as the contact of the end of the core with the back wall of the shell was broken this force was instantly eliminated. It seemed thus that a residual magnetic field was responsible for holding the core after Vi had dropped to 0 V. Hence this feature is considered to be responsible for the delay t_4 - t_5, to a certain degree, together with the other components of argument ii. Hence to improve this constant delay of the system, some (or all) of the following steps may be taken in system development :

- Increase somehow the force that retracts the pin to its datum (return spring or other),
- Reduce the inertia that this force has to overcome. This may be done by replacing the aluminium levers with plastic ones.

- Do not allow full recovery of the solenoid core, so that residual magnetism is not generated.

- Use double acting solenoids.

The last of the three sections of the displacement characteristic is the *retraction delay*. The interval t_5-t_6 is clearly due to the mechanical properties of the system and there is nothing that can be done to alter it but to modify the system, by adding retraction forces. However addition of retraction forces means greater forces to overcome during pin insertion, and thus more powerful actuators. Thus a balance of compromise has to be calculated in any case. Finally The interval t_6-t_7 indicates a slight vibration at the instant that the pin has reached its datum and it is expected to be due to the backlash in the joint between the core of the solenoid and the lever. Resolution of this issue is not necessary as it is expected that the present vibrations are too small to cause a hazard in skiving.

5.5 Method for investigation of skiving overshoot

Having obtained a value for the response characteristic of the actuating mechanism, it was essential to evaluate the skive overshoot of the mechanism in practice. To do this, dynamic experiment was carried out. The dynamic experiment was simply the implementation of skive stripes on leather components. This was done at relatively low conveyor speeds (52.63 mm/sec), to achieve long execution time without the need of skiving extremely large stripes, and thus needing very large components. The depth of cut was adjusted to be in the region of 40% to 50% of component thickness. Component thickness was in the range of 1.6 to 1.8 mm. Measurement of the length of the skive stripe could be easily translated into time duration of skiving, given the conveyor velocity.

The logic behind this experiment is that, if measurable skive overshoot does not occur then the effects of knife drag and/or pin response time are negligible. If overshoot occurs, then it is necessary to compare the time taken for the overshoot, with the response time of the actuating mechanism. The latter comparison would indicate whether the alleged pin retraction delay is the only cause for the overshoot. In case that there is a difference between the two, that will be the contribution of the knife drag to the overall delay and consequent overshoot.

To implement the above plan skive stripes were made, then measured to estimate the time of skiving. In each case the intended time of skiving was evaluated by calculating the time elapse between the corresponding software instructions.

For this experiment it was considered important to be able to instruct and execute with high accuracy and repeatability the following cycle of control :

insert pin
hold for time tl
retract pin

This implies the ability to define, by the driving software, a specific time interval through which the skiving operation is intended to be performed, if possible with tolerances in the regions of few tens of nsec. In other words, before any experiment took place it had to be reassured, that it was possible to state the intended length of skiving l_p (fig 5.1) within fine tolerances.

To achieve this it was necessary to program in assembly language. Furthermore the program structure should be such that, the part which defines the time of pin holding is long enough, with respect to the duration of the execution of the rest of the program, so that the latter becomes negligible. In such a case, the time execution of the code responsible for skiving becomes virtually equal to the duration of the whole program. Hence it is possible to make accurate measurements in experimentation.

5.5.1 Dynamic evaluation of skive overshoot

A suitable program was written in M68000 assembly language, to produce a train of 0->1->0 pulses on a solenoid, where 0 corresponds to pin retraction and 1 to pin insertion. The program was adjusted to execute specific actuation cycles which should theoretically result in corresponding lengths of cut. Those lengths were :

case i. program instruction time t_p = 2.359 sec (for 1 T)
settings : active pins = 1
distance between knife and pin 0.5 mm
belt speed =52.63 mm/sec
substrate thickness = 1 mm
This should result in intended length of cut t_p = 124.1 mm.
The length obtained was t_s = 124.7 mm, i.e. overshoot 0.6 mm.

case ii. program instruction time t_p = 21.233 sec (for 1 T)
settings : as in case i, except that active pins = 10
This should result in intended length of cut t_p = 124.2 mm.
The length obtained was variant across the same skive edge as
minimum t_s = 126.4 mm , i.e. minimum overshoot = 2.2 mm
maximum t_s = 127.2 mm , i.e. maximum overshoot = 3.0 mm
The central regions of the skive edge were longer than the outer ones

case iii program instructs the shortest possible skiving y-length (y-resolution)
settings : as in case i except that no superstrate was used
computed y-resolution due to delay characteristic : 5 mm
(with 37.97 msec total effective delay for depth of skiving 0.9 mm)
obtained y-resolution = 4.55 mm

The above results are averaged values taken from several samples and the maximum combined error of measurement in experimentation is +/- 0.005 mm.

5.5.2 Conclusions for causes of skive overshoot

The primary conclusions from the above results are :

- The intended length of cutting is shorter than the actual length obtained i.e. the condition $t_p <> t_s$ is true, thus overshoot takes place.
- The overshoot is dependent on the amount of pins used (i.e. width of skive strip) and the overshoot in such cases is variable.

From the results of case i alone, it may be concluded that the overshoot (0.6 mm) is less than the one computed from the static characteristic of the actuating mechanism (1.61 mm). The direct conclusion from this is that the static response characteristic of the actuating mechanism (for pin retraction) is improved in dynamic conditions due to the other forces assisting retraction, as explained earlier.

However case ii indicates that the theory explained in section 5.3 (fig 5.2) is valid. It is evident that the knife drag is present and that it is responsible for system delay in component retraction, and the corresponding overshoot. The variance of the overshoot in this case may be improved or even eliminated with the optimum choice of the substrate thickness. In any case, this variance will always be related to the leather type and thickness of the component, factors which determine its stiffness along its plane.

Nevertheless the above conclusions do not eliminate the need for improvement in the response of the actuating mechanism (and resolution), due to case iii. In this case it is observed that although the response of the actuating mechanism is improved by the system forces (1.45 mm overshoot instead of 2 mm), the response still limits the y-resolution. This limitation may not be directed towards the knife drag alone, because the overshoot in this case is larger than that of case i.

Hence the most influential factor for skive overshoot is the knife drag but this is a conclusion only for low conveyor speeds. At high speeds the response of the actuating mechanism will inevitably increase overshoot. This is because there will be a limit for conveyor speed, above which the improvement in the response due to dynamic conditions, will be counterbalanced and exceeded by the difference between the linear speed of the conveyor and the speed of pin retraction (66 mm/sec as calculated from the static characteristic).

5.6 The need for higher pin matrix resolution

So far it has been identified how the response of the actuating system, influences the y-resolution of the skiving system. It is as easy to observe that the value of the y-resolution (as for the x-resolution too) is primarily dependent upon the physical size of the pins used in the pin matrix. This means that the wider pins used, the lower the system resolution. Since early days, it was suspected that the present resolution of 5 mm pin spacing, would not be satisfactory for commercial purposes. This was confirmed with the stepping effect on diagonal skive edges, and with the inability of superstrates to completely smooth this feature.

Unfortunately increasing system resolution is not a straight forward solution. The reason for this is that implementation of a particular pin resolution depends upon more than one variable. To justify this statement, let us undertake the problem of increasing pin resolution, from a high level of reasoning. This reasoning is graphically illustrated in figure 5.14.

Increasing pin matrix resolution would have direct consequences in three main directions for consideration. The first such issue would be the interface between the pin and the leather. Higher pin resolution could result in damaging the upper surface of the superstrate, because of the smaller pin tips. Furthermore the smoothing effect of the superstrate currently used may not be sufficient for higher resolution. Hence due to the above two issues the choice for superstrate would have to be re-evaluated.

The second area of consideration would be the design and implementation of a high resolution pin matrix. The current mechanism involves cylindrical pins, moving through the holes of the housing. With higher resolution, the shape of the pin would have to be re-considered, as smaller diameter pins could imply, bending (damage). Also, the housing could have to be modified due to the new shape but also due to the necessity of drilling adjacent holes very close with each other (present hole spacing = 1 mm). Hence a completely novel design might be necessary for greater pin compactness. Having considered such a mechanism, this should comply with given expectations for serviceability, durability and cost of manufacture, due to the high precision necessary. With pin resolution increasing, the first two characteristics would inevitably tend to decrease and the latter would unquestionably increase.

The last area for consideration would be concerned with the choice of actuator and/or actuation method. If the same type of actuator would be used, i.e. solenoid, increasing pin resolution would mean increasing volume requirement for packing the solenoids together, into solenoid banks. If this is not possible within the present volume boundaries, then there is choice available between two alternatives.

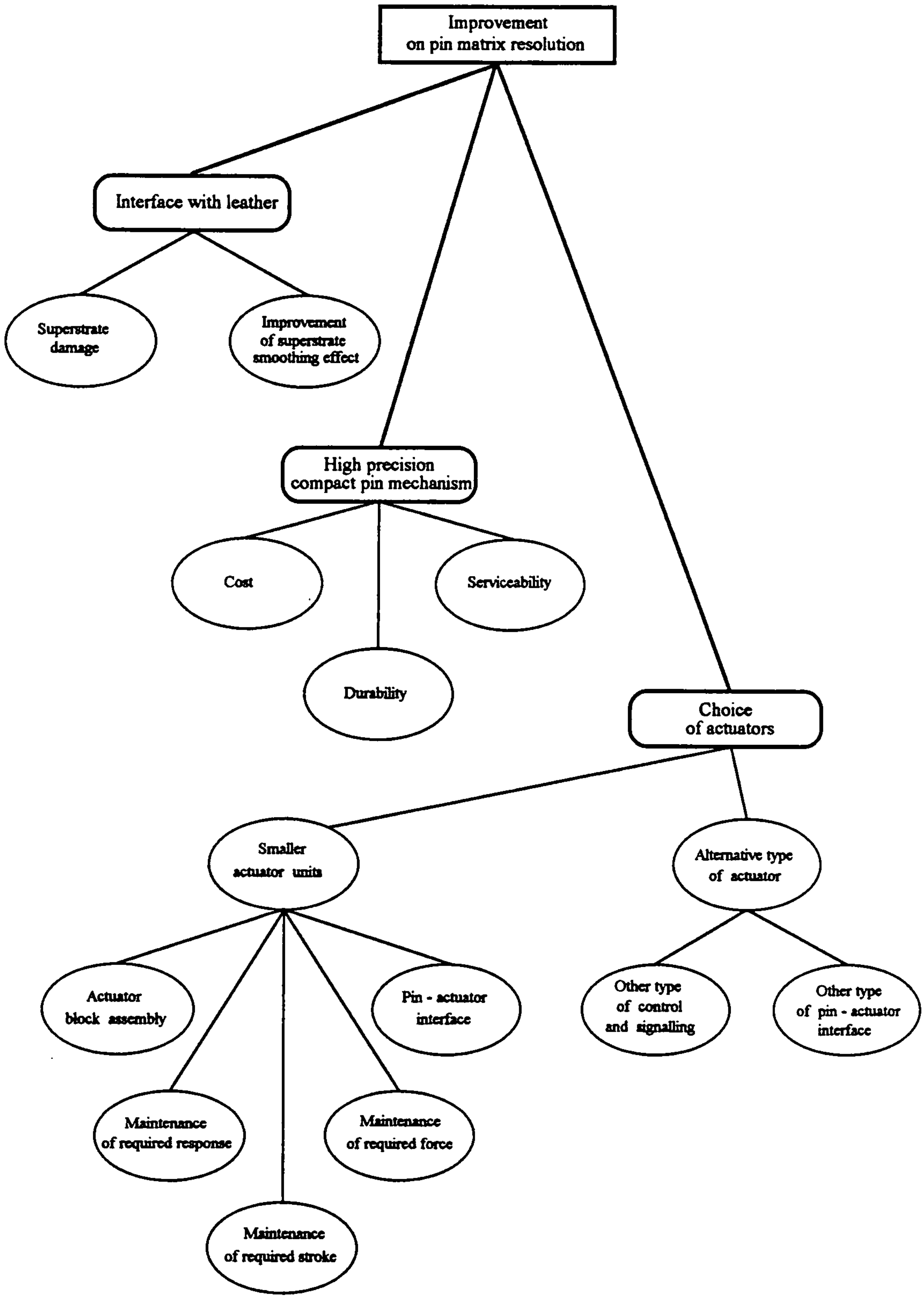


Fig. 5.14 The logical issues involved with increasing pin matrix resolution

One is to use smaller solenoids and the other to modify the mechanism of transmission of movement between solenoids and pins (currently the levers). With the first option it must be kept in mind that by reducing solenoid size it is unlikely to maintain pin stroke and force required, although this is also relative to the particular design of the solenoid [14]. With the second option, a completely new transmission design would be necessary, perhaps one that would allow circular solenoid banks instead of straight ones, or even replacement of the levers with strings. In any case the issue of system response should always take prime consideration.

Finally, if the solenoid were to be replaced with a different type of actuator two major areas would be influenced. One is the form of control and signalling and amount of electronic hardware that would be necessary for a particular actuator. The other area again is the method of movement transmission and the type of movement amplification that may be necessary.

The reasoning procedure described above is typical for improving the physical resolution of the skiving system. These considerations were taken into account for the design of the high resolution skiving module that is described in chapter 9 Further system enhancements, and for alternative actuation methods considered.

5.6 Conclusion

In this chapter it was explained how the electro-mechanical features of the actuating mechanism influence the performance in skiving quality. To examine this influence closely it was necessary to make assumptions about other possible factors contributing to the same system features and attempt to distinguish between influencies by elimination.

Through these attempts it has been demonstrated that the regulation of the behaviour of the present skiving mechanism is a complex issue. Optimum balance for best skiving quality may only be achieved as a careful fine tuning, between the influencing factors discussed here and in chapter 4.

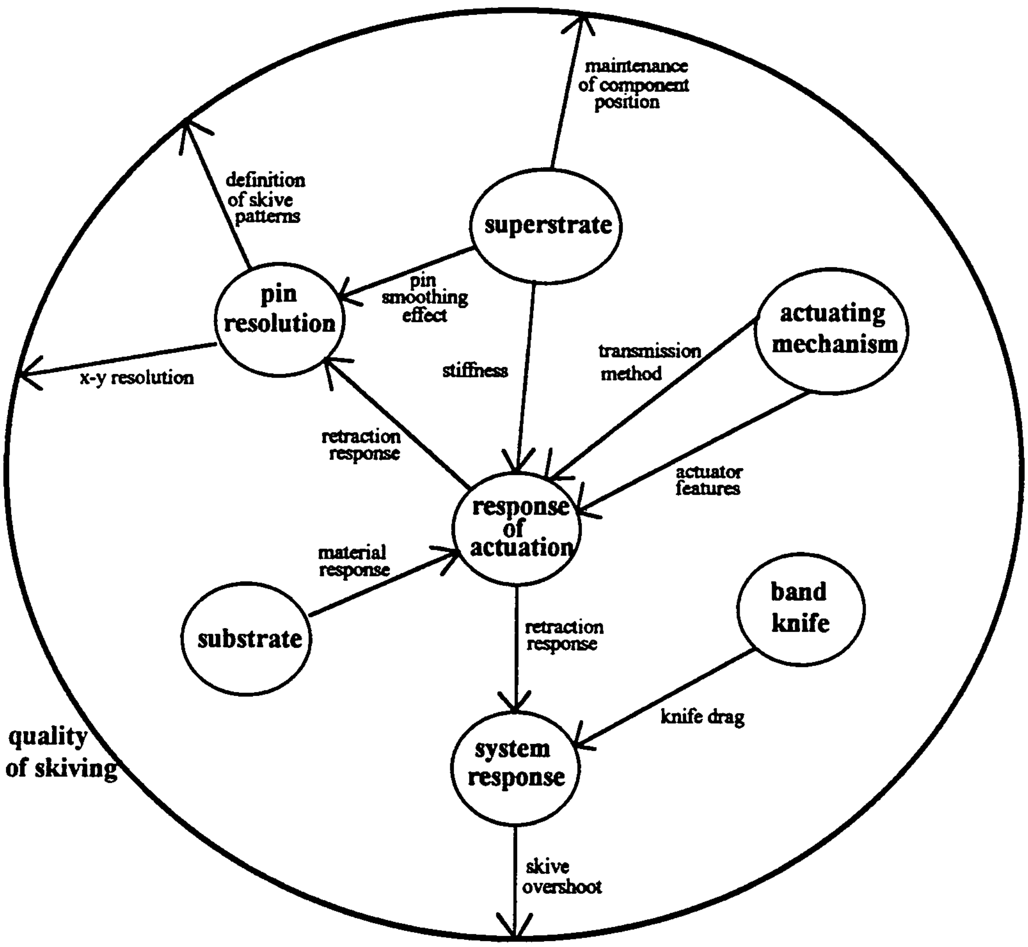


Fig. 5.15 The interaction of system parameters to define quality of skiving

Also, in many cases, it may seem helpful to modify constants such as pin resolution, actuator response etc., in order to obtain a better system balance. Although the scope of this research lies short of implementing this fine tuning or system unit development it is essential to demonstrate the way in which the constants of the system interact. This is illustrated by means of a function diagram in figure 5.15.

In this diagram the quality of skiving is represented with the outer circle. Within the circle are contained all the system components that form the "engine" of skiving quality. These components are represented by the smaller circles. Their interaction is indicated with the arrows. Arrows between components indicate particular features of one influencing another. Arrows between components and the outer shell indicate the system features of the outer logical layer, that determine directly skiving quality. Although this diagram is derived by those issues already discussed, only the main influencing factors are shown, for reasons of simplicity.

CHAPTER 6

THE MECHANICAL INTEGRATION OF THE SKIVING SYSTEM

6.1 Introduction

In the previous sections there has been a description of all logical steps taken to verify a suitable method for automating the process of skiving. It was also indicated which system parameters were responsible for the satisfactory behaviour of the skiving mechanism. Having come to a stage of controlling the processing mechanism to produced the desired result, this mechanism should be integrated with the rest of the overall system components, to prove that the process may be fully automated.

This chapter is concerned with the mechanical aspects of the integration of all individual modules to a fully automatic skiving system. These elements are five :

- the vision rig
- the splitting machine
- the twin belt handling mechanism
- the driving motors
- the skiving mechanism

The schematic diagram of figure 6.1 illustrates how the above elements are assembled to produce the overall mechanical structure of the skiving system.

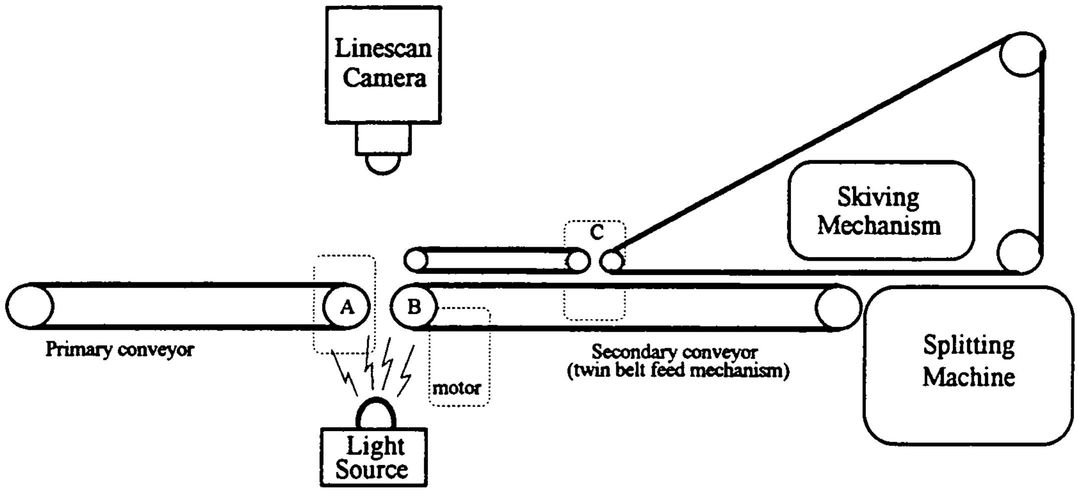


Fig. 6.1 The main elements forming the mechanical assembly of the automated skiving machine

6.2 Integration of the vision rig

The vision rig used in this project was identical to the one used during the research for the automation of the stitchmarking process [3]. Initially it comprised of a steel base structure containing a camera support, a line scan camera, a light source underneath, and a dual - stage conveyor system. Its primary and secondary single conveyors were designed to feed through components, for the process of identification and to later present those components to the process area. Also suitable adjustment of the relative conveyor distances, to allow trouble free component flow, and the position of the light source were issues already been resolved [3].

However the secondary conveyor used for the stitchmarking process was of different and unsuitable structure for the process of skiving. Furthermore prior to integrating the vision rig to the splitting machine, the latter had already been modified provided with the appropriate substrate embedded conveyor. All the experiments already discussed were carried out upon this basis. It was therefore necessary to remove the secondary conveyor mechanism from the vision rig. Also it was essential to modify the front end

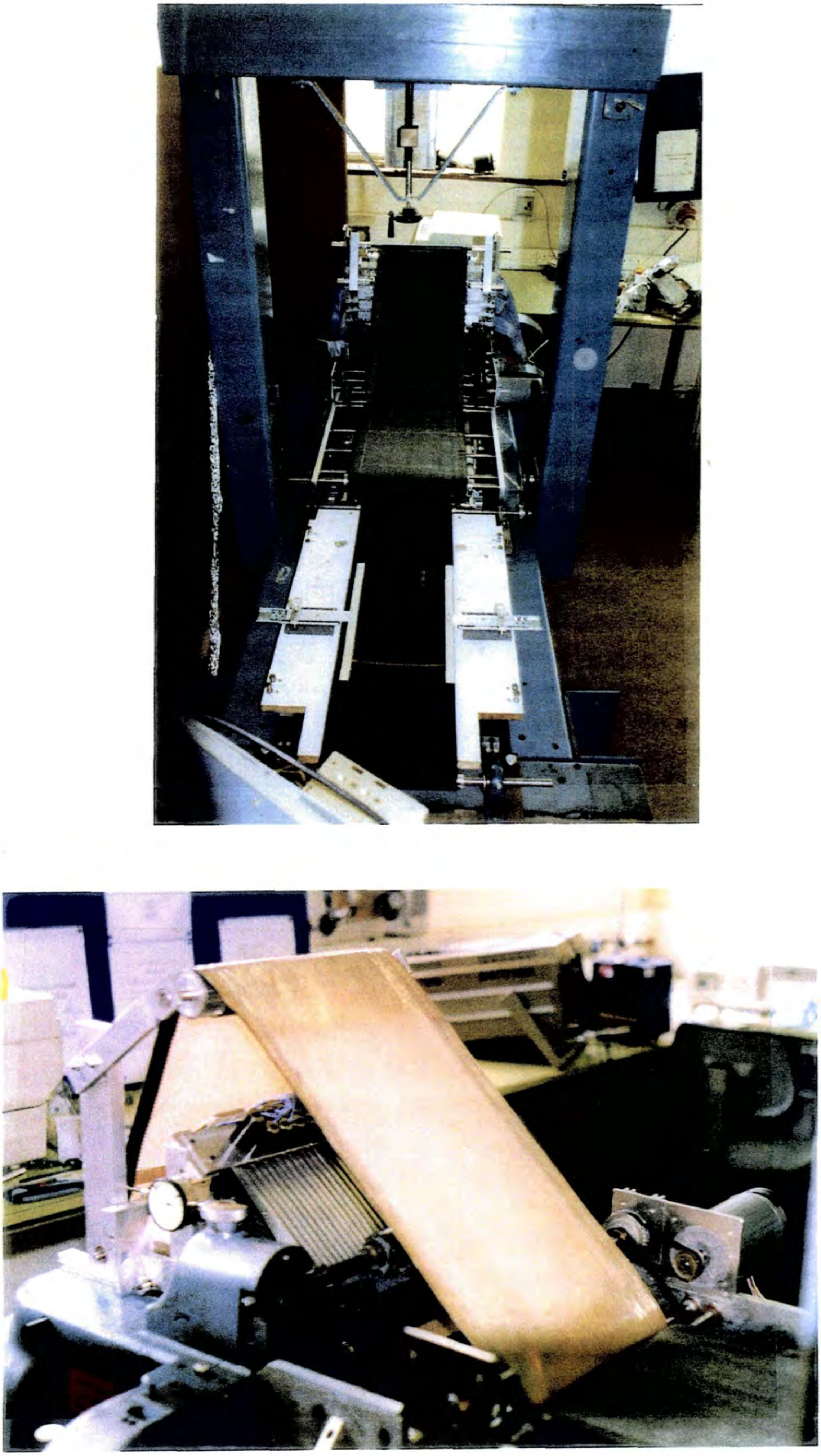


Fig. 6.2 The fully integrated automatic skiving system

of the base structure of the vision rig, so that it could be brought together with the splitting machine, to form a single unit. All necessary procedures thus took place, to ensure that the newly integrated system would be free from vibrations during operation, and that the two conveyor systems would be at exactly the same operating height and orientation. The photograph in figure 6.2 illustrates the integrated system.

The main disadvantage with the mechanical structure of the current system is that, it is not possible to transport it without a major dismantling procedure, and loss of critical system adjustments. However, this was acceptable for an experimenting system and in any case the future commercial system would inevitably have a different structure. It is expected that the prototype system would employ a much newer type of splitting machine, such as the one illustrated in figure 2.2. In this case it would also be expected that the vision rig and conveyor system would be components mounted upon (i.e. belonging to) the modified splitting machine and not vice versa.

6.3 The construction of the twin belt feed mechanism.

As explained in chapter 4, the twin belt feed mechanism consists of two individual conveyors, the upper, the superstrate/conveyor and the lower one compliant with the substrate layer. Both mechanisms undertake a role in the process of skiving as well as in component transfer. However their mechanical structure and assembly is totally different.

Because both conveyors are meant to be in strict synchronisation with the overall system function, it was necessary that they are made of timing belts or that they should at least contain a means for mechanical timing with the system. Another requirement for the conveyors is that they should be flexible. Finally the lower conveyor should maintain a flat surface along its entire width.

One of the best possible solutions for this task was to use timing belts, as they contain the properties of durability and flexibility and they produce virtually no backlash, when in mesh with timing pulleys. The lower conveyor mechanism was initially made of a single 240 mm wide timing belt, upon which the substrate material could be laid.

This option proved to be unsuccessful because the timing belt tends to buckle across its width, when tensioned. To overcome this problem, the conveyor was made out of a series of 25 mm wide adjacent timing belts. The overall belt is driven by two timing pulley bars, one at each end. These bars contain a series of suitable flanges to limit sideways belt movement. Figure 6.3 illustrates the structure of the lower conveyor belt. Please note that geometric proportions have been altered for the purpose of illustration.

The superstrate material is cemented upon the belts, forming a single flat conveyor bed. It must be noted that this belt structure contains gaps between the individual timing belts. These gaps are equal to the width of the separating flanges of the pulley bars. In theory these gaps could present the problem of discontinuity of the substrate base, and influence skiving in those regions. However, because pin insertion occurs above the front pulley bar, these gaps are covered by the presence of the flanges, and the discontinuity of the substrate base is eliminated in the critical regions.

The upper conveyor mechanism is made by two basic elements, as shown in figure 6.4. There are only two timing belts, one at each side, across the width of the conveyor. The timing belts are only responsible for maintaining system synchronisation. On the flat side of the belts are cemented the two sides of the middle material, which is the superstrate mentioned earlier. The overall width of the upper conveyor is greater than that of the lower conveyor, so that when the two come in contact, the timing belts of the upper lie outside the boundaries of the lower conveyor.

The above solution was the only possible alternative because of the two following reasons :

- The upper conveyor must maintain synchronisation with the lower one
- The active part of the upper conveyor cannot include the presence of any material other than the superstrate.

Hence unless a suitable superstrate material was found to include at its edges a means for timing, the lower conveyor has to be consisted of two individual components. During experimentation for the trial of alternative superstrate materials, (described in chapter 4), in some cases it was not reliable to cement the superstrate directly onto the timing belts.

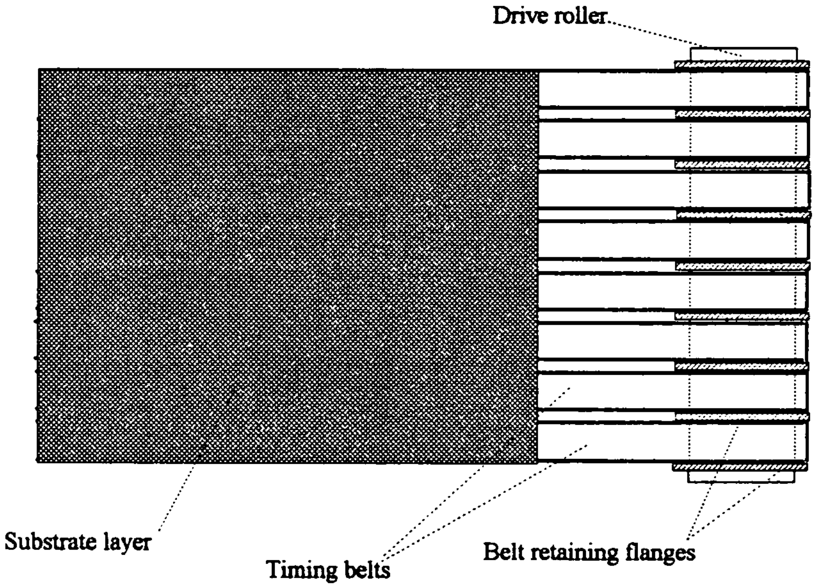


Fig. 6.3 The structure of the lower conveyor, part of the twin belt feed mechanism

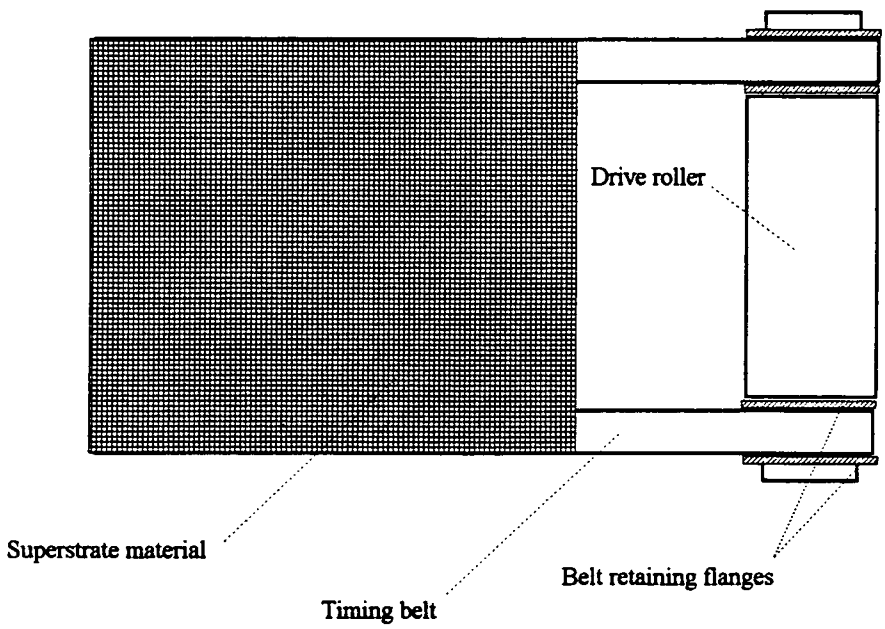


Fig. 6.4 The structure of the upper conveyor, part of the twin belt feed mechanism

This difficulty was at its extremes in the case of the Tygaflor material. The reason was that the PTFE surface could not be cemented reliably, even if etched. To overcome this problem the following solution was tried and proved to be a reliable joint. The superstrate sheet was stitched along its sides to stripes of thin cotton tape. The other sides of cotton tapes were in turn cemented to the timing belts.

In this case the presence of the stitches and the glue impregnating the cotton cloth, introduced stiffness. This stiffness caused problems in the regions where the upper conveyor had to change direction over rollers with relatively small diameters, and also in the area over the knife guide, where sharp angles are present. Because of this the conveyor could not possibly be operated, without applying to it extreme tensioning forces. In turn these forces could not be allowed, because they cause bending in the drive shafts of the conveyor rollers, and large forces against the insertion of pins. For these reasons it has been concluded that the choice of the superstrate should be such that direct joints with the timing belts are possible.

As it is shown in figure 6.1 the upper part of the twin belt mechanism (referred to as the upper conveyor) consists of two smaller conveyors. The initial idea was to implement a single upper belt, running in a triangular path. However the limitations in standard timing belt sizes made this impossible. Larger size (length) of timing belt meant belts of thicker pitch and thus less flexible. For the purpose of flexibility it had been concluded that the largest pitch tolerable is the XL range and the largest timing belt of this range is the 600XL with 1.6 m length.

A solution that could be suggested for this problem was to shorten the lower conveyor, to eliminate the need for a secondary upper conveyor. This solution could not be implemented, because in this case the distance between the skiving mechanism and the vision gap would be too small, to accommodate large leather workpieces. Also, it has to be kept in mind that component recognition has to terminate before skiving may commence.

Hence it was decided that the upper conveyor would consist of two parts. Nevertheless this option introduces a potential advantage to the overall system. This is because if there are two or more upper belts, it is inevitable to have a gap between them, no matter how small. This gap could be used to give access to optical (or other) sensors, if position sensing for component movement was to be implemented,

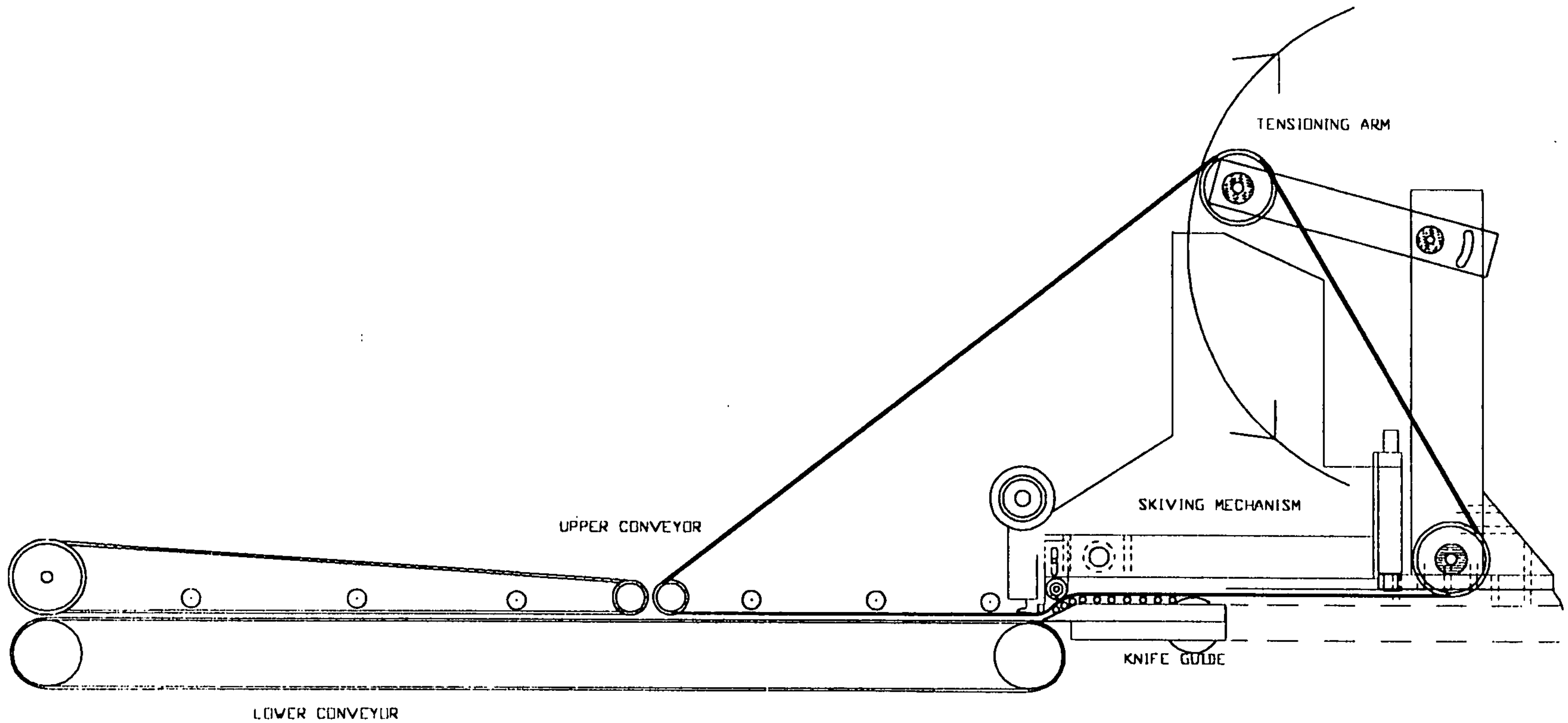


Fig 6.5 Drawing of the twin belt feed mechanism, integrated with the skiving mechanism and the splitting machine

in future system development.

Figure 6.5 gives a more detailed view of the twin belt feed mechanism mounted to the cast body of the splitting machine. This is an accurate scaled drawing of the real mechanism. The first belt of the upper conveyor has not tensioning adjustment facility, as it runs on fixed ends. Also the first roller (LHS) of this belt is positioned slightly away form the vision gap, if compared with the corresponding roller of the lower conveyor. The reason for this was to avoid interference with the vision system, which relies upon the lower conveyor to define the vision gap.

The second belt of the upper conveyor is designed to run underneath and over the skiving mechanism. Belt tensioning is implemented via the movement of the adjustable arms, above the skiving mechanism, holding the top idler timing roller. The gap shown between the two parts of the upper conveyor, was kept to a minimum, by choosing smaller timing pulleys, at both facing ends.

Due to the structure of the upper belt, and due to the nature of the superstrate material, it is evident that the middle regions of the upper conveyor would inevitably present some floppiness. One could argue that full contact of the tri-layer may not be kept always, in regions before entering the process area.

Therefore is those regions component movement could always take place due to unforeseen reasons. One way to avoid this was to provide the central regions of the conveyor's rollers with enough thickness, so that, when the timing belts are tensioned, so would the interior regions of the superstrate. This was implemented and the results were as expected beneficial.

To assist this purpose even further, the system was provided with six intermediate free rollers as shown in figure 6.5. These rollers rotated in vertical slots, i.e. their vertical position was not fixed to avoid component jamming or shift, and to allow for variability of component thickness. Because of the slots, the rollers are capable of lifting when the incoming component passes underneath, and assist tri-layer contact by applying their own small weight. Going one step further, the component grip could be assisted also by applying springs at these rollers, forcing them even further against the components. However, as mentioned earlier, there is a limit of roller pressure above which leather components tend to move and lose their original position [10]. Thus it is important that this is kept in mind during future system development.

The rollers mentioned above serve another purpose too. Because the substrate is always in contact with the pins, although its smooth surface, it was considered necessary to lubricate it and thus to slow down wear. The lubricant used is a silicon based liquid and its re-circulation is maintained with the aid of these rollers.

6.4 Component exit from the process area

To this stage it has been explained how the twin belt feed mechanism assists component transfer to the process area. However immediately after the instant when the trailing edge of the component has left the pin matrix, the only means of further transport away from the mechanism is the upper belt alone.

During this interval, the component is expected to slide around and over the knife guide, only with the aid of the upper belt. This is illustrated in figure 6.6. This situation caused some concern initially, for as the fact that components could curl and jam due to the knife guide, during skiving. Later on, having smoothened the sharp edges of the knife guide, these concerns proved to be unnecessary, as components flowed out of the mechanism uninterrupted. This of course was also due to the presence of an extra guide roller added underneath the skiving mechanism base. This roller shown in the drawing of figure 6.6. It is an idler roller containing two timing pulleys and it is supported by adjustable holders. By suitable adjustment in the vertical direction, this roller forces the upper belt to follow the closest possible path to the direction of the slope presented by the knife guide. If the adjustment is done correctly the processed components are successfully guided out of the skiving system.

It must be noted that the implementation of the addition of this roller was a particularly difficult task, due to the lack of room, between the pin matrix, the skiving frame base and the knife guide. However it had been concluded that without the presence of this roller, components were often not able to exit the process area. Since this conclusion it has been defined that the above guide roller is one of the most essential components of the skiving mechanism, if such a mechanism includes a knife guide.

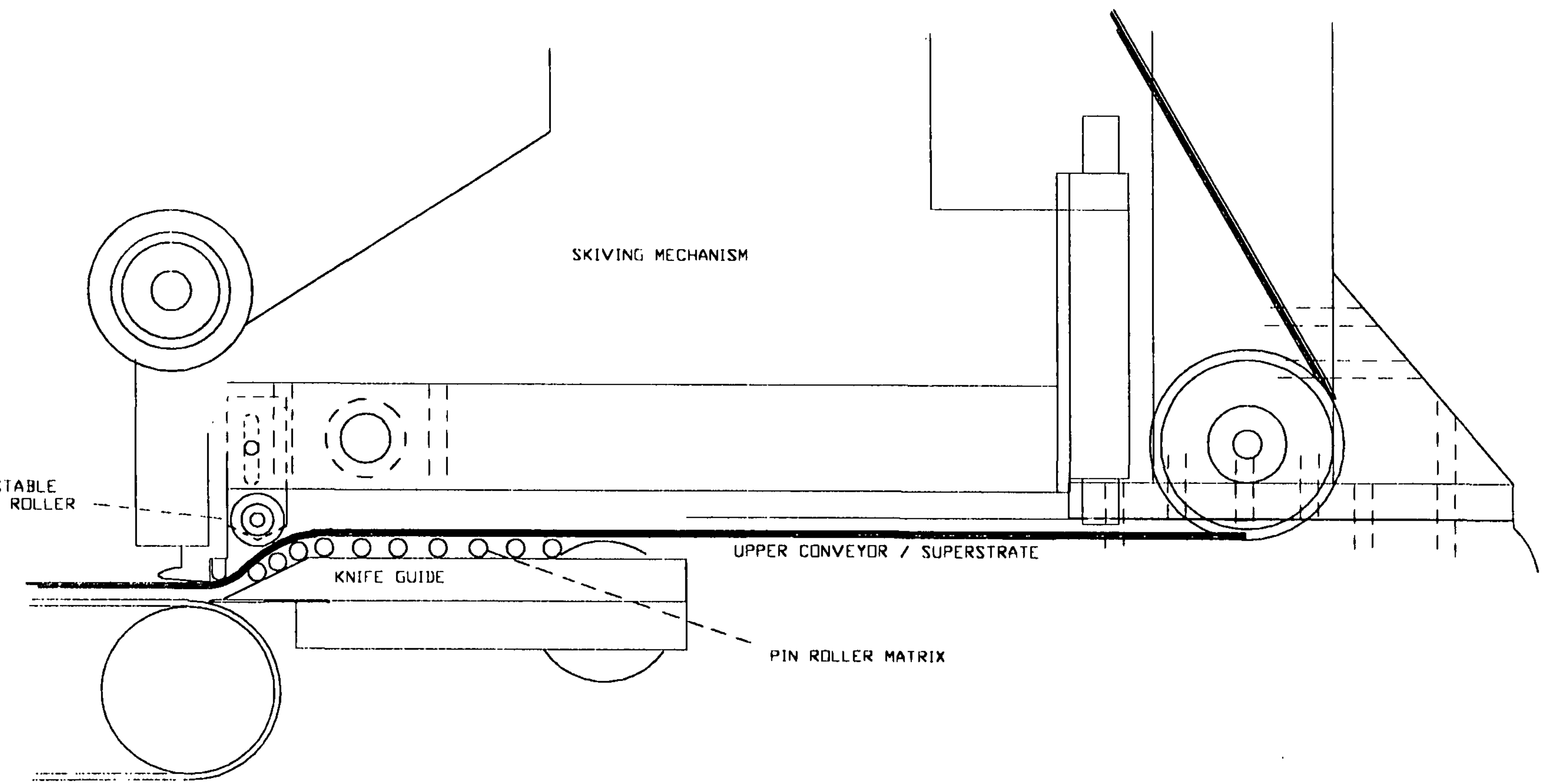


Fig. 6.6 Close profile of the skiving process area. The elements involved in component exit from the process area.

