Position sensing in restricted environments in automated manufacturing

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Hubbard, James (1996) *Position sensing in restricted environments in automated manufacturing*, Durham theses, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/5303/

Position Sensing in Restricted Environments in Automated Manufacturing

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A thesis submitted for the degree of
Master of Science

School of Engineering
University of Durham

1996

Abstract

Position Sensing in Restricted Environments in
Automated Manufacturing

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M.Sc. Thesis 1996

This thesis describes a successful attempt to identify angular movement of leather components, when transported from one operation to another, by a conveyor system. The automated manufacturing process of skiving leather components was utilised for this research. Skiving is the localised thinning of the leather components to enable the joining of these without forming thick and unsightly joints. This process had been automated, but its performance could be enhanced by combining an additional sensing system.

The research work was directed towards integrating a relatively small and low cost form of sensing system onto a dynamic matrix skiving machine. Two key areas of the research were the identification of suitable sensor technology and the investigation of the environment within which they operate.

The sensors form a vital and necessary part of any type of identification process and are used to acquire relevant data. The thesis describes a variety of sensor technologies and their suitability for use in restrictive environments. These environmental restrictions of the skiving process and the component material influence the choice of sensor.

Following the study of sensor technologies, the second phase was aimed at implementing an automatic position sensing system. Therefore the main specification of the system was to detect the leather components, and their orientation prior to, and following transportation through the process.

The final part of this work presents the results obtained from the introduction of the sensing arrays. It also identifies areas that may be investigated further to improve the system, concerning the particular restricted environment utilised in this research.

Declaration

I confirm that the work contained in this thesis has not been previously submitted by me for a degree in this, or any other University. All material, unless otherwise referenced, is the authors own work.

Acknowledements

This research project was funded by New College Durham.

The author wishes to thank Dr. C. Preece and Prof. J.E.L. Simmons who supervised this project. In addition Mr. D.C. Reedman of B.U.S.M. Ltd. for his guidance and encouragement throughout the course of this research.

The author also appreciates the assistance given by his colleagues at New College Durham and the technical support staff within the University.

I dedicate this work to:

my wife Ann

and

my children
Karen & Anthony

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Symbols

	description	**units**
L_c	Component length.	mm
L_{ST}	Line scan time	seconds
N_S	Number of line scans	
θ_R	Rotational angle of component	degrees
T_c	Duration component detected.	msecs
T_{d1}	Time between input applied and reading threshold voltage.	msecs
T_{d2}	Time difference to reach initial state.	msecs
t_s	Scan time of sensing devices.	seconds
V_c	Velocity of component.	mm/sec
V_h	Threshold voltage of sensors.	volts
W_c	Component width.	mm
W_T	Speed of conveyor system	mm/sec

CHAPTER 1

Introduction

1.1 Main Theme

The positioning of objects in manufacturing industry has many applications and ranges from the setting of components prior to the process to the actual identification of the components before the process can be carried out. It is this latter process that will be investigated in the research project and will be described in this dissertation.

The automated process that was to be utilised for the research is used in the manufacture of shoe components and relates to the skiving of the components. This involves the machining of pre-cut components to reduce their edge thickness, which are made from various types of leather and in an assortment of sizes. The machining is to prevent any external undulations in the upper part of the shoes and increase the quality of the joint, by actually producing a roughened area. It is therefore necessary to produce the hide components with a relief on the reverse side, an operation known as skiving, which may then be utilised both to cement and stitch the components together.

If we consider a simple lap joint shown in figure 1.1, then it can be seen that an unsightly ridge will be automatically formed. However in figure 1.2, the area around the joint has been skived to produce a relatively flat surface.