In any case, because component accumulation /and or jamming is still conceivable, (although very rarely occurred), it is suggested that the surface of the knife guide is compliant with a matrix of pin rollers, as shown in figure 6.6. This is a simple and low cost system enhancement, recommended for future system development.

6.5 Mechanical drives of the component transport system

As explained in chapter 3, for the desire to eliminate the need for movement feedback, and for the requirement of strict timing synchronisation, all parts of the transport system are driven by stepping motors. The stepping angle of the motors used, has been decided during the implementation of the stitchmarking system and was related with the operating resolution of the vision system. The skiving transport system is driven by three individual motors all controlled by a single stepping motor control unit. The drive points of the system are identified as points A,B and C in figure 6.1.

Because of the different conveyor roller sizes, (for reasons already explained), it was necessary to manufacture suitable gear reduction or amplification mechanisms so that all belts of the conveyor system move at the same linear velocity. The schematic diagram in figure 6.7 illustrates the way in which all moving parts of the mechanism are linked and driven, as well as the gear ratios between them. In this drawing the real geometric proportions of the contents has been altered for illustration purposes. Another view of the component transport system (twin conveyor only) is given in drawing 6.8. This is a realistic drawing transparency of the plan view of the conveyor system and comprises of all system rollers, driving and driven ones. The function of each rollers is given below :

Roller	*Purpose*
A	Driven by E. (primary conveyor)
B,C,D,G,H	Idler rollers lying on vertical slots on the side support plates. They maintain tri-layer contact and lubricate the superstrate. They are covered with Nercoprene in the middle sections to ensure soft contact.
E	Driving A via a timing belt and timing pulleys. (prim. conveyor)
F	Driven by E via the idler pulleys.

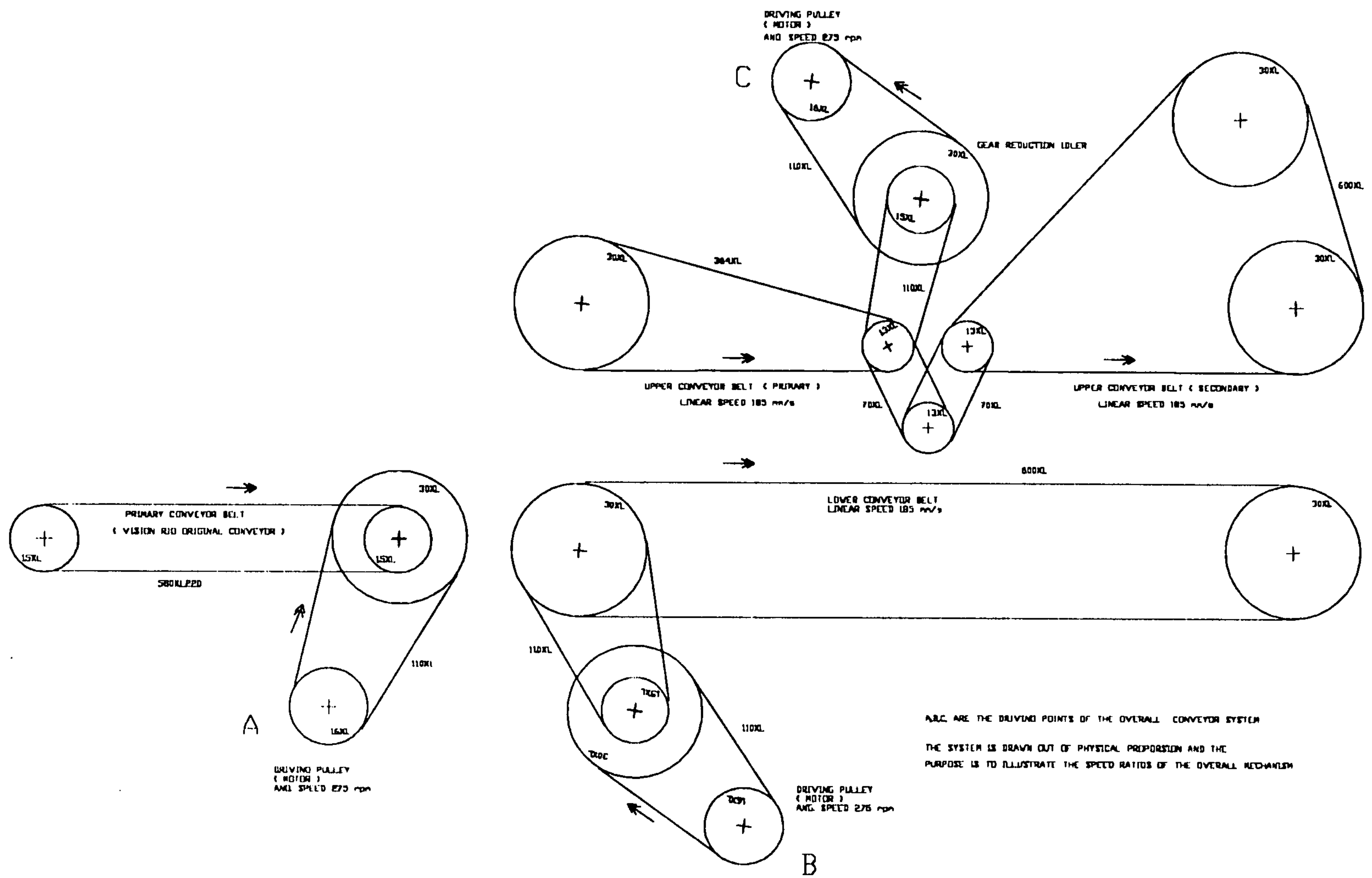


Fig. 6.7 The drive mechanism of the component transport module of the automated skiving system.

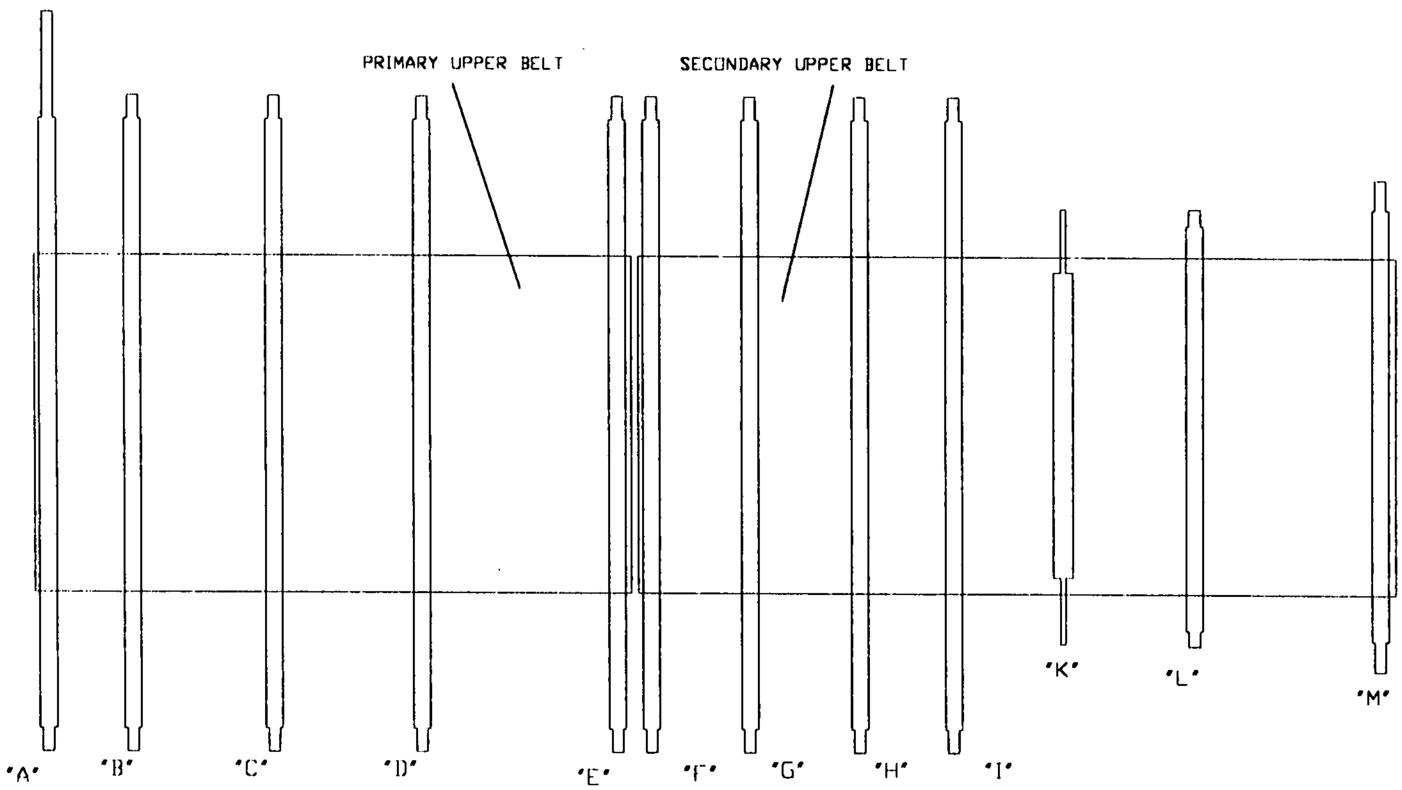


Fig. 6.8 The mechanical structure of the twin belt conveyor mechanism

I	Initially an idler roller but later modified to a fixed one. Covered by Nercoprene to allow for incoming component thickness. It is driven by F and is provided with timing pulleys. It maintains tri-layer contact just before component entry to process area.
K	Driven by F. Guides upper belt over the knife guide.
L	Driven by F. Guides upper conveyor over the actuating mechanism and maintains belt tension.
M	Driven by F. Located at the base of the support column. Maintains component contact with upper belt, during exit from the process area.

6.6 Conclusion

The mechanical integration of the skiving system involved four major tasks. The modification of the vision rig, the modification of the splitting machine, the construction of the twin conveyor system and their assembly to a single unit. The most demanding and complicated issue has been the construction of the twin belt feed mechanism. This is because in this particular system the transport mechanism is responsible for carrying three additional tasks, apart of its main one.

These tasks are component recognition, position maintenance and participation in the skiving process. However one issue that was not attempted to be resolved in this research is to maintain the conveyor surfaces clean from leather dust and small component cut-offs. This task is necessary to maintain good tri-layer function and to avoid interference with the vision system. This issue is not new nor particular to the skiving system and it is expected to be resolved by BUSM at a later stage. Also it would be important to note that during this project the primary conveyor of the transport system was not altered from its original form. This was a conveyor made out of a single wide timing belt. Although this did not cause any problems due to lack of vibrations, it is assumed by default that the construction of this conveyor should ideally be identical to the secondary lower conveyor.

Also, it is expected that the technology applied to the stitchmarking process [3], to ensure successful component passage over the vision gap, should be applied in the skiving system too. During experimentation it was clarified that some particularly floppy leather components slightly bend over the vision gap during recognition and their image was distorted. Although this happened rarely, it is concluded that the skiving system is in need of the resolution given for the stitchmarking process.

The overall physical construction of the system, is not that of a commercial product. However during the integration and during the later successful behaviour of the skiving system, the critical issues of the design of the system were identified, and they will form a basis for the implementation of the future prototype.

CHAPTER 7

THE ELECTRICAL INTEGRATION OF THE SYSTEM / GENERATION OF SKIVE PATTERNS

7.1 Introduction

Having completed the mechanical integration of the skiving system, the following and final stage was to integrate the system electrically. The electrical integration of the system comprises of all the necessary software and hardware which would enable all the logical functions described earlier to take place. The overall electrical operation in the system may be divided into two major phases, as shown in figure 7.1. The generation of skive patterns and the execution of skive patterns.

The first major task includes all sequential sub-processes from the instant that the component enters the recognition function until the instant in which the skive pattern for this component has been defined and generated according to its position and orientation in the conveyor. This chapter describes the main aspects of the implementation of this stage. The second major stage contains the sequence of functions involved in the implementation of the handling, timing and executing the derived skive pattern. This stage is the main theme of chapter 8.

It must be noted that the hardware and software configurations presented do not represent the best or most efficient possible method of implementation. In contrast

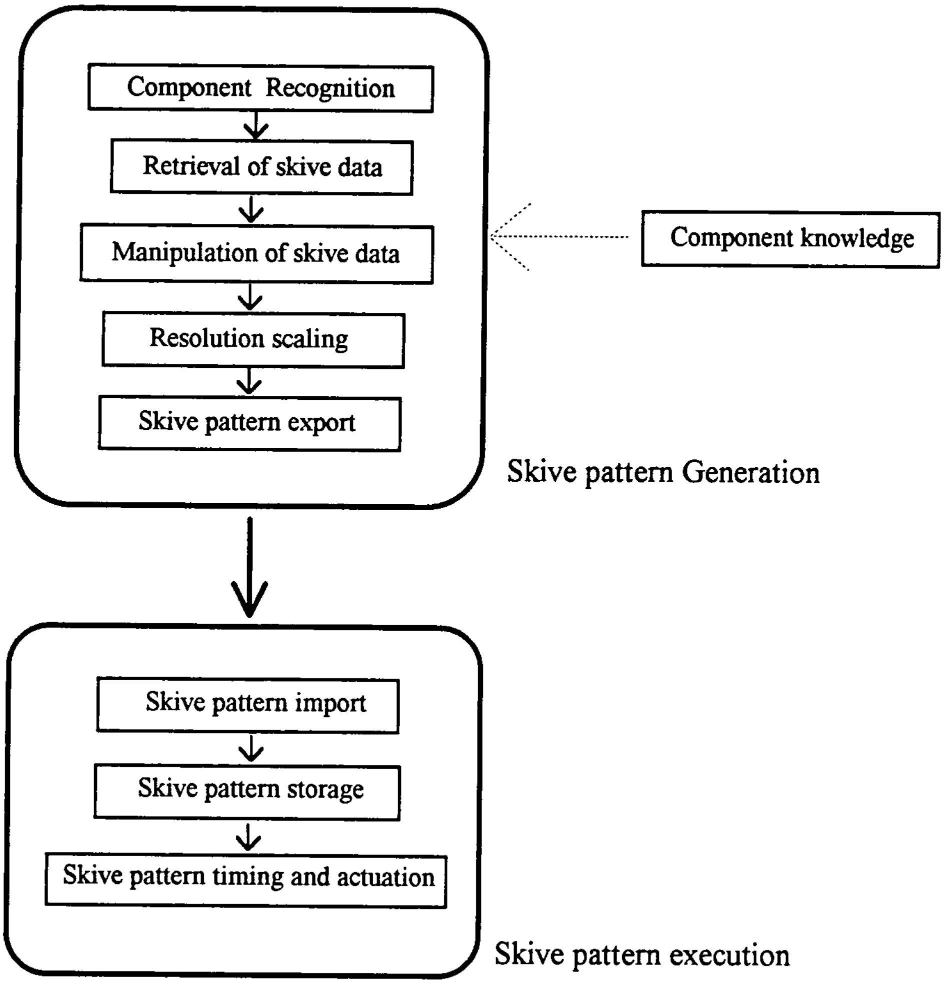


Fig. 7.1 The two major functions of the electrical system

some of the electrical modules used rely on relatively old technology. This work may be portrayed as a successful attempt to prove that the automation of such a process is possible.

The stage of generation of skive patterns is based on the electrical system used in the research for the automation of the stitchmarking process. A similar attempt for electrical system integration has been made[3] successfully in the past by the University of Durham jointly with BUSM and this was to produce a system which could perform automatic stitchmarking on leather workpieces. The work presented in this chapter, in contrast with the content of chapter 8, does not involve novel software specifically written for skiving. This part of the electrical integration was focused upon understanding the way the recognition system works for stitchmarking and identifying its potential control areas to transform it into a system suitable for the skiving process. Having reached this stage the implementation involved mainly enhancement and modification of existing software and hardware to enable automatic skive pattern generation, but also give to the system the flexibility to accommodate different operating resolutions. The latter is because of the possibility of using a skiving mechanism of higher resolution in the future. This feature could be useful even for using this part of the system for different processes, without facing again the necessity for a major system design modification.

7.2. An overview of the hardware architecture of the system

Due to various technology limitations in system integration, the original research stitchmarking system consisted of a number of hardware inter-communicating electronic units. The various software tasks were allocated upon these units, in a way that maximum overall system speed was achieved. The overall hardware configuration of the stitchmarking and skiving systems can be compared in the schematic diagrams in figures 7.2 and 7.3 respectively.

In both systems the linescan camera captures the silhouette of the component being processed. The Z8000 Slave board extracts the useful geometric features of the current shape that are to be used for identification. All belt movements are timed with the camera timing hardware and the overall motor control is held by the Z8000 Master. On this board there are assembly language programs stored in EPROMs, which are responsible for the overall movement control, process sequencing and sub-tasks allocated to the Slave processor. These programs are also responsible for observation and control of the various flags and status signals of the hardware units involved in the overall process, e.g. printer, camera etc.

The Z8000 system is linked with the Compaq 386 personal computer and passes to it the data derived by the Slave and device status signals. The central control of the system, as far as the user is concerned, is held by the Compaq computer. The overall system function is initiated via C and FORTRAN programs that are executed on the Compaq PC. This in turn calls functions to be executed within the surrounding devices

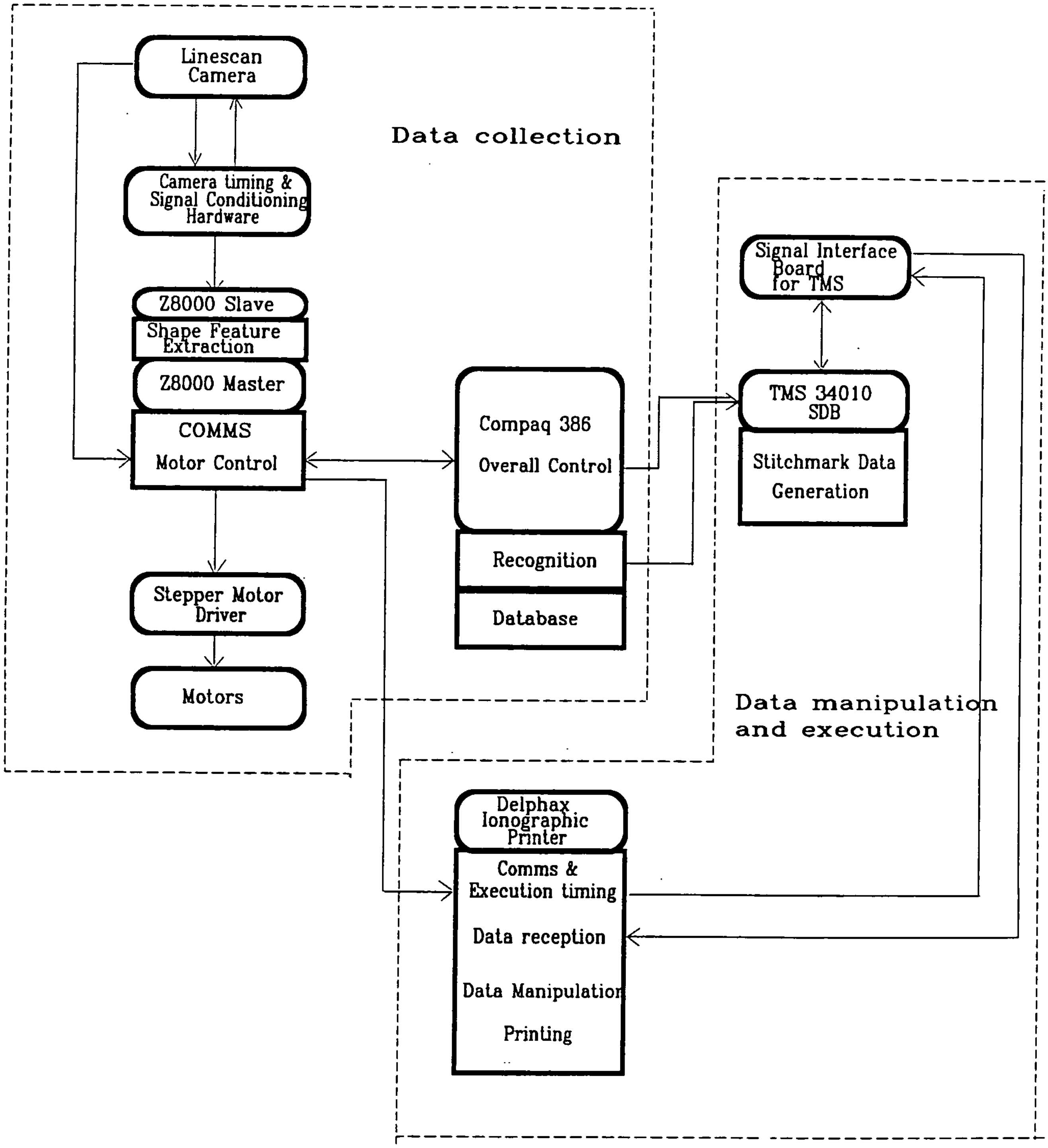


Fig. 7.2 Schematic diagram of the hardware architecture of the stitchmarking control system.

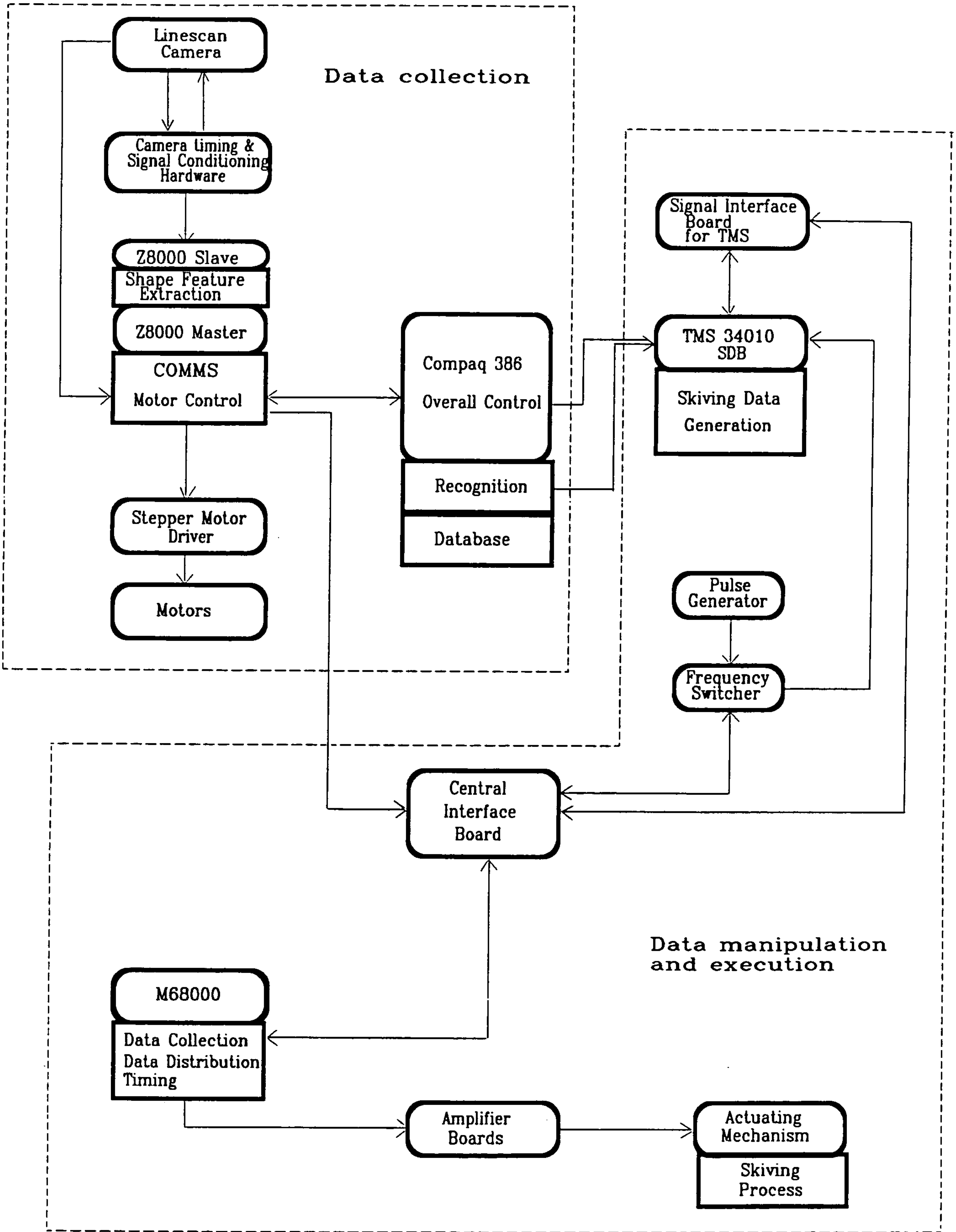


Fig. 7.3 Schematic diagram of the hardware architecture of the skiving control system.

and some within itself. It is here also that all device error messages and status signals are displayed. Finally the PC is also responsible for running the 'teaching' process for new components and skive silhouettes (explained in sections 7.3.4 and 7.3.5).

The database containing all known components to the system and their skive patterns, is held in the hard disk of the PC. The relevant software use the geometric features of the shapes, extracted by the Z8000 Slave, and recognise the leather component under process. Recognition is done by referring to the data which is permanently stored in the database. Having recognised the incoming component, next task is to pass onto the TMS graphics processor the data concerned, defining the exact region where the component should be operated.

The TMS34010 Software Development Board, is responsible for the rapid processing of this data. The definition of the skive (or stitch) pattern is done according to the present orientation and position of the current component. Finally the TMS board exports the skive image to the execution module, which of course is different for skiving and stitchmarking.

The transmission of skive or stitch pattern data is done with a suitable communications protocol, which is different for each system, because of the different execution hardware modules. In the first case shown in the schematic diagram of figure 7.2 the pattern data receiving and executing module is the Delphax ionographic printer and its internal communications hardware, and in the second case, as shown in figure 7.3, the Motorola 68000 system which drives the skiving actuation mechanism.

Therefore the common ground between the two systems is the recognition, the conveyor control, and the *primary output* of data generation. The primary output of pattern data is simply the retrieval of the relevant raw data. The point at which the two systems follow their own distinct ways is the *secondary output* of data generation, i.e. the stage of pattern definition for the given conditions. This is the point where the data which is to be output to the relative process (skiving or stitchmarking) is scaled, manipulated and transmitted in ways most appropriate to the process concerned. To aid therefore the description of the overall system it is convenient to divide the overall system into two basic function areas:

i. Data collection module.
   Function : Scanning, feature extraction,

recognition, component pattern data selection.

ii. Data manipulation and execution module.
Function : Pattern data manipulation,
transmission, reception, actuation.

These two modules are also identified in the schematic diagrams in figures 7.2 and 7.3, for both systems and it may be stated that most (but not all) of the differences between the two systems are within the latter one.

7.3 The data collection module

In this module the incoming component is identified, using the component knowledge of the relevant database. This identification includes retrieval of the originally taught skive pattern data for a given shape.

7.3.1 Component transport to the process

The conveyors are driven by 200 step/rev stepper motors and their driving signal timing is defined by the camera hardware. This means that the overall movement of components through the system is strictly timed with the camera linescan rate. The central control for any belt movement is held by the Z8000 processor (master), which is responsible for initiating any conveyor movement as well as conveyor accelerating and decelerating procedures. The experimental linear system speed is 185 mm/sec. The motor control is implemented as an open loop system, i.e. there is no sensor to provide any feedback information about missed steps but the motors are operated within their capabilities.

During the process, the belts are accelerated reaching the constant speed of 185 mm/sec, the component passes the vision gap and finally the belts are decelerated down to a complete halt. The acceleration and deceleration procedures are carried out having of course ensured that under no circumstances they may coincide with camera scanning. The conveyor halt, that follows recognition is maintained for approximately 3 seconds. This time is necessary for the execution of software routines which will recognise the scanned component, and recalculate its skive pattern data, which is to be transferred to the process device afterwards. When this data is determined the Z8000 accelerates again the conveyors, to reach the same constant speed, and delivers the component to the process area.

7.3.2 Component recognition

The linescan camera which is responsible for capturing the silhouette of the incoming components, is mounted 0.95 m above the gap between the two conveyor belts. Suitable screw adjusters enable optimum alignment so that image capture is done accurately. The component is scanned as one linescan per motor step, and each linescan produces a 2048 pixel long image on the imaging device of the camera, which is a 27 mm long sensor. Each shadowed pixel will give rise to a logic 0 and each illuminated to a logic 1. The lens used enables a 58 mm focal length which is too long for the sensor employed but, it is only the central part of the image that is used, where best quality is accomplished.

The camera sensor and lens are adjusted to produce a pixel spacing at the component of 0.203 mm. The Z8000 Master receives interrupts from the camera hardware timed with the "start scan" and "end scan" pulses generated by the camera. For each interrupt received the Z8000 sends a driving pulse to the motors, which in turn advance the conveyors and thus the scanned component by 0.203 mm. This repetitive function results in forming an image consisting of successive strips at 0.203 mm centres. The camera is supplied and synchronised with a 4 MHz clock and each linescan action takes 1.1 msec resulting in the linear conveyor speed mentioned above as : (0.203 / 0.0011) mm/sec = 185 mm/sec.

7.3.3 Extraction of features of the scanned shapes

This section of software modules has been adopted in its existing form and used as in the stitchmarking system. Details about their function are given by N. R. Tout [3].

7.3.4 The system database

The database holds all known shapes. This information is used to identify each individual leather component that is to be processed by the system. As far as the database is concerned different sizes of the same shape are also different subjects each containing its own data.

The database software as well as the data itself are held and handled within the Compaq 386 personal computer. To add a new shape in the database, the overall system must be switched to 'teach mode'. During the teach process the new leather workpiece is placed on the primary conveyor, the conveyor then advances, the component is scanned by the camera and it is then left on the secondary conveyor. If another component is to be 'taught in', the previous one is removed from the conveyor and the process is repeated.

7.3.5 Definition of the skive data

Although the software technique used for storing "known" shapes in to the database is the same for both skiving and stitchmarking systems, definition process of the skive and stitching patterns on shapes is different for each case.

During the 'teach' procedure each new shape is displayed on the monitor of the PC. With the aid of a mouse, the user may define the lines, along which the component has to be stitchmarked. In the case of skiving, These lines define the region in which the component has to be skived. This definition of data is referred to as stitchmarking, or in this case, skive data. These lines are defined as interpolated splines, between sets of points that the user locates with the mouse. This data is stored in a file other than the file containing the main component data. One such file is opened for each known component. It is worthwhile noting that the outline of the shape is not stored in this file. The only data contained is the Cartesian coordinates of the points used for the spline interpolation.

Although the same software is used for both cases the effective system output is different. The output result of this line definition was to print stitch lines in the corresponding locations on the actual leather component, by the ionographic printer. The lines where defined as of pixel width on the monitor, corresponding to an adjustable (by the printer) width printed on the leather. A typical print width would be 0.5 mm.

However the requirement for the skiving process is very much dependent upon its effective operating resolution, defining the thinnest possible line to skive. In the first implementation of the integrated system the minimum line width of skiving was approximately 5 mm. This implies that a spline defined on the monitor as one pixel wide, would correspond to a 5 mm wide skiving strip. In addition this strip would also be elongated at each end by 2.5 mm (half the resolution), with respect to the spline length defined on the screen.

It may be then deduced that the relation between the length L_t of a line defined by the teach software would relate to the actual length l_p of the skived line as:

$$l_p = L_t + [2 \times (R/2)]$$

where R is the effective operating resolution of the pin on the leather. Of course this calculation is theoretical and does not take into account any other factors that may influence the geometry of the actual skiving strip (e.g., speed, knife drag, leather hysteresis etc.).

According to the relation explained above, to define a 10 mm wide strip of skiving, two parallel splines have to be drawn on the screen separated by 5 mm. Following this procedure, areas of any dimension or shape may be specified using the existing software. The implementation of this specification however is subject to the pin resolution.

As an alternative to the above method, there are suitable software modifications possible, to enable the effective resolution of the pin to be seen on the screen when defining areas to skive. Another option would be the ability of area definition rather

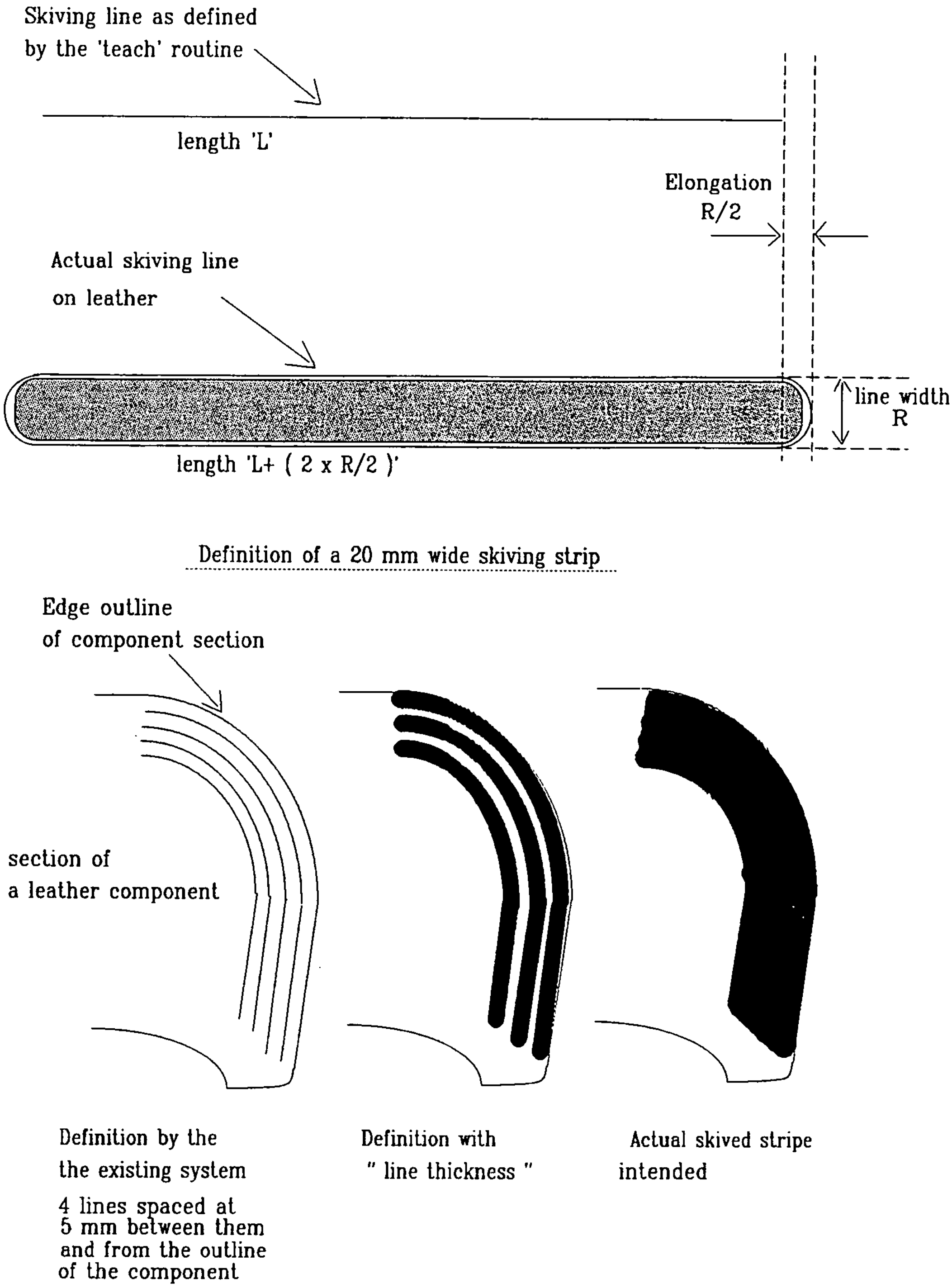


Fig. 7.4 The definition of skive regions on leather components

than a variable 'pen width'. However redesigning the 'teach' software was out of the scope of this research and it would involve further modification of geometric ratios and routines, in the process of manipulation of the skiving data in the TMS 34010 graphics processor. The drawing in figure 7.4 illustrates the present relation between a taught spline and its corresponding skiving strip, as well as the other hypothetical options for future software development.

7.4 Generation of skive patterns

When the incoming component has been scanned, a series of mathematical manipulation processes take place. The purpose is to convert the standard component skive data received from the database, to suit the orientation of the component, but also to the operating resolution of the system. This section explains the method used and implementation of software enhancement within the integrated system, so that it may successfully produce the necessary form of output for the skiving process.

7.4.1 Development of a generic method for resolution scaling

In the stitchmarking machine the Delphax printer was operated at resolution of 0.1 mm. Therefore the data manipulations and transfer functions within the TMS were designed to be fixed on this resolution basis. In addition, the overall system was designed to be a dedicated one to the stitchmarking process.

When attempting to integrate the skiving system, it became apparent that not only the great difference in x-resolution (from 0.1 mm to 5 mm) was a problem to overcome, but also the different operating speeds between the skiving machine and the Delphax printer and the appropriate communications protocol. The printer hardware could handle fast data transfer, in contrast to the skiving controller and actuation mechanism.

Considering that the resolution problem could be overcome using the existing image processing hardware and software, a new view was added to the current task of system integration. This system could form the basis of an experimental system, which could host different future processes, during their research stage, which are based on dynamically generated actuation, and are dependent on information from a vision system. There are a number of candidate processes, such as decorative hole punching on leather components, which are expected to be automated in the future and could benefit from a flexible skiving system.

Furthermore it was expected that in the future there would be the need to re-examine the behaviour of the skiving system with an actuation mechanism of higher resolution, to identify the minimum resolution necessary for smooth skive edges. The two above considerations led to the decision that the electrical integration of the current system should be implemented with flexibility in mind. This implies to avoid building dedicated hardware as much as possible, and to attempt to overcome most problems via the software route, leaving "keys" on the way, for future alteration on both communication speed for skive patterns and resolution. Thus this particular section of the research was oriented towards a generic solution.

7.4.2 The allocation of skive pattern data in the TMS memory

As mentioned earlier, the data that defines the areas (lines) that are to be skived on a particular leather component is stored in a separate file. These lines are interpolated splines based on the points defined by the user, and the method used is cubic interpolation. To reduce computation time for each access of this data, only the coordinates of the points defined by the user are stored, plus the dummy points required for the interpolation, before and after the end points of each line defined. Storing the dummy points permanently saves time too, because they do not have to be recalculated each time that interpolation is necessary. All Cartesian coordinates are derived with respect to the centroid of the shape.

The cubic interpolation is performed by the TMS34010 Software Development board (SDB), which holds the capability of fast processing. After shape recognition, the following process is to rotate and translate the splines computed so that they become coherent with the orientation and position of the component that is being processed. The TMS provides two on board separate memory blocks. The one (DRAM) is used for primary storage of the skive data (i.e. the encoded skive pattern). In this memory block it is possible to perform fast data manipulations, with the aid of powerful graphics routines provided.

The second memory block, the video RAM (VRAM) is a temporary data storage, from where data is supposingly output to a VDU (execution module in our case). Memory addressing here is synchronised with the video clock, a pulse necessary to clock out the stored image. In this system, this pulse is controlled by the execution hardware. When the image data is held in this memory, it is not possible to make any alterations to it, but only to transfer it out of the SDB.

Hence the skive data is initially retrieved from the database. It is then manipulated by the SDB and scaled to resolution in the DRAM of the TMS board. It is then transferred to its VRAM with the purpose to be clocked out to the controller of the actuation mechanism, i.e. the M68000 system. The sequence of the tasks allocated to the TMS board is illustrated in the drawing of figure 7.5. The next few sections describe in more detail the tasks carried out by the TMS board.

7.4.3 Skive pattern data scaling for different resolutions

In the skiving system the cubic interpolation has been adopted as used in the stitchmarking system. The rotation and translation functions applied the actuation data are based on the following rules :

$$x' = x\cos(q) + y\cos(q)$$
$$y' = -x\sin(q) + y\cos(q)$$

$$x' = x + D_x$$
$$y' = y + D_y$$

where q is the clockwise angle of rotation and D_x , D_y the translation distances along the x and y directions (i.e. across and along the conveyor belt respectively). These values reflect to the differences in orientation and position found, between those at which the shape was originally taught to the system and those at which the present component was scanned.

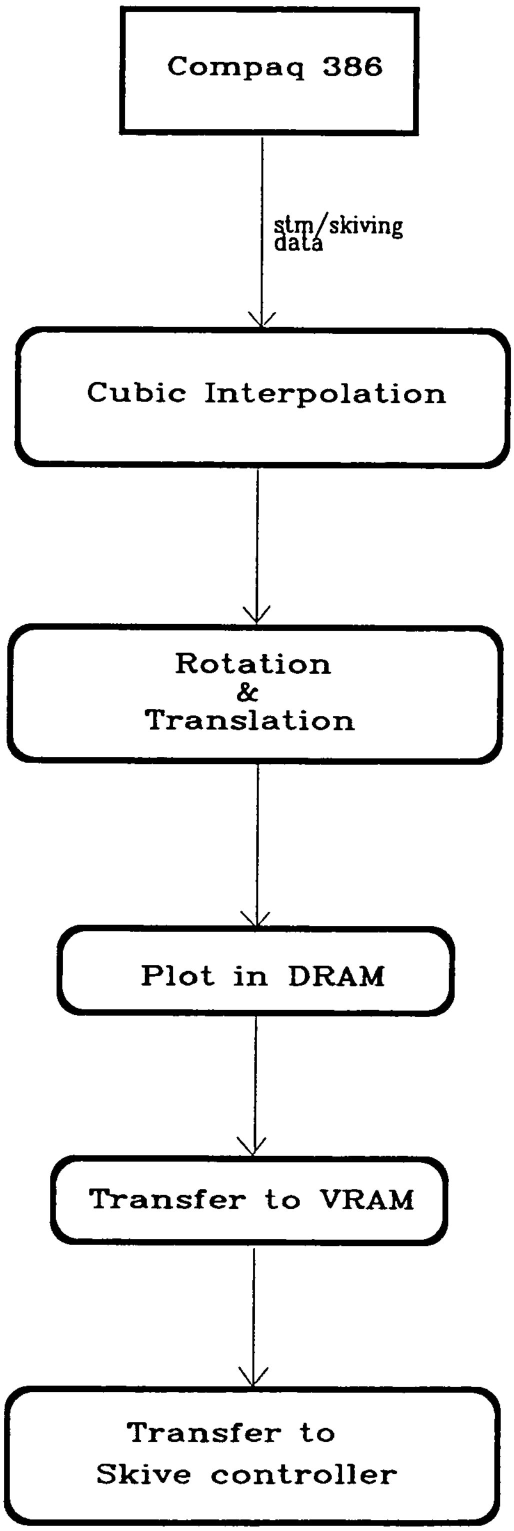


Fig. 7.5 The function sequence performed by the TMS SDB Board

The arrangement of the skive pattern data in the DRAM of the is shown in figure 7.6. A block of (600 x 1,024) = 6,144 bits of DRAM is used and it is big enough to accommodate the biggest shape handled by the machine. However for compatibility reasons a block of 1,024 x 1,024 bits had to be defined as the DRAM map although only the first 600 bits of each line would carry valid data (1024 is the closest power of 2 AND >= 600). Within this block the lines are plotted as line formed by x,y coordinate points and this memory block is simply used as an x,y Cartesian table with origin the top left corner. There is no need to plot the outline of the shape. This would be only decorative because only the stitch/skiving data is to be transferred out for use. Suitable limits do not allow any points to be plotted outside the valid area.

As it is expected when plotting the already interpolated lines, discontinuities will appear due to fact that it is only a limited number of points defining the line, that may be stored. This is taken care off by using a suitable function which does not only plot the points but draws a line between them on the memory table. Option of defining line thickness is also available, but it is not used in the case of the skiving machine due to the very low working resolution already existing.

For reasons of memory storage requirement the original resolution, in stitchmarking, of 2400 pixels per memory line was reduced by 4 at this stage, forming 600 bit long lines and later, during transfer to VRAM, it was zoomed back to 2400 pixels per line. This compromise did not affect the accuracy of printing due to rounding errors, and consequently it would not affect the accuracy of the skiving machine. In contrast the resolution was already too large for the purpose of skiving and the transfer requirement too demanding. To overcome this problem the following method was used.

If we assume a shape defined by x,y coordinate points and corresponding to x,y limits 600 and 1024 then this may be transformed into a shape defined at 5 mm resolution by dividing the total working width (600) by 18.75 so that it becomes 32. This number corresponds to the number of actuated pins (32) in the skiving machine and this arrangement assumes one bit of memory per pin of the skiving machine and of working x-resolution 5 mm. A similar operation on the y-axis of the memory table will bring the y-resolution to what it should be for the skiving machine. Because the y-resolution

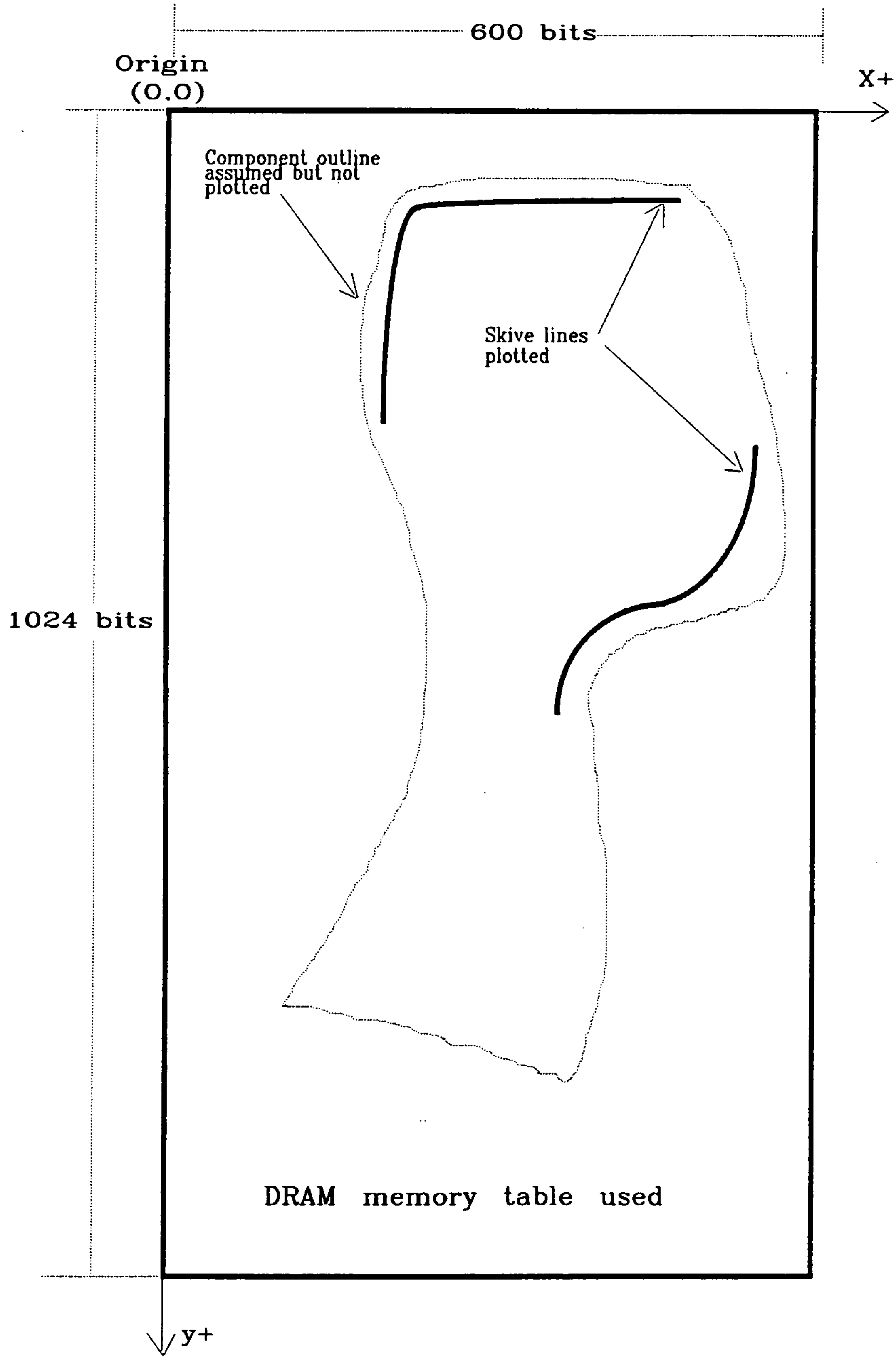


Fig. 7.6 Plotting the skive pattern data in the DRAM of th TMS SDB board.

of the skiving mechanism is 4.55 mm the correct y-division factor would be:

5 / 4.45 x 18.75 = 21.07

This implies that all the already calculated x,y coordinates of the stitchmarking lines that are to be plotted into the DRAM have to be divided by these factors, to become skive lines. Thus this function is effectively zooming-in the stitchmarking lines to transform them into skiving lines, but also it effectively zooms-in the overall memory table needed.

This principle is shown by means of an example in figure 7.7. The map shown represents a top left portion of the DRAM used, which is bit addressed and in which data is plotted as in a Cartesian system with origin the top left corner (0,0). The shape " big 'A' " is assumed to be the skive pattern for a particular component. For reasons of simplicity in illustration, the skive pattern 'A' consists of single skive lines only.

By applying the transformations described, the smaller 'A' is produced first by scaling the resolution in x and then in y. The final small 'A' defines the skive lines plotted at the working resolution of the skiving machine. The points shown with black dots are points that are plotted on the memory because, after the transformation, they have integer values for coordinates. Those marked with white dots are points that are 'lost', i.e. they will not be plotted because they do not address the 'centre' of a bit of the map any more.

At this stage it becomes apparent that after applying the scaling function to a line, some of its points could be lost, creating thus discontinuities on the new line. However, the TMS function used to draw the lines into the DRAM (function Draw_Line in program Spline_Draw in Appendix A-7) can eliminate discontinuities. This function not only joins any loose ends along the line, but it also approximates the nearest bit and relocates each 'lost' point responsible for forming a gap larger than a bit long. This can be seen in the example shown in the lower part of the map in figure 7.7, where an extreme case is illustrating a line with all its points 'lost' after scaling, but all recovered by the function mentioned to form the same line but at :

$$Y_{new} = Y_{scaled} + 0.5 \qquad (1)$$

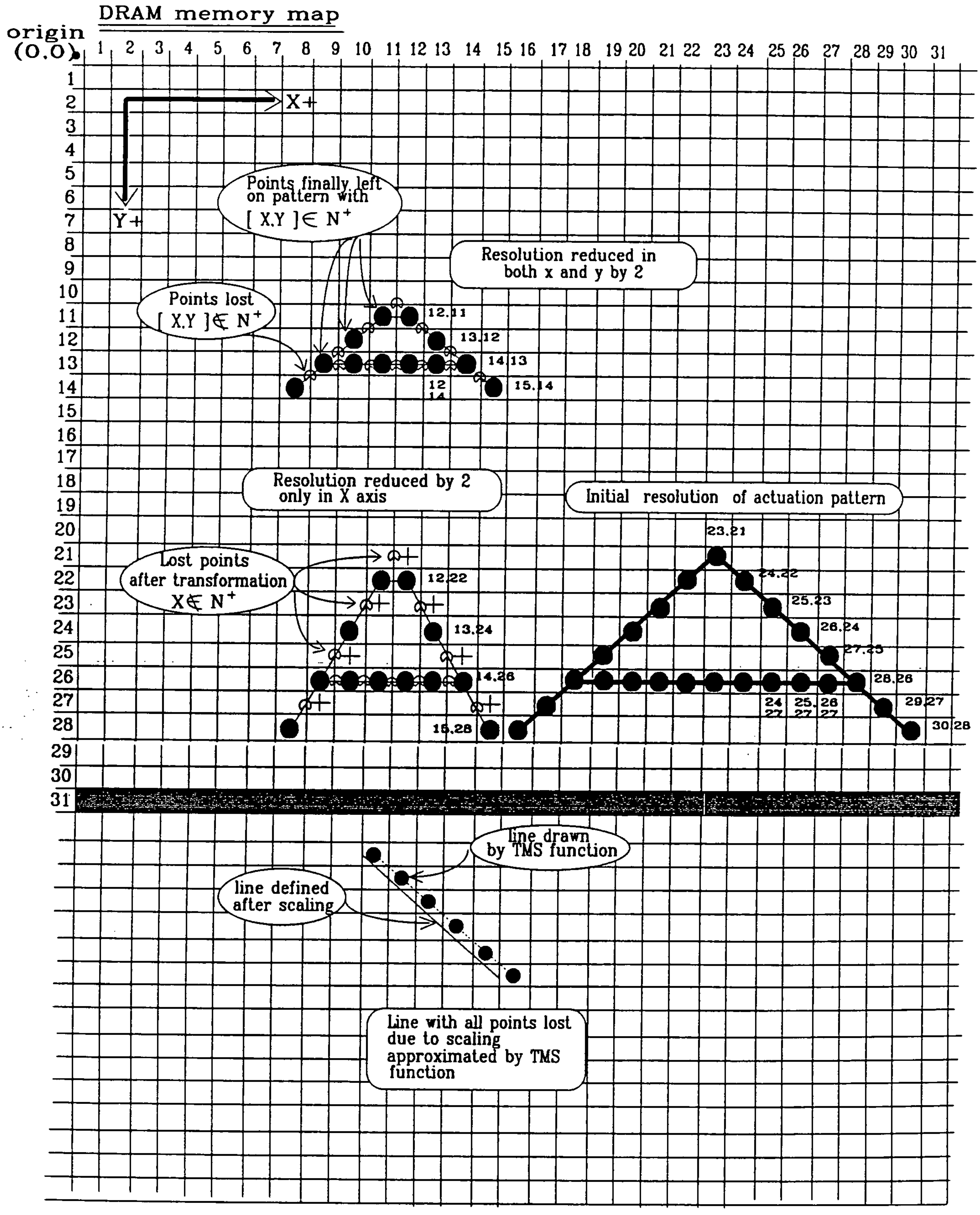


Fig. 7.7 An example illustrating the method used for changing the effective resolution while plotting the skiving lines in the DRAM of the TMS board.

This effect may also be observed as an image distortion, in the case of scaling only in the X axis, as shown at the left of the original big 'A'. In such a case the lost points, leaving behind them bit wide gaps, would be approximated and plotted at the locations shown with crosses. In this case similarly point recovery is operated as :

$$X_{new} = X_{scaled} + 0.5 \qquad (2)$$

Whether these points would be plotted as at X + 0.5 or at X - 0.5 is simply a threshold definition case in the relevant software routine.

One may argue that this is a defect of the method of resolution scaling, but it really is the inevitable compromise when having to draw diagonal lines at a resolution of 5 mm. Nevertheless there is an alternative. This is to use an alternative function which would simply plot the valid points forming the line (instead of constructing it), directly as derived by the interpolation function. However the second alternative would produce gaps, and the overall effect would be less.

In any case it must be stated that because the distortion effect is directly due to the system resolution, if the latter was increased in a future skiving system, the distortion would decrease by default. This may be derived by the method of scaling itself, because it would operate in exactly the same way, irrespective of the pin resolution. Hence an offset of a single memory pixel would correspond to a smaller real length.

A third option to reduce the above image edge distortion, would be to modify the (Draw_Line) routine, so that it performs with some compromise between the two options described above. This could be done, for example, by *not* plotting the 'lost' points which are located between two valid ones. Such a function would of course still draw the 'lost' line shown in figure 7.7. However for the case of the X-scaled 'A' some form of horizontal pin vibration whilst operating would be necessary to cover the small gaps in the diagonal lines of 'A'. Because such a capability does not exist in the present actuating mechanism the first option was chosen for implementation.

According to the scaling method used and described above, for defining a new working resolution and plotting the data at the new scale the following equations may be used :

for x,y points directly scaled

$$\forall \left[{(X.Y)}/{K} \right] \in N^{+} \Longrightarrow (X'.Y') \equiv \left(\frac{X}{K} . \frac{Y}{K} \right) \tag{3}$$

approximation for "lost" points

$$\forall \left[{(X.Y)}/{K} \right] \notin N^{+} \Longrightarrow (X'.Y') \equiv \left(\frac{X}{K} \pm c . \frac{Y}{K} \pm d \right) \Big\backslash_{c.d \in R^{+} \wedge 0 \leq c.d < 1 \,:\, (X'.Y') \in N^{+}} \tag{4}$$

Where K is the resolution reduction factor

7.4.4 Transfer of skive pattern data to video RAM of the TMS

The function following the data manipulations and plotting into the general purpose ram of the TMS (VRAM), is to suitably transfer it into the video RAM of the SDB so that it may be output to the skive processing device.

In the stitchmarking system this was done in eight stages. The SDB does not have sufficient video memory for the complete relocation of all the DRAM map described in section 7.4.3. The memory capacity requirement would be : 600 x 1024 x 4 x 4 bits = 2,457,600 bits, whilst the DRAM can provide only 2,097,152 bits ("4" refers to the initial zoom-in by 4 in both x and y dimensions). Furthermore to make full use of the capabilities of the TMS instruction power, a video line should be 2^n bits long [28].

This presented a further limitation, as a print line was composed by 2400 dots (printing width 203 mm x printer resolution 11.8 dots/mm). The next number >=2400 which is a power of two is 4096. Thus for each video line output there would be 1696 bits wasted, but needed to be sustained within the definition of a video line. This led to braking down the original DRAM picture into 8 portions. These memory portions are named slices, and are transferred one at a time to VRAM and from there to the processing device. The schematic drawing 7.8 illustrates a representation of the data allocation in the memory tables and transfer between them.

Therefore the DRAM image had to be broken down to 8 slices of 600 x 128 bits and to be transferred to VRAM. In VRAM the allocated x,y table was 4096 X 512 bits,

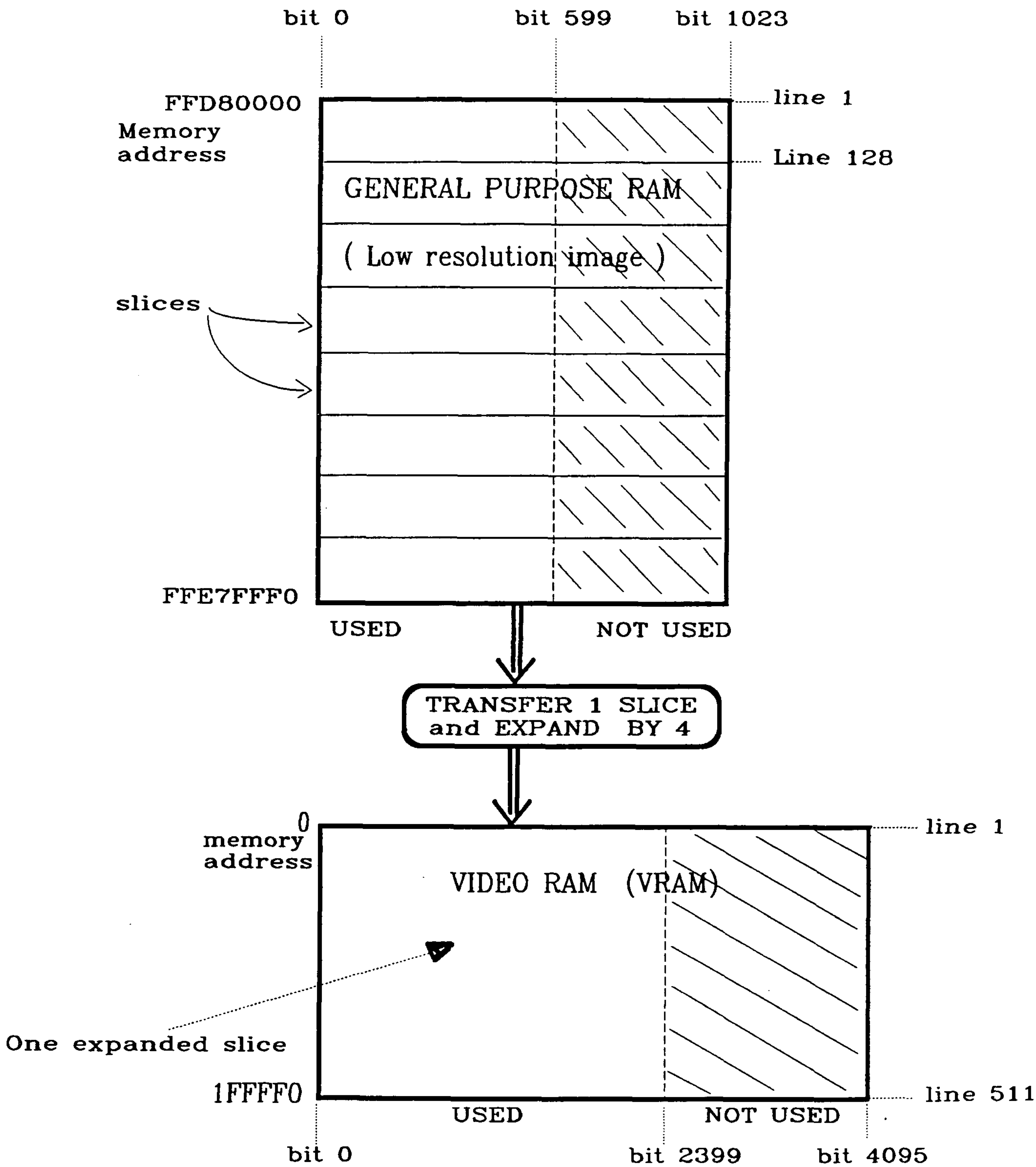


Fig. 7.8 Memory maps of the VRAM and DRAM of TMS34010 Software Development Board as defined initially.

which reaches the total capacity of the TMS board. During this transfer the TMS graphics function 'pxlblt' (pixel block transfer) is used. It is a very powerful function because it allows expansion of the pixel block transferred, while this transfer takes place [29]. This enabled the recovery of the initial resolution of 2400 dots per line as each pixel block which was transferred was expanded in both x and y by 4 while its transfer was being executed. Thus each pixel block of 600 x 128 was transferred as 2400 x 512, with its contained image data also expanded accordingly within.

Once each block is transferred into the VRAM it is then output to the actuating controller module line by line, as it would to a VDU. The next block transfer commences only when line 460 of the current slice is output so that overwriting of memory map lines before export is avoided.

This transfer arrangement has be broken down, as far as the skiving system is concerned, once the data in the VRAM is already plotted in a different resolution scale. The modified pixel block definitions are illustrated in drawing 7.9. The relevant software functions are included in appendix A-7. In this case, the effective DRAM pixel map was reduced from 600 x 1024 bits to 32 x 44 bits, suitable for the current skiving resolution. Because the current image limits used for skiving lie well within the first slice it is only necessary to use the very first slice. In this way the whole of the skive pattern image can be transferred to the DRAM by the first slice transfer. However the availability of the remaining slices as well as their function have been left on the system for use by a future higher resolution skiving system. This is because as the skiving resolution increases, the more slices are likely to be used.

The video RAM arrangement is also different in the skiving system. In skiving only one single block of 32 x 44 is required. However due to limitations in defining the new video synchronisation pulse widths, this number had to be increased to 48 (explained in section 7.4.5). Hence this resulted forming a VRAM (and consequently DRAM) pixel block of 48 x 44, from which only the 32 x 44 contains valid usable data. Nevertheless the original DRAM block definition was maintained, leaving thus all the area between bit 47 and bit 599 as 'not used', but available for use with a different resolution reduction factor.

Because there is no requirement with skiving resolution for image zoom-in and zoom-out (mentioned earlier), the expansion function of the DRAM data, applied

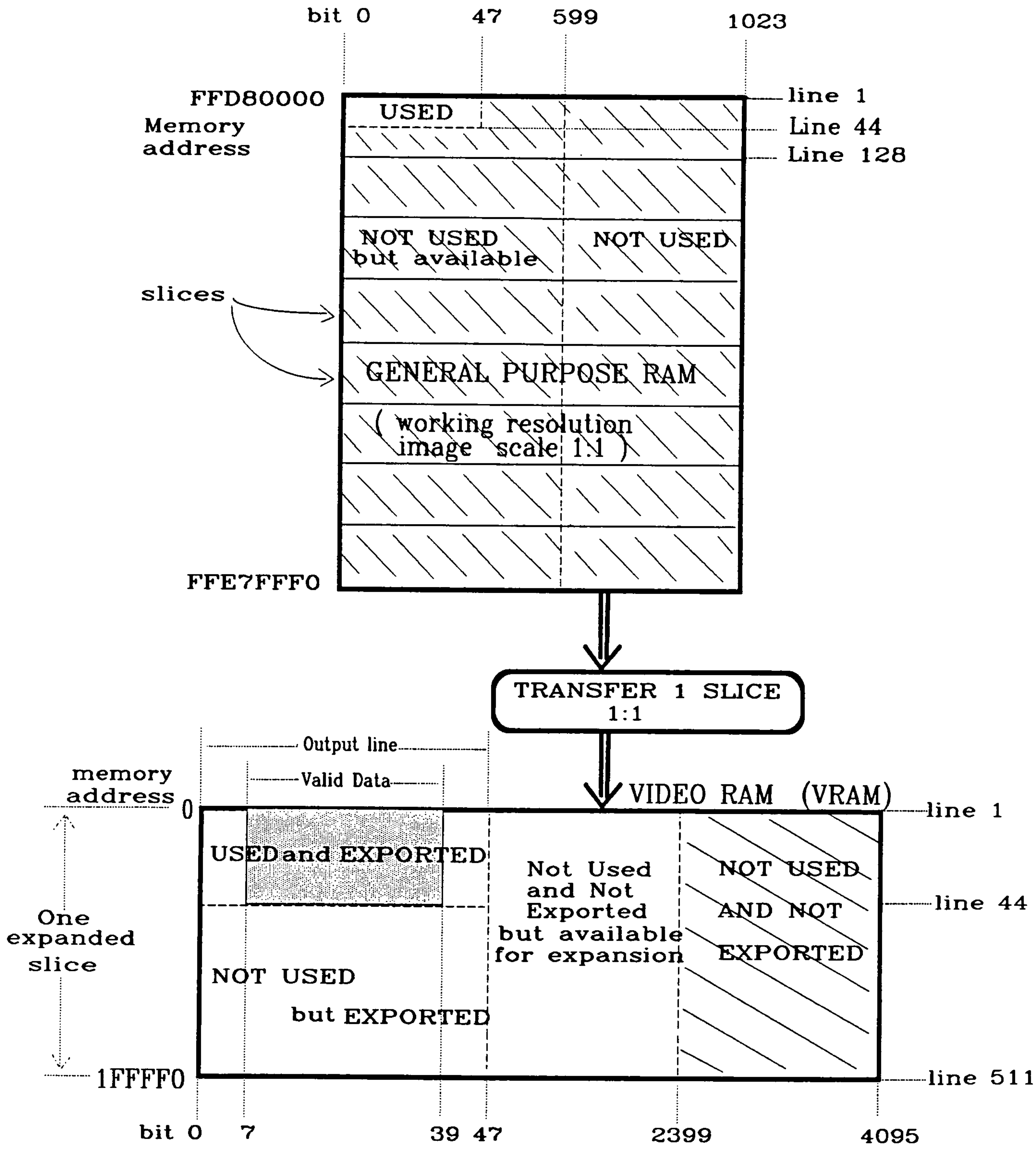


Fig. 7.9 Memory maps of the VRAM and DRAM of TMS34010 Software Development Board as defined in the automated skiving system.

during memory transfer, becomes now redundant. The skive pattern data is plotted in the DRAM at working resolution in the first place and is then passed unscaled into the VRAM. Therefore in this case the 'pxlblt' function is defined as a one to one transfer.

7.4.5 Image export from the TMS video RAM to the skive controller

Image export from the TMS VRAM is implemented by means of serial communication. When the complete skive pattern image is drawn into the VRAM of the SDB, i.e. in the first slice, each line is clocked out to the actuation hardware in serial mode. Although the TMS provides the option of parallel data transfer, for reasons of data format compatibility, the serial transfer offered the simplest type of protocol to implement. This is done at a rate of 10 MHz, an already reduced rate, if compared with the capability of the TMS (40 MHz).

The two major functions of the TMS SDB already described, i.e. resolution scaling and image re-mapping, may assumed to be two independent processes, each one targeted at its own memory (DRAM and VRAM). These processes, although synchronised during data transfers, they are driven by independent clocks.

The clock for operations in the DRAM is internal, but the clock for extracting data from the VRAM has to be provided by the receiving device (VDU by default). This signal is referred to as 'DotClock' and it determines the frequency of data transfer. In the stitchmarking process, the Delphax printer supplied the DotClock at 10 MHz. In the skiving system however, the skive controller (M68000) could not operate at such communication speeds. Also in the case that the system was used for a different purpose in the future, its controlling device would not necessarily be able adopt to that rate.

Hence it was necessary to find out whether the DotClock could be set at a rate compatible with the Motorola board, and more important, whether it could become a variable, able to adapt to different process requirements. In addition to this particular requirement, although the DotClock speed might have to be reduced dramatically, this should not affect the overall skiving system throughput.

Data export from the VRAM is executed with two basic timing signals, the HSync and the VSync. The HSync (horizontal synchronisation pulse) defines the length of a line exported. The VSync (vertical synchronisation pulse) defines the 'depth' of a complete video screen. The significance of the VSync in this system is to define the size of a slice (=512 HSyncs). Thus by referring to figure 7.9 it is deducted that in the skiving system, to export a complete image would require 48 HSync pulses and only 1 VSync.

The video side of the SDB board may be configured to operate in two modes. It may be set-up to function under external or internal synchronisation. In the first case the device responsible for producing the HSync and VSync pulses is the video device, which in our case is the M68000 computer.

In the stitchmarking system, the ionographic printer provided these pulses. This was done accurately by deducting the HSync as a subdivision of the DotClock, equal to an integer value of DotClocks. The VSync is determined by the Z8000 board and passed to the TMS via the Deskew board of the printer, so that the transfer process is timed with the belt movement. Due to the large number of data forming a slice, it had to be ensured that slices do not overlap during printing. Apparently this requirement becomes redundant in the skiving system due to the very low resolution image and thus the extra time available for its storage and execution.

The device responsible for all communications in the stitchmarking system is the Deskew Board of the printer. The de-skew board is so called because one of its functions is to apply a correction to the printing so that it is not skewed when transferred to the paper. Figure 7.10 indicates the basic communication signals between the TMS board and the printer.

The serial link for image data transfer is implemented by the SData and RClk pulses. The RClk rate is equal and synchronised to the SData and its function is to latch each individual image bit into the Deskew board memory. The purpose of the interface board shown in figure 7.10 is to convert the 4 bit per pixel data format (colour format) presented by the TMS to a 1 bit per pixel format, compatible with the rest of the hardware. This board is used in the skiving system too.

In the skiving system the SDB is re-programmed to operate at internal synchronisation. The basic interface signals in the skiving machine are shown in the schematic

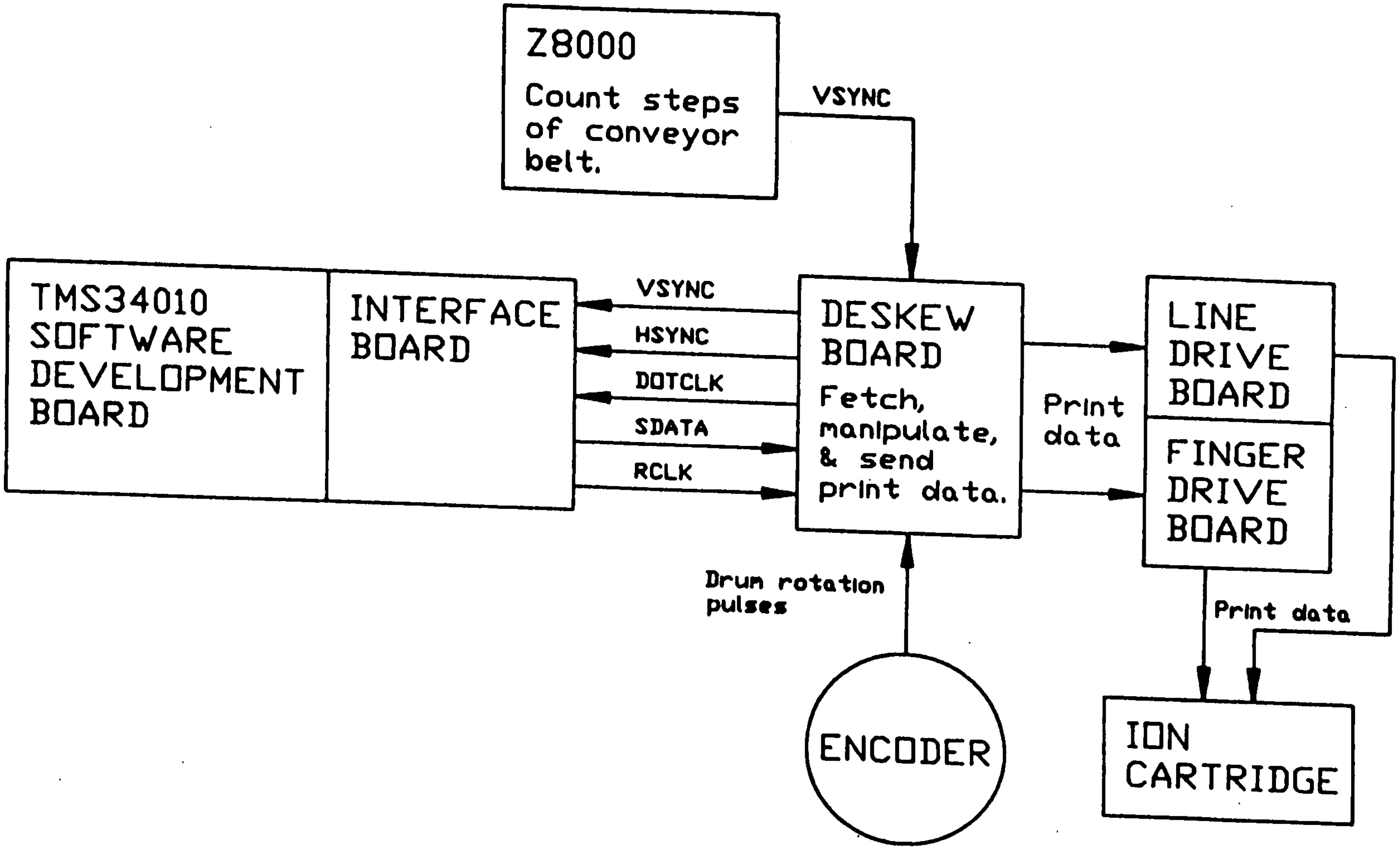


Fig. 7.10 The main synchronisation signals for the image data transfer to the ionographic printer.

diagram of figure 7.11. A deeper analysis of the interface is carried out in chapter 8. In this case the TMS generates its own synchronisation pulses. This is implemented by deducting them from the DotClock signal which receives from the skive controller.

The implication with this choice is that there is less hardware requirement for actuation. This reduces the task of the overall external timing to the TMS, down to producing only the DotClock frequency. In this case it is the M68000 that has to be timed with the received HSync and VSync signals, and it may be said that in this system the M68000 takes the place of the printer Deskew board.

In the present system configuration, as x and y image resolutions have been kept equal for the first trial of the system (5 mm), the VSync signal is not used by the M68000 because all image data is contained within the first slice. However if a different x to y ratio was to be attempted and the image required more than 512 lines of VRAM storage, then a VSync interrupt could be of use to the M68000 software. This would be in case of low memory availability on board. Thus the VSync is left 'available' on board for future need (for more details refer to chapter 8 and to circuit diagram in figure A-8.1. in Appendix A-8).

The timing signals together with the source (DRAM) and destination (VRAM) memories for the data transfer are defined by means of setting program parameters. The relevant software functions in the Compaq are designed to run by the TMS board and written in a TMS version of C language. The relevant program listings are presented in Appendix A-7 . The constants SPTCH and DPTCH define the length of the source and destination lines for the transfer from the DRAM to the VRAM. This is done by defining the increment as a number of memory bits, at which the memory pointer has to advance each time, to be located at the start of a new valid image line.

The first constant has been set to define as source a 1024 bit long line although only 38 bits are used effectively due to the resolution reduction function explained in section 7.4.4. This is illustrated in figure 7.9. This offers flexibility in defining a different resolution in the future without having to redefine memory blocks used and a series of system parameters involved. Each line is then transferred to an equal line in the VRAM using 1:1 transfer and pixel size = 1. For each line in VRAM however there are 4096 bits available. In the stitchmarking system each 1024 bit DRAM line

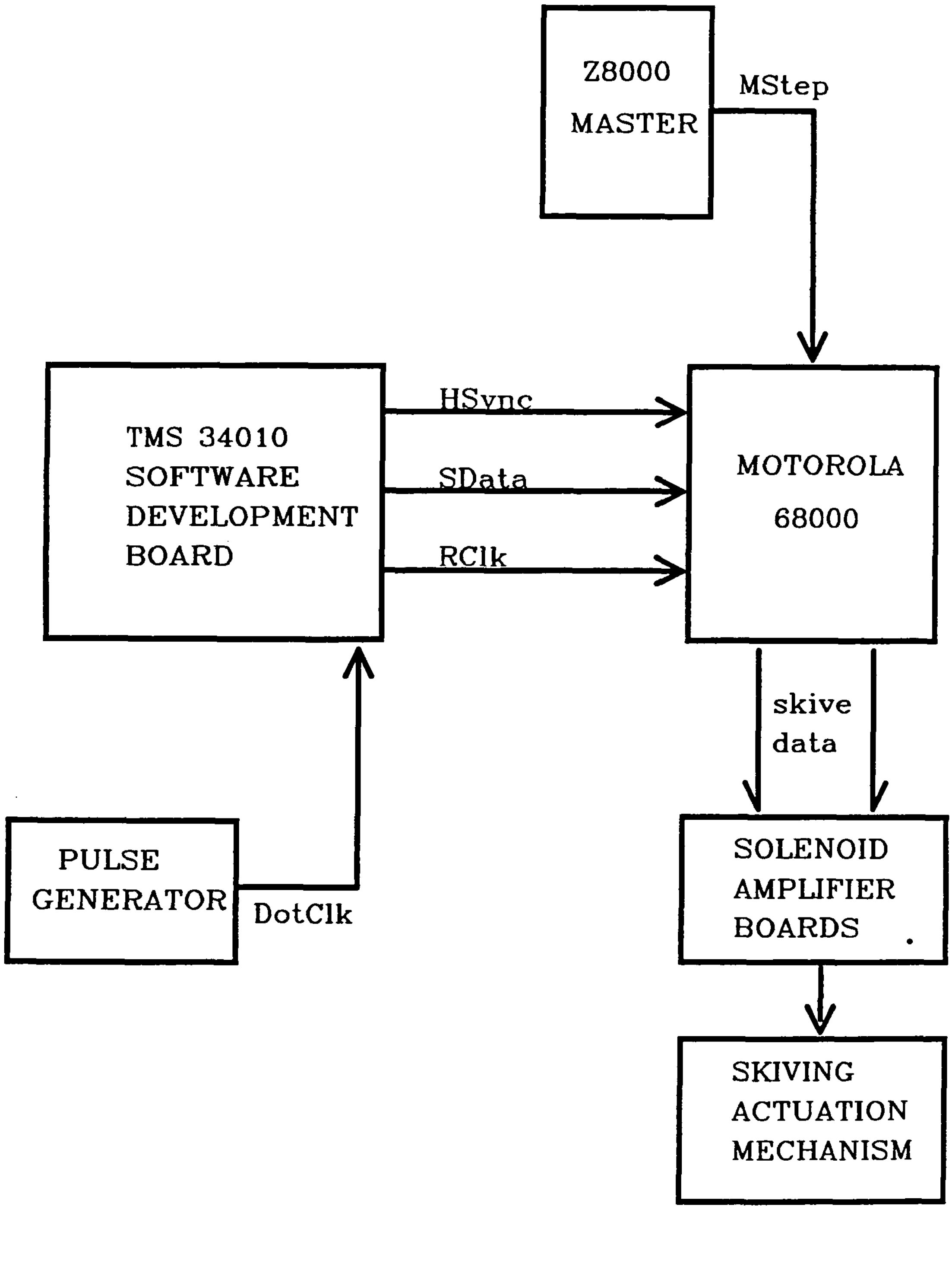


Fig. 7.11 The main synchronisation signals for image data transfer to the skiving machine

was transferred as 4:1 to the VRAM thus occupying a full VRAM line (4096) but only 2048 (=4x600) bits of it where containing valid information and where exported. Thus the DPTCH constant had to be defined as 4096.

This definition remains the same in the skiving system, thus allowing the possibility for future expansion in the memory actually used. However in the present system only 48 bits of each VRam line are exported. With reference to drawing 7.9, it is understood that further modification of the VRAM map to accommodate a different resolution is simple. This is because the part of the memory map which is not used (bit 48 - 2399 in X and 45 - to 511 in y) could become instantly available by simply redefining the video signals to suit a new image resolution.

The length of line exported defines the length of the line effectively used, containing 32 valid bits. This flexibility in system use was due to the fact that the TMS instruction set allows a 'window' definition within a block of memory employed. This means that it is possible to export to the receiving device only a part of each video line drawn in the VRAM. The length of the line exported is determined by the length of the HSync pulse used, and what remains is simply not transferred out to the receiving device.

The length of the synch pulses is calculated by setting the appropriate constants (refer to function init_dmg in Appendix A-7) as number of bits for the HSync and number of HSyncs for the VSync. The relevant timing diagrams for these pulses are given in figure A-8.2. in Appendix A-8. Also, it is because of value restrictions in defining these pulse widths, that to export the 32 bit valid line, a 48 bit line had to be exported containing the valid data in its middle 32 bits, as illustrated in figure 7.9. Due to this restriction, it was necessary to translate each DRam x,y coordinate by +8 so that the valid data arrives in VRam in the format explained. This transformation can be carried out before or after the function of resolution scaling. The 8 extra bits on either side of the VRam lines had to be 'ignored' by the software of receiver M68000 as it is explained in chapter 8.

Therefore the output of the TMS board exported to the M68000 is a 48 x 44 memory block, but the present system configuration allows instant expansion by simply redefining the HSync pulse. In this case the horizontal image limit is 1024 and may be increased up to 4095 if a 4:1 transfer is applied during the DRAM to VRAM transfer. However if a length larger than 2400 is used for image plotting, further modifications of parameters will be necessary.

7.5 Conclusion

The function of generation of skive patterns involved is implemented by the TMS34010 video controller. The major concern in this stage was to provide two distinct facilities to the system. The ability to scale easily the pattern image resolution and to provide a compatible image data format for the skive controller. This was implemented as explained in this chapter, and the outcome was successful.

The TMS system is really designed to function as a video controller unit. It provides fast processing and image transfer. To use it in a process such as skiving, to generate executable images, involved effectively the simulation of the function of the video device by the M68000 skive controller. Its earlier use in the stitchmarking process was justified due to the high operating resolution and the high transmission rates used. However its employment in skiving was implemented only as a relatively rapid and effective solution for the purpose of this research. The alternative to this would be a complete redesign of the vision system to suit the skiving process.

Due to the relative low resolution in skiving, the total number of image bits to be processed and transmitted is small. Therefore the basic need is fast processing during component recognition. In skiving the need for very fast communication rates, offered by the TMS, becomes redundant. Furthermore the use and programming of the TMS board proved to be an unnecessarily complex issue. Thus it would be logical to state that the use of the TMS system in a future commercial product would not be the best solution.

Finally as it has been mentioned, the continuous flow of the components is briefly interrupted (3 sec) after recognition, to allow for information processing during recognition. This may be seen as a failure to achieve a continuous flow through skiving operation. However this is not so because this feature is there simply for reasons of computing speed because the computer technology used here is relatively old. This problem may be easily overcome with the use of more modern processing power, e.g. the replacement of the recognition hardware with a multi link Transputer system. It is worthwhile noting that such an enhanced vision system has recently been developed by BUSM for the process of automatic pallettless stitching on leather components [15].

CHAPTER 8

THE ELECTRICAL INTEGRATION OF THE SYSTEM / ACTUATION OF SKIVE PATTERNS

8.1 Introduction

This chapter describes the method in which skive patterns are transmitted and executed by the controlling device of the skiving mechanism. The skive patterns after having been generated in the video memory of the TMS SDB board, they are transmitted by means of a communications link to the M68000 system. This computer is responsible for timing and executing the process of skiving.

To enable efficient data transmission between the TMS and the M68000 it was necessary to define and implement a suitable communications protocol. Also it was necessary to operate the SDB at very low clocking rates so that transfer speed compatibility is achieved between the two. In parallel with image transmission, the M68000 temporarily stores the received data in a suitable format for execution. When the complete skive pattern has been received and when the leather component has arrived in the process area, skiving commences.

This part of the electrical system integration, is designed particularly for the process of skiving. It involved the implementation of the interfacing hardware and writing the software for control of the skiving mechanism by the M68000. However it is implemented in a suitable form so that future system resolution enhancement could be easily accommodated.

8.2 M68000 interfacing for process control

The function of the M68000 based computer is to receive the skiving image produced by the TMS34010 and perform the dynamic matrix control on the skiving mechanism. It is thus responsible for timing the whole actuation process with respect to the belt movement. The main timing signal paths, involved with the function of the Motorola board are illustrated in the schematic drawing of figure 8.1.

In the stitchmarking system, as mentioned earlier, the Z8000 Master had the responsibility for the overall timing of the printing process. The Z8000 Master had to produce and transmit to the printer and SDB the VSync pulses, which were effectively the timing link between motor displacement movement and pattern execution.

In the skiving system this task has been taken away from the Z8000 processor because, the SDB was programmed to function in internal synchronisation mode, thus producing itself the VSync signal. This timing link has now become a link between the SDB and the M68000. Also the Z8000 always 'knew' at any time where the component was located along the secondary conveyor, while it was moving, because it was producing the pulses for the stepper motors. This task is also removed from the Z8000 computer.

It was mentioned earlier that the conveyors halt for a brief period, immediately after component recognition, for allowing time for all calculations of the skive data to be carried out. The leather component is always stopped at a defined distance from the vision gap, no matter its identity, size or orientation. This distance is calculated as a fixed number of motor steps, immediately after the trailing edge of the component has been scanned. This means that the location of the leading edge of the component is variable, depending in the length of the specific component at the particular orientation.