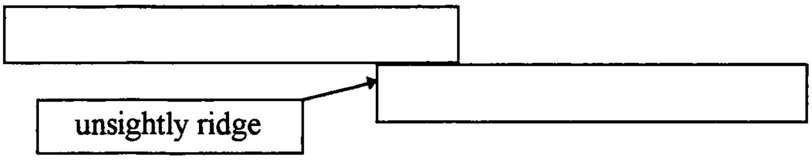


Figure 1.1 simple lap joint of two pieces of individual leather

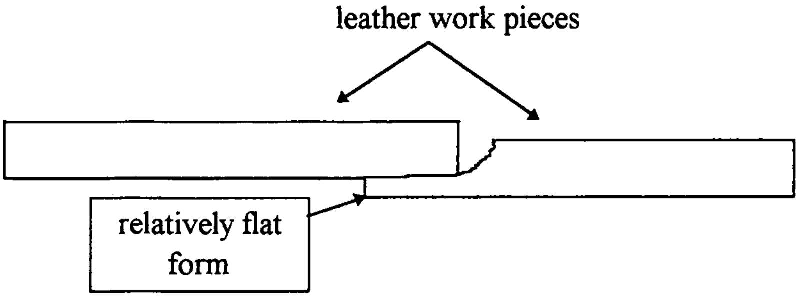


Figure 1.2 Skived joint of two leather components

A large range of processes are required to produce the complete article and it is anticipated that the completed research may be integrated into more than one of these processes.

Each of the processes that are carried out can be placed into two distinct categories, the first being associated with the soles of the shoes and the second being the construction of the shoe upper, skiving is one of the major processes involved in the manufacture of shoe uppers. As the majority of processes in this industry are carried out using manual techniques and manufacturing costs are high, then alternative forms of manufacture are necessary. One such process under investigation at present within the University is the automation of the skiving process[1][2], and it is this process that will be used to investigate the positioning of objects in restricted environments further. The construction of early machining facilities in the manufacture of shoe components necessitates that the components must be placed in a specific orientation before the process could commence. It was envisaged that this identification process may be automated and hence improve the time necessary to manufacture components.

The identification process of the various components has been dealt with in another research project, with the two projects running in parallel with one another, it essentially consists of a camera, and a transportation process. The camera is used to identify both the type and orientation of a component prior to the component being placed onto a particular process.

The object of this research was to investigate the methods that may be employed to ensure that once the components have been identified by the camera system that there was no large movement in the components during the transportation process to the machining head. This movement could possibly affect the accuracy of the machining process. It is at present not possible to place the camera any closer to the working head due to the time necessary for the computer to process all the information, and the configuration of the loading system.

Due to the constraints mentioned previously it was therefore necessary to obtain a relatively small and cheap form of sensing system that will give information related to the movement of the components during transportation, from the information obtained it will be necessary to produce statistical data that will allow the component to progress through the process or for the particular component operation to be abandoned.

CHAPTER 2

Analysis of the system

2.1 Introduction

The research work was to be carried out on a fully automatic skiving system that has been developed at the University from a number of research projects, in conjunction with British United Shoe Machinery Company (B.U.S.M.). The completed system is broadly based on a method of dynamic matrix skiving, which is an existing shop-floor term at B.U.S.M. and defines the laborious technique of interior skiving.

The system adopted for automatically producing the interior skiving consists of two distinct elements, i) some form of mechanical action that will duplicate the skiving carried out in the manual process and ii) a recognition system that will give the system information on both the component type and its orientation. This chapter will describe each of these key areas, and their effects on the development of an inexpensive form of identification.

2.2 Dynamic Splitting

The method that was chosen to carry out this localised splitting of the leather components consisted of a fixed belt driven knife and an actuator pin, which depressed the leather component against the cutting edge of the knife. In order to produce a flow-through of components it was necessary also to obtain a suitable transfer system. This transfer system would be required to be manufactured from a soft spongy type material, which would allow the leather components to buckle slightly under the pressure applied to it from the actuator pin.

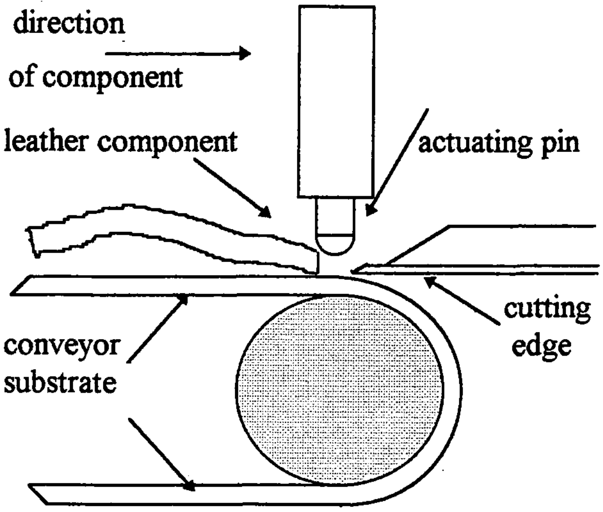


Figure 2.1 Component deforms under pressure

To prevent the effect of the leather buckling towards the actuating pin, when point pressure is applied, as shown in figure 2.1, a superstrate is placed between the actuator pin and the component, as shown in figure 2.2. This superstrate also prevents movement of the component between the recognition system and the skiving mechanism.