This 'current length' of the component may then be calculated by the Z8000 with

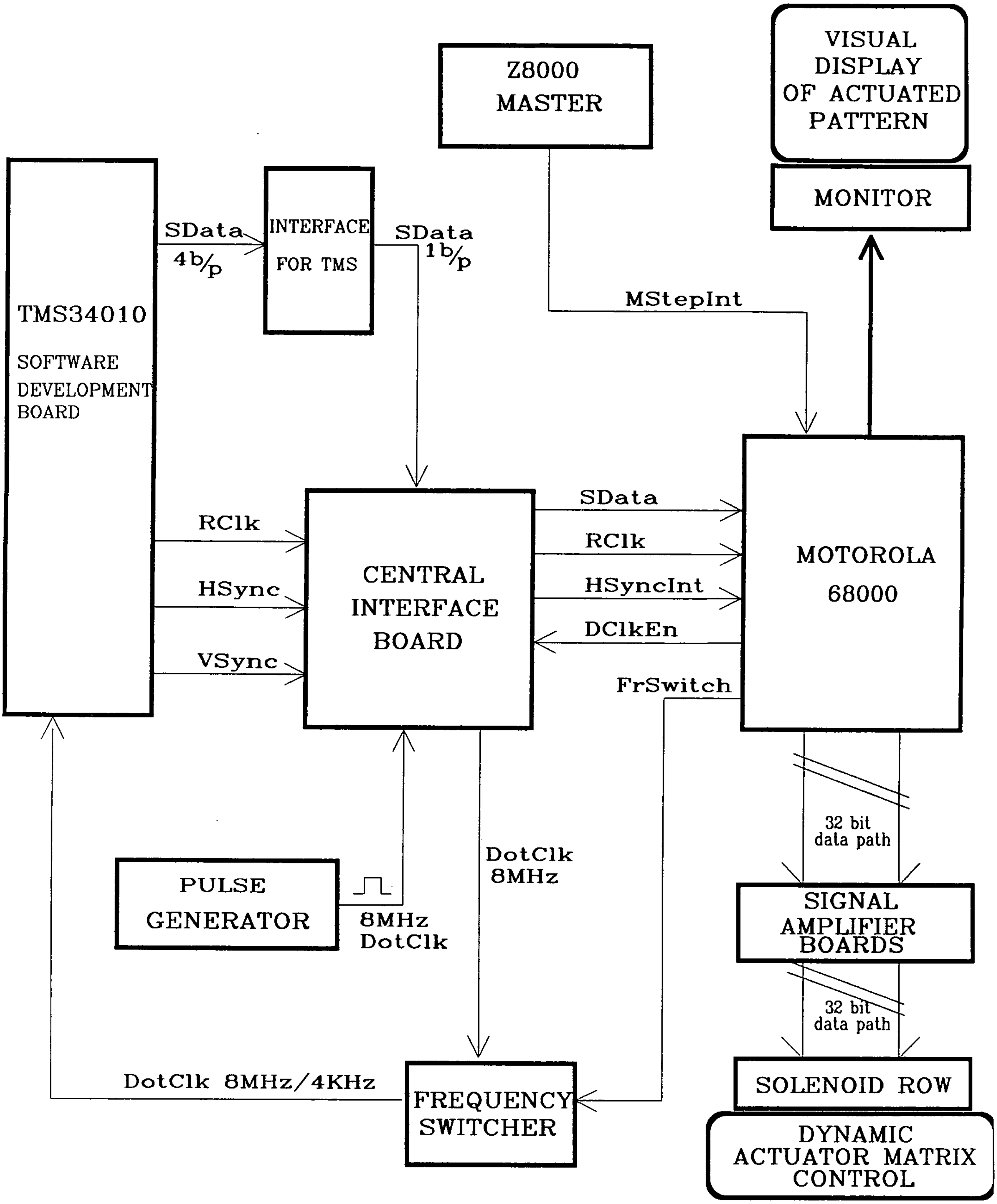


Fig. 8.1 The main signal paths in the interface of the TMS34010 to the skive controller M68000.

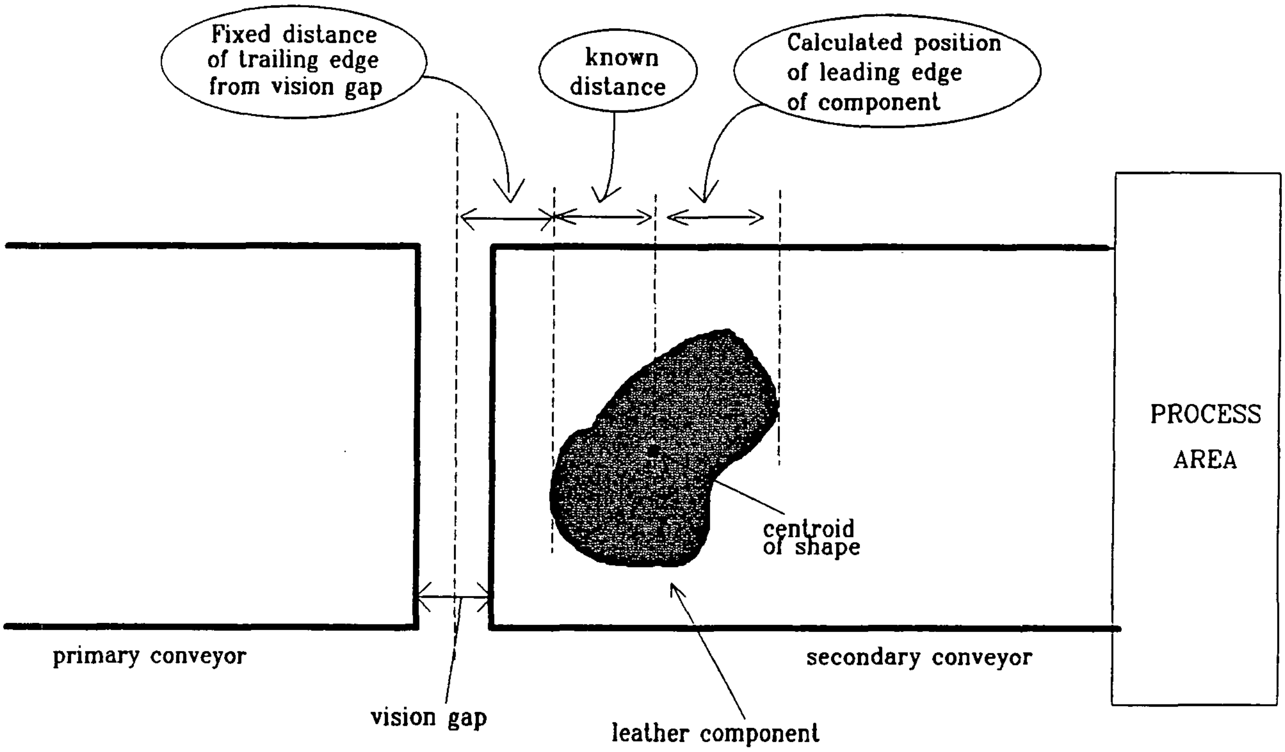
reference to the centroid of the shape. The location of the leading edge of the component is then calculated as the length of the component plus the distance of the trailing edge to the vision gap (constant). The relative diagram in figure 8.2 illustrates this principle. Therefore when the component starts moving again towards the machining area, its position is always known and so is the time at which the process should commence.

In the present case this vital information should be passed to the 68000 processor. To carry out this task would involve a time consuming re-programming of the Z8000 EPROMs and introduction of direct communication links between Z8000 and M68000. However because the priority here was to prove the possibility of automation of the skiving process, a compromise was preferred.

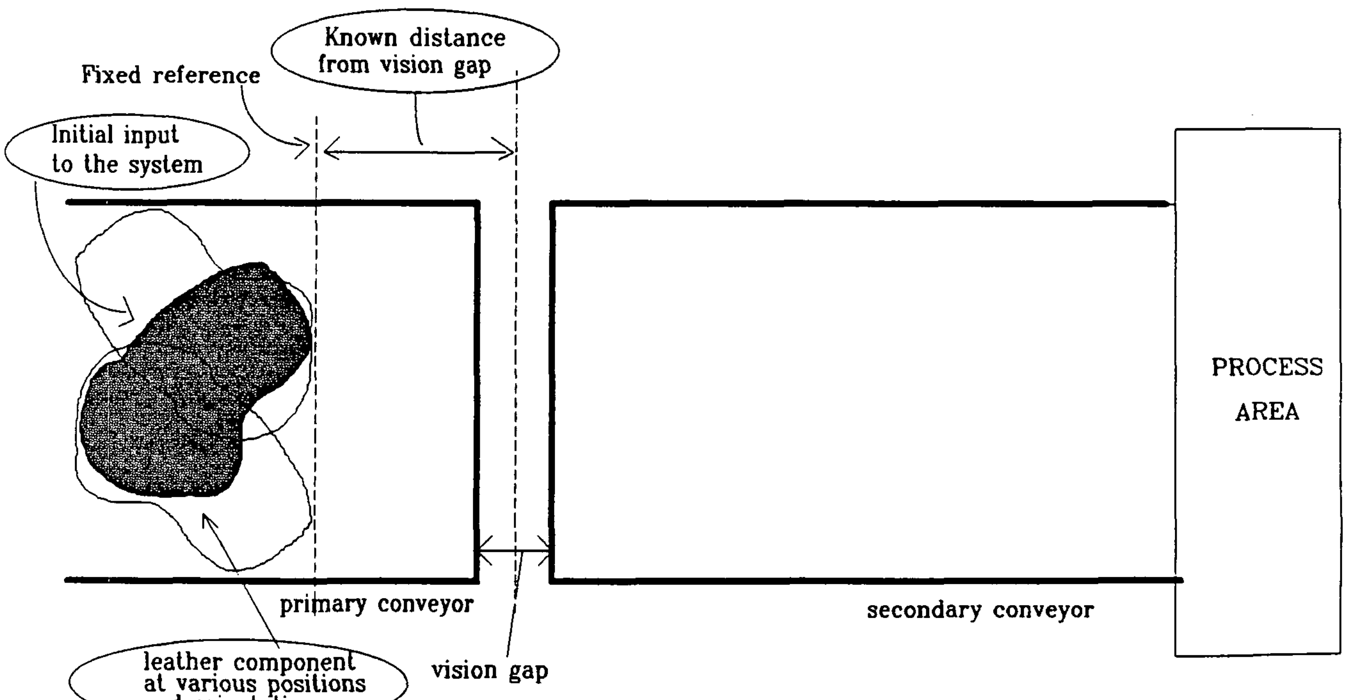
The Z8000 passes to the M68000 via a hardware link, the motor step pulses while transmitting them to the stepper motor controller. This enables the M68000 to calculate the position of the leading edge of the leather component at any time, even before vision scanning. The restriction therefore here is that all components when input to the system will have to be placed on the primary conveyor, so that their leading edge lies at a fixed distance from the vision gap. This of course does not imply any restriction in the orientation or in the position across the conveyor belt. This compromise is not considered to delete any of the requirements for efficiency of the automated skiving machine, nor is it in any way an obstacle in proving the automation of the system.

The task of the central interface board, shown in diagram 8.1, is to distribute all the vital signals between all the hardware involved in transmission and execution of the skiving data. The circuit diagram for this board is illustrated in figure A-8.1. in Appendix A-8. The SData signal (the skive image data path) is maintained at 1 bit per pixel as used by the stitchmarking process.

The interface board for the TMS is now modified due to the different hardware requirements faced in skiving. Its task is reduced into only modifying the SData signal format. Other signals such as RClk (data latching pulse), HSync, VSync and DotClk are now communicated directly to and from the TMS, due to signal compatibility, which the printer Deskew board was lacking in the stitchmarking system.



Stitchmarking process



Skiving process

Fig. 8.2 Methods of tracking the location of the leading edge of the leather component during component transfer.

To drive the VRAM data export, the DotClk used is supplied by a general purpose high frequency pulse generator. This is supplied to the C.I.B and it is gated by the DotClkEnable signal provided by the M68000. Hence the TMS is supplied with this signal only when this is allowed to do so by the M68000 software, i.e. the M68000 initiates skive pattern transmission. It has to be noted here that unlike the stitchmarking system the VRAM of the TMS board is not clocked continuously but only when image export to the M68000 is to be commenced. The reason for this is that this first experimental system was not meant at this stage to perform repetitive component processing.

8.3 Communication speeds for skive pattern transmission

The speed of transmission, determined by the DotClk rate, had to be kept as low as possible, so that the 8 MHz M68000 processor could cope with the serial communication. The M68000 could cope with transmission rates in the region of 6 KHz. A series of tests were carried out to observe what would be the minimum frequency of DotClk, at which the TMS would respond in image extraction without producing any problems. Let us remember that the TMS processor runs at a 10 MHz transmission rate and it is not designed for such slow operations.

However the two-sectioned design of the TMS allowed for a large variance in the clock of VRAM data export, without interfering with the speed image processing in DRAM. The lower limit was found to be around 3.4 KHz. Any frequency at this region or lower would tend to distort the image export process. The present system was thus set to run at serial communications rate of 4 KHz. The benefit of this result is the knowledge that this system could accommodate transfer of image data to any actuation driver between the limits of 10 MHz and 4 KHz. Thus another point in system flexibility was resolved.

By reducing the DotClk frequency it was also found that although the TMS could export the data successfully at this rate there was a considerable time gap between enabling the DotClk signal by the M68000 and the transmission of the first image line by the TMS. This time interval proved to be proportional to the reduction of the DotClk frequency from 10 MHz downwards. In the case of using 4 KHz as a DotClk frequency the delay lasted for about a minute, and this could not be tolerated. Apparently the TMS processor, although it internally works at its own independent frequency, it uses this external frequency (DotClk) to perform internal initiation routines before any VRAM export scanning is commenced.

To overcome this problem, a frequency switching circuit was designed and applied on the DotClock path. The relevant circuit diagram is shown in figure A-8.3. in Appendix A-8. The function involved here is to supply the TMS with a high frequency (8 MHz), during initialisation, so that this time delay is reduced down to tolerable levels (a few msec). At the instant that the TMS is ready to start export of valid data, the M68000 'switches' the DotClk frequency to 4 KHz via the FrSwitch signal (fig. 8.1), and the image transmission process commences. The detection of this instant of ' TMS readiness' is identified by the presence of the first HSync pulse. This implies that image export transfer is starting.

As explained in chapter 7, the HSync and VSync signals are generated and supplied to the C.I.B. by the SDB. The HSync is used as an interrupt for the M68000 to indicate the start of a new incoming image line. The VSync is not used by the existing software configuration but it is available on the C.I.B for future modification. More information about the significance and use of the signals shown in figure 4.6.1 are given in the program documentation denoted as A-8.4 in Appendix, and in the general description of the control software in section 8.5.

8.4 The function states of the M68000 control

The overall function sequence of the M68000 is shown in the state diagram in 8.3. The computer is initially in idle state, even after the user initiates the overall process. The first basic function which is to receive the image data is triggered by the TMS sending the first HSync pulse. Each data bit (image pixel) is then temporarily stored upon reception, in a pre-defined on board memory map. When the image has been received in full, the output process to the skiving mechanism begins, timed closely with the movement of the conveyor belt. However this will begin only when the 'process area reached' condition is satisfied.

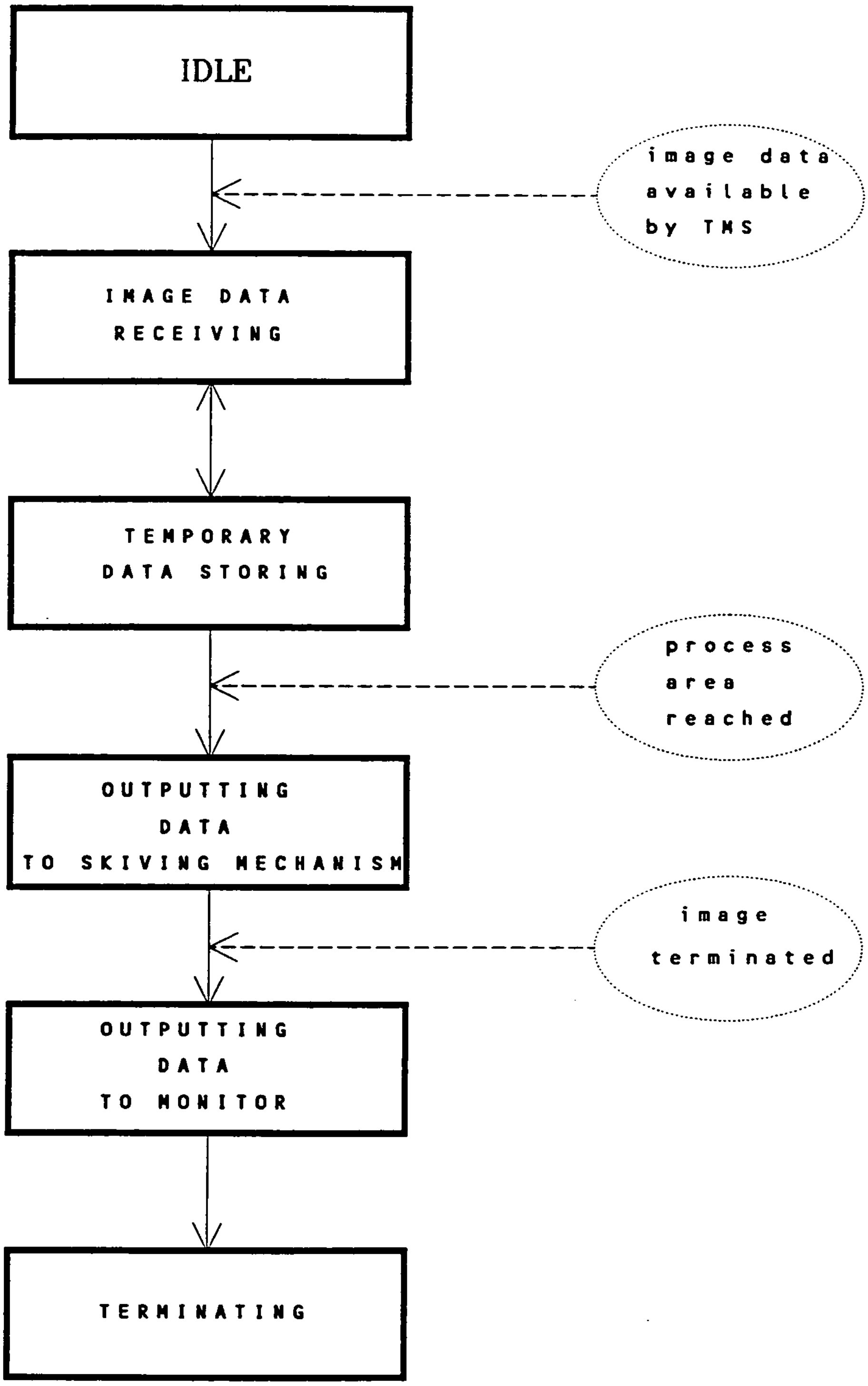


Fig. 8.3 The function states of the M68000 operation.

When the output process is terminated, i.e. when the leather component has been skived, the M68000 begins to display on the monitor the pattern which it actually received from the TMS, and actuated by the skiving machine. This display may then be compared to the resulting skived area and useful observations for the behaviour of the system may be deduced. The monitor displays the skiving pattern graphically, as a set of all individual intended pin impressions identified on the screen by '0's. After the visual display the 68000 terminates its process.

8.5 Image data reception and execution

The data concerning the skive patterns that have to be processed on the leather component, is received, stored and passed onto the execution module (skiving mechanism) by software written for this purpose. This program is written in M68000 assembly language for high performance and it is interrupt driven. It was written in the department's UNIX environment, where it is also compiled and stored as program file. The M68000 is linked to the UNIX system from where it accesses the file, downloads the program and runs it on its own memory. The M68000 control software is listed documented in section A-8.4 of Appendix A-8.

A part of the on board memory of the M68000 is dedicated to store the image of the skiving areas transmitted from the VRAM of the SDB. This storage is only temporary until execution of the skiving data. The relevant memory allocated is treated as an x,y array and the image is plotted in binary form. The width of the array is equal to the number of pins (32). Each pixel in a horizontal line of the array reflects to the future state (down or up) of the corresponding pin on the skiving mechanism. Thus if a particular pin is to be depressed during the execution of a certain line, the corresponding memory bit will be set at logic state 1 and vice versa.

As it is shown in figure 8.4 each 48 bit long line transmitted from the TMS is chopped at the ends, so that only the valid data is passed for storage. One of the 8 parallel I/O ports of the M68000 board is used to pass to the memory array one bit at a time. Thus the parallel port is configured here to perform serial transmission using only one bit (bit '0'). This option was taken due to two important reasons :

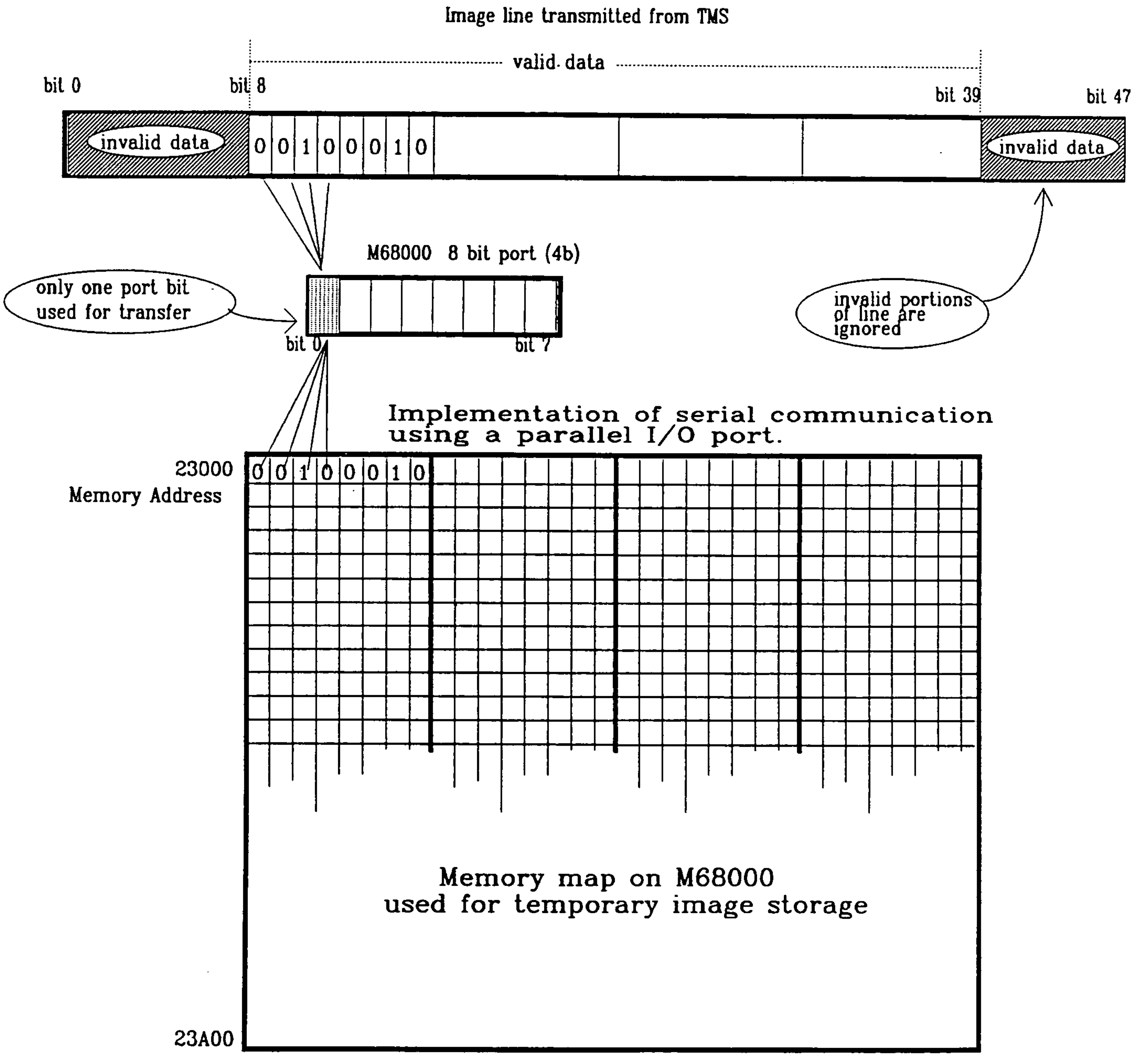


Fig. 8.4 Reception of skive pattern image data by the M68000 system and its temporary storage.

i. The transmission speed could be kept sufficiently low (4 KHz).

ii. The need for designing a serial communications protocol with handshaking was eliminated with this option.

The incoming bits are then stored into adjacent memory locations using post-incrementing bit addressing. The 8 invalid bits at each end of the original input line are simply ignored by means of bit counting.

During data output to the actuating mechanism the reverse operation takes place. In this case the image line is transferred to 4 separate bit buffers (data registers), each one loaded with a quarter of the line length (8 bits), as shown in figure 8.5. This is done again by bit addressing and by the use of bit-shift operations. The reason for using four buffers is that the I/O ports of the M68000 are only 8 bit wide and therefore four of them are needed, to form an x-line. When the last buffer is filled with data, the line is passed onto the ports in four instructions. These signals are then amplified by the amplifier boards provided and the solenoids are actuated respectively.

The timing of the program execution on the M68000 with the overall process is illustrated by means of a flow chart in figure 8.6. The first action is to initialise all variables and constants, and to 'tune' to the output of the TMS. The latter issue is explained in the program description in section 8.5.

The motor step pulses are received as interrupts and their count begins at the moment that the conveyors start to advance. The time to read the image data from the TMS is translated into a fixed time of component travel. After recognition the component starts advancing towards the process area. When an appropriate number of steps is reached, it is guaranteed that the TMS has already transferred its first memory slice (and thus all the skiving image) into its VRAM. A few motor steps later the M68000 starts receiving the data. The complete skive pattern is then transmitted to the M68000 well before the component arrives in the process area.

The M68000 is in total control of its communication with the TMS board. It commences communication by starting the DotClk signal at the appropriate time. The use of the frequency switching, mentioned in section 8.3, takes place in the initialisation routine before data transmission.

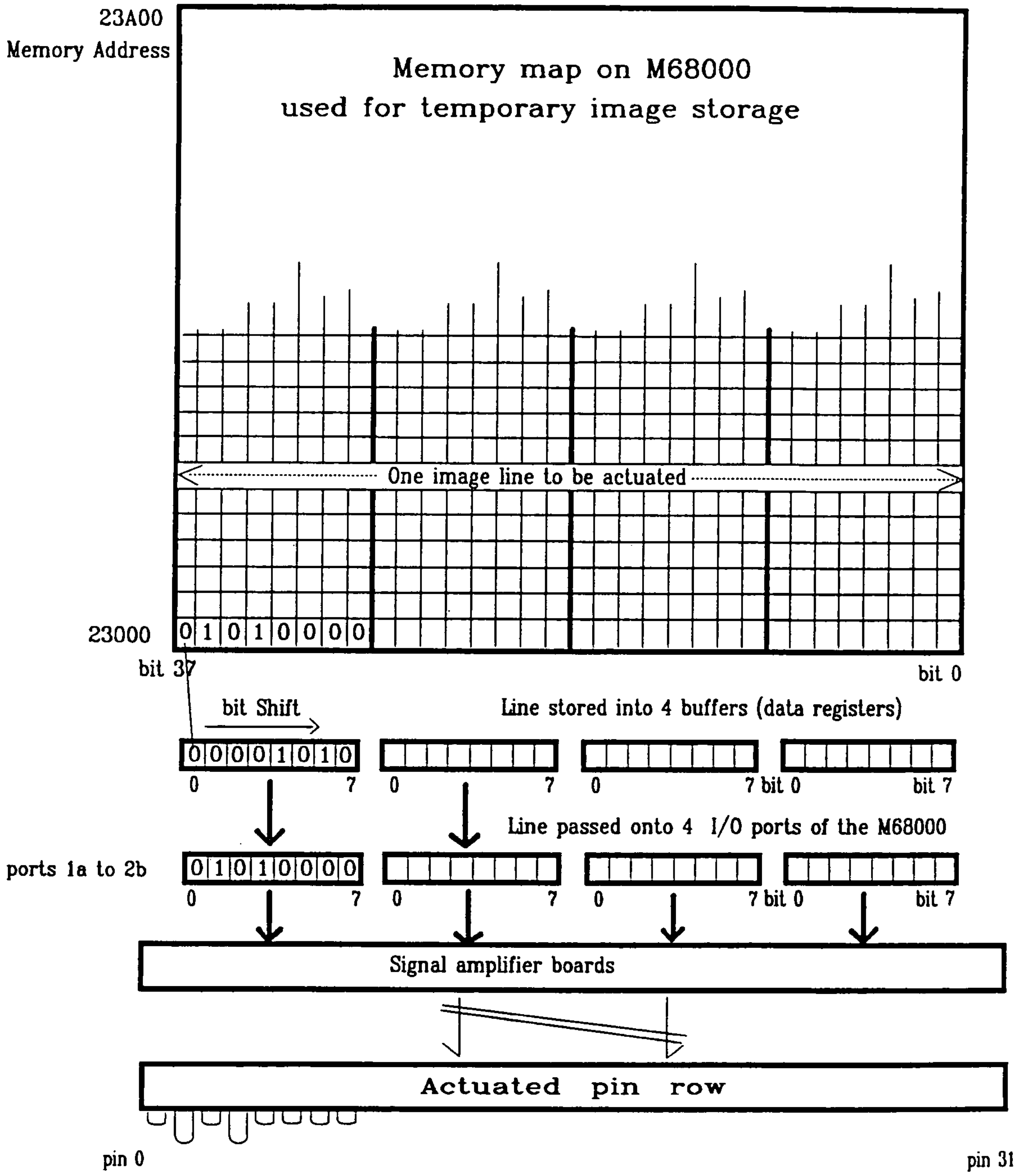


Fig. 8.5 Skive pattern image lines output from the M68000 to the actuating mechanism

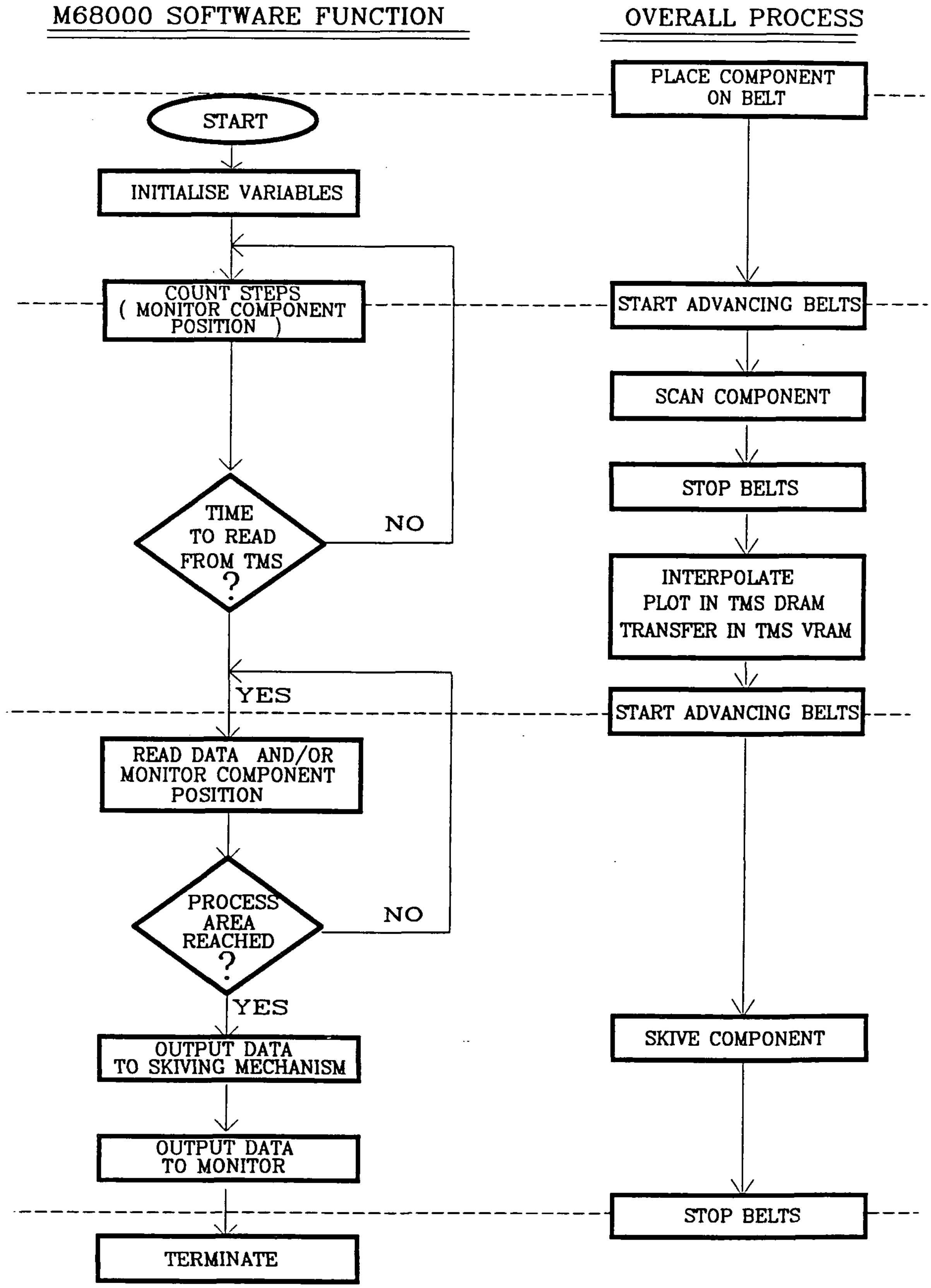


Fig.8.6 Flow chart of the M68000 software in timing relation to the overall process flow.

As shown in the flow chart in figure 8.7 the DotClk is initially switched on at high frequency (8 MHz) until the first HSync pulse is received. It has to be noted that the image in the TMS VRAM has already been translated by 8 lines in the y+ direction to provide time for tuning between the two devices. Thus when the first HSync pulse is received as an interrupt, the DotClk is switched 'off'. The motor pulses are then being counted and when time for image transfer occurs the DotClk is switched 'on' at the communications frequency (4 KHz). After the 8th HSync pulse the M68000 starts to receive the image data.

As mentioned earlier the M68000 is responsible for the process timing with the conveyor movement as well as for the data communication and execution. Because of this, during data reception from the TMS, the control program must be running in a pseudo concurrent form (real concurrency is impossible due to a single processor used [22][32]), so that no incoming data bits are missed nor motor steps are disregarded. By taking advantage of the difference in pulse period between the two signals, this was possible to implement without the use of multi-level interrupt hierarchy. More details about this method are given in the program description in section 8.5. Also the overall control method of image bit storage, component position monitoring and image output to the actuators, is illustrated in the flow chart in figure 8.8.

8.6 The function of the M68000 control software

This section describes the structure and the method used in the software for the M68000. The program is written in M68000 assembly language format mainly for the reason of fast program execution and I/O handling. The overall function of this software is to manipulate and transport the output of the Texas Instruments Board 34010 to the skiving actuation mechanism.

8.6.1 Program structure

The program is designed to work on interrupt basis. The use of interrupts is constrained into the use of a single interrupt level so that further priority complications

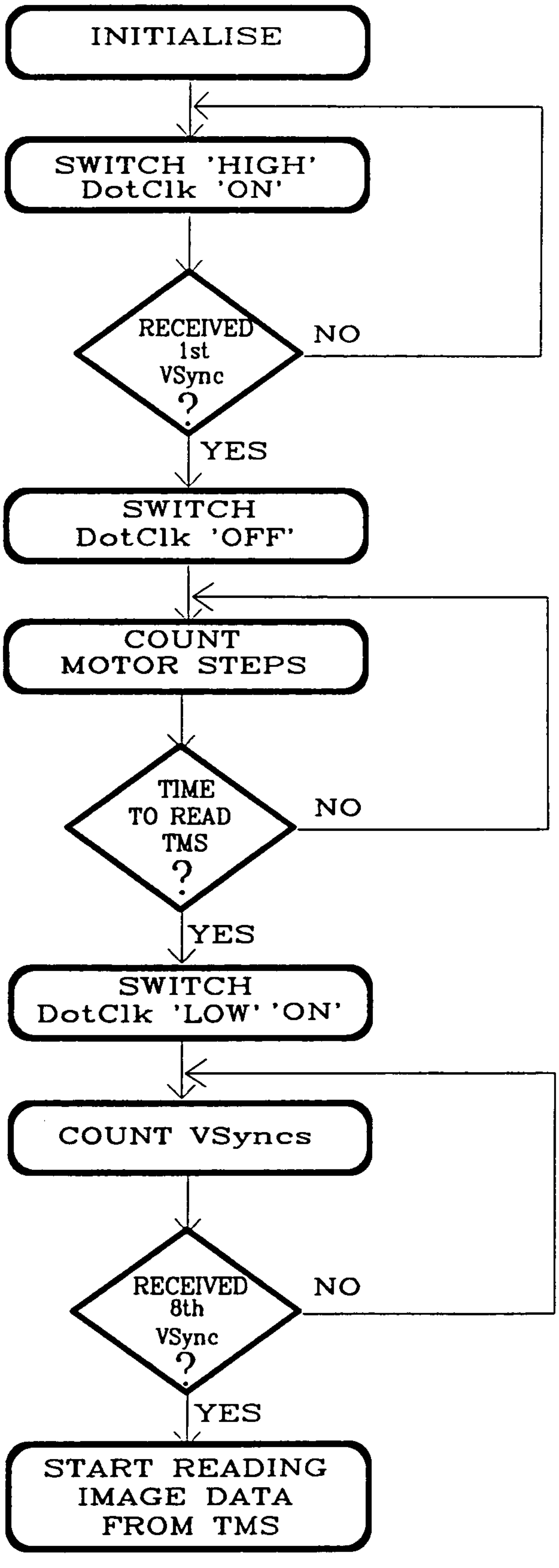


Fig. 8.7 The flow of functions during initialisation until reception of the image data by the software on the M68000

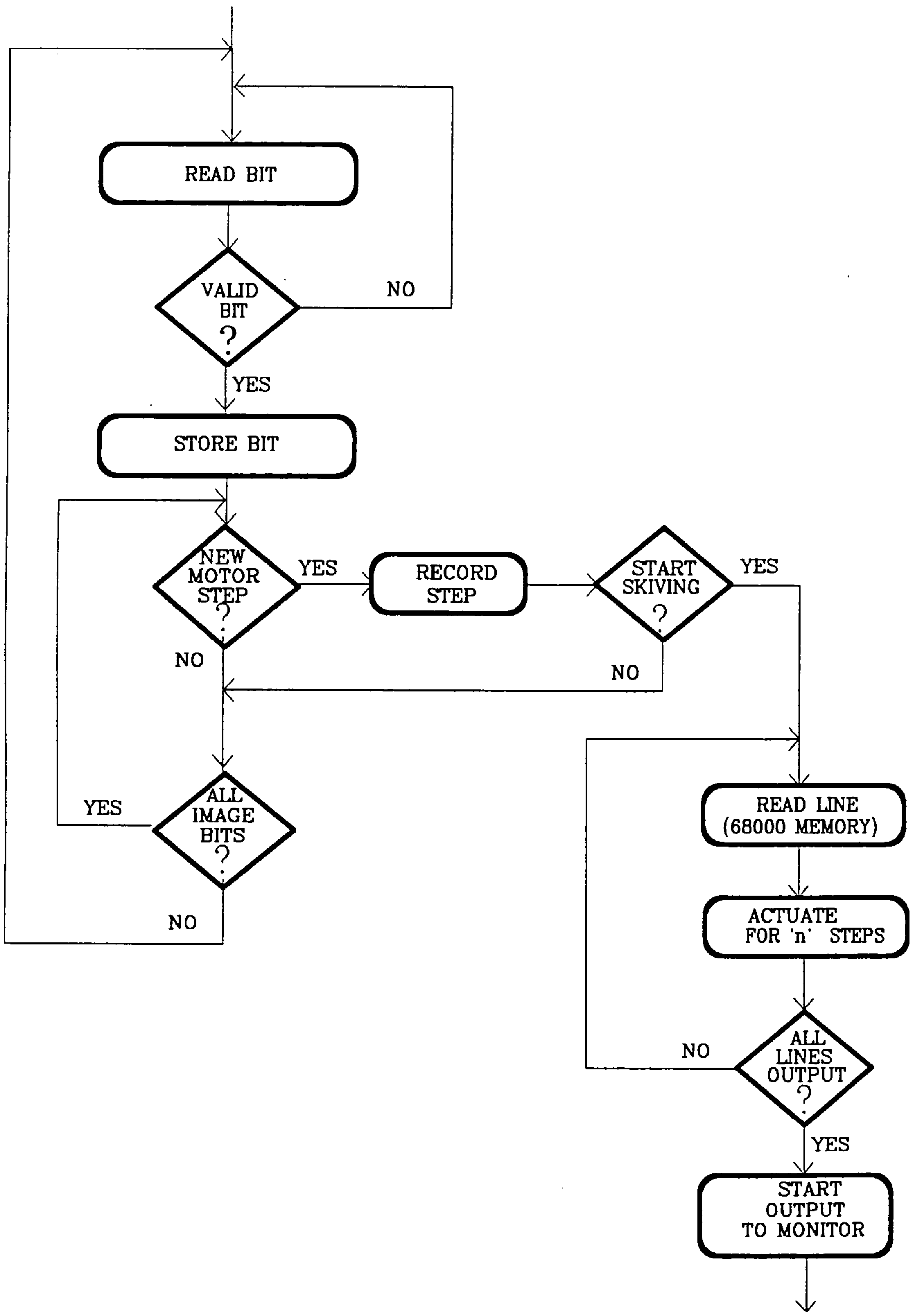


Fig.8.8 Flow chart of the method used for image data reception and actuation, in the software of the M68000 system.

and extra execution time consuming code are avoided. This means that all interrupts have theoretically the same priority but in practice only one interrupt may be served, at a given instance of program execution. Furthermore not any interrupt may be served at any time. Interrupts are supplied with "identification labels" so that each may be served only when its function is wanted. These ID codes simply define an interrupt and its service routine active or redundant.

All interrupt communication is carried out via the central interface board, which is responsible for interfacing the M68000 ports (refer to fig. A-8.1 in Appendix A-8). The logic sequence of events of the program is illustrated in the flow charts in figures 8.7 and 8.8

8.6.2 Interrupt handling

The main program (labelled 'main program function' in the program listing), is in effect the interrupt handling unit. Also when interrupt servicing is terminated, i.e. when the leather component is skived, the main program leaves this responsibility and outputs the actuated shape to the VDU for the purpose of illustration and comparison between the actual physical output and the intended one.

When entering the main program all initiations including interrupt set-up have been carried out. At this stage the frequency switching unit (controlled from M68000) is set to high output (8 MHz) so that all TMS initiations are done fast and at this very instant the main program expects the arrival of the first set of HSync pulses to switch the operating frequency back to the transmission rate (4 KHz).

To implement the interrupt handling method mentioned in section 8.5.1, the unwanted interrupts are disabled during each relevant execution period. The logic function of the program is designed in a such a way, so that only one interrupt is necessary to be served during a single execution phase. The interrupt handling section of the main program contains 5 interrupt waiting loops. These loops are operated in sequence. Once a loop has been exited there is no re-entry to it. These loops are formed to allocate tasks to the interrupt server for each of the 5 logical M68000 program execution phases of the automatic skiving process. The 5 phases are described below:

i. Waiting for TMS initialisation and readiness of ability to output.

Action : Stop TMS (Switch DotClock off) on arrival 1st HSync (no data contained in TMS DRAM yet).

ii. Component transport to and through vision gap until conveyors halt for skiving data derivation. Conveyors start again. TMS image data not ready.

Action : Count motor steps, i.e. keep track of component position.

iii. TMS image data defined and available.

Action : wait for first HSync pulse to arrive (start of valid data map). Switch DotClock frequency to low (8 KHz). Allow next 15 HSyncs to occur (first 16 lines contain no data)

iv. Image data transmission.

Action : TMS transmits image data to M68000. M68000 receives data and creates its own image map. In the same time it keeps track of component position. When all data received and stored, waits until the component reached the skiving process.

v. Image data export for execution (skiving process).

Action : M68000 exports to the solenoid amplifier boards the image data, in synchronisation to belt movement.

In the case of phase iv. more than one variables are to be tracked in real time. The variables are the data coming in from the TMS and the stepping motor signals. Both should be read efficiently so that "incoming" data bits are not missed nor motor pulses are neglected. The first would result in image distortion and the latter would result in timing malfunction.

The convention in this case would be to use two distinct levels of interrupts, one for each signal. However this could not guarantee elimination of the possibility described above. The large difference in the frequencies of the two signals allowed the use of another technique. During the relevant interrupt loop the data signal is received as interrupt but the motor step interrupt is converted to a simple I/O input. During the time elapse of a stepping pulse and also the time between stepping pulses, a number of image data pulses have inevitably occurred. After receiving each individual image bit there is enough time to examine the state of the motor pulse input and determine whether a new pulse has occurred. This is confirmed by a high-low-high transition. (This method is applied by server 4; refer to program listing).

8.6.3 Display of the executed skive image

Having exited the fifth interrupt wait loop, the main program leaves the interrupt handling procedure and simply dumps its image map to the monitor, indicating each individual pin actuation within the intended skiving area. The same memory image map is used for both actuation and display. This map is not manipulated in any way after the end of data reception from the TMS. Furthermore the same algorithm is used for the extraction of the skive pattern in both cases. Therefore this guarantees that the image displayed does not differ at all from the one actuated. This means that the display is a good quality tool for the inspection of the performance of the overall system.

8.6.4 The interrupt service routine

As described above the *interrupt handling unit* of the main program consists of 5 sequential interrupt loops to be serviced. For the purpose of reducing code and increase program execution speed, only one service routine was constructed for the service of all interrupts.

This routine contains a *task allocation unit* of its own and 5 *servers*. The servers are sections of code dedicated to satisfy a particular interrupt requirement, such as skive image storage or execution. Each of these servers are meant to serve one interrupt only during a particular time period, i.e. only while its corresponding interrupt wait loop is active. Each interrupt waiting loop passes its own "signature" to the "*identification label*" (defined as Int_ID in program listing). This identifies what execution phase the program is in and therefore which server should be called at any time. Hence a server may be called only if the correct ID is shown. The ID itself is an incrementing integer never returning to a previous "signature" and therefore declaring redundant servers with signatures used previously. This ensures that there may never be the case where a server is called for the wrong service.

The task allocation unit is the first execution stage of the subroutine and its role is to examine the ID of the interrupt loop which called for service and instruct the appropriate server to take action. therefore the subroutine is entered and exited more than one times but only a specific section of it is executed in each occasion. This task allocation unit is short in code, thus minimising time overheads, and it successfully simulates a multi-subroutine system with interrupt priority service. The schematic diagram in figure 8.9 illustrates the functional structure of the software.

8.7 The significance of software parameters to the process.

Once a line is output to the port it is maintained active for a certain amount of time, equal to a number of motor steps. This is because if a line was actuated instantaneously, although the corresponding pins would be pressed, there would not be enough time to actually deform the leather and thus to achieve skiving in the specified area. Therefore by maintaining the current line actuation by a number of motor steps,

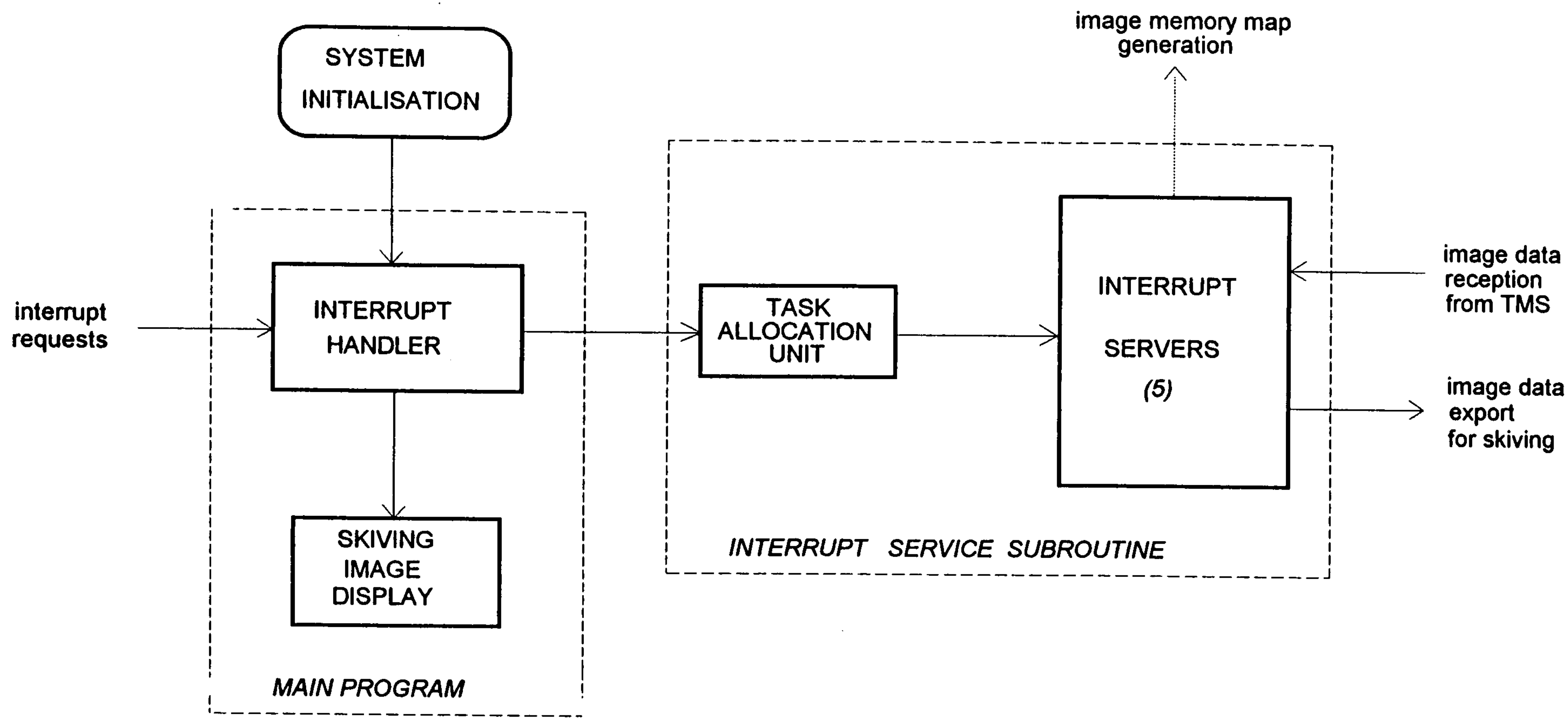


Fig. 8.9 Schematic diagram of the structure of the M68000 control software.

i.e. for a certain belt displacement, it is possible to control the 'width' of a 'horizontal' skiving line.

The term horizontal refers to the direction perpendicular to the direction of belt movement, and this introduces a secondary variable/controller of the y-resolution of the process (refer to constant SPerLn in program listing). This implies that it is possible to vary the y-resolution of the process by simply increasing this value without needing to vary the original y-resolution in DRAM of the TMS. With the aid of this variable it is also possible to tune the process so that it produces the same result on the leather under different motor speeds. For example :

Motor Speed = X mm/sec and SPerLn = K steps

should produce the same skiving line width as

Motor Speed = 2X mm/sec and SPerLn = K/2 steps

This of course does not take in consideration other influencing factors as :

i. t_k : knife drag on the leather (variable with belt speed variance).

ii. t_{d2} : recovery time of the actuation mechanism (influenced by belt speed variance).

iii. t_{d1} : time response for actuation depression (influenced by leather properties)

iv. t_w : time from starting cutting until reaching valid skiving line depth. (influenced by leather properties and belt speed)

v. h_d and h_r : hysteresis due to time elapse for full leather depression and recovery (influenced by belt speed variance).

Although it may not obvious, in extreme conditions these factors could influence dramatically the validity of the analogy stated above. For example an extremely small value for SPerLn could result in no skiving at all or in skiving line not deep enough.

To determine a point where a balance for these factors is achieved and therefore the smallest SPerLn value, which would produce the thinnest possible horizontal skiving line with valid depth, it is necessary to experiment with a particular system and at a given conveyor speed. Let us not forget that even the shape of the tip of the pin, the actuator force, or the leather thickness could influence this limit.

As mentioned earlier the present machine was running at 185 mm/sec. For this speed and for the present actuation mechanism used, it was found that the limiting value for SPerLn was 6. One could argue that the limiting value in motor steps would be the one which, under a given linear speed, corresponds to a belt displacement equal to the width of a pin, i.e. to the theoretical y-resolution (argued in chapter 5). This argument would not stand because the evaluation of the minimum value for SPerLn is in reality a complex task. If for example V is the linear velocity of the conveyor then a more realistic calculation of $SPerLn_{min}$ for the minimum line width L_{min} would be:

$$\mathbf{L_{min} = (h_d - h_r + t_k + t_{d2} - t_{d1} + t_w) \times V}$$

and

$$\mathbf{SPerLn_{min} \times F = (h_d - h_r + t_k + t_{d2} - t_{d1} + t_w) \times V}$$

where F is the system conversion factor for motor steps to linear belt displacement. In any case it must be stated that the experimental method of defining these values is the most reliable, due to the complexity of the system.

Another issue with program parameters, influencing the performance of the overall process, is to ensure that all data has been received and stored in the M68000 memory before reaching the process area. This adjustment is a balance between the operating DotClk frequency and the y-resolution, i.e. the total amount of data bits to be transmitted. Therefore if expansion of the memory tables is attempted in the future due to a higher system resolution, a higher communications frequency has to be employed, if transmission time has to be kept the sufficiently low.

The present configuration of the size of the M68000 memory map allows variability in working y-resolution for up to 150%, i.e. for y-res = 2.5 x 32 = 80. This was done with the view to experimentation into methods of improving the effect of the poor resolution on the leather solely by higher y-resolution of the image in the memory, combined with specific software manipulations of the actuation signal. An example would be to define a series of short actuations of the pin within the specified actuation time of a horizontal line, and/or to introduce delays at various instances during actuation, etc. In any case the M68000 board may accommodate larger memory maps than the present one, if this becomes necessary.

8.8 Conclusion

The integration of the skive controller module to the image generating module has been successfully carried out, as a set of inter-communicating software and hardware units. However in an ideal environment it would be desirable to be able to reduce the number of hardware modules involved and thus simplify the system. The ideal solution therefore would be to assume that a single device is responsible for generating the skive pattern image and controlling the skiving process. Nevertheless this work proved that the implementation of a fully automatic skiving system is viable, and therefore such a system could form the basis of a future commercial product. The results of skiving, using this system are illustrated and described in chapter 9.

The implementation of the skive pattern transmission and execution formed the second major phase of the electrical integration of the skiving system. From the above description it is concluded that the present configuration produces flexibility for resolution enhancement, but it is also evident that the same electrical/software may potentially be used for the automation of different processes, that rely in actuation of two dimensional patterns in real time control.

CHAPTER 9

Suggestions for further system enhancements

9.1 Introduction

The full automation of the skiving system has at this stage been proved viable. This statements is based upon the fact that skiving can be automated to operate as a flow through component oriented process. Such a process may receive components at any possible orientation and identity and produce skiving without having to modify the component's flow to perform its processing.

However there is another issue which determines whether the automatic skiving system has the potential to eventually become a commercial product. This issue is the quality of its output. The results of the present research system although acceptable, given the operating resolution, they clearly identify the need for higher resolution, for the imaginary commercial prototype.

It seemed thus logical, as a final stage in this research, to look into the possibilities of increasing system resolution. This stage is considered as an effort to suggest alternatives, at least in theory, which may be considered and implemented by BUSM, in the system development stage. This chapter describes these considerations and related experiments, for the purpose described above. However it must be stated that not all options presented in this chapter have been researched into considerable depth. The main effort was directed towards the implementation of the new high resolution skiving mechanism and into evaluating the conditions for using repetitive pin action for skiving.

9.2 The quality of output of the current skiving system

Having completed the electrical integration, described in chapter 8, the skiving system was operated to produce skive patterns. Similar components were input to the system at different orientations and positions on the conveyor, and skiving was performed in a fully automatic manner. The photographs in figure 9.1 illustrate a typical example of a component being input to the system at four different angles. The projected skive line seen in all patterns is due to malfunction of one of the actuators and should be ignored in observation.

The general conclusions from the results obtained are the following :

- The skiving process can successfully be fully automated and behave as a flow through component oriented process.

- Skive patterns are actuated with precision of half the effective operating resolution. In the case of the 5 mm resolution system, the *accuracy in locating skive patterns* is +/- 2.5 mm. This effect is due to the necessary rounding in calculating the "nearest pin" to actuate. Figure 9.2 illustrates this principle. In the example shown, an skive image has been translated to the RHS by half the operating resolution, due to "pin rounding". This is seen as the location of the skive pattern following translation by $| x | +1$. However this may happen as a pattern translation in one of both directions and in one or in both axies (i.e. in x, y or x AND y). It is important to state that this effect is expected to exist no matter what the working resolution is. However in higher pin resolutions this effect is expected to become so small enough not to be noticeable, and/or to form a reason for component rejection.

- Skive pattern distortion is also subject to the necessary rounding mentioned above. Hence skive pattern distortion is observed only as a *localised distortion* in areas where the pin chosen to actuate deforms the original pattern. The term localised

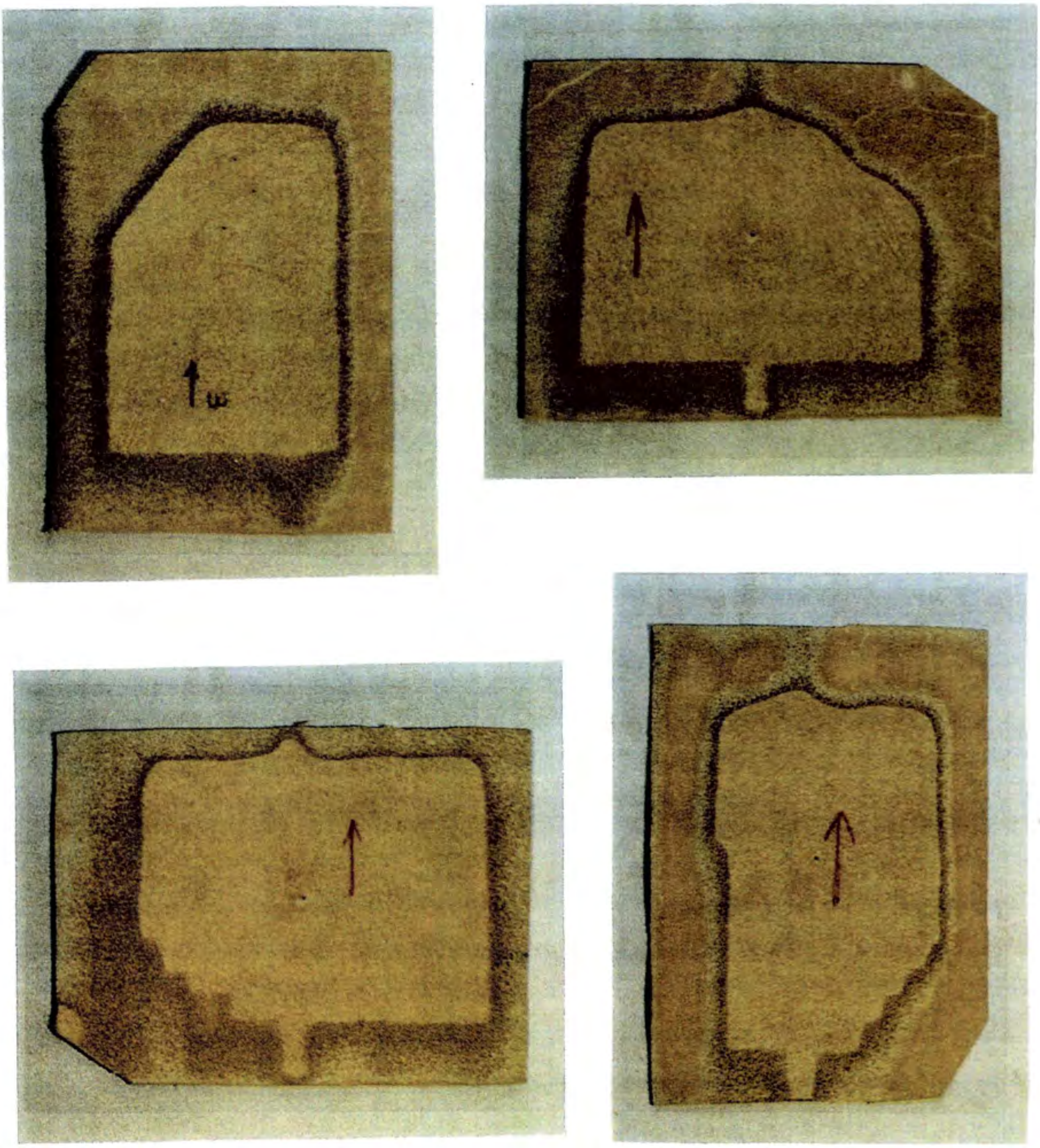


Fig. 9.1 Typical result samples of fully automated skiving based on 5 mm pin resolution. The photographs illustrate four components of similar identity, entered into the system at four different angles.

identifies the difference between a total skive pattern distortion and one subjected to a particular small region of the component. Total pattern distortion has not occurred in this system, and such a hypothetical event would be due to malfunction of resolution scaling. The drawing in figure 9.3 explains graphically the principle of localised pattern distortion. In this example, the skive pattern intended to include side edges oriented at a small angle with the y-axis. This may result in partial deformation of the those edges. This is observed as discontinuity of the pattern edges, taking the form of a step. This occur form one point onwards, where the side edges reach values rounded to the neighbouring pin (| x | +1). The stepping effect in diagonal skive lines, discussed in chapter 5, is an amplification of the effect described above.

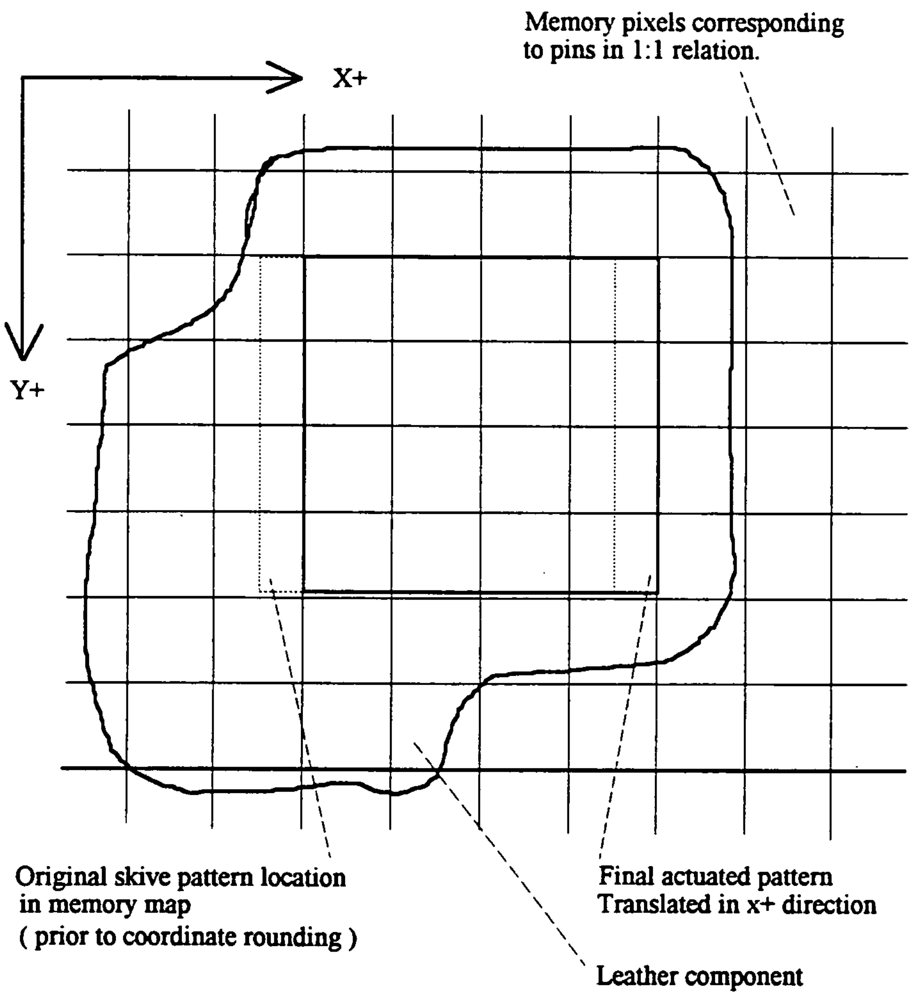


Fig. 9.2 Skive pattern translation in actuation.

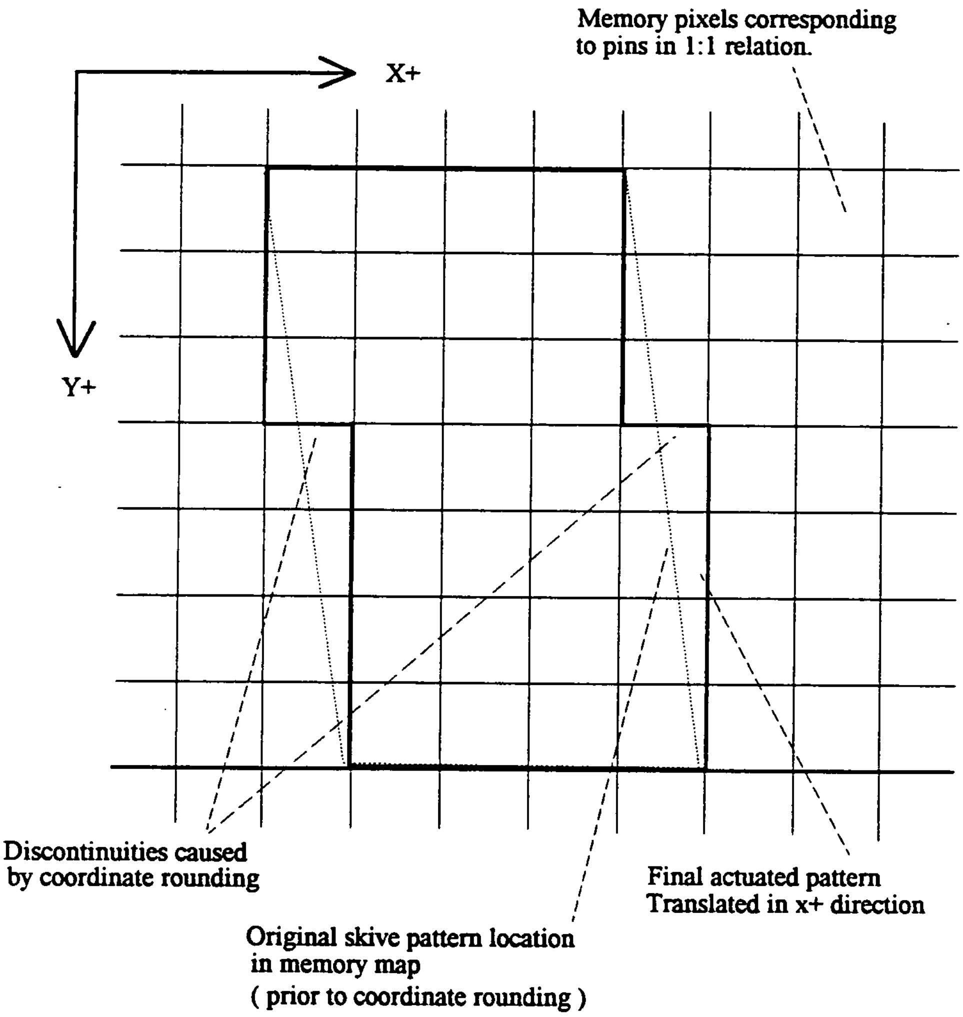


Fig. 9.3 Local distortion in actuation of skive patterns.

- Due to the above, it is concluded that if the present accuracy of actuating skive patterns is not satisfactory for industrial and/or marketing purposes, the only solution for improvement is to increase the operating resolution of the system. Such a system enhancement is considered to improve all the features described above.

9.3 Alternative solutions for improving the effects of poor resolution

From the conclusions presented it seems that the major concern of system development will be the issue of the pin resolution. In the final part of this research, steps were taken to identify possible alternatives for improving the existing resolution. The conclusions from this effort was that there are three different possible routes that one may take to resolve the problem :

i. To invent a different method of actuation, the output of which is not so highly dependent upon the system operating resolution.

ii. To employ a different type of actuator, which may enable one or more of the three following benefits :

--- small actuator size to achieve close assembly
--- elimination (or simplification) of the current pin / lever mechanism, to allow the possibility of a more dense matrix design.
--- direct contact between actuator and pin matrix or even between actuator and tri-layer system.

iii To improve the resolution of the current mechanism. This would involve inventing a novel structure for the mechanism, which could accommodate more solenoids and more pins.

The following few sections describe the above considerations.

9.4 Skiving based on repetitive pin actuation

Following the first route of investigation, mentioned above, a new idea for performing actuation in skiving was considered. Up to this stage it has been described how a skiving stripe may be implemented by continuous pin impression, while the component is moving. Theoretically the same could be achieved by successive pin insertions and retractions if they are implemented at a suitable frequency. This idea assumes that there is a an operating frequency at which the two following conditions are met :

- the pin maintains full operating stroke
- the leather does not recover between successive pin insertions.

This principle assumes that the *latency* of the tri-layer is such that the leather is kept in skiving conditions, because at such hypothetical frequency, the leather simply does not have enough time to recover. Latency of the tri-layer system is defined as the limiting time elapse, that is not sufficient for the skived area to retract far enough, to cause unacceptable skiving discontinuity.

The reason for which this idea was considered to be a solution to the resolution problem, was due to the possibility of using existing technology of printer head mechanisms, that are based upon this principle of operation. The first logical step in this investigation would be to evaluate the latency of the tri-layer system in skiving.

9.4.1 Evaluation of the latency of the tri-layer system

For this purpose, it is important to emphasise that the latency had to be calculated dynamically and with the tri-layer system in operation.

Another important issue is to distinguish between full leather retraction (recovery), full system recovery, and the latency issue examined here. The first two issues differ from the meaning of latency examined here and are irrelevant to this investigation. The target was to identify the point in time during leather retraction at which the leather stops being skived. It was already known that a part of total pin displacement behaves as a "dead zone", i.e. although the tri-layer system is pressed skiving does not occur until a certain amount of travel is reached. Similarly skiving does not stop when the leather is fully retracted, but after a certain (smaller) amount of retraction.

An experimenting mechanism was set-up to obtain the results explained above. The main features of the experimental setup are given figure 9.4 The mechanism consisted

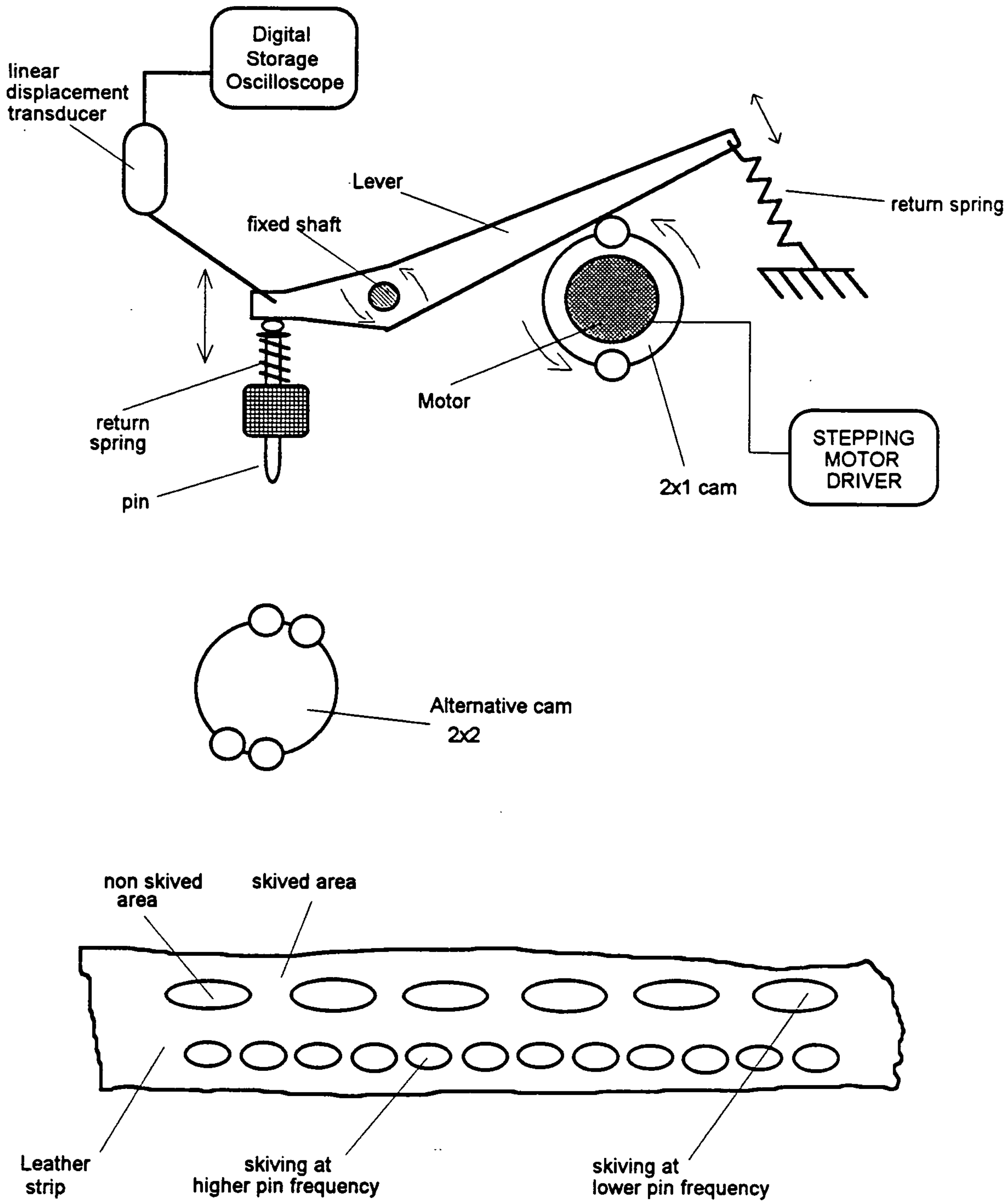


Fig. 9.4 The experiment set-up for the investigation of the tri-layer system latency.

of a fixed stepper motor turning a cam mechanism which was acting upon the drive lever of a pin. The resulting motion was a sinusoidal form of pin movement, the period of which was determined by the angular velocity of the rotor. The whole experiment set-up was implemented on the skiving machine. The motor/cam fixture was mounted on one of the end levers of the skiving head, and testing was carried out in a dynamic sense, i.e. with the machine in skiving operation. The reason for employing a cam mechanism rather than using the existing actuator was to eliminate the response characteristic already discussed in chapter 5 and to ensure constant pin force along the entire cycle of motion.

The twin belt conveyor delivered a long stripe of leather through the skiving process area and this was skived while the pin was driven to fast successive stroke cycles. All other pins were not used, i.e. they were constantly retracted. An illustration of the skiving effect on the leather is also given in figure 9.4., where one may observe the difference between a high frequency driven skive pattern and one generated at a lower frequency.

The suggestion here was that, by increasing the stroke frequency, the latency of the system may be identified at the critical frequency value in which the mechanism performs a continuous skiving line on the leather workpiece. When this occurs it means that at this particular frequency, and for the given conveyor speed, there is not enough time for the leather to recover between two sequential pin actions. This definition of course is relevant to what skiving continuity is, and from what point it is acceptable by the industry.

Thus at such hypothetical frequency, skiving should not be interrupted and should look continuous, as if the pin was permanently pressed. Having obtained this frequency value, the system latency may be derived. Furthermore this frequency value would identify the practical feasibility of the principle examined and would point at what type of mechanism could possibly perform this repetitive action successfully.

Apart of the frequency factor, the latency of the tri-layer system, is considered to be subject to the *effective mark to space ratio* of the input motion. This is defined as the ratio between the time in which the pin is within a displacement responsible for skiving, and the time in which pin displacement does not cause skiving.

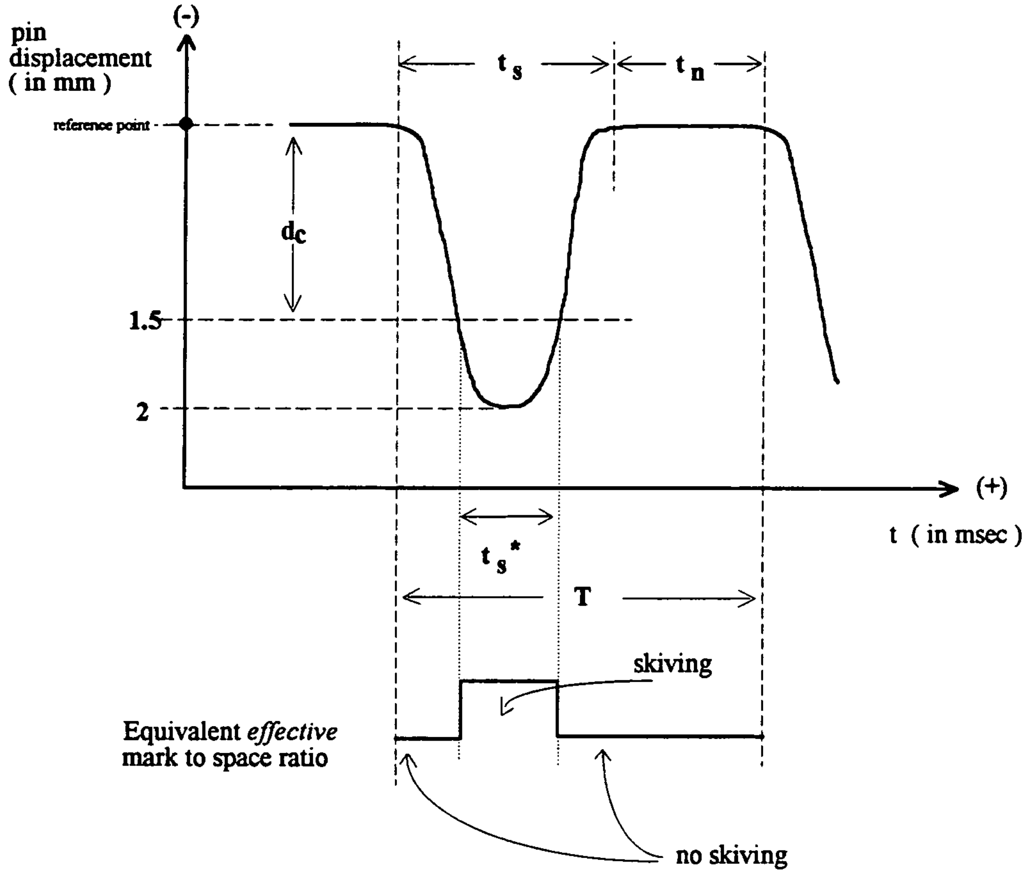


Fig. 9.5 The characteristic of pin displacement, driven by the cam mechanism.

The linear displacement transducer shown in figure 9.4 enables capture of the pin movement against time on the digital storage oscilloscope. This makes possible the observation of the input pin displacement characteristic and furthermore its analysis. Although the transducer is not linked directly to the pin, it was made sure that during all experimentation the pin was in contact with the lever. This was observed with the aid of a light strobe. Also, to ensure continuous contact between the lever and the cam, an additional return spring was added to the lever. Contact between the two was observed in the same way.

The diagram in figure 9.5 illustrate the profile of pin motion against time. The constant **T** is the period of a stroke cycle, i.e. the effect of a single wheel of the rotor. The constant $\mathbf{t_s}$ is the active time of the pin. The pin is in motion only during this time.

The constant t_n is the non active pin time, i.e. the time during which the cam does not touch the pin lever. The ratio between the two is the intended skive ratio, as if the mechanism started to skive at the instance of lever engagement by the cam and until the lever is completed relaxed.

However in reality this does not happen. It takes a vertical pin displacement d_c for skiving action to start taking place. To determine this displacement value a secondary test was carried out. The pin was displaced from resting point (and while skiving) at successive intervals of 0.1 mm and skive depth readings were taken, until a sufficient skiving of 50% (0.7 mm) of leather thickness was achieved (at full stroke). This experiment defined the minimum skiving pin stroke, and it was found to be 1.3 mm.

The above implies that all skiving took place during a time span t_s*, during which the pin is found to be within skiving stroke. The constant t_s* is thus called the *effective skive time*. Therefore the *effective non skiving time* is T-t_s* . Hence the ratio t_s* / (T-t_s*) is the effective mark to space skive ratio. This is the ratio to be taken into consideration, when researching into a suitable ratio value to achieve continuous skiving. The effective mark to space ratio is illustrated in figure 9.5, in relation to the pin displacement characteristic.

Having defined the above constants, the expectation is that if at a particular frequency continuous skiving was achieved, this implies that the *actual* mark to space ratio on the skived leather should gradually increase, with increasing frequency, due to the latency of the tri-layer. Note that the above ratio is defined as skived over the non skived length.

The initial experiment with the 2x1 cam produced effective m-t-s ratio equal to 0.4. The results indicated that with the above ratio, and by increasing pin frequency, it was impossible to achieve a continuous skive line on the leather. This was apparent because the actual mark to space ratio on the leather seemed to be slightly but gradually decreasing rather than increasing. This is illustrated in the chart of figure 9.6, where the lower characteristic represents the ratio achieved, with the 2x1 cam.

It became thus apparent that it was necessary to increase t_s*. To implement this a 2x2 cam arrangement was used, as drawn in figure 9.4. By positioning two wheel cams together the effective m-t-s ratio is improved. from 0.4 to 1.18. The small gap between the wheel couples was set so that the discontinuity of stroke, when passing from one wheel to another, would not interfere noticeably with the depth of skiving.

The result for operation with the 2x2 cam was as initially hypothesised. The relevant characteristic of the 2x2 cam shown in chart 9.6, indicates clearly that the skived mark to space ratio increases with frequency and should tend to infinity at the frequency value corresponding to the system latency. This gave the opportunity of actually achieving a continuous skive line.

The limiting frequency at which, this occurred was found to be approximately 100 Hz. Thus the latency of this particular tri-layer system, and for the effective m-t-s ratio given, is 10 milliseconds. The reason why the complete characteristic (up to 100 Hz) is not shown in chart 9.6 is because of the practical problem faced in measuring mark to space ratios in higher frequencies.

However it must be stated that this value represents the frequency in which it was not possible to observe (visually) any discontinuities in the leather stripe. "Near continuous" skiving was obtained at lower frequencies such as 70 Hz onwards. The

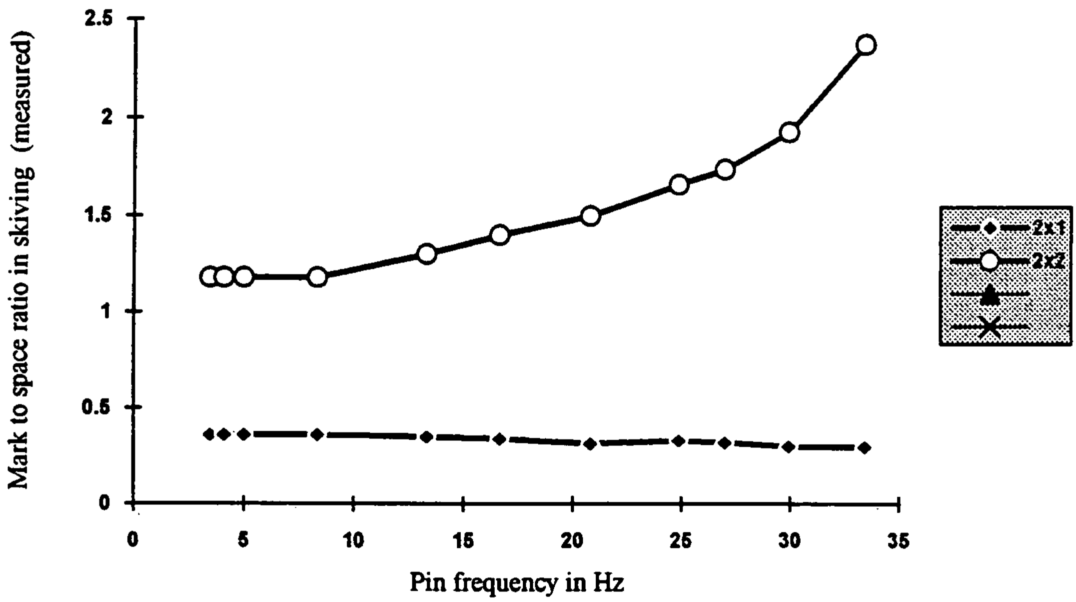


Chart 9.6 Comparison of the skive mark-to-space ratio characteristics, for the two different cam mechanisms.

limit from which industry would define acceptable the continuity of a skive line is not yet defined. For this reason of safety the 100 Hz limit was taken as the minimum valid frequency.

Finally another interesting observation was that the depth of skiving was reduced by increasing the frequency. This is illustrated in the characteristic of chart 9.7. It was observed that the skive depth decreased rapidly in the region of 3-5 Hz and then relaxed. It was thus necessary to start with initial skiving depth of 1.05 mm, to achieve a final depth of 0.7 mm at higher frequencies. This observation is explained as a variance of system latency with varying displacement due to pin impression. Hence it is important to keep this feature in mind, if this method is implemented in the future.

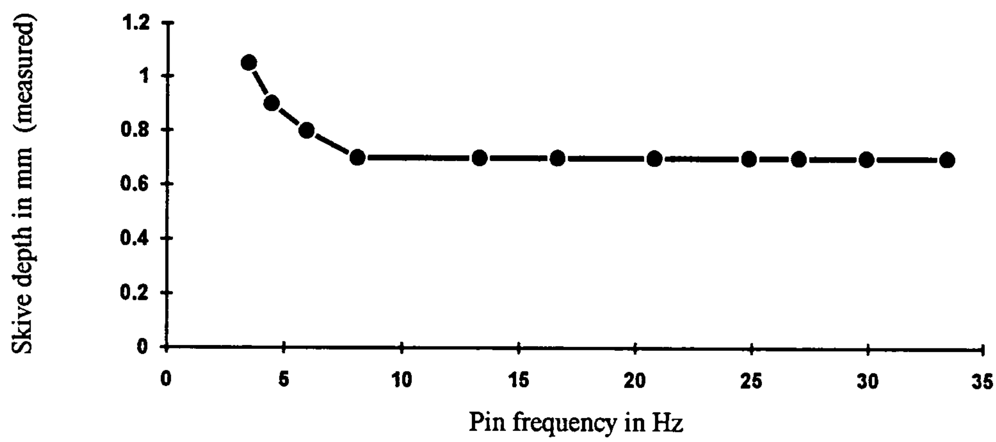


Chart 9.7 Variance of skive depth with pin frequency.

9.4.2 Actuation utilising repetitive pin action

Having proved that it is possible to skive by repetitive pin action, and also having identified the related system latency, it was possible to suggest implementing skiving using existing technology. The current technology involved in printer head mechanisms can provide both high operating resolution and a minimum possible number of components in the skiving mechanism. If this implementation is viable, then cost of manufacture and system serviceability seem promising too.

A step further from just suggesting this, was to investigate the suitability of two selected printer mechanisms. The first was the Printronix P9012 . This is a hammer bank shuttle printer containing a series of hammer/pins. The hammer bank consists of hammers mounted on a laterally and continuously oscillating shuttle. The pin tips are very small (0.2 mm) and provide 0.035 mm operating resolution [16] . A full line of dots may be printed on each half cycle (i.e. left to right and right to left) of the shuttle. Figure 9.8 illustrates the principle of operation. In this form of operation the printer head is capable of printing characters and graphics to high precision and speed.

From the specification of this mechanism, it seemed that it could operate in frequencies higher than the tri-layer latency, thus indicating suitability for skiving in this issue. Furthermore its capability to print a complete line of data simultaneously was another promising feature. The printer mechanism was extracted from its base and was modified to be tested for suitability in skiving. However the results indicated that to achieve skiving there is the need for both longer pin stroke and force. If these characteristics are available in another mechanism based upon this principle of operation, then it is considered worthwhile experimenting with.