2.3 The Three-layer Transport System

The superstrate has several characteristics that are necessary for the process to operate, these include a stiffness along its plane, minimum thickness to reduce the amount of force required to buckle leather and superstrate, one surface that is semi-rough and one surface that has a relatively low coefficient of friction.

The substrate that is used to transport the leather components to the cutting edge also requires several properties and includes high friction on its upper face, which is in contact with the components. In addition, it should have uniform thickness, with a spongy like form, that will not be permanently deformed, and a resistance to fatigue.

These properties of the substrate and the superstrate will then allow the leather components to buckle locally, when any vertical movement/pressure is applied by the actuator pin.

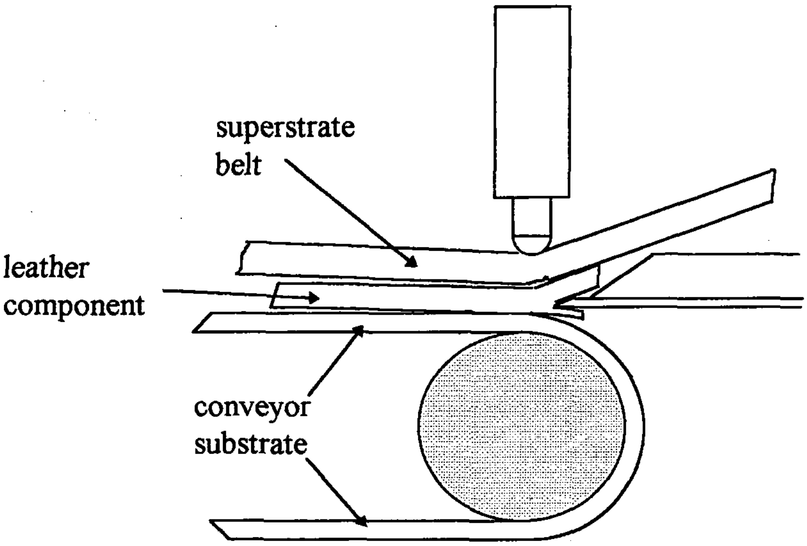


Figure 2.2 Three layer transportation system

2.4 Component Transportation

As shown in figure 2.2, the transportation to the cutting edge was achieved using a three-layer system that is driven by stepper motors, this mechanism then provides a hardware solution to the problem of timing within the overall process.

The remainder of the transportation of the components within the overall system includes an additional conveyor feed belt. This belt will pass the leather workpiece from a filling station, past a recognition system and then into the three-layer transportation system. This additional conveyor is also driven using stepper motors.

2.5 Recognition System

The recognition system was required to both identify each type of component and its orientation. It is therefore essential that the recognition system should not be considered in the simple anthropomorphic manner as the eyes of the system, but rather in a broader way as an integrated part of the overall system.

A recognition system that suited the skiving process had been developed for a similar process in the shoe industry, that of stitch marking[3]. In both the processes of stitch marking and skiving, it was noted that neither process alters the outline shape of the components. Therefore any form of inexpensive position recognition system that is developed for the skiving process can be immediately used on the stitch marking process. It also implies that any data base that may contain shape information can be used on both processes.

The component recognition system utilises a line scan camera that forms an image of the passing component. The image is translated into a raster scan and used to determine the component type. To achieve the image a light source is located opposite the camera as shown in figure 2.3.