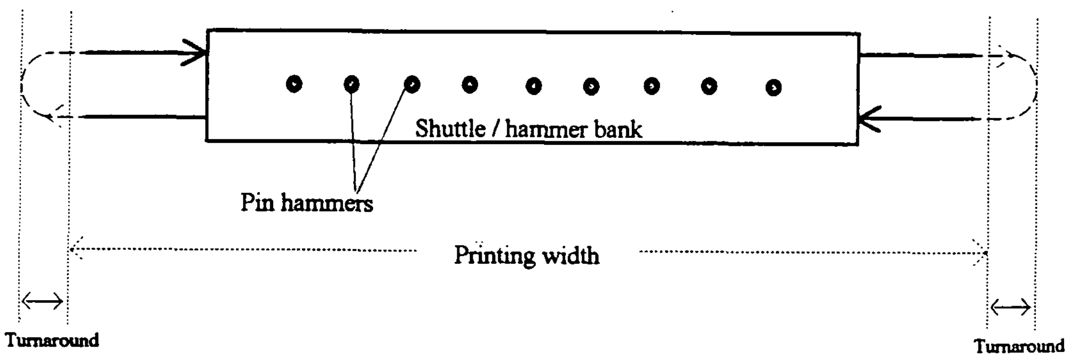


Fig. 9.8 Representation of the shuttle / hammer bank print mechanism considered for skiving.

Another printer mechanism experimented with was the 300/600 LPM 1982 Dataproducts (refer to fig. A-9.3 in appendix A-9). This is also a hammer bank printer mechanism but it works in a different way. Figure 9.9 illustrates the basic principles of the actuating mechanism. This hammer bank is permanently fixed and the working resolution is 4 mm. Each hammer is responsible for typing a character. The hammer plate contains a flattened coil, and it is able to spring across its plane and between permanently located magnetic plates. A series of adjacent magnets and hammers form the printing mechanism. Actuation occurs when current is driven through the coil of the hammer plate.

Although the resolution of this mechanism is not by far better to the current skiving one, it was considered possible that a more dense hammer matrix could be manufactured. This printer may operate in frequencies 140 Hz, but more modern

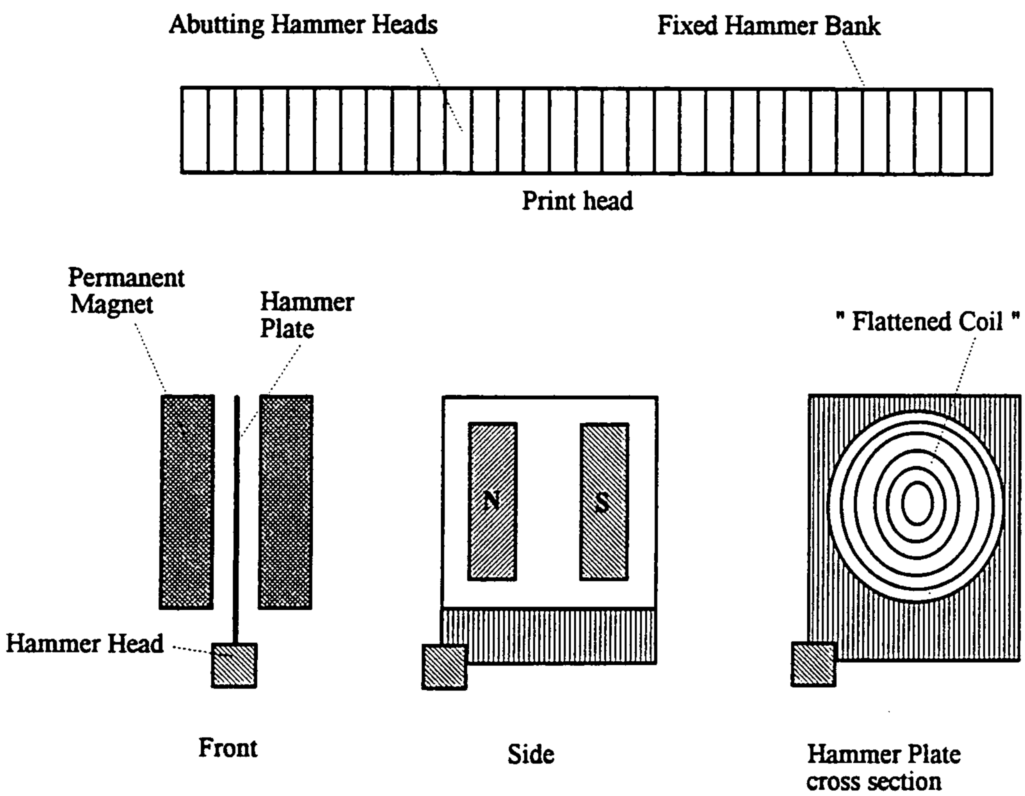


Fig 9.9 Illustration of the principle of operation of the magnet based hammer bank printer mechanism, modified for skiving.

versions of it can reach rates in excess of 800 Hz. Furthermore the hammer stroke could be easily modified to be in excess of 4 mm, i.e. more than adequate for skiving.

The main reason for which this mechanism was considered worth experimenting with, was the expectation of larger actuating force, if compared with the Printronix P9012. In any case, after modification of the mechanism to be fitted into the skiving rig, it was once more proved that the force provided was not adequate for skiving.

By experimenting with the mechanism to its limitations, it was found that the maximum hammer force obtainable is 15 Newtons, about half of what is necessary for the present skiving system. However, this mechanism is worth considering again, if a future developed skiving system is made to operate without the presence of the knife guide, thus requiring much lower pin forces.

9.5 Alternative options for actuation in skiving

This option, is the second alternative listed in section 9.3 and is a different approach for solving the problem of skiving resolution. Rather than changing the method of pin movement in skiving, the replacement of the actuator itself (solenoid) with different actuation technology was questioned. In this phase three alternative types of actuation were considered, Hydro/Pneumatic, Electro-Rheological, and Piezo-Electric. However for various reasons it was concluded that these such actuator systems were not promising enough to form the basis of an immediate implementation in skiving. A brief description of the relevant considerations and conclusions is provided in the next three sections. The content of these sections should be taken only as a brief and general consideration of alternatives.

9.5.1 Actuation based in principles of Hydraulic / Pneumatic operation

The main theme of this option was that a pin matrix could be actuated using either compressed air or liquid under pressure.

The main attraction of this solution is that provided that a higher pin matrix was designed, there would be no problem for the dense packing of the actuating units. Both alternatives would involve thin pipes delivering pin or air pressure to the pin matrix, thus reducing the requirement of large volume of the skiving mechanism. Furthermore, the actuating devices, i.e. electro-mechanically operated valves, could be located at a distance from the immediate process area giving thus flexibility in their overall assembly.

Going a step further in consideration, the pin matrix could be eliminated if pressurised air or liquid was used in the form of directed jets, that could provide the force and displacement needed for skiving. However this solution would required a firmly enclosed environment of actuation interfaced with the leather components, for the reasons of noise and safety, and/or system protection from the liquid used.

The main drawback with this option of actuation in general, was the delays caused during actuation of the valves. Each valve should be operated twice, to determine the time of skiving by a pin, thus increasing the response overhead. Furthermore the compressibility of air, and the response in air pressure build-up, seemed to be another cause of hesitation, if considering the need for availability of a constant pin force for skiving. In any case this solution would not decrease the number of components needed to actuate the pin matrix, in contrast it would increase dramatically the overall cost of the skiving mechanism.

9.5.2 Actuation based on Electro-Rheological fluids

Electro-Rheological are fluids known to possess the capability of changing their viscosity when they are subject to particular voltages [17],[18]. If such a fluid is under a controlled flow environment, the change of viscosity may be suitably used to produce linear displacement of a small component. It may also be used to vary friction between moving components and thus inhibit movement of an actuator [30]. E-R fluids have already been used for tactile sensing in robot grippers, and operate at high frequency of response. This feature was considered as a possibility to produce controlled displacement for actuation in skiving. In this case the problem of pin size and spacing is transformed into the problem of implementing very small pipes containing small moving or deflecting components (the actuators).

According to this idea, the displacement could be produced at a point where the pipeline delivering the fluid, would be deliberately weaker, or connected to some type of moving (projecting) mechanical element. The main issues for consideration in adopting E-R fluids in skiving are the following :

- The amount of energy input to the system, necessary to drive a large number of individual actuators.
- The implementation of the actuator itself.
- The amount of input energy necessary to obtain the desired displacement.

Having examined the above issues, it seemed that the use of E-R fluids was not a practical solution for skiving [19]. The main reason was that the viscosity of E-R fluids merely doubles with stepping input voltage. The necessary input involved large voltages (2-3 KV step voltage), to achieve 1 mm of linear actuator displacement. Also, sealing the link between the moving part of the actuator and the fluid, appeared as another intricate problem. Furthermore, the high cost of the fluid itself, and the overall amount of components involved in implementing the circuit for a multiple output actuator bank, would introduce unjustifiable costs for the actuation of the skiving system. It was thus concluded that although the idea in using E-R fluids was theoretically viable, it was the wrong approach for the current problem.

9.5.3 Actuation based on Piezo-Electric ceramics

Another approach, towards increasing system resolution, was the use of Piezo-Electric ceramics. Piezo-Electric ceramic devices are usually used to detect accurately very small movements [20]. A small deflection on applied on a P-E ceramic plate causes change in the voltage at the circuit connected to it. However such plates may be used in the reverse way. If a voltage is applied between the two sides of the plate, it causes deflection of the ceramic plate itself.

Under applied voltage, individual ceramic plates may produce only small displacements, in the regions of microns. Hence it initially looks like such actuators may not be suitable for actuation in skiving. However the displacement produced by bending of the ceramic plates can be amplified. This may be implemented by using more than one P-E plates, in a structure similar to the one shown in figure 9.10.

More than two P-E ceramic plates are initially cemented onto each side of a suitable metal plate. This is done in a high temperature furnus and with special adhesive [20] . The plates are then subjected to high dc voltage, at terminals A and B, for a short period of time, to induce crystal polarisation. This produces a high displacement P-E actuator, with an amplified stroke, dependent upon the length of the metal plate and the number of P-E plates used. After polarisation, smaller voltages (200-400 V) may be applied for actuation. The actuating dc voltage to the system is again applied at A and B, now producing amplified bending, which may be exploited as a linear displacement h, as shown in figure 9.10.

Since the P-E actuator is a device operated with static charges, there is low power requirement due to the absence of electric currents. Hence a large number of such actuators may be used within a relatively small volume without the overhead of heavy wiring, nor the need for expensive electrical hardware. Furthermore such actuators

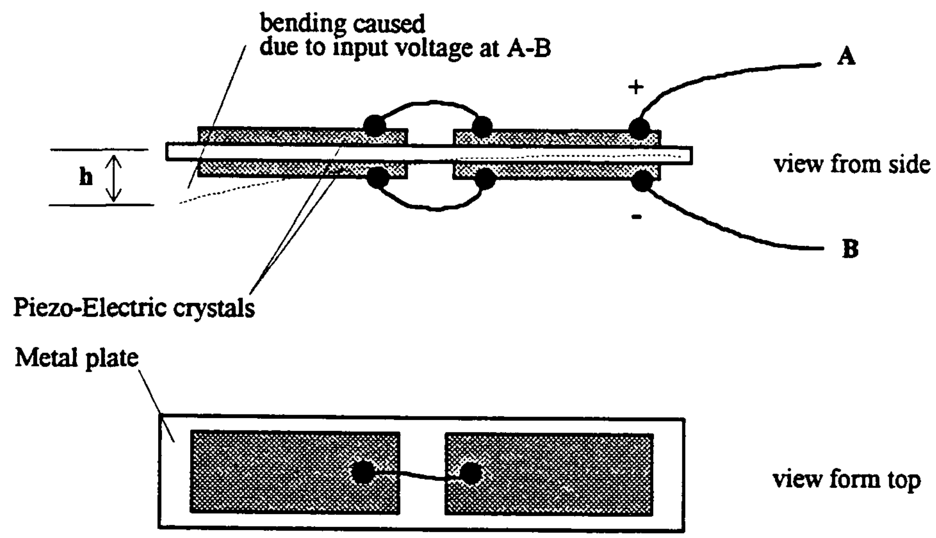


Fig. 9.10 Construction of a Piezo-Electric actuator for skiving

could be manufactured compact enough, so that it is easy to implement an actuator row for the purpose of skiving. After a relevant enquiry, the ceramics company GEC Alsthom Ceramics Ltd confirmed that actuating strokes of 1 to 1.5 mm could be obtained by devices 2.5 mm wide and 35 mm long. Also actuators of this type could operate at frequencies as high as 10 KHz, i.e. well in excess of the requirement for skiving.

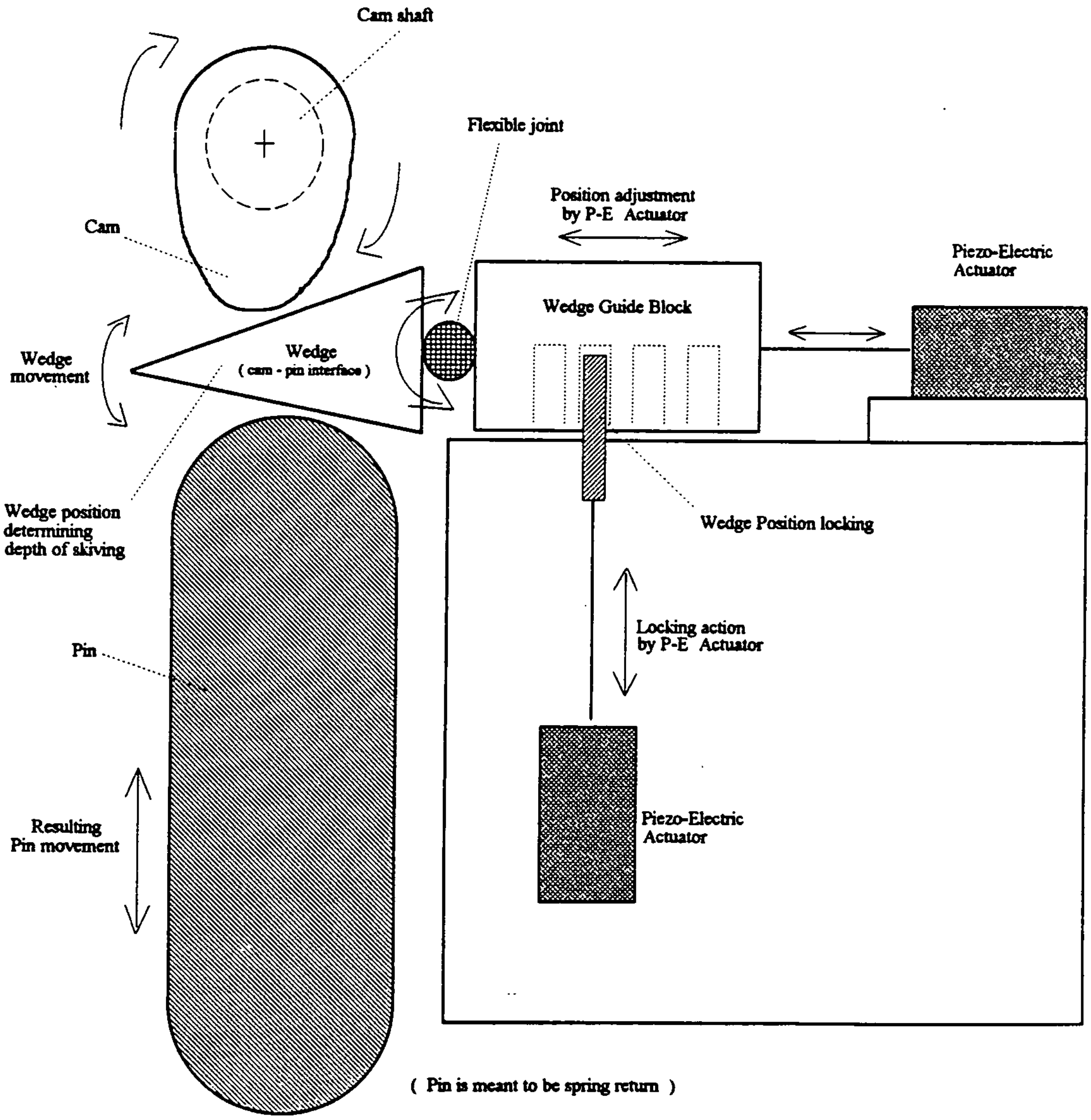


Fig. 9.11 An alternative actuation method for skiving, utilising repetitive pin action and stepped skive depth control, produced by two independent piezo-electric actuators

It seemed therefore that this type of actuator could be a promising option. However the last but not least requirement for its suitability for skiving is the output force. This has not been clearly defined yet because such a device has not been manufactured. Theoretical calculations indicated that the force capability lies in the region of a few tenths of a Newton. According to this, P-E actuators could not be used directly to cause direct displacement on the tri-layer system, unless the force requirement is reduced dramatically in ways already suggested. In any case, P-E actuators may be used, as triggering devices to perform skiving, rather than as the direct cause of skiving. The principle of this suggestion is illustrated in figure 9.11.

According to this idea, skiving depth is defined by the position of a triangular wedge, interface between the pin and a continuously rotating cam. The cam is meant to be common to all the pins. However each pin has its own wedge interface and two P-E actuators. The wedge may be moved by one of the P-E actuators towards or backwards from the pin. At the extreme limits if this movement, the pin will either perform no skiving at all or it will operate at its maximum skive depth. The wedge displacement may be accurately determined by the input voltage to the P-E actuator. Furthermore the force required for the movement of the wedge is minimum due to its small mass.

The second P-E actuator is responsible for locking the wedge in the selected position. This is done by inserting a small lock shaft in the key holes provided in the wedge guide block. This of course implies that skive depth control may be simulated in a given number of steps, equal to the locking positions of the wedge guide block. The locking action is necessary to stop horizontally induced forces by the cam acting against the P-E actuator. In this way work expected by the P-E actuator becomes minimum and it is dependent upon friction between the wedge guide block and the surface along which it is sliding. It is worthwhile noticing that the wedge is linked to its guiding block by a flexible type joint, so that vertical movement due to the cam action, is not transmitted to the guide block.

The timing problem with the above actuating mechanism is relatively simple. Let us assume that the cam is running at a given angular velocity, providing pin movement at a frequency such 110 Hz (slightly above tri-layer latency). Given the high response of the P-E actuators (10,000 KHz, i.e. roughly 100 times faster) it is expected that within a single cam revolution, there is more than enough time, to unlock the present skive depth position, select another and lock into it. The P-E actuators are expected however to become slower when linked with the guide block and the lock shaft. Although this is not expected to present timing problems, it must be proven in practice, by implementing a certain design for the actuating mechanism.

Hence it has been shown that actuation based in Piezo - Electric ceramics, can potentially form a solution for the problem of increasing the skive resolution. It is ambiguous whether they may be successfully employed in the present skiving mechanism design, without some form of mechanical amplification of force. The potential of this type of actuation is more obvious for an alternative, indirect type of actuation method, such as the one described.

9.6 High resolution solenoid based skiving system

The last option examined, for the purpose of improving skive resolution, was to investigate into a different design of pin matrix and actuation linkage, so that a higher resolution model may be tested using the same type of actuator, i.e. solenoids.

Having considered a number of different options, as described earlier, it was concluded that, changing the type of actuation to improve resolution, would be a major research task, perhaps a research project in its own. Also, it had not been proven yet in practice, that by increasing pin resolution (i.e. reducing pin size and spacing), the effect of stepped diagonal lines and localised pattern distortion would improve at all. Furthermore, if this proves to a valid hypothesis it would be desired to identify a resolution limit, which would be responsible for producing skiving quality acceptable to industry.

Hence it was concluded that developing the existing skiving method would be the fastest and most reliable route, in order of proving the above hypothesis. Also by having identified the resolution limit mentioned, the future identification of a more suitable actuating method would be aided, by knowing the exact number of actuators and their size necessary. This attempt to increase the current skive resolution has formed the concluding part of the research project presented in this thesis.

To implement a higher resolution pin matrix, it was necessary to somehow change the shape of the pin. Cylindrical pins presented limitations in doing so because of the two following reasons :

- Pins of very small diameter, e.g. 1 mm, would be subject to bending, due to shear forces by the moving superstrate/conveyor.

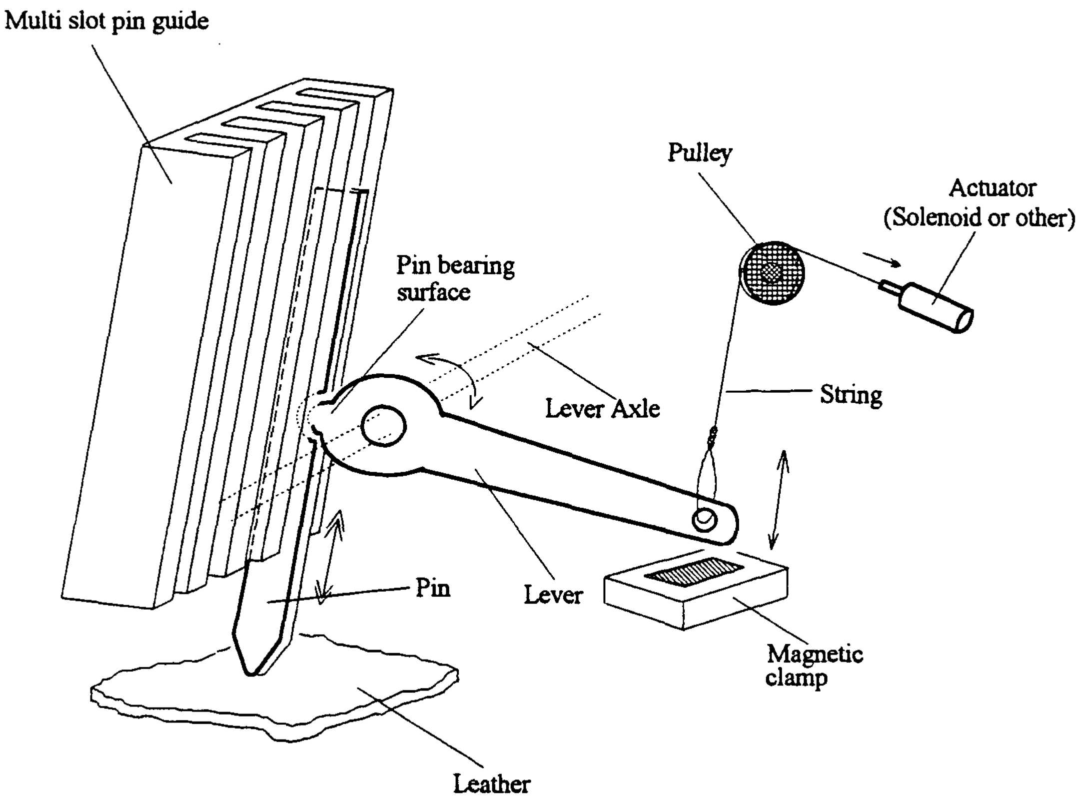
- The holes to accommodate smaller pins would be subject to fine error tolerances, thus intricate to manufacture. In any case, there are practical limits in manufacturing, as to how close the holes should be drilled.

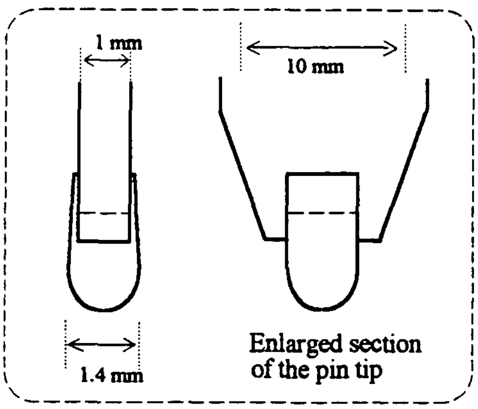
The pin shape shown in the relevant enlarged section in figure 9.12, was considered to maintain pin stiffness, while reducing pin width. Each pin consists of a 10 mm wide by 1 mm thick metal plate at the one end of which the pin tip is inserted and afterwards soldered. The pin tip itself consists of two sections. The rounded end and the chamfered sleeve which attaches it to the pin plate.

The pin size chosen for higher resolution was 1 mm width. This refers to the width of the plate, while the maximum width of the rounded tip is increased by 0.2 mm each side due to the presence of the sleeve. The pin plates are set to slide vertically within slots, provided by a multi-slot pin guide, made out of plastic. The choice for plastic was made due to its relative ease in milling the adjacent slots.

Due to manufacturing limitations, the closest centre distance between slots possible was 1 mm. This limit allowed milling of satisfactory repeatability, without any damage of the slot walls. This resulted in a 2 mm effective skive resolution, with the additional advantage of minimising the gap between pin tips (0.2 mm). The latter feature was considered to be an additional aid to eliminate the stepping effect on skive lines. The possibility of pin tip interference between adjacent pins was considered negligible, due to the very small area of contact involved.

Having concluded considerations about the design of the pin matrix of new high resolution skiving mechanism, it was thought essential to test the influence of the new resolution in skiving. This should be done before commencement of design and manufacture of the overall new skiving mechanism. To test the effect of the resolution, a small sized, experimental rig was made containing only fifteen pins.





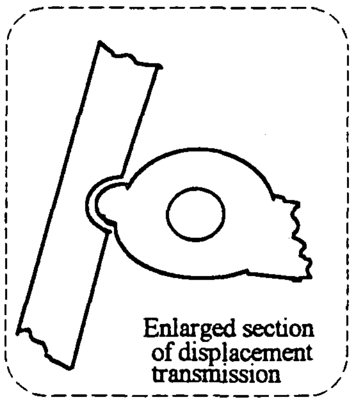


Fig 9.12 Illustration of the functional principles of the high resolution solenoid based skiving mechanism.

This was fixed on the skiving machine in the place of the current skiving mechanism. For this test, skiving action was simulated manually. By making the pins long enough (or the slot guide short enough) so that the pins project out of the upper face of the slot guide, it was possible to impress the pins manually upon the passing leather components and cause skiving.

To perform this, a special lock-and-slide wedge mechanism was made and fitted on the upper face of the slot guide. This enabled instantaneous insertion of all fifteen pins, by means of a switch, while allowed progressive manual pin release at a speed desired by the user. This progressive pin release, caused a diagonal skive pattern edge, while the component was moving. The angle of the skive edge depended simply on the speed that the user released adjacent pins with the above mechanism. The resulting skive edge was effectively a diagonal trailing skive edge, of an interior skive pattern, i.e. the type of trailing edge where the stepping effect is most apparent.

After experimentation and skiving of a number of components it was observed that the stepping effect of diagonal lines was eliminated (or too small to notice by eye). These results brought the overall conclusion that the skive resolution chosen (2 mm) was adequate for quality skiving and this was agreed by BUSM too. It was also concluded that the new resolution could be safely taken as a reference limit for skiving resolution, for any alternative future skiving mechanism. The photograph in figure 9.13 illustrates typical examples of diagonal skive edges, obtained during the experimentation described above. In these examples the smoothing effect of the increased resolution is clearly apparent.

After obtaining the above results it was decided that the design and manufacture of the new high resolution skiving mechanism should be implemented. The pin plates were made out of sheet material, namely gauge steel, and were laser cut, to avoid permanent bending during cutting. As shown in figure 9.12 the pins are driven up and down within the slots by means of a transmission engagement as shown in the relevant enlarged section in figure 9.12. Pin movement is once more provided by levers, rotating around a fixed support axle, and providing a ratio of 3:1 of mechanical advantage.

The number of pins involved in the high resolution model is 120. Furthermore the desired industrial width of skiving is 360 mm, requiring 180 pins. The main concern in

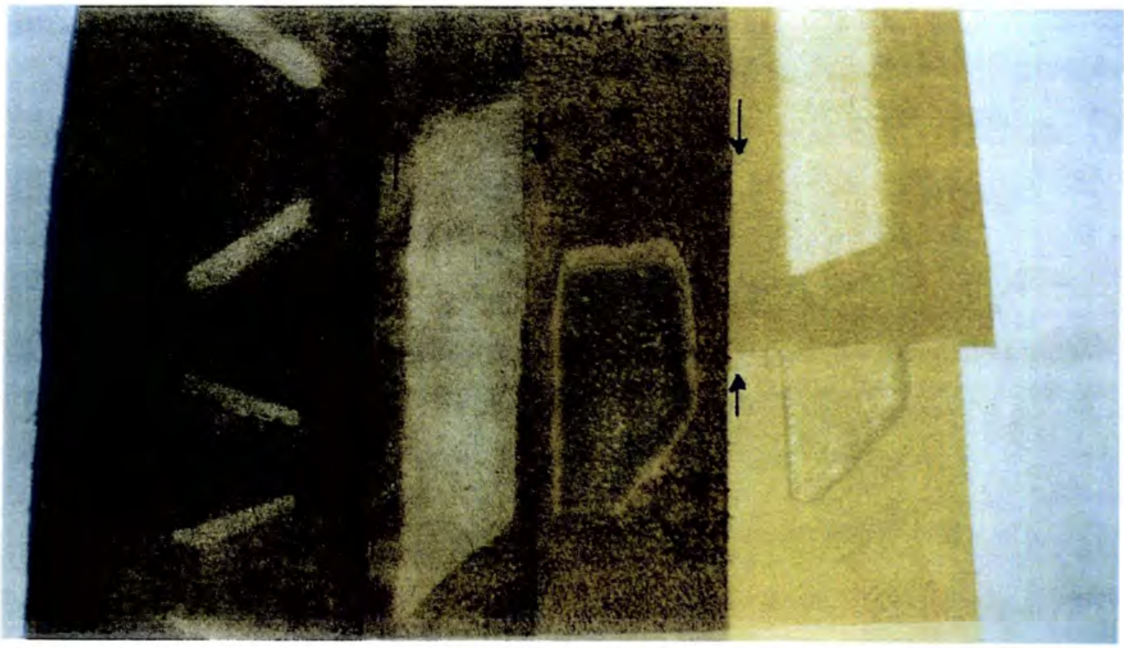
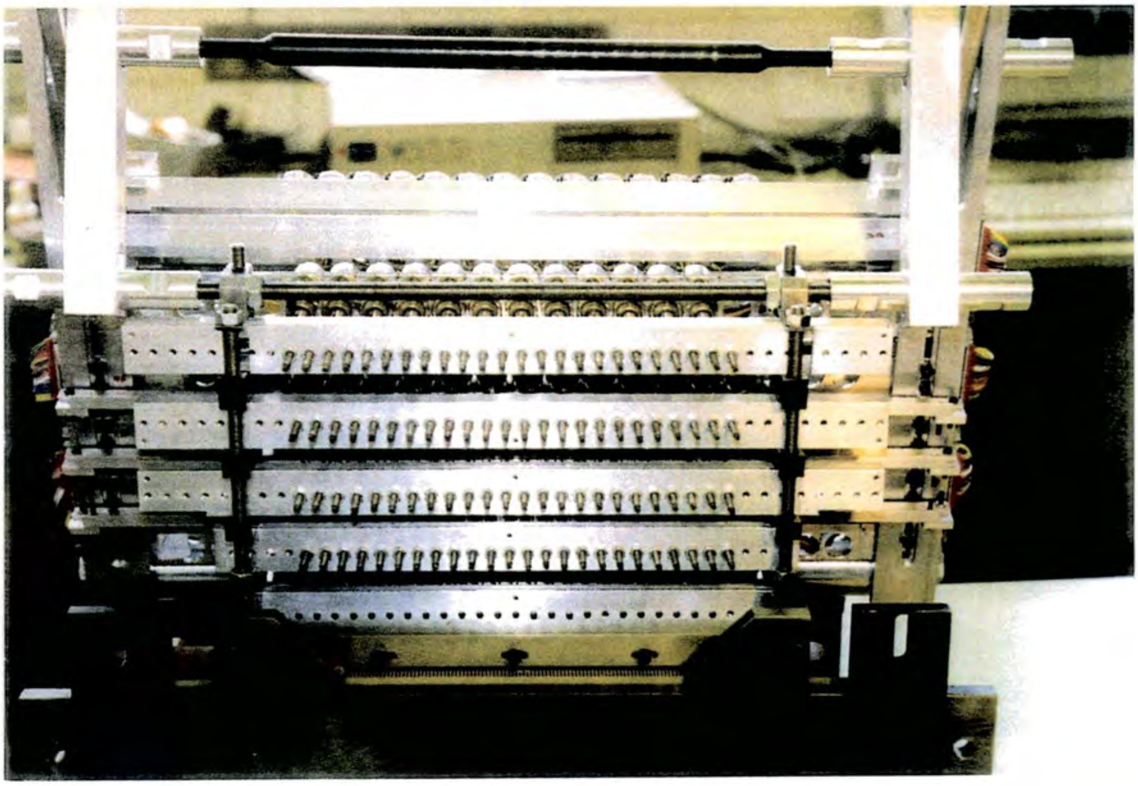


Fig. 9.13 The elimination of the stepped diagonal skive edges, by the high resolution skiving mechanism.

designing this mechanism was the allocation of the large number of solenoids. To effectively provide more volume and flexibility in allocating the solenoids it was considered to use flexible links with the levers. It was necessary to be able to drive the levers with the solenoids located at different angles, positions and/or distances, relative to the levers.

The solution adopted was to use steel wires as the linking mechanism and displacement transmission to the levers. The wires have the advantage of being able to transfer movement through suitable pulleys which could be located at different heights, angles and distances from the lever row. This type of transmission has been successful for years in other types of complex mechanisms such as looms. However before



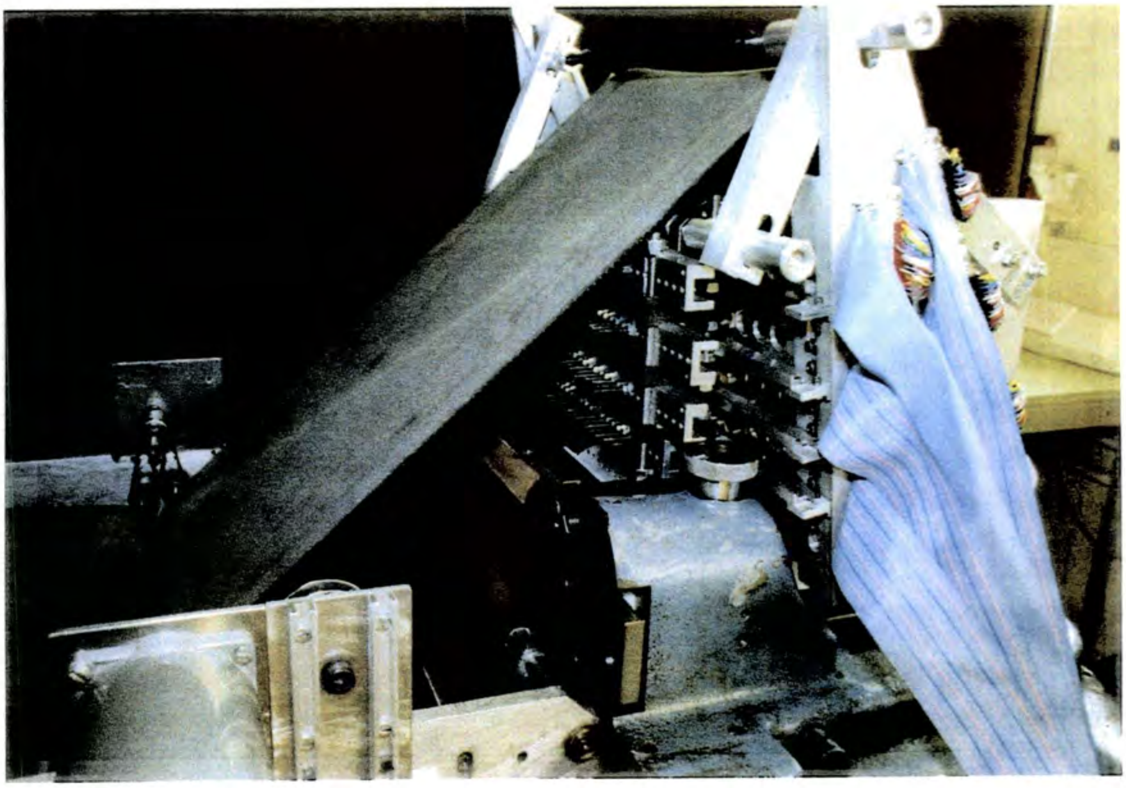


Fig. 9.14 The new high resolution (2 mm) skiving mechanism, operating under steel wire displacement transmission. (top : front view)

implementation it was still not known how successfully this could be done in skiving, where greater strain forces are involved. In the manual skiving experiment it was observed that the pins were capable of returning to their datum after release. It was hence considered that in this mechanism the return forces of the tri-layer system may be sufficient to return the pins in automated skiving of the same mechanism. The only additional problem to overcome would be the force due to the residual magnetism of the solenoid plungers when in full stroke. Therefore some additional return force for the levers could be provided by a row of magnets placed directly underneath the lever row.

Upon the above principles of operation, a new high resolution mechanism was designed, manufactured and assembled, comprising 120 pins and the capability of expansion for a future 180 pin model. The design was also done with flexibility in mind so that the same mechanism may easily be adapted to a modern splitting machine. Initial tests of the new skiving mechanism indicated that it could successfully operate skiving, provided that the pin return forces were increased. This validated both the new design of pin shape and the idea of using wires as the displacement transmission media. The photograph of figure 9.14 illustrates the new high resolution skiving mechanism. The detailed design and implementation of the new mechanism was carried out by a further member of the research team and will form the basis of a separate thesis.

9.7 Conclusion

After having fully automated the skiving system, its results were observed to inspect the skiving quality obtained by the current mechanism. It was noticed that although the overall process was behaving satisfactorily, the skiving quality was not up to industrial expectations due the skive edge stepping effect and the effect of local pattern distortion. It was thus concluded that the main attention in further research should be directed towards finding a method of improving skiving quality.

In this chapter it was explained that the hypothesis was that the only system factor responsible for these unwanted effects was the poor operating skive resolution. Following a series of alternative considerations into how this problem could be overcome, a series of alternative methods of actuations were conceived and it is expected that the information presented will form a useful reference tool, during the future development stage of the skiving system by BUSM. The most promising of all options considered was the one using Piezo-Electric actuators. BUSM has stated that they will examine into more depth this option, by a separate research effort into alternative actuation methods for skiving, which is expected to commence in the near future.

Apart of the suggestions for alternative actuation, by increasing the current resolution using a modification of the initial design of the skiving mechanism, it was proved that by increasing the skive resolution, all unwanted features in skiving improve. Furthermore, it was proved that if the future commercial skiving mechanism is set to operate at 2 mm resolution, the quality of skiving should not differ from the quality met in today's industrial manual skiving process.

The high resolution skiving mechanism constructed during this research period proved successful, together with the idea behind it. The stage of overall assembly and early trials coincided with the end of the final stage of this research programme. It is expected that in the near future this mechanism, after the necessary "fine-tuning", it will be integrated with a new vision system, developed by BUSM and only recently completed. On this basis, further research will be carried out to examin other aspects of the behaviour of the automated skiving system, which BUSM may choose to examine before undertaking manufacture of the industrial prototype, which they hope to be in time for 1994 exhibition in Pirmasens, Germany.

The new vision system is a much faster one, utilising a multi link transputer based electronic circuit, for fast data transfer. This system has been designed for another project of automation, namely the Pallet-less Automatic Stitcher. The modification of the above vision system as well as the M68000 software to accommodate it has just commenced. The structure of overall electrical network linking the new vision system with the skiving system, was suggested to BUSM during the final stage of this research programme and may potentially lead to a prototype. The diagram shown in figure 9.15 illustrates the basic features of the electrical network of the future skiving system.

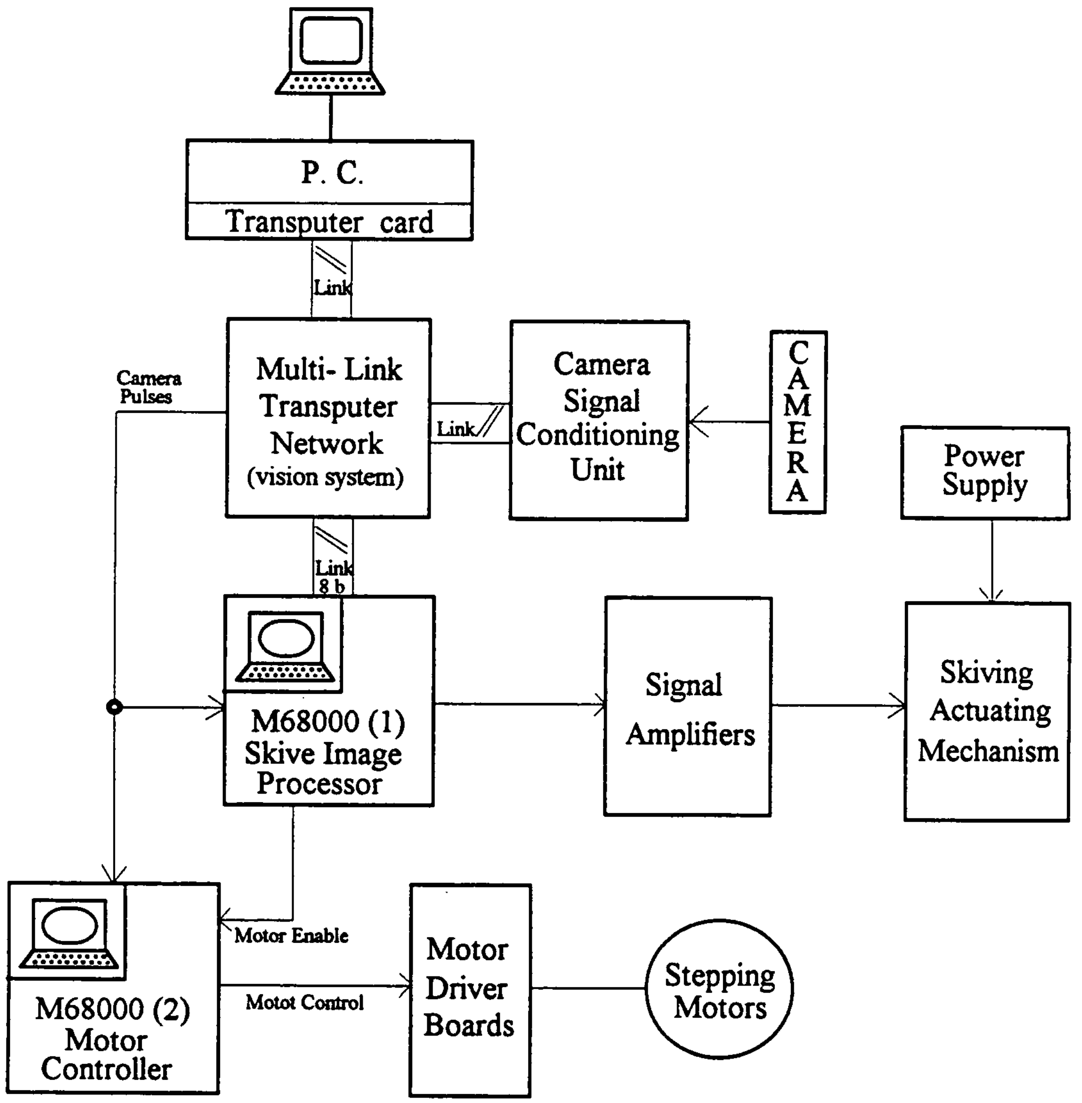


Fig. 9.15 The basic structure of the future skiving system in the development stage.

CHAPTER 10

Conclusion

10.1 Introduction

As explained in the introduction of this thesis, the main aim of this project has been directed towards two basic issues. The first was to derive a valid method for the automation of the skiving process and the other to produce evidence that full automation of skiving is viable.

The overall conclusion is that both above targets were successfully reached. The method of dynamic matrix skiving proved to be a suitable process to perform skiving. Furthermore, through the logical steps of this research effort, it has been seen how all manual aspects of this process can be eliminated producing a stand-alone fully automated skiving system. However there are specific areas of the skiving system that require further research, before meeting all conditions for industrial system development.

10.2 The suitability of dynamic matrix skiving.

Initially the manual method of skiving was investigated and the possibility of simple modification for automation was dropped. This was because of the complexity of component manipulation in three dimensions, required to guide the components through the disk-knife skiving mechanism.