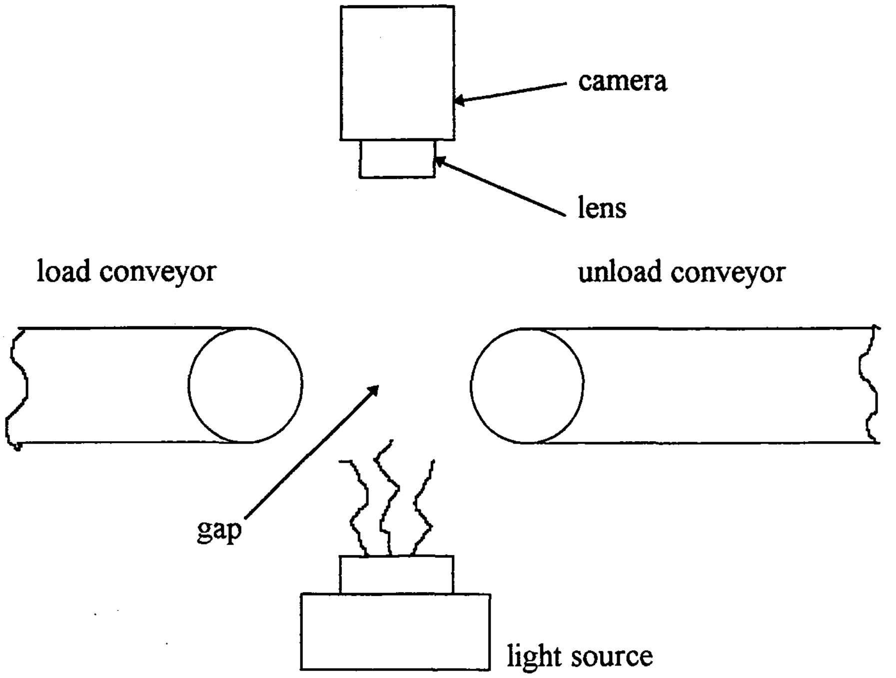


Figure not to scale

Figure 2.3 Shape recognition configuration

Due to the necessity of the light source being under the camera lens, it is unavoidable that the transportation system requires a gap of a specific width[3] . This then implied that the transportation system required a gap and that the additional conveyor belt previously mentioned in this chapter is required. This then performs the simple task of carrying the components from the load area, up to the recognition system.

2.6 Transportation System Control

The restrictions that are placed on the configurations of the complete manufacturing process determine the control methodology that may be used. Hence the timing of the overall process, as shown in figure 2.4, will be determined by the timing of the least adaptable sub-system, which in the present process configuration is the camera scan rate. The recognition of the shape, against those contained within the data bank, produces a short time delay. This delay occurs in the transportation system as the leather component enters the three layer transport conveyor.

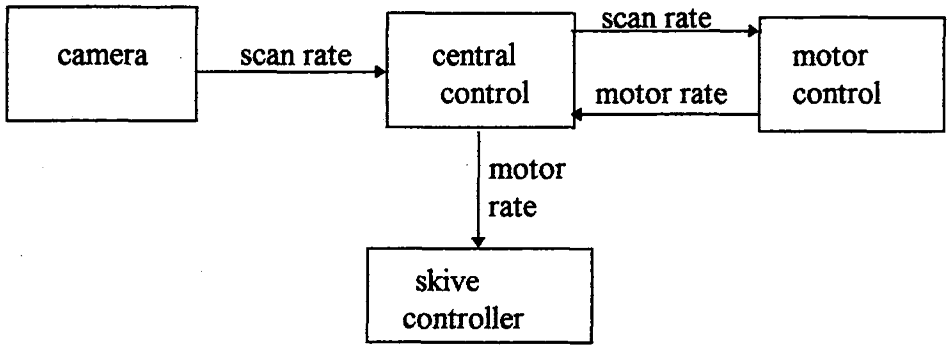


Figure 2.4 Timing links within skiving process

The timing of the two conveyor systems must not be independent, as this would produce problems transferring from one to another. In addition the skiving process must occur at a particular time following the scanning process, due to the time delay required in processing the component orientation. Consequently the rate at which the component passes the actuator pins head is automatically fixed.

This final point will also relate to the length of time the actuator is required to be energised, while dictating the speed at which the components pass the recognition system.

2.7 Overall Construction

The three elements discussed previously are integrated together to form the overall mechanical structure shown in figure 2.5.