However, by excluding the above possibility it did not imply that the actual mechanics of splitting leather should be ignored altogether. It was concluded that the way in which splitting is performed in manual matrix skiving could be simulated by pin matrix skiving. The only difference in this case was that pre-set skive patterns could be eliminated and they could be dynamically generated as sets of finite areas of skiving of a given resolution.

The main obstacles with the method of dynamic matrix skiving proved to be the following three :

- the issue of operating resolution

- achieving leading edge skiving

and

- maintenance of component position while skiving

Although initially it seemed that these issues could become the reason for rejecting the above method, it was later proved that the problem of operating resolution can be solved and that the safety resolution value could be taken as 2 mm. Implementing a more reliable skiving mechanism, or choosing the best possible actuator for the job, is by now a subject of further future research and industrial development.

Furthermore the later two problems were overcome by the introduction of the twin belt mechanism, comprising the upper superstrate/belt. The dual function of the upper belt, i.e. component feed-in and involvement in skiving action was the most important stage in proving that dynamic matrix skiving can be successfully employed in automating skiving.

Having proved the validity of dynamic matrix skiving as a potential method for dynamically controlling and performing skiving, this process was integrated with all necessary elements to form a fully automatic system. In this system components may be input at any position and/or orientation on the transport mechanism, can be recognised as to their identity and relative position, and consequently skived without the need of any intermediate manual interference.

Although the recognition technology used in this project was not new, it was necessary to enhance it, so that it is suitable skiving. Through this effort it became apparent, what are the characteristics that the recognition system should possess to become integrated with the skiving mechanism. The novelty in this work was the implementation of the software (mainly) and hardware modules responsible for varying the image resolution, and transmitting and manipulating skive patterns for process execution.

A useful conclusion from this effort was that a recognition system should preferably contain flexibility in two features, the image resolution and the speed of image data transmission. This particular observation is important if recognition of similar types objects is to be performed for a number of different processes. This is particularly important if these processes are implemented by the same company and are expected to be linked together in the future. Relative to the above, it is worthwhile mentioning that even the new transputer based vision system, does not contain such facilities [15].

The results of skiving of the automated system indicated clearly that automatic skiving is possible. They also brought to notice that the issue of resolution has to be successfully resolved by either alternative actuator technology or by modification of the existing mechanism, such as the one attempted in the latter stage of this project. In the final stage it was proved that the resolution necessary for acceptable skiving quality is within capabilities of manufacture. Furthermore a range of alternative solutions was investigated to provide some useful information for future development. The decision as to what route should be followed for implementing a high resolution commercial machine will be defined in the forthcoming research and development stage. The most promising option, at least theoretically, is either a high resolution solenoid based mechanism, or the one based on piezo-electric actuators.

10.3 Fulfilment of the specification of this research project

In the introduction of this thesis (chapter 1), a list of statements was given, defining in more detail the technical aims from this research project. The conclusion at the end of this project was that all those specifications have been proved viable, and the proof is that the skiving system implemented contains potentially all of them. The current automatic skiving system contains the following properties :

- *Component oriented process.*

  The system implemented does not in any way disturb the original form of entry of leather components. The dynamic matrix skiving process aided by the recognition system is capable of adapting the process to the given environment rather than manipulating the component.

- *Flow through process.*

  The skiving mechanism itself does not need to move around the component. This introduces the advantage that components may be processed without any interruption of their flow, while being skived. The only point at which components are stopped for a brief period (1.5 sec) is immediately after recognition. However this is simply because of the relatively low processing speed of the computing hardware used. It is therefore justified to argue that given faster processor capabilities, the system has the potential to be an continuous flow through processing machine.

- *Intelligent process.*

  The automatic skiving system implemented can recognise any component, provided that the latter is known to its database. It may then produce skiving to the desired regions of the component irrespective of the orientation or position of the incoming component on the conveyor. Furthermore the intelligence of the system may be enhanced, if desired, by introducing a component dislocation sensing device and/or a device sensing the surface of the component, ensuring that it is lying on its correct side. These two functions would enable rejection (i.e. no skiving) of components when necessary, to minimise material waste.

- *Dynamic output generation.*

  The system has the capability to generate and transmit to the execution module skive patterns, while the overall process is running uninterrupted. These patterns are formed as images consisted of pixels, each pixel corresponding to a finite amount of component area, equal to the system resolution. In turn, the dynamic matrix skiving mechanism can actuate these patterns while the component is flowing through the system and without the need for using pre-set jigs or fixtures to perform skiving. In other words the mechanism is able to generate any possible skive pattern without needing to use specialised tools for specific cases. However the quality of replication of skiving patterns at different angles is highly related to the resolution of the skiving system.

- *Component flow up to 185 mm/sec (or more).*

The skive samples presented in this thesis are implemented with the system running at linear conveyor speed of 185 mm/sec. Of course the higher the conveyor speed, the more the possibilities for malfunction (i.e. jamming) and the more the exaggeration of the effects of the response of the actuating system. In any case skiving has been performed successfully in speeds as high as 250 mm/sec without mechanical failure. It would be expected that the final decision as to what should be the optimum setting of throughput, would take into account the performance of the new high resolution skiving mechanism, as well as the durability of the upper conveyor belt.

- *Capability to skive any skive pattern.*

As already explained, there is no limitation concerned with the geometrical properties of the actuated skive profiles.

- *Adjustable depth of skiving.*

The depth of skiving is adjustable by means of a manual setting. This setting specifies the amount of thickness removed from the leather component in the areas where it is skived. Furthermore by suitable setting the skiving mechanism is capable to split while skive, i.e. to remove a constant amount of the components thickness across the whole component while performing an even deeper split (i.e. skiving) in the selected areas where the skive pattern is located. Although the latter was not included in the original targets of this research, its potential was observed during general experimentation with the skiving system. The importance of this particular feature is that the future developed skiving system could take over the process of splitting as well as perform skiving. In this case not only a new automated process would be introduced to industry, but also, another one would seize to exist as separate process.

- ***Capability to skive all types of skiving.***

The system is capable of performing both interior skiving and edge skiving in all leading, trailing and side edges of the component. However it has been observed that there is a difference in the profiles of leading and trailing skive edges and it has been concluded that this is due to the nature of skiving itself. It is also influenced by the behaviour of the actuators used. In any case, this effect is adjustable simply by altering the conveyor speed. The slower the speed of processing the smaller the difference between leading and trailing skive profiles. On this basis one will have to compromise between system throughput and variability of edge skive profiles. The decision for the exact point of compromise may be taken after the related industry establishes the limits of tolerance for the above variability.

- ***Maintenance of component quality.***

The system implemented in this research can perform skiving without causing any damage or physical alteration of the input components (other than skiving itself), in any stage of component transport. The twin belt conveyor system ensures that the upper side of the component does not come into direct contact with any mechanical parts during the process. Furthermore the system does not employ chemicals that could cause damage on leather components.

10.4 Suggestions for further related research

The high resolution wire based mechanism that was recently manufactured, although successful in performing skiving, it appeared under question in the issue of reliability. This was due to the large number of individual components, particularly the metal wire and their joints to the levers and solenoids.

The option for using solenoids as actuators is in itself promising because they are repeatable and reliable devices. However it has not been proven to this stage whether it is possible to achieve variable skiving profiles, by suitable manipulation of their input signal. Thus if it is absolutely necessary that the skiving system should contain such a feature, the above possibility should be investigated, preferably as the first continuation of research in this field. This is because if it fails to produce variable depth of skiving using solenoids then it is inevitable that some other type of actuator has to be employed, and therefore this should be the main direction of further research. If the above hypothesis does not fail then it is worth attempting to design a similar mechanism by replacing the wires with thin levers, and preferably double acting solenoids, to improve system response.

Another issue that needs investigating is the reliability of the structure and material of the upper conveyor. Although a suitable material has been defined in this research, its durability may not be known until the development stage. The PVCF superstrate material used seems to perform satisfactorily if well lubricated with silicone oil, in the surface where pin friction takes place. However by increasing resolution, and thus reducing the size of the pin tips, it seemed that the material will eventually deteriorate.

During the trial of the new high resolution mechanism, a solution for this problem was attempted. This included an interface between the pins and the upper surface of the superstrate material itself. The relevant trials involved a static superstrate film made of 0.08 mm thick Tygaflor, protecting the main superstrate belt. The result was the elimination of any sign of wear in the main superstrate. Furthermore the structure of the Tygaflor film ensured its capability of withstanding pin impressions without permanent indentations. Skiving was performed successfully, with the only drawback being the reduction in x-resolution. Hence, before making any decision in the issue of the superstrate belt, it is highly recommended to experiment further with the above belt structure.

In many instances in this research, it has been shown that it would be beneficial, if the skiving system comprised of its own design of knife mechanism, in order to eliminate the obstacle of the knife guide. Due to the commercial impact that it is expected to be made in the market with the introduction of an automatic skiving system, it seems worthwhile manufacturing a dedicated knife mechanism. This could be introduced even as an improvement in the hypothetical "mark 2" skiving machine.

Finally, it is expected that one area of immediate research interest will be attempting to perform accuracy tests, related to the performance of the component transfer system. Although the results of skiving seemed satisfactory, it is necessary to evaluate how reliably the component's position is maintained throughout skiving. To implement this successfully it is essential to minimise local skive pattern distortion, caused by the low resolution mechanism. Therefore these tests will have to be carried out after fine-tuning the new high resolution skiving mechanism. Depending upon the outcome of this investigation the structure of the component transport mechanism may have to be developed further.

When the above results have been obtained and it is concluded that the component transport mechanism behaves well within an acceptable tolerance band, it may be viable to perform tests to examine with precision the repeatability of the output of the skiving system. To implement this with a certain degree of confidence, it is suggested that some type of artificial material is used in the place of leather components. This is because in order to obtain reliable results for the repeatability of automated skiving, it is necessary to keep constant all variables related with the physical properties of the input component.

10.5 Epilogue

During this research project it has been investigated how to automate the process of skiving in leather components. Initially a principal method was identified, on the basis of which the process could be automated. The second phase involved defining the synthesis of all essential elements for the implementation of the automatic system. The main benefit of this effort has been the proof that the idea of automated skiving system is indeed realistic and its implementation viable. Following future research to underpin the output quality of the system, it is expected that there will eventually be a commercial stand-alone system. If one attempts to look further into the future, the automatic skiving system has the potential to be linked with other processes and become an individual component process station within a larger multi-tasking system.

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Patents

The collaborating company BUSM has applied for a patent related to the skiving system described in this thesis. The details of the application for UK patent are given below. Also separate applications for patents for the Republic of China and India are now underway.

"Matrix Skiving using row of individual controllable pressure applying pins to deform workpiece in advance of band knife"

UK patent number 9224347.6
Application for patent made by BUSM on 20 November 1992 (BUSM folio 0503)

APPENDIX A-2

Drawings for 3-d pin matrix skiving

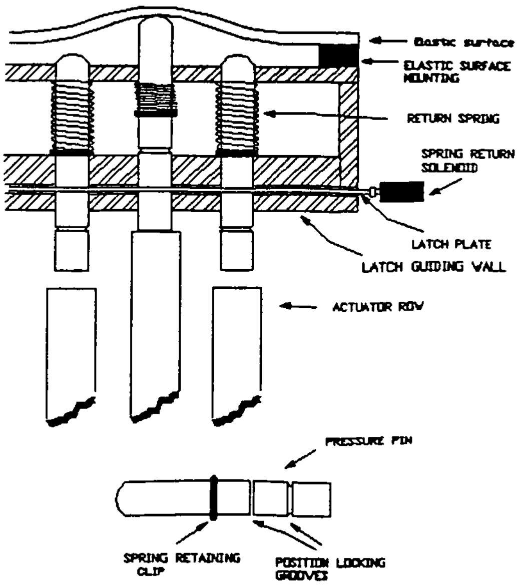


Fig. A-2.1 Formation of a 3-dimensional pin matrix
(side view)

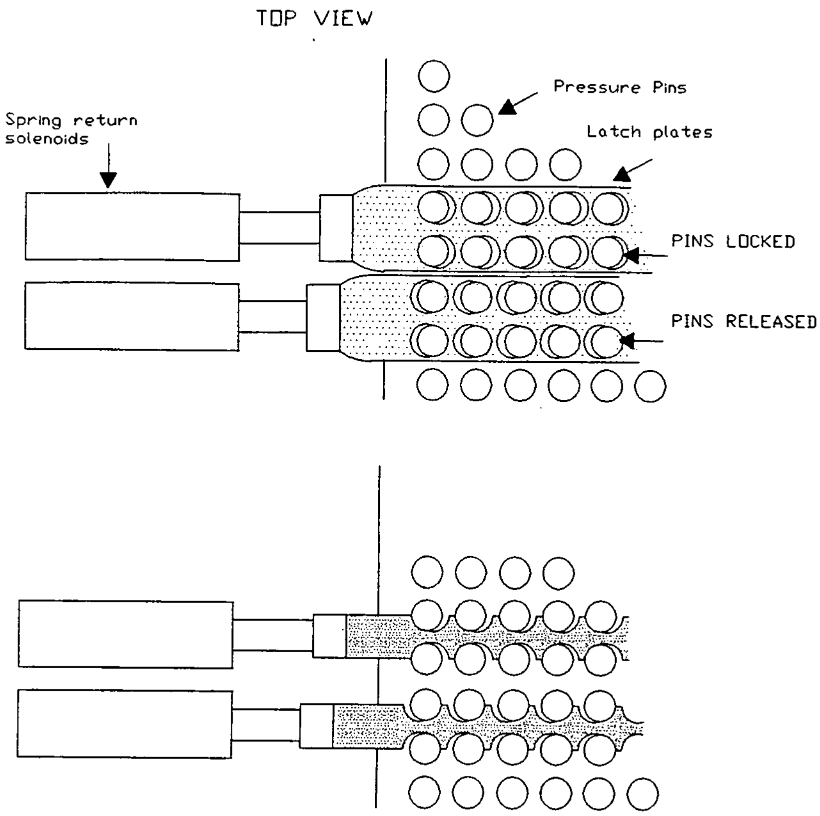


Fig. A-2.2 Suggestion for pin locking mechanism.
(alternative designs)

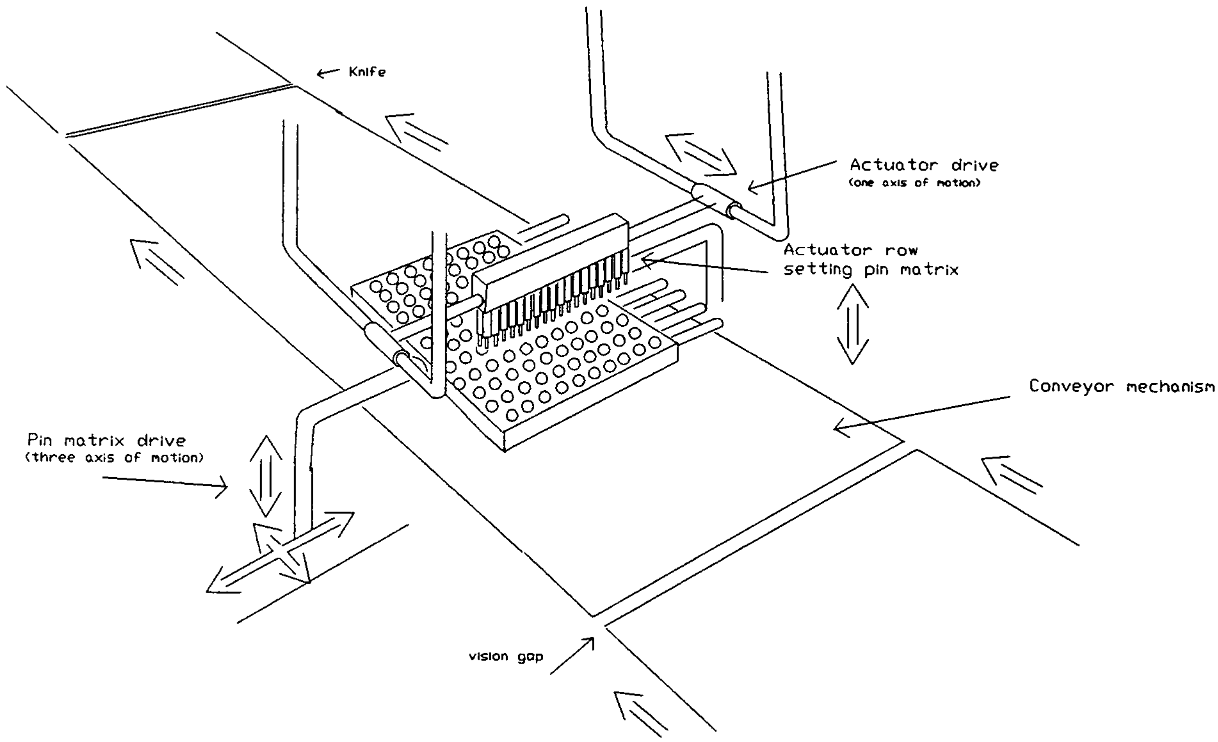


Fig. A-2.3 A hypothetical system using 3-d pin matrix for skiving.

APPENDIX A-4

Detailed drawing of the skiving process area

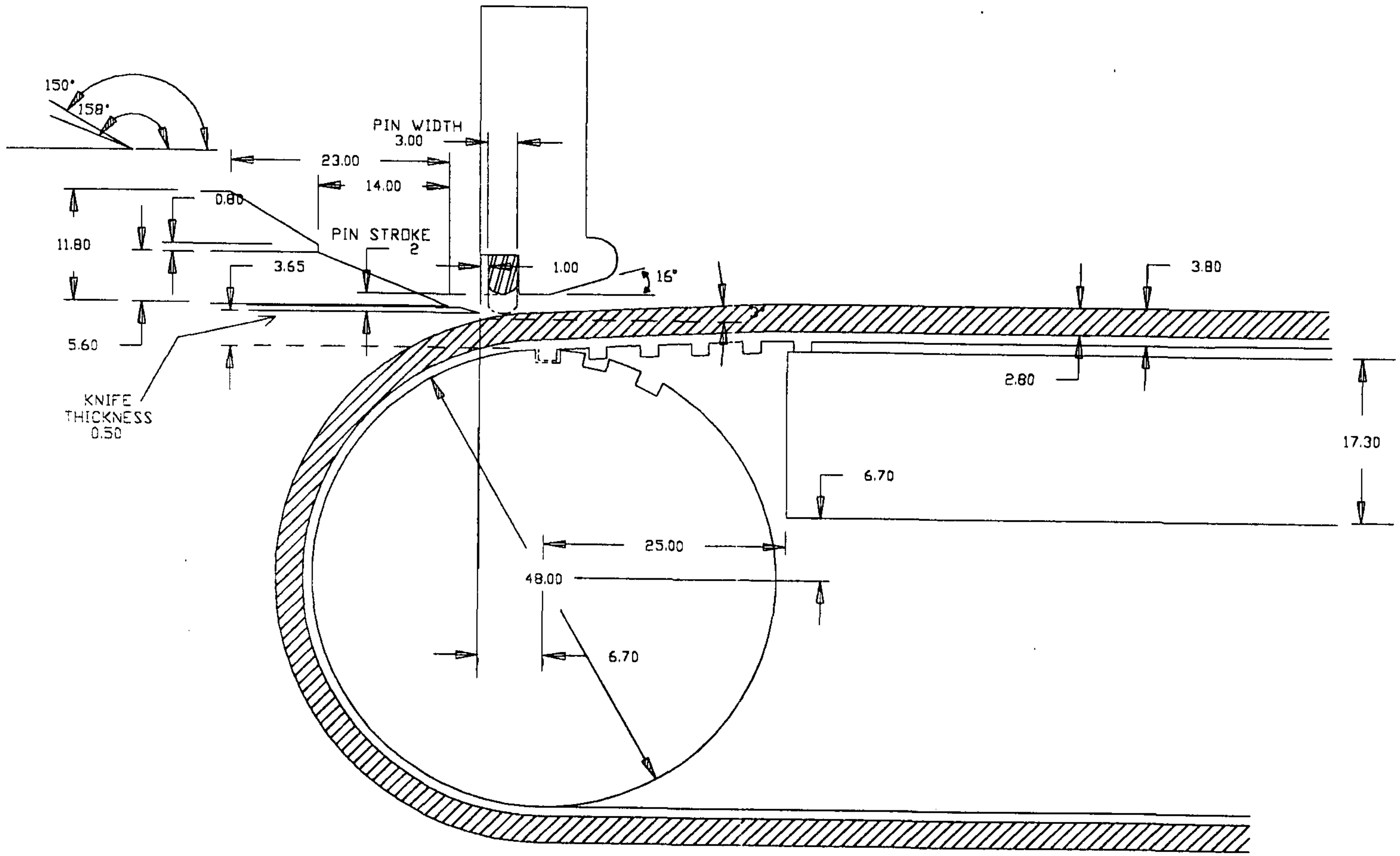


Fig. A-4.1 Detailed measurement of the geometric characteristics of the skiving process area

APPENDIX A-7

Program modules from the TMS and Compaq systems enhanced to operate for the skiving process

(These program modules are enclosed for the purpose of future reference into modification of the vision system for the process of skiving)

```
 * Copyright 1987 (c) BUSM. Ltd.
 *-------------------------------------------------------------
 * TMS34010 Delphax Graphics Function Library    N.R. Tout.,
 * Modified by S. Topis   10/12/91
 *-------------------------------------------------------------
 * init_dimg function
 *
 *   The GSP is initialised for working using the Image-RAM.
 *   Enable video, load x-y offset, set pixel size, and enable external video
 *   synchronisation.
 *   This was derived from the function init_vid.c in the gspfuncl.
 *   This function must be called prior to calling any of the graphics
 *   functions.
 *   The  (600 dots/line x 1024 lines) is built up in
 *   the Image-RAM. This  memory map is available always no matter the
 *   resolution reduction applied to the image  itself to suit the skiving process.
 *   The register values defined below are dedicated to the frame output for the existing
 *   skiving head (32 pin wide). However because of the flexibility provided by the
TMS to
 *   allow partial output of the already VRAM map defined,  it is possible to redefine
the exact
 *   size of the desired "window"  of VRAM to be output. This is done by  setting  the
VSynch
 *   and HSynch  pulse train structures accordingly. In this way a different output
resolution
 *    may be accomodated  without the penalty of  time delays.  Refer to the
appropriate timing
 *   diagram in appendix ST09-B and to figure 4.4.2 in the main text.
 *-------------------------------------------------------------

/* Names of GSP I/O registers and B-file registers */
#include "gspregs.h"
/* Names of default codes for colors 0 and 1 */
#include "colors.h"
/* Definition of constants for graphics system */
#include "constant.h"

#define IMAGE_ADDRESS    0xFFD80000      /* Start of RAM for the reduced
                                  resolution image. */

/* Declare external functions. */
  extern int poke();
  extern int peek();
  extern void poke_breg();
  extern void sys_error();
```

```
/* Declare global variables. */
  extern int screensize;
  extern short xorg, yorg;
  extern int xyorigin;
  extern short penwide, penhigh;
  extern int pensize;
  extern short screenwide, screenhigh;

/* Values to be loaded into first 10 I/O registers during
 *  initialization. */
 int regvals[] =      {0x0001,  /* hesync */

                  0x0002,       /* heblnk */
                  0x0005,       /* hsblnk */
                  0x0006,       /* htotal */

                  0x0001,       /* vesync */
                  0x0002,       /* veblnk */
                  0x0202,       /* vsblnk */

                  0x0203,       /* vtotal */
                  0xf010,       /* dpyctl*/
                  0xfffc, /* dpystrt*/
                  0xffff, /* dpinit*/
                  0};

void init_dimg()
{
 int address,  /* 32-bit GSP I/O register address */
    i,       /* array index */
    *regval;  /* pointer to I/O register value array */

        regval=regvals;
        screenwide=600;
        screenhigh=1024;

 /* Concatenate screen width and height to form 32-bit int */
        screensize = screenwide + (screenhigh << 16);

 /* Load the first 11 I/O registers with initial values. */
        address = IO_BASE;
        for (i = 0; i <= 10; i++)
        {
        poke(address, regval[i]);
        address += 16;
        }
```

```
    /*
     * Configure pixel size at 1 bit.
     */
        poke(PSIZE, 1);
    /*
     * Set x-y offset to establish memory address of pixel at top left
     *   corner of Image-RAM.
     */
        poke_breg (OFFSET, IMAGE_ADDRESS);  /* Specify start of image. */

    /* Set up CONTROL register--
     *   T = 1:  Enable pixel transparency
     *   W = 3:  Enable up window clipping, but not WV interrupt
     *   PBH = PBV = 0:  Array move starts at upper left pixel
     *   PP = 0:  Select replace operation
     *     *   CD = 0:  Cache-disable off.
     */
        poke(CONTROL, peek(CONTROL) & 0x00DF | 0x00C0);
    /*
     * Set default destination pitch to pitch of Image-RAM to reduce
     *   startup overhead of functions.
     */
        poke_breg (DPTCH, 1024);

    /* Set CONVDP register to correspond to contents of DPTCH. */
        asm("    LMO  B3,B0           ");
        asm("    MOVE B0,@>C0000140    ");  /* load CONVDP */
        asm("    MOVE B0,A8            ");

    /* Default origin coincides with top left corner of screen. */
        xorg = yorg = 0;
        xyorigin = xorg + (yorg << 16);


    /* Set drawing pen to its default size. */
        penwide = 1;  penhigh = 1;
        pensize = penwide + (penhigh << 16);

    /* Initialize register-based global variables for viewport 0. */
        poke_breg(WSTART, 0);
        poke_breg(WEND, screensize - 0x00010001);
        set_color0(WHITE);
        set_color1(BLACK);

} /* end of "init_dimg" function */
```

```
/* Copyright 1987 (c) BUSM LTD.
 *----------------------------------------------------------------
 * TMS34010 Graphics Library for Skiving Image Generation development.
 *  N.R.Tout. ,  Modified by S. Topis 6/12/91
 *----------------------------------------------------------------
 * init_dzoom function
 *
 *   Initialise for zooming the image in the slice-RAM, while using the
 *  M68000 controller.
 *   This is the normal resolution image, and has 2400 dots/line and
 *  512 lines.
 *----------------------------------------------------------------
 */

/* Names of GSP I/O registers and B-file registers */
#include "gspregs.h"

#define VRAM_ADDRESS    0x00000000      /* Start of VRAM. */

/* Declare external functions. */
  extern int poke();
  extern int peek();
  extern void poke_breg();
  extern void sys_error();

/* Declare global variables. */
  extern int screensize;
  extern short xorg, yorg;
  extern int xyorigin;
  extern short penwide, penhigh;
  extern int pensize;
  extern short screenwide, screenhigh;

void init_dzoom()
{

        screenwide=600;
        screenhigh=512;

  /* Concatenate screen width and height to form 32-bit int */
        screensize = screenwide + (screenhigh << 16);
  /* Initialize register-based global variables for viewport 0. */
        poke_breg(WEND, screensize - 0x00010001);

/*      poke_breg(VCOUNT, 0);
        poke_breg(HCOUNT, 0);
```

```
*/
        poke (PSIZE, 1);  /* Pixel size for the VRAM. */
    /*
     * Set x-y offset to establish memory address of pixel at top left
     *   corner of screen.
     */
        poke_breg (OFFSET, VRAM_ADDRESS);  /* Specify start of image. */

    /*
     * Set default destination pitch to pitch of screen to reduce
     *   startup overhead of function.  */

        poke_breg (DPTCH, 4096);

        poke_breg (SPTCH, 1024);  /* Pitch of source. */

    /* Set CONVDP register to correspond to contents of DPTCH. */
        asm("    LMO  B3,B0          ");
        asm("    MOVE B0,@>C0000140    ");  /* load CONVDP */
        asm("    MOVE B0,A8          ");

} /* end of "init_dzoom" function */
```

```
*****************************************************************
* c-callable subroutine. Zooming has been reduced to 1:1 for the skiving process
* (originally was 1:4)   *
* N.R.T.  18.2.88. ,  Modified by S.Topis 7/12/91        *
* R02 uses PIXBLT B,L for skiving image transfer from Image-RAM to VRAM.
*****************************************************

FP      .set    A13
STK     .set    A14
        .file   "zmdslice.c"
        .globl  _zoomdslice

* DEFINE CONSTANTS.
*       Copy gspregs.asm, but don't include in listing.
        .nolist
        .copy   gspregs.asm         ; I/O and B-file registers.
        .list
*****************************************************
* FUNCTION DEF : _zoomslice
*****************************************************
_zoomdslice:
        MMTM        SP,A5,A7,A9,A10,A11,FP
        MOVESTK,FP
        MOVE*FP(-32),A5,1                   ; Location of the source array.
        MOVE@VCOUNT,A9

* Transfer each line 4 times. First, work from the top to the centre.
        MOVI 1*65536+600,DYDX
        MOVI 0,A7                           ; (DADDR).
        MOVI 512,A10                                  ; Lines to transfer.
LOOP1:
        MOVK        1,A11                   ; Times for each source line.
LOOP2:
        MOVEA5,SADDR
        MOVEA7,DADDR
        PIXBLT      B,L

        ADDI 1000h,A7                       ; To next line of destination.
        DSJS  A11,LOOP2

        ADDI 400h,A5                        ; To next line of source.
        DSJS  A10,LOOP1
        MOVE@VCOUNT,A10

        MMFM        SP,A5,A7,A9,A10,A11,FP
        RETS 2
        .end
```

```
/* Copyright 1989 (c) BUSM. Ltd./Durham University.
 *-----------------------------------------------------------------
 * TMS34010 Delphax Graphics Function Library    N.R. Tout.   16/5/89,
 * Modified by S.Topis  8/12/91
 *-----------------------------------------------------------------
 * init_vram function
 *
 *   The GSP is initialised for working using the VRAM.
 *   Enable video, load x-y offset, set pixel size, and enable external video
 *   synchronisation.
 *   The image (2400 dots/line x 512 lines) is built up in the VRAM.
 *-----------------------------------------------------------------*/

/* Names of GSP I/O registers and B-file registers */
#include "delib\gspregs.h"
/* Names of default codes for colors 0 and 1 */
#include "delib\colors.h"
/* Definition of constants for graphics system */
#include "delib\constant.h"

#define VRAM_ADDRESS    0x0     /* Start of VRAM. */

/* Declare external functions. */
  extern int poke();
  extern void poke_breg();

/* Declare global variables. */
  extern int screensize;
  extern short xorg, yorg;
  extern int xyorigin;
  extern short penwide, penhigh;
  extern int pensize;
  extern short screenwide, screenhigh;


void init_vram()
{
 int address,  /* 32-bit GSP I/O register address */
     i,        /* array index */

        screenwide=2400;
        screenhigh=512;

 /* Concatenate screen width and height to form 32-bit int */
        screensize = screenwide + (screenhigh << 16);
```

```
    /*
     * Configure pixel size at 1 bit.
     */
        poke(PSIZE, 1);

    /*
     * Set x-y offset to establish memory address of pixel at top left
     *   corner of Image-RAM.
     */
        poke_breg (OFFSET, VRAM_ADDRESS);  /* Specify start of image. */

    /*
     * Set default destination pitch to pitch of Image-RAM to reduce
     *   startup overhead of functions.
     */
        poke_breg (DPTCH, 4096);

    /* Set CONVDP register to correspond to contents of DPTCH. */
        asm("    LMO  B3,B0          ");
        asm("    MOVE B0,@>C0000140   "); /* load CONVDP */
        asm("    MOVE B0,A8          ");


    /* Default origin coincides with top left corner of screen. */
        xorg = yorg = 0;
        xyorigin = xorg + (yorg << 16);

    /* Set drawing pen to its default size. */
        penwide = 1;  penhigh = 1;
        pensize = penwide + (penhigh << 16);

    /* Initialize register-based global variables for viewport 0. */
        poke_breg(WSTART, 0);
        poke_breg(WEND, screensize - 0x00010001);

} /* end of "init_vram" function */
```

```
/* Copyright 1988 (c) BUSM LTD. / DURHAM UNIVERSITY.

 *----------------------------------------------------------------
 * Program spline_draw() (splndraw.c)      R.Yardley / N.R.Tout. 27.3.88. ,
 * Modified by S.Topis 16/1/92
 *----------------------------------------------------------------
 *In this program the resolution reduction for the skiving process is implemented, as
 *down-scaling
 *of the skiving image (lines). This is done by applying the necessary transformations
 *to the x,y
 *coordinates of the splines already solved. The constants used are dedicated to the
 *skiving process
 *but may be altered to suit a different resolution and/or  x,y  reference point (origin)
 *for image
 *location and execution.

        Draw the previously evaluated spline.

                ----------------------------------------        */
extern void pen_line();
extern void draw_line();
extern void put_pixel();

struct spline

{
        short N;            /* Number of coord-pairs in this spline (max 18). */
        short x[20];        /* X-coords (up to 18, + 2 dummy points). */
        short y[20];        /* Y-coords (up to 18, + 2 dummy points). */
        double ax[20];
        double bx[20];
        double cx[20];
        double ay[20];
        double by[20];
        double cy[20];
};

spline_draw(sd)
struct spline *sd;

{
        short i;
        long xt, yt, xt_previous, yt_previous;
        double t, ts, tc;

        xt_previous = (long)sd->x[1];
```

```
yt_previous = (long)sd->y[1];
   xt_previous = ((xt_previous/14.5)-4);
  yt_previous = ((yt_previous/18)+32);

for (i=1; i < sd->N; i++)
{
        for(t=0.1; t<1.1; t+=0.05)  /* For a more accurate curve decrease the
                            increment of t. */
                            /* Note that rounding errors affect the value
                            needed for the upper limit. */
        {

        ts = t*t;
        tc = ts*t;

        xt = (long)( sd->ax[i]*tc + sd->bx[i]*ts + sd->cx[i]*t + sd->x[i] +0.5 );
              xt = ((xt/14.5)-4);

        yt = (long)( sd->ay[i]*tc + sd->by[i]*ts + sd->cy[i]*t + sd->y[i] +0.5 );
              yt = (yt/18)+32;

        draw_line( xt_previous, yt_previous, xt, yt );
                xt_previous = xt;
                yt_previous = yt;
        }
}
}
```

APPENDIX A-8

Drawings and software developed for linking the M68000 controller to the overall skiving system

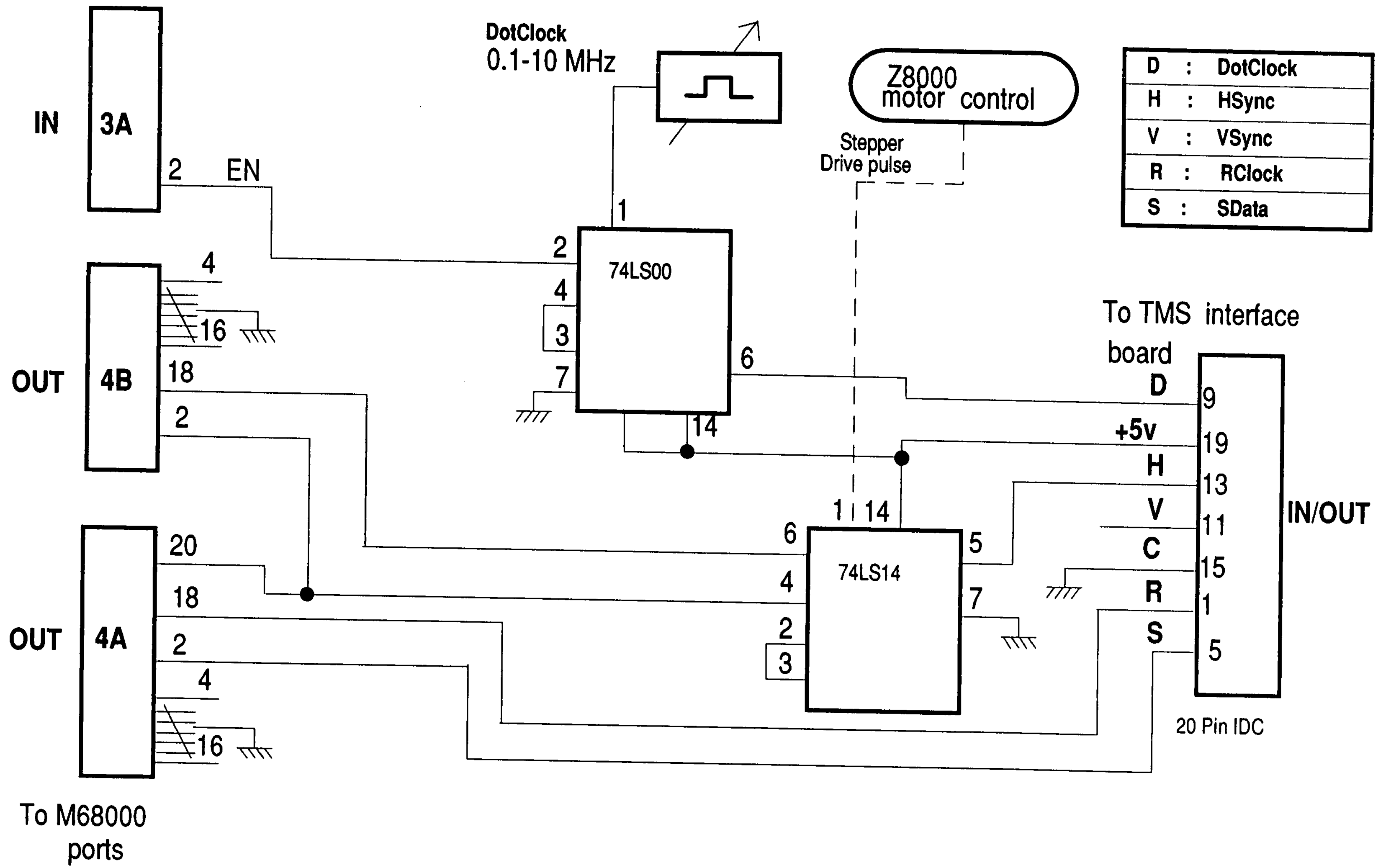


Fig. A-8.1 The control signals in the Central Interface Board.

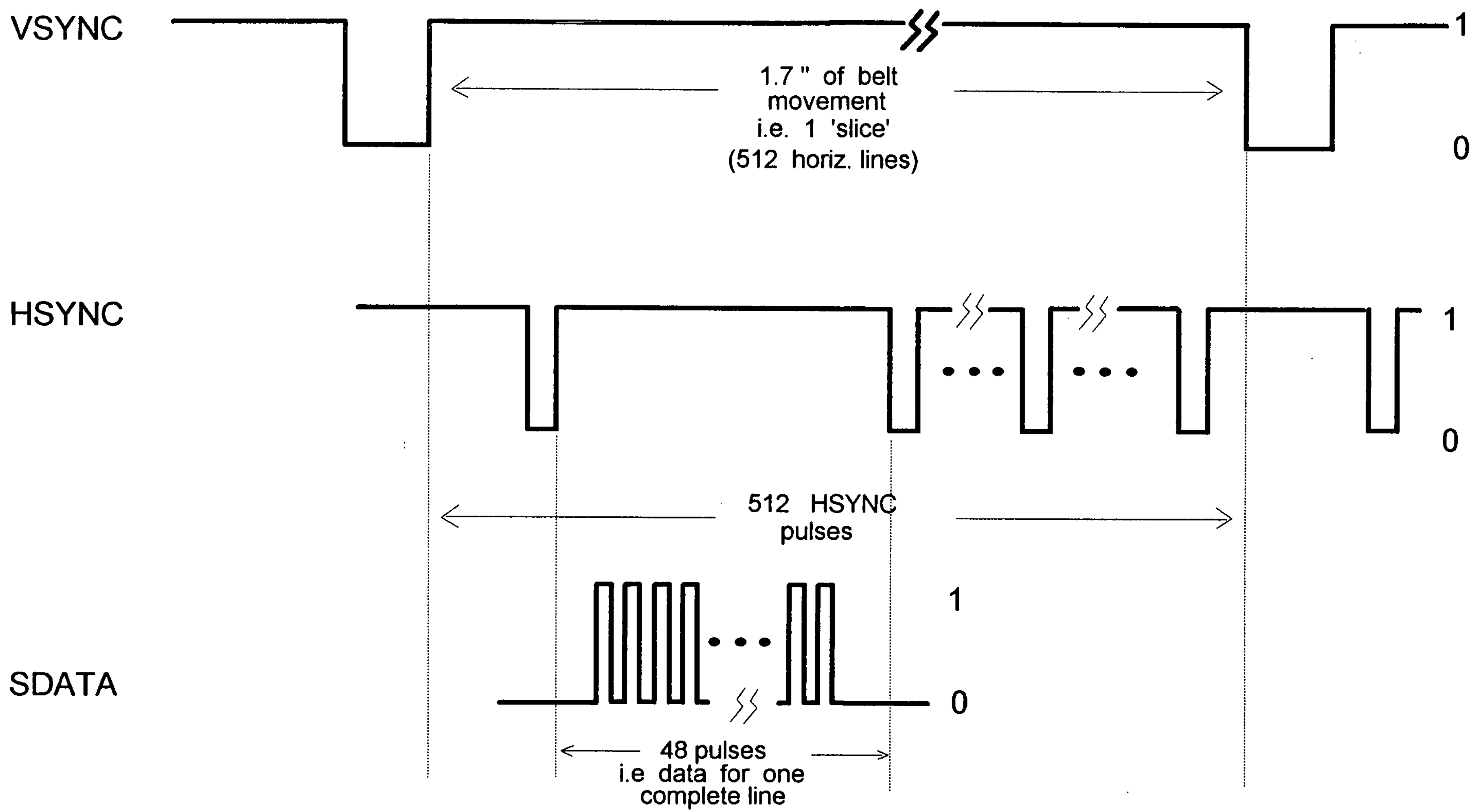
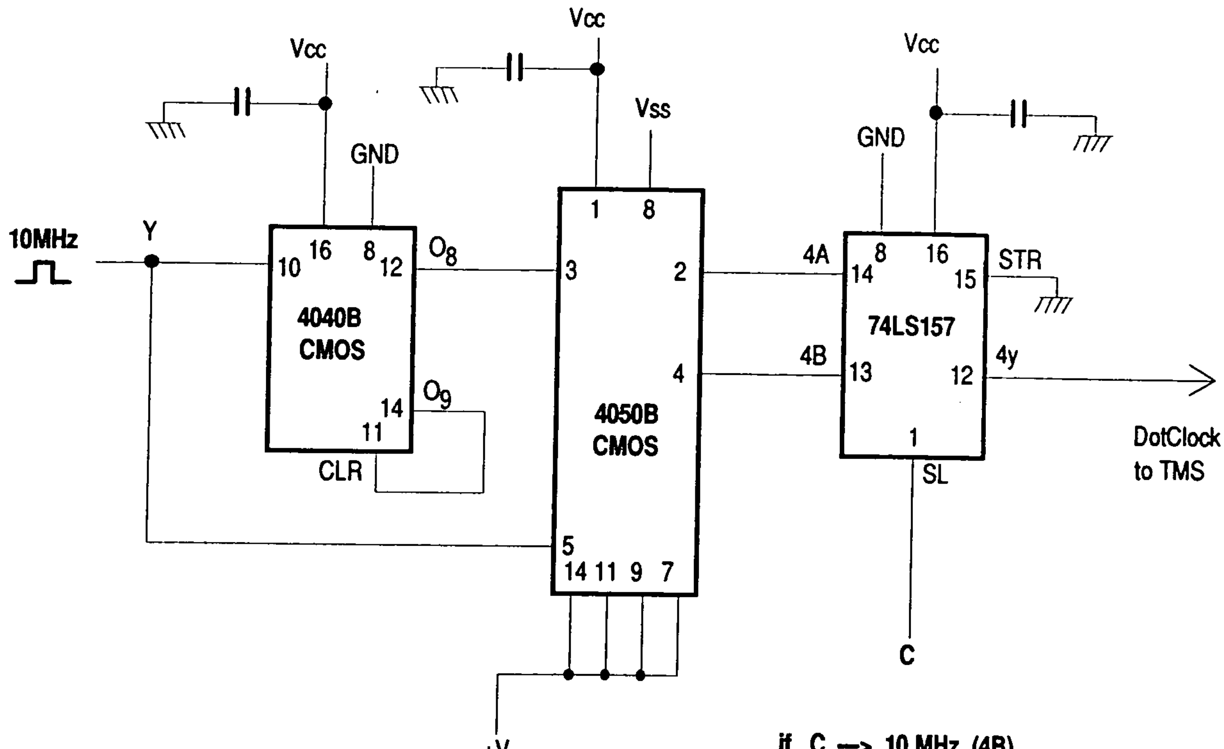
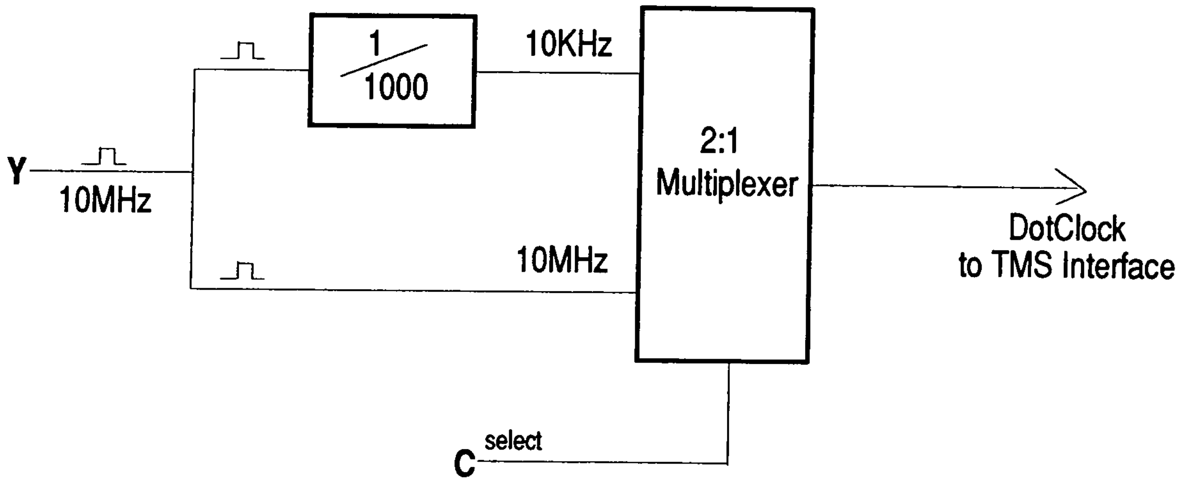


Fig. A-8.2 Relationship of the main synchronisation pulses of the TMS output as defined for the skiving process with resolution of 5mm.