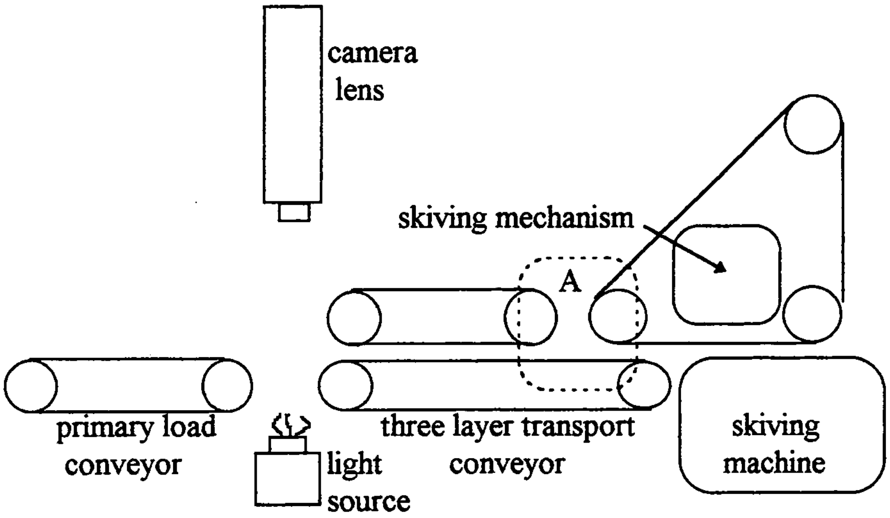


Figure 2.5 Overall mechanical structure of automated skiving machine

It can be seen that the upper substrate belt of the three layer transport conveyor consists of two separate belts. Initially this was to be implemented with one continuous upper belt. However, limitations were placed on this design due to the availability of standard size timing belts.

This produces an advantageous gap between the two belts, that will be utilised to gain access to the components, as shown at point A. The 7 mm gap formed, presents its own restrictions when considering a suitable sensing system for integration onto the automated skiving process. When the components are placed onto the primary conveyor system, there is open access to them as they travel towards the recognition system. This access therefore allows sensors to be utilised above the conveyor to provide additional information.

2.8 Conclusion

In this chapter an overview has been given of the apparatus that has been developed to produce a prototype system, for the automated skiving of leather components. It has also explained how the various elements and factors within the process have been integrated together to produce an automated skiving process. The complete system will provide B.U.S.M. with a structure from which future modification and developments will enable them to manufacture automatic skiving systems.

In providing a solution to a problem and using standard belts for the conveyor systems, a gap has fortuitously been generated. This gap provides a point closer to the actual skiving machine cutting edge than that used at present for the camera. The gap allows momentary access to the components as they are transported through the process.

Due to the construction of the three layer transport system the leather components are totally enshrouded within the system. This then prevents the detection of any movement of the components as they are transported to the skiving mechanism. Additional sensors and systems are therefore required to detect if any movement has occurred, and hence enable the actual skiving of the leather to be aborted.

The overall analysis of the system, has provided information on the processes involved in automatically skiving leather components. It has also indicated two areas where additional sensing systems may be placed. These are above the primary conveyor and the gap.

The next phase of the research was therefore directed towards the identification of suitable sensors and their integration into the present skiving process. These stages in the development process are examined in chapters 3, 4 and 5.

CHAPTER 3

Sensor Investigation

3.1 Introduction

In order to achieve a system that may replace the manual skiving process, it must contain as many human qualities as possible. The specific human qualities that are required for the process are i) the ability to handle the flexibility of the leather components and ii) be able to detect visually the presence of the leather components. The system developed must perform equally, or better, than the present manual operation.

For any manufacturing process to take place it is essential that the component position and orientation are known, in addition to detecting any deviations that may have occurred. If any deviations have developed during the process then the information obtained could initiate any remedial action necessary.

An extensive range of sensors and control products are at present available from a variety of sources. Therefore prior to discussing the various classes of sensors available in some detail, it will be beneficial to classify them under specific sensing abilities, as shown in figure 3.1. This then will provide the framework within which to discuss the sensors. In general the most common sensors used are force and imaging devices.

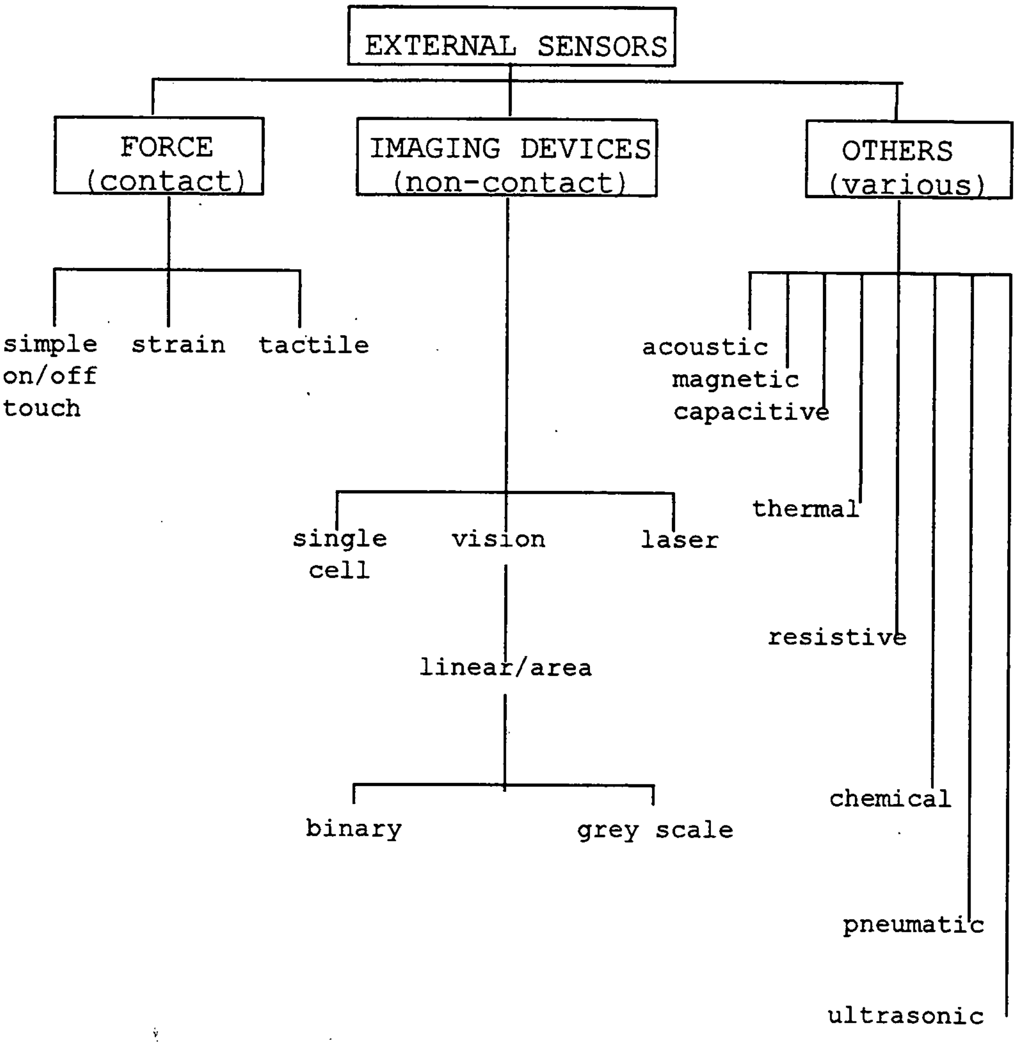


Figure 3.1 Sensor classification table

3.2 Force/Contact Sensor

Force, pressure, temperature and tactile sensors all respond to contact with the object and are included in this category. They may be used to identify the presence or absence of a component by the use of an on/off, i.e., binary device.

3.2.1 Simple Touch Sensing

The most common sensors used in simple touch sensing is the limit switch. These devices are manufactured as standard models, with customers being able to specify the circuitry, switching functions, switching power, housing and terminations. Additional versatility is also provided with a plug-in version.

Another form of touch sensing device is the basic switch, which once again is produced in a range of standard models with a choice of actuators, switching characteristics, switching power, switching functions and termination types.

3.2.2 Tactile Sensor

A tactile array sensor is a special type of force sensor composed of a matrix of force sensing elements. The force data provided by this type of device may be combined with pattern recognition techniques to describe a number of characteristics about the impression contacting the array surface.