Circuit diagram



Function diagram

Fig. A-8.3 Circuit diagram of the frequency switching unit

A-8.4

The M68000 control software

S. Topis, 1992, School of Engineering and Computer Science, University of Durham

Control software for dynamic pin matrix skiving

(32 pins at 5mm resolution)

System : **M68000**

Programming language : **M68000 assembler**

Program listing

```
        |*******************************************************************
                        | ADDRESSES OF PORT REGISTERS USED
        |*******************************************************************

0007 4623        oraa2 = 0x74623         |addresses of I/O registers
0007 4621        orab2 = 0x74621
0007 4603        oraa1 = 0x74603
0007 4601        orab1 = 0x74601
0007 4643        oraa3 = 0x74643
0007 4641        orab3 = 0x74641
0007 4663        iraa4 = 0x74663
0007 4661        irab4 = 0x74661
0007 4607        ddra1 = 0x74607         |addresses of DDR registers
0007 4605        ddrb1 = 0x74605
0007 4627        ddra2 = 0x74627
0007 4625        ddrb2 = 0x74625

0007 4647        ddra3 = 0x74647
0007 4645        ddrb3 = 0x74645
0007 4667        ddra4 = 0x74667
0007 4665        ddrb4 = 0x74665

0007 467D        ier4  = 0x7467d         |addresses for interrupt registers
0007 467B        ifr4  = 0x7467b
0007 4679        pcr   = 0x74679
```

```
|******************************************************************************
              |   ADDRESSES OF CONSTANTS AND VARIABLES USED
|******************************************************************************

0002 2000      MapSize = 0x22000      |address for map size constant
0002 2010      PTotHlf = 0x22010      |address for half the number of pins
0002 2020      LTotal  = 0x22020      |address for LineTotal constant
0002 2030      SPerLn  = 0x22030      |address for Steps-per-line constant
0002 2040      STotal  = 0x22040      |address for StepTotal
0002 3000      MTop    = 0x23000      |address for the top of image memory map
0002 2050      Int_ID  = 0x22050      |address for the interrupt I.D.
0002 2060      EOD_FL  = 0x22060      |address for "end of data" flag
0002 2070      CurMem  = 0x22070      |address that the mem ptr will refer to
0002 2080      NewStep = 0x22080      |address for step status flag
0002 2090      StepSum = 0x22090      |addr for temporary storage of SPerLn
0002 20A0      CurLine = 0x220a0      |addr for temp stor of line count
0002 20B0      InpTime = 0x220b0      |addr for const indicating the point
                                      |from which, DRAM data transfer begins
0002 20C0      LnFull  = 0x220c0      |addr for flag indicating whether
                                      |a line has been actuated and/or
                                      |whether "line_thickness" has been
                                      |reached
0002 20D0      HSCount = 0x220d0      |addr for HSync_interrupt counter
0002 20E0      DatVal  = 0x220e0      |addr for "valid data flag" used to
                                      |define the 32 valid bits within the
                                      |48 bit long lines
```

```
|*******************************************************************************
                    |   INITIALISATION OF PORT REGISTERS
|*******************************************************************************

000000 13FC 0000 0007      movb  #0x00,ddra4       |sets both ports of via4 as input
   4667
000008 13FC 0000 0007      movb  #0x00,ddrb4
   4665
000010 13FC 00FF 0007      movb  #0xff,ddra2       |sets VIA1, VIA2 and VIA3 as output
   4627
000018 13FC 00FF 0007      movb  #0xff,ddra1
   4607
000020 13FC 00FF 0007      movb  #0xff,ddrb1
   4605
000028 13FC 00FF 0007      movb  #0xff,ddrb2
   4625
000030 13FC 00FF 0007      movb  #0xff,ddra3
   4647
000038 13FC 00FF 0007      movb  #0xff,ddrb3
   4645

000040 13FC 0015 0007      movb  #0x15,pcr         |CA2 CA1 & CB1 int on "+" active edge
   4679                                              |DATA  interrupt on CA2
                                                     |MOTOR-STEP int. on CA1
                                                     |HSYNC interrupt on CB1
```

```
|*****************************************************************************
                        |  SETTING INITIAL OUTPUTS FOR PORTS
|*****************************************************************************

000048 13FC 00FF 0007      movb  #0xff,oraa1      | Initially all pins are retracted
   4603
000050 13FC 00FF 0007      movb  #0xff,orab1      |  "   "  "  "   "
   4601
000058 13FC 00FF 0007      movb  #0xff,oraa2      |  "   "  "  "   "
   4623
000060 13FC 00FF 0007      movb  #0xff,orab2      |  "   "  "  "   "
   4621
000068 13FC 0002 0007      movb  #0x02,oraa3      | Clock for DRAM data transfer is
   4643                                             | initially switched "on" so that
                                                    | it may be switched "off" exactly at
                                                    | the end of a line output (later during
                                                    |   HSLp1 )
000070 13FC 00FF 0007      movb  #0xff,orab3      | ( the pulse generator output to the
   4641                                             | DRams is controlled as "on/off"
                                                    | by bit 0 of ouput port a3. Port b3
                                                    |   is not used.)
```

```
|*****************************************************************************
                    |  SETTING THE VALUES OF CONSTANTS
|*****************************************************************************

000078 23FC 0000 0A00     movl  #0x0a00,MapSize     |declare total number of info bits
   0002 2000                                          |expected; ie the size of Memory
                                                    needed
000082 23FC 0000 0010     movl  #0x010,PTotHlf      |declare half number of pins per line
   0002 2010
00008C 23FC 0000 0050     movl  #0x050,LTotal       |declare total number of lines
   0002 2020
000096 23FC 0000 0008     movl  #0x008,SPerLn       |declare motor steps per line
   0002 2030                                        |(assumes resolution 32 x 80)
0000A0 23FC 0000 0700     movl  #0x0700,STotal      |declare total time of steps before
                                                    skiving
   0002 2040
000AA 23FC 0000 0480      movl  #0x0480,InpTime     |define point at which the 68000 starts
   0002 20B0                                        |to read from the TMS. Definition is
                                                    |made as "a number of steps"
0000B4 23FC 0000 0000     movl  #0x0,HSCount        |initialise HSync_interrupt counter
   0002 20D0
0000BE 23FC 0000 0000     movl  #0x0,DatVal         |data valid flag is "down" for the first
   0002 20E0                                        |8 bits of the line.
```

```
|*****************************************************************************
                         |   INITIALISE VARIABLES, POINTERS AND INTERRUPTS
|*****************************************************************************

0000C8 46FC 2000           movw   #0x2000,sr        |Switch "off" supervisor mode

0000CC 23FC 0000 0000      movl   #0,NewStep        |Set flag to "expect new step"
    0002 2080
0000D6 23FC 0000 0000      movl   #0,Int_ID         |VSync is current Interrupt I.D.
    0002 2050
0000E0 23FC 0000 0000      movl   #0,EOD_FL         |Flag shows "not End of data" received
    0002 2060
0000EA 41F9 0000 02F2      lea    Subr,a0           |initialise for interrupt call
0000F0 203C 0000 0001      movl   #1,d0
0000F6 4E4F                trap   #15
0000F8 000F                .word  15
```

```
|*******************************************************************************
                          |   MAIN PROGRAM FUNCTION
|*******************************************************************************

0000FA 13FC 00FF 0007           movb  #0xff,ifr4
    467B
000102 13FC 0090 0007           movb  #0x90,ier4
    467D
00010A 0C39 0001 0002  HSLp1:   cmpb  #1,Int_ID
    2050
000112 6700 0008                beq   Next2
000116 4EF9 0000 010A           jmp   HSLp1

00011C 13FC 0010 0007  Next2:   movb  #0x10,ier4        |Disable HSYNC interrupt
    467D
000124 13FC 00FF 0007           movb  #0xff,ifr4        |Clear interrupt flags
    467B
00012C 13FC 0081 0007           movb  #0x81,ier4        |Enable only Motor_Step Interrupt
    467D
000134 4E71                     SLoop1: nop             |Loop for initial Step_Int acceptance
000136 0C39 0002 0002           cmpb  #2,Int_ID         |Check if current interrupt no longer
    2050
00013E 6700 000A                beq   Next3             |wanted; ie if Int I.D. is now changed
000142 4E71                     nop
000144 4EF9 0000 0134           jmp   SLoop1

00014A 13FC 0001 000Next3:      movb  #0x01,ier4        |Disable Motor_Step interrupt
    467D
000152 13FC 00FF 0007           movb  #0xff,ifr4        |Clear interrupt flags
    467B
00015A 13FC 0090 0007           movb  #0x90,ier4        |Enable HSync interrupt
    467D
000162 13FC 0000 0007           movb  #0x00,oraa3       |Enable pulse generator for DRAM
                                                                   of TMS
    4643                                                |(High frequency initially)
00016A 0C39 0003 0002 HSLp2:    cmpb  #3,Int_ID         |Check if current interrupt no longer
```

```
     2050
000172 6700 0008                beq   Next4            |wanted; ie if Int I.D. is now
                                                          changed
000176 4EF9 0000 016A           jmp   HSLp2

00017C 13FC 0010 0007   Next4:  movb  #0x10,ier4       |disable HSync interrupt
     467D
000184 23FC 0002 3000           movl  #MTop,CurMem     |Reference of memory ptr is
                                                          initialised
     0002 2070                                         |A1 uses it later in SERV2
00018E 06B9 0000 0004           addl  #0x4,CurMem
     0002 2070
000198 223C 0000 0000           movl  #0x0,d1
00019E 2A3C 0000 0000           movl  #0,d5            |Line bit counter is initialised
0001A4 13FC 00FF 0007           movb  #0xff,ifr4       |Clear flag register
     467B
0001AC 13FC 0082 0007           movb  #0x82,ier4       |Enable only Data Interrupt
     467D
0001B4 4E71             DLoop:  nop                    |Loop for Data interrupt
0001B6 0C39 0004 0002           cmpb  #4,Int_ID
     2050
0001BE 6700 0008                beq   Next5
0001C2 4EF9 0000 01B4           jmp   DLoop

0001C8 13F9 0000 0002   Next5:  movb  0x02,ier4
     0007 467D
0001D2 23FC 0002 3000           movl  #MTop,CurMem     |Load reference of mem. ptr
                                                          with Map-Top
     0002 2070
0001DC 23F9 0002 2030           movl  SPerLn,StepSum   |Load step counter with "motor
                                                          steps per line of actuation"
     0002 2090
0001E6 23F9 0002 2020           movl  LTotal,CurLine   |Load Line counter with
                                                          number of total lines
     0002 20A0                                         | of data stored in memory
0001F0 23FC 0000 0000           movl  #0,LnFull        |Set flag for line-thickness waiting
```

```
     0002 20C0
0001FA 13FC 00FF 0007             movb  #0xff,ifr4       |Clear flag register
     467B
000202 13FC 0081 0007             movb  #0x81,ier4       |Enable only Step Interrupt
     467D
00020A 4E71               SLoop2: nop                    |Loop for Motor Step Interrupt
00020C 0C39 0005 0002             cmpb  #0x5,Int_ID
     2050
000214 6700 0008                  beq   Resume
000218 4EF9 0000 020A             jmp   SLoop2

00021E 13FC 0000 0007     Resume: movb  #0x00,ier4       |Disable all interrupts
     467D
000226 13FC 00FF 0007             movb  #0xff,oraa1      |release all possibly pressed pins
     4603
00022E 13FC 00FF 0007             movb  #0xff,orab1
     4601
000236 13FC 00FF 0007             movb  #0xff,oraa2
     4623
00023E 13FC 00FF 0007             movb  #0xff,orab2
     4621
000246 46FC 2700                  movw  #0x2700,sr       |Back to supervisor mode. At this
                                                         point actuation is finished and on
                                                           | screen pattern display begins
00024A 43F9 0002 3000             lea   MTop,a1          |a1 points to the top of the
                                                           memory
000250 2A3C 0000 0020             movl  #32,d5           |d5 is pin counter
000256 23FC 0000 0050             movl  #0x50,LTotal     |Initialise line counter
     0002 2020

000260 223C 0000 0000     OutScr: movl  #0,d1
000266 1219                       movb  a1@+,d1          |Get pin data
000268 0C81 0000 0000             cmpl  #0,d1            |Check pin data
00026E 6700 001C                  beq   NoChar           |IF data is 0 then output No
                                                           character
000272 203C 0000 004F             movl  #0x4f,d0         |Else output "O"
```

```
000278 4E4F                      trap  #15
00027A 0002                      .word 2
00027C 203C 0000 0020            movl  #0x20,d0
000282 4E4F                      trap  #15
000284 0002                      .word 2
000286 4EF9 0000 02A0            jmp   NextPn
00028C 203C 0000 0020   NoChar:  movl  #0x20,d0        |Output No character
000292 4E4F                      trap  #15
000294 0002                      .word 2
000296 203C 0000 0020            movl  #0x20,d0
00029C 4E4F                      trap  #15
00029E 0002                      .word 2

0002A0 0485 0000 0001   NextPn:  subl  #1,d5           |Count pins
0002A6 0C85 0000 0000            cmpl  #0,d5           |Check for end of line
0002AC 6700 0008                 beq   NewLin
0002B0 4EF9 0000 0260            jmp   OutScr
0002B6 04B9 0000 0001   NewLin:  subl  #1,LTotal       |IF new line check for last line
    0002 2020
0002C0 0CB9 0000 0000            cmpl  #0,LTotal       |IF last line passed, end program
    0002 2020
0002CA 6700 0022                 beq   EndPr
0002CE 2A3C 0000 0020            movl  #32,d5          |else reload pin counter and
0002D4 203C 0000 000A            movl  #0x0a,d0        |output C/R
0002DA 4E4F                      trap  #15
0002DC 0002                      .word 2
0002DE 203C 0000 000D            movl  #0x0d,d0
0002E4 4E4F                      trap  #15
0002E6 0002                      .word 2
0002E8 4EF9 0000 0260            jmp   OutScr

0002EE 4E4F             EndPr:   trap  #15             |END OF MAIN PROGRAM
0002F0 000E                      .word 14
```

```
|*******************************************************************************
            |  S E R V I C E   R O U T I N E    USED BY ALL INTERRUPTS
|*******************************************************************************

0002F2 0C39 0001 0002   Subr:  cmpb  #1,Int_ID
    2050
0002FA 6700 0050               beq   SERV2            |choose appropriate service
0002FE 0C39 0002 0002          cmpb  #2,Int_ID
    2050
000306 6700 0084               beq   SERV3
00030A 0C39 0003 0002          cmpb  #3,Int_ID
    2050
000312 6700 00DC               beq   SERV4
000316 0C39 0004 0002          cmpb  #4,Int_ID
    2050
00031E 6700 0228               beq   SERV5


000322 13FC 00FF 0007   SERV1: movb  #0xff,ifr4
    467B
00032A 0C39 0001 0002          cmpb  #1,Int_ID
    2050
000332 6700 0328               beq   Exit

000336 13FC 00FF 0007          movb  #0xff,oraa3      |Stop generator signal at
                                                           HSync pulse
    4643
00033E 13FC 0001 0002          movb  #1,Int_ID
    2050
000346 4EF9 0000 065C          jmp   Exit


00034C 13FC 00FF 0007   SERV2: movb  #0xff,ifr4       |Clear flag for next interrupt
    467B
000354 0C39 0002 0002          cmpb  #2,Int_ID        |Service not terminated ?
    2050
```

```
00035C 6700 02FE                    beq   Exit

000360 04B9 0000 0001               subl  #1,STotal         |Register motor step occured
    0002 2040
00036A 0CB9 0000 0400               cmpl  #0x400,STotal     |Check if time to start reading data
    0002 2040                                                 |occured
000374 6700 0008                    beq   OutLp             |if time, then set this service no
                                                                  longer available
000378 4EF9 0000 065C               jmp   Exit
00037E 13FC 0002 0002     OutLp:    movb  #2,Int_ID         |Service no longer available
    2050
000386 4EF9 0000 065C               jmp   Exit

00038C 13FC 00FF 0007     SERV3:    movb  #0xff,ifr4        |Clear flag for next interrupt
    467B
000394 0C39 0003 0002               cmpb  #3,Int_ID
    2050
00039C 6700 02BE                    beq   Exit
0003A0 2C39 0002 20D0               movl  HSCount,d6
0003A6 0686 0000 0001               addl  #1,d6
0003AC 23C6 0002 20D0               movl  d6,HSCount
0003B2 0C86 0000 0001               cmpl  #1,d6             |When first HSync pulse arrives
0003B8 6700 0008                    beq   LowF              |switch to low frequency
0003BC 4EF9 0000 03CA               jmp   Cont              |generator signal

0003C2 13FC 0002 0007     LowF:     movb  #0x02,oraa3       |bit D1 of oraa3 enables low
    4643                                                        frequency
0003CA 0C86 0000 0010     Cont:     cmpl  #0x10,d6          |Ignore the first 16 lines of data
                                                              as they do not contain valid info
                                                              |(vertical clipping in VRAM)
0003D0 6700 0008                    beq   EndSer
0003D4 4EF9 0000 065C               jmp   Exit

0003DA 13FC 0003 0002     EndSer:   movb  #3,Int_ID
    2050
0003E2 13FC 0010 0007               movb  #0x10,ier4        |Disable HSync interrupt
```

```
    467D
0003EA 4EF9 0000 065C              jmp   Exit


0003F0 13FC 00FF 0007  SERV4:  movb  #0xff,ifr4          |Clear flag for next interrupt
    467B
0003F8 0C39 0004 0002          cmpb  #4,Int_ID           |if wrong I.D. abort current
                                                            service
    2050
000400 6700 025A               beq   Exit
000404 2279 0002 2070          movl  CurMem,a1           |A1 points to the point in data
                                                            where the last WRITE
                                                            |happened or to the MTop if it
                                                            is the first call for SERV2
00040A 0CB9 0000 0001          cmpl  #0x1,EOD_FL         |Check End-of-Data Flag
    0002 2060
000414 6700 00D4               beq   StepLp              |if End-of-Data do not write to
                                                            memory, only count motor steps
000418 0685 0000 0001          addl  #1,d5               |Increment bit counter
00041E 0CB9 0000 0001          cmpl  #1,DatVal           |Check for valid data present
    0002 20E0
000428 6700 0022               beq   RdData              |If valid then read it
00042C 0C85 0000 0008          cmpl  #8,d5               |Check if 8th bit is received
000432 6700 0008               beq   DValid              |If yes, then indicate that valid
                                                            data is expected
000436 4EF9 0000 04AA          jmp   DInval              |If not, continue rejecting bits

00043C 23FC 0000 0001  DValid: movl  #1,DatVal           |Set valid data flag "up"
    0002 20E0                                            |note that valid data starts
                                                            with the next incoming data bit
000446 4EF9 0000 04EA          jmp   StepLp              |Proceed without reading the
                                                            info of the current bit
00044C 1839 0007 4663  RdData: movb  iraa4,d4            |Read port
000452 4604                    notb  d4
000454 1304                    movb  d4,a1@-
```

```
000456 23C9 0002 2070              movl  a1,CurMem        |Store mem position for future
                                                          reference
00045C 0681 0000 0001              addl  #0x1,d1           | NEW
000462 0C81 0000 0004              cmpl  #4,d1
000468 6600 0012                   bne   Con
00046C 223C 0000 0000              movl  #0,d1
000472 06B9 0000 0008              addl  #0x8,CurMem
    0002 2070
00047C 04B9 0000 0001    Con:      subl  #1,MapSize       |Count Total info expected
    0002 2000
000486 0CB9 0000 0000              cmpl  #0,MapSize       |Has all expected data been
                                                             received ?
    0002 2000
000490 6700 0008                   beq   DatEnd            |If YES, mark "end of data"
000494 4EF9 0000 04AA              jmp   DInval            |Not End-of-Data
00049A 23FC 0000 0001    DatEnd:   movl  #01,EOD_FL        |End-of-Data, set flag
    0002 2060
0004A4 4EF9 0000 04EA              jmp   StepLp

0004AA 0C85 0000 0028    DInval:   cmpl  #40,d5           |Check if reached end of valid data
0004B0 6700 0008                   beq   FlDown            |If yes, set valid data flag down
0004B4 4EF9 0000 04C4              jmp   contn             |If not continue

0004BA 23FC 0000 0000    FlDown:   movl  #0,DatVal        |valid data flag is now down
    0002 20E0
0004C4 0C85 0000 0030    contn:    cmpl  #48,d5             |Check if end of line is reached
0004CA 6600 001E                   bne   StepLp             |If not, continue
0004CE 2A3C 0000 0040              movl  #0x40,d5           |If yes, delay after 48th pulse
                                                             to avoid
0004D4 0485 0000 0001    SpkDel:   subl  #0x1,d5            |any spikes coming during
                                                               Hsync start
0004DA 0C85 0000 0000              cmpl  #0x0,d5
0004E0 6600 FFF2                   bne   SpkDel
0004E4 2A3C 0000 0000              movl  #0,d5               |If yes, Initialise bit counter
                                                              for next line
```

```
0004EA 1639 0007 4661   StepLp: movb  irab4,d3          |Load step status to buffer.Assumes
                                                        that bit 0 of port 4b receives
                                                           |Step as input
0004F0 4603                     notb  d3
0004F2 0C03 0000                cmpb  #0,d3             |Check the step status; ie H or L
0004F6 6700 0026                beq   SPass             |If L,set flag for expecting new step

0004FA 0C39 0000 0002           cmpb  #0,NewStep        |If H,check flag, ie check if it
     2080                                                  | is a new step or still the
                                                            previous one
000502 6700 0022                beq   Next              |If Old step, ignore it & continue
000506 04B9 0000 0001           subl  #1,STotal         |If New step, register and
     0002 2040
000510 13FC 0000 0002           movb  #0,NewStep        |set flag accordingly
     2080
000518 4EF9 0000 0526           jmp   Next              |Continue
00051E 13FC 0001 0002   SPass:  movb  #1,NewStep        |Set flag for expecting new step
     2080
000526 0CB9 0000 0380   Next:   cmpl  #0x380,STotal     |Check if Step-Total is reached, ie
     0002 2040                                            |if it is time for skiving
000530 6700 0008                beq   InitSk            |If YES then start Skiving
000534 4EF9 0000 065C           jmp   Exit              |If Not then go round the loop again
00053A 13FC 0004 0002   InitSk: movb  #4,Int_ID         |Change interrupt I.D., the current
     2050                                                 |interrupt is no longer needed
000542 4EF9 0000 065C           jmp   Exit


000548 13FC 00FF 0007   SERV5:  movb  #0xff,ifr4        |Clear flag for next interrupt
     467B
000550 0C39 0005 0002           cmpb  #5,Int_ID         |IF wrong interrupt I.D. abort
     2050
000558 6700 0102                beq   Exit              |current service

00055C 0CB9 0000 0001           cmpl  #1,LnFull         |Is current line actuated ?
     0002 20C0
```

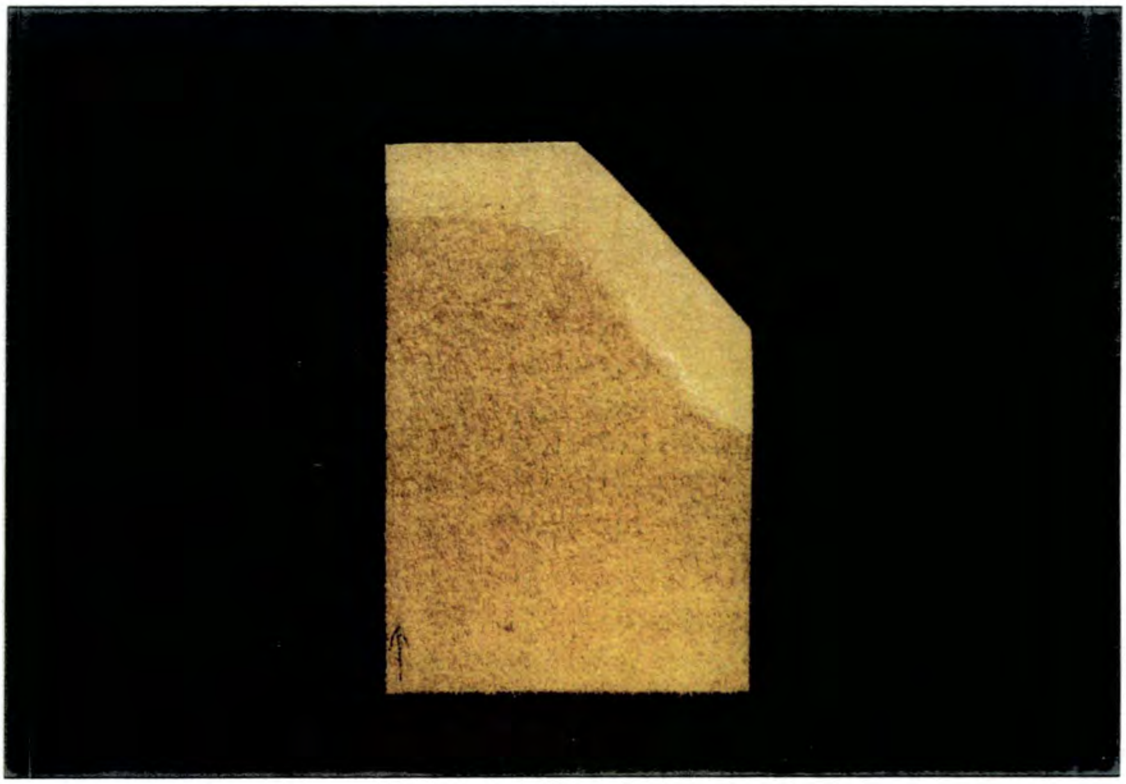
```
000566 6700 0096              beq   SCount           |Yes, then only count steps
                                                      until line thickness is reached
00056A 2279 0002 2070         movl  CurMem,a1        |A1 points the memory
                                                     location where
                                                      |the last read & actuate
                                                     happened OR to the top of the memory
                                                      |if it is1st time that Serv3 is called
000570 2C3C 0000 0000         movl  #0,d6
000576 2C39 0002 2010         movl  PTotHlf,d6       |D6 is pin counter for the current
                                                        half line
00057C 243C 0000 0000         movl  #0,d2            |D2 is temp data store for 1st half
                                                     line
000582 263C 0000 0000         movl  #0,d3            |D3 is temp data store for 2nd half
                                                     line

000588 E29A            Half1: rorl  #1,d2            |Loop for loading 16 bits (pins) of
00058A 1419                   movb  a1@+,d2          |data into a single register (D2)
00058C 0486 0000 0001         subl  #1,d6
000592 0C86 0000 0000         cmpl  #0,d6            |All 16 bits in D2 ?
000598 6700 0008              beq   NextH            |If Yes, D2 contains the
                                                     information for the first 16 pins of the
                                                        |current line
00059C 4EF9 0000 0588         jmp   Half1

0005A2 2C39 0002 2010  NextH: movl  PTotHlf,d6       |Reload counter for next half

0005A8 E29B            Half2: rorl  #1,d3            | Repeat process for next half of
                                                       line
0005AA 1619                   movb  a1@+,d3          |Note: at the end of the two
                                                       processes
0005AC 0486 0000 0001         subl  #1,d6            |the half line info is contained
0005B2 0C86 0000 0000         cmpl  #0,d6            |into the HIGH halfs of D2 and D3
0005B8 6700 0008              beq   OutLn
0005BC 4EF9 0000 05A8         jmp   Half2

0005C2 E09A            OutLn: rorl  #8,d2            |move information into LOW D2
```

```
0005C4 E09A                          rorl  #8,d2
0005C6 E09B                          rorl  #8,d3          |move information into LOW D3
0005C8 E09B                          rorl  #8,d3
0005CA 23C9 0002 2070                movl  a1,CurMem      |Save mem position for future
                                                            reference
0005D0 4602                          notb  d2
0005D2 13C2 0007 4603                movb  d2,oraa1       |Start actuation
0005D8 E09A                          rorl  #8,d2          |Each of the 2 Words in D2 and D3
0005DA 4602                          notb  d2
0005DC 13C2 0007 4601                movb  d2,orab1       | is sent to the 4 8-bit ports
0005E2 4603                          notb  d3
0005E4 13C3 0007 4623                movb  d3,oraa2
0005EA E09B                          rorl  #8,d3
0005EC 4603                          notb  d3
0005EE 13C3 0007 4621                movb  d3,orab2
0005F4 23FC 0000 0001                movl  #1,LnFull      |Register that current line has been
    0002 20C0                                               |actuated

0005FE 04B9 0000 0001  SCount: subl  #1,StepSum           |Counts Steps of motor per line of
    0002 2090                                               |actuation
000608 0CB9 0000 0000                cmpl  #0,StepSum     |Reached 1-line thickness ?
    0002 2090
000612 6700 0008                     beq   LCount         |Yes, line is finished, check
                                                            LineTotal
000616 4EF9 0000 065C                jmp   Exit           |No, expect more steps for
                                                            current line
00061C 23FC 0000 0000  LCount: movl  #0,LnFull            |Register that the next line has not
    0002 20C0                                               | been actuated yet
000626 04B9 0000 0001                subl  #1,CurLine     |Count line actuated
    0002 20A0
000630 0CB9 0000 0000                cmpl  #0,CurLine     |Check if LineTotal is reached
    0002 20A0
00063A 6700 0008                     beq   EndSk          |If Yes, process is finished
00063E 4EF9 0000 0652                jmp   NewLn          |If No, proceed with new line

000644 13FC 0005 0002  EndSk:  movb  #5,Int_ID            |Interrupt no longer needed
```

```
        2050
00064C 4EF9 0000 065C              jmp   Exit
000652 23F9 0002 2030   NewLn:  movl  SPerLn,StepSum        |Reload steps-per-line counter
        0002 2090

00065C 4E73             Exit:   rte
```

APPENDIX A-9

Illustrations of results of skiving and of the high resolution skiving mechanism



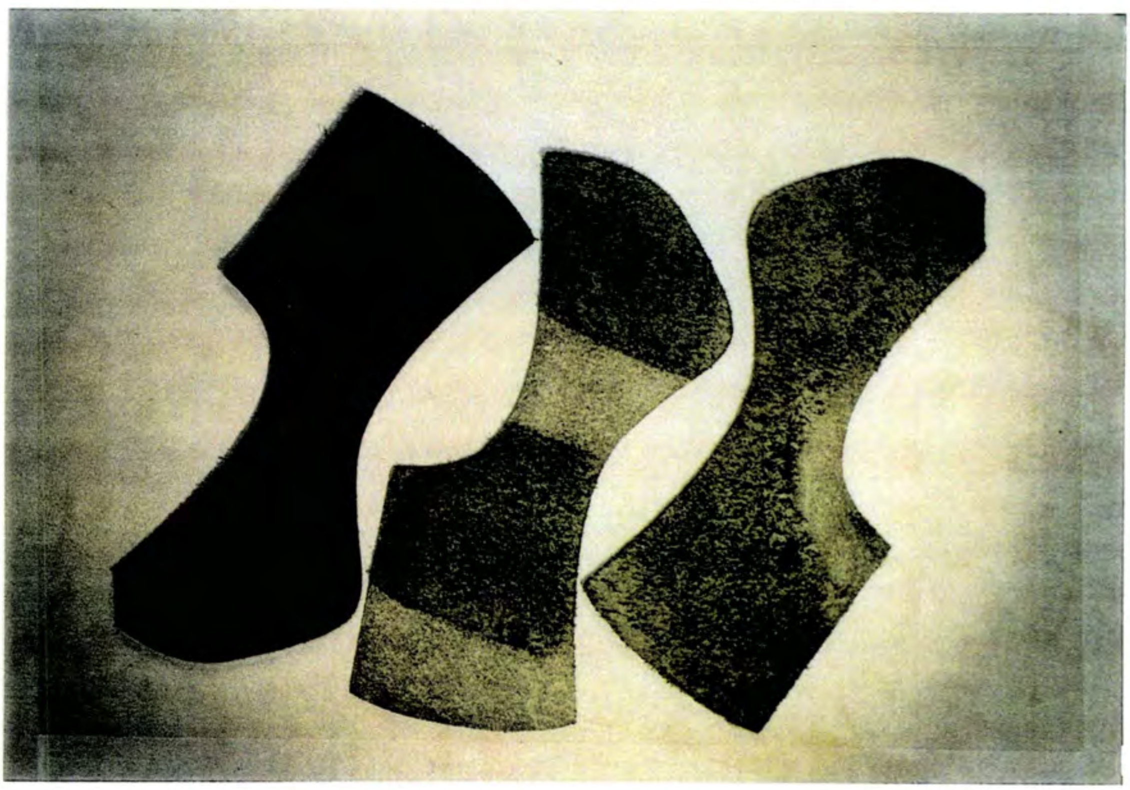
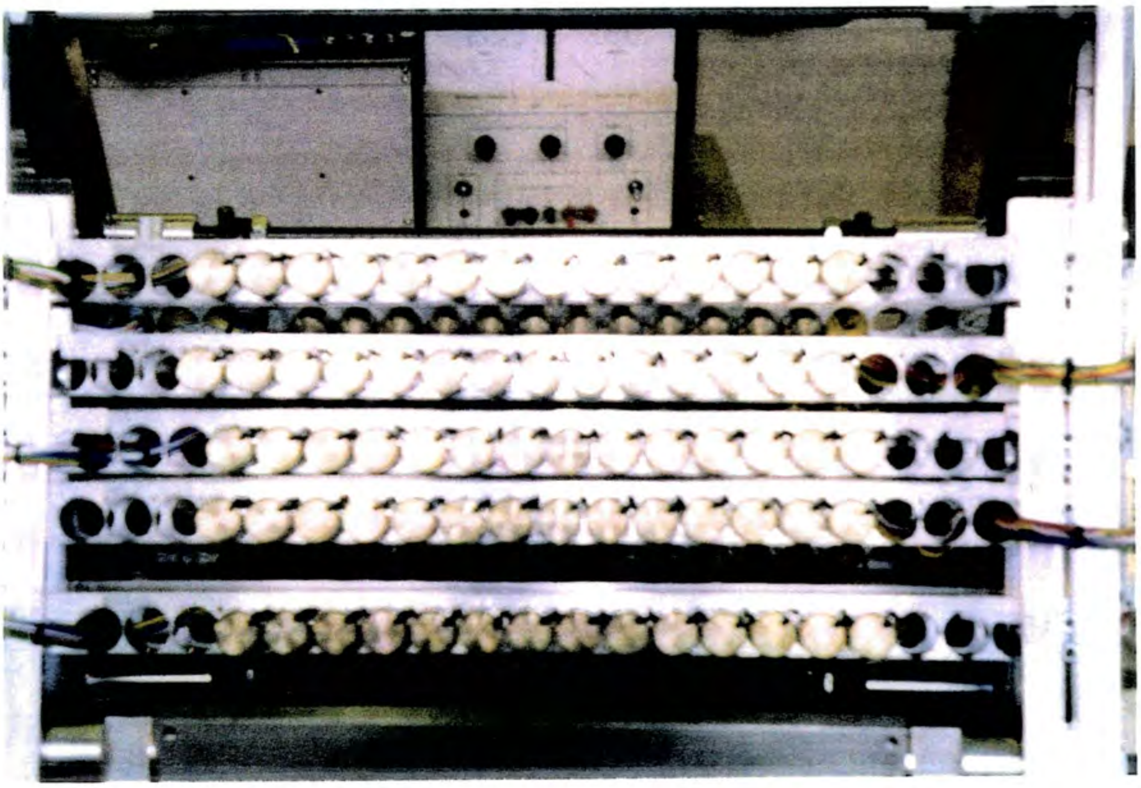


Fig. A-9.1 Some additional samples of skiving, using the low resolution skiving mechanism.



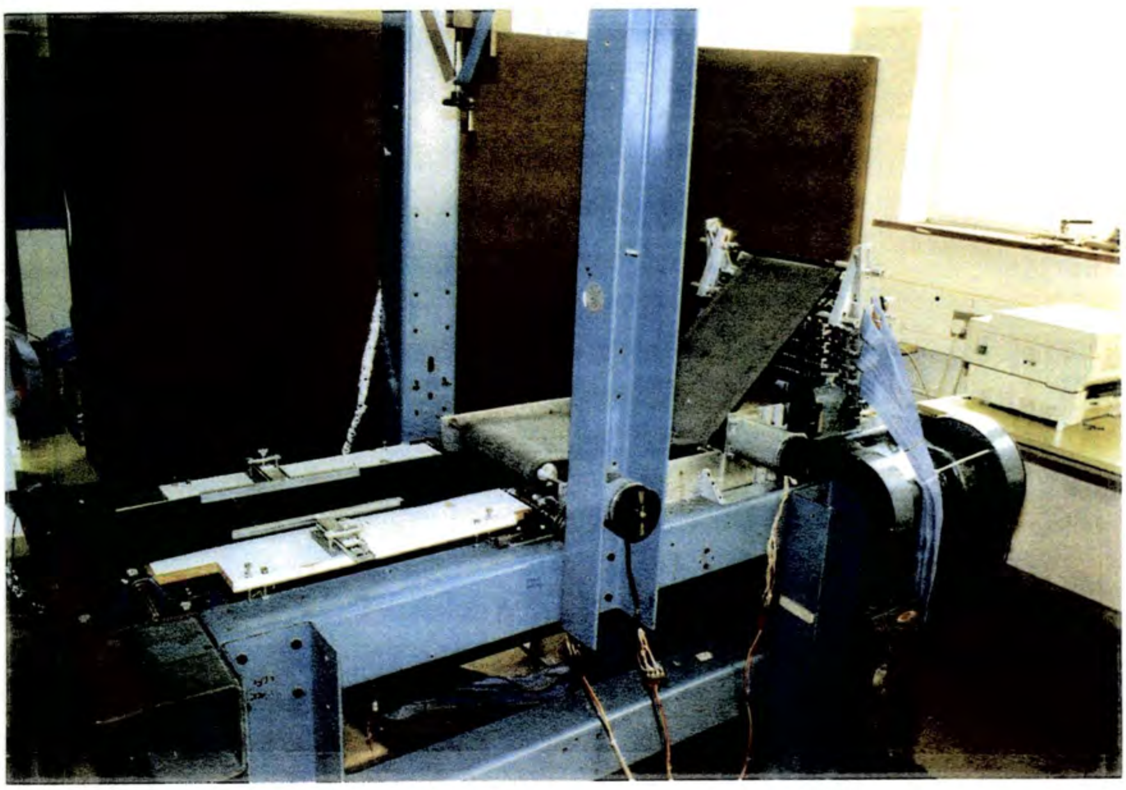


Fig. A-9.2 The high resolution skiving mechanism, integrated with the overall skiving system. (top : a rear view of the mechanism showing the allocation of the solenoids).

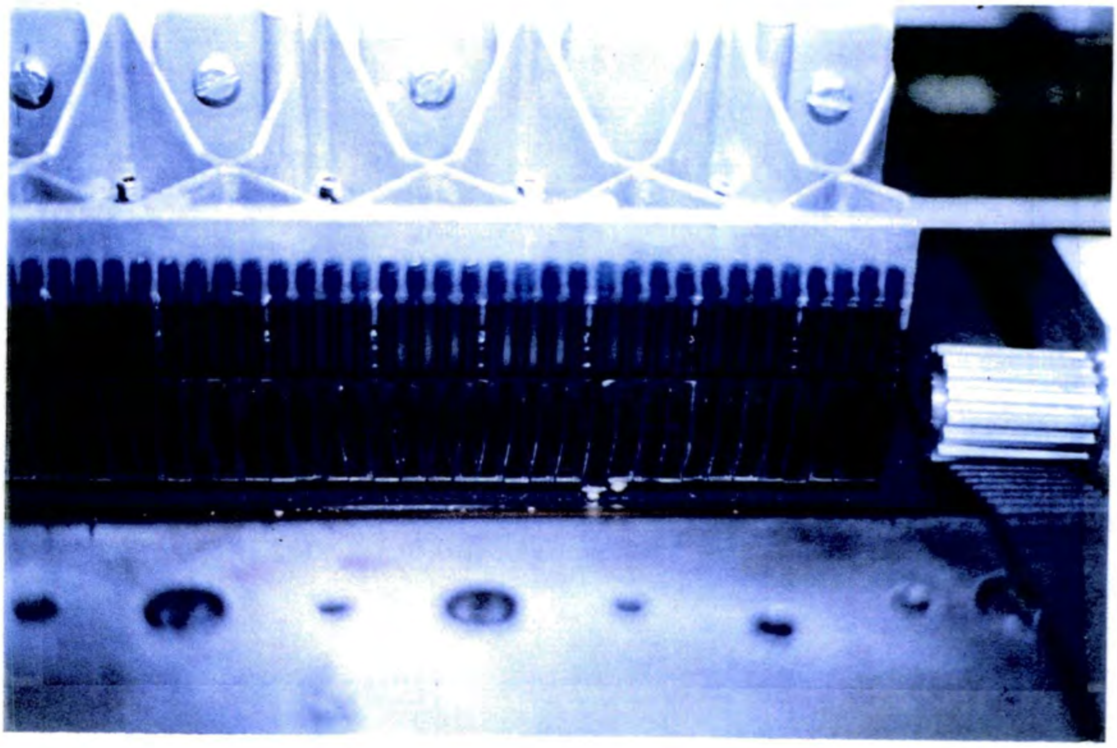


Fig. A-9.3 Experimentation with the modified line printer head to perform skiving. The photo illustrates the printer head located in the skive process area, having an individual actuator (hammer) at full stroke. The hammer tip has been provided with a suitable rounded tip for skiving.