For the application investigated in this thesis, a tactile sensor must therefore have the following qualities, i) shaped as a sensor array, in order to give information on shape and orientation of components, ii) able to survive for a reasonable amount of time in a factory floor environment.

Three types of tactile sensors were identified and their characteristics are described below. The first of these is an electro-mechanical sensor, which contains a miniature button that transmits a pressure signal to a compliant membrane. The second is a Piezo-Electric type. Unfortunately this type has a major drawback as it produces electric charges not only by pressure change, but also by temperature changes. The final exemplar is the Piezo-Resistive type that utilises a piece of Piezo-Resistive foil or discs of Piezo-Resistive elastomer as its sensing elements. However, these materials exhibit non linearity and hysteresis, but these drawbacks may be accepted in some applications.

Clearly there are opportunities in manufacturing industry for the use of tactile sensors, however, there are very few commercially available sensors of this type. A survey by Nicholls and Lee [4] indicated that tactile sensing is still in its early stages of development, and that there is a potential for low cost, robust, accurate and repeatable sensors of this type, that can be easily integrated into manufacturing systems. In future years, with further development, these types of sensors may be used for the verification of the sensed component and its location, which are parameters more appropriate to industrial problems [5].

3.2.3 Pressure Sensors

When the leather components are transported to the skiving mechanism, within the three layer transport system, downward force is applied by the tension of the upper belt. This force may be utilised, in conjunction with pressure sensors, to detect the presence of the components.

The simplest form of pressure sensing is usually carried out using some form of strain sensing device. Two of the most common types of strain gauges are i) the bonded wire and ii) the semiconductor strain gauge. These gauges may be used to derive compressive and tensile stresses.

A wide variety of devices exist which operate by contact pressure, air pressure, Piezo-Electric or optics. However, one device that may have possible uses within the shoe manufacturing industry, utilises a fibre optic cable laid inside rubber to form a sandwich. The fibre optic cables are surrounded by a spiral outer sleeve, this produces micro bending in the fibre when a force is placed on it. This force creates modulation of the light in the fibre and changes in the speckle pattern at the end of the fibre.

Another sensor, which utilises this principle of micro bending has also been produced. The major difference being that this particular sensor detects the presence of a component, by changes in air pressure within the rubber.

A difficulty with both these sensors may be that accurate positioning information could not be achieved, hence the output from such devices may only indicate a disturbance or possibly the magnitude of that disturbance. These devices have good life expectancy and at present the cost per unit is falling.

Another device that may be included under the heading of pressure sensors is the centroid sensor. This device outputs the centre of pressure of a two dimensional pressure distribution and the total force applied. Since the sensor is made from thin material, it is pliable and has sheet like form. The centre of pressure and the total force output are direct and do not require any computational effort. The sensor requires only four wires, has a low output impedance and has exceptional immunity to electrical noise.

The sensor has a three layered structure, with the outer two layers being manufactured from electrically conductive material coated film. The inner layer is made of pressure conductive rubber. The resistance of the rubber along the thickness varies according to the pressure distribution. The drop in resistance of the rubber due to a pressure disturbance causes a current distribution proportional to the resistance drop. Thus this current density induces a voltage distribution on the outer surface layers.

The error in centre of pressure is bound by 1% of the size of the sensor. Therefore for a sensor measuring 30 mm by 40 mm, then the directional error would be ± 0.3 mm in one direction and ± 0.4 mm in the other. The sensitivity of this type of sensor may be 100 gm/cm^2. However, with a better quality of pressure conductive rubber it may be improved to 20 gm/cm^2 [6].

3.3 Imaging/Non-contact Sensors

In this category of sensing systems it is light that is being sensed, and includes light from that part of the electromagnetic spectrum containing both infra-red and visible light. The light or reflected light may be utilised to detect the presence of the leather components.

3.3.1 Infra-red Sensors

A number of companies produce light-emitting diode (L.E.D.) sensors. They all operate on the same principle of a sending device and a receiving device. If the light beam between the two devices is broken, then a component is present. One particular company manufactures a miniature reflective opto-switch, which comprises of a Gallium Arsenide infra-red emitting diode for the transmitting device. The receiving device is a spectrally matched photo-transistor mounted side by side on a parallel axis. The complete package is housed in a plastic moulding, which reduces ambient light noise. The photo-sensor responds to radiation only when a component passes within its field of view and enables a variety of applications.

3.3.2 Vision Sensors

To examine a component or a specific scene with more sophistication than a simple infra-red sensor, then a much more complex system is required. These are commonly termed vision systems or imaging systems. These systems comprise of a camera, electronic hardware, interfacing equipment, a computer and software. There are a variety of commercial imaging devices available. At present camera technologies include black-and-white vidicon cameras, and the newer, second generation, solid state cameras. Solid state cameras used for component identification include charge-coupled devices (CCD), charge injection devices (CID), and silicon bipolar sensor cameras.

The output of the camera is a continuous voltage signal for each line scanned. The voltage signal for each scan line is subsequently sampled and quantised. This results in a series of sampled voltages being stored in digital memory. This analogue to digital conversion process for the complete screen results in a two dimensional array of picture elements.

It can be seen that the process of capturing the image of the component, to actually storing it in memory is very complex. Once the image has been captured, processing time is required to identify the component and its orientation, before recalling the necessary skiving pattern. Therefore a time delay exists from the component passing the camera to the data storage being utilised. This time delay will be reduced as microprocessor speeds increase.

A digitised image may also be obtained by the use of charge-coupled device (CCD). In this technology, the image is projected by a lens system onto the CCD that detects, stores and reads out the accumulated charge generated by the light on each portion of the image. Light detection occurs through the absorption of light on a photo-conductive substrate, e.g. silicon. Charges accumulate under positive control electrodes in isolated wells, due to voltages applied to the central electrodes. Each isolated well represents one pixel and can be transferred to output storage registers by varying the voltages on the metal control electrodes [7].

3.3.3 Laser Sensing

Laser systems are used for both ranging and structured light vision systems. The laser produces a highly directional, monochromatic beam of coherent light.

The infra-red laser produces a dot of light on the object to be measured. The image of the dot is detected by a separate sensor. Because the sensor's field of view is fixed, the position of the dot between itself and the component may be compared to a reference point and hence be directly related to the component's position. If the component moves, then the dot changes its position and so does its image on the sensor. This movement can then be registered and the new position calculated by a microprocessor. These measurements can be made 30 times per second, using a standard computer and relevant software.

3.3.4 Alternative Non-contact Methods

Air pressure sensors may be utilised to sense the presence of an object when moving, by the creation of localised pressure variations. However, there are fundamental problems associated with their use, based on the wide variations in atmospheric pressures possible and the increase in local pressure due to gusts of air. Therefore the problem of relating an air movement to a component movement is extensive. This is predominately due to the difficulty of locating the position of the source of interference within the industrial environment.

3.4 Other Forms of Sensing

There is a wide range of other sensing techniques, that may be applicable to the detection of sheet components in manufacturing processes. Some of these are very simple in nature while others are potentially sophisticated and not yet commercially available. This is due to the fact that the sensor cost is strongly dependent upon the production volume and also the manufacturing techniques employed. Table 3.2 below illustrates the relationship between advanced sensor technologies cost and production volume, within the European market.

	Silicon	**Thin Film**	**Thick Film**	**Integrated Optics**	**Fibre Optics**
Product line Investment (£ million)	1-2	0.5	0.2	0.5-1	0.2
Sensor production/year	High 100,000	Medium 20,000	Medium 5,000	Medium 20,000	Low 500
Sensor Costs(£) (in volume production)	Very Low 0.1-1	Low 0.3-3	Low 1-10	Low 5-50	Medium 5-500
Miniaturisation	High	Medium	Low	Low	Very Low
Integration	Monolithic	Hybrid	Hybrid	Hybrid	Discrete components
Flexibility	Low	Medium	High	Low	High

Source : Harmer 1990[8]

Table 3.2 Comparison of sensor technologies

From the table it can be seen that for high precision specialised sensors, e.g., fibre optics gyroscopes, the volumes are low and the costs are high, due to the use of discrete components, manual production and time-consuming assembly. At the other end of the scale, silicon sensors have been produced for high volume markets, where the introduction of automatic production and monolithic integration results in very low cost.

3.4.1 Acoustic Sensing

Acoustic sensing may be subdivided into ultrasonic and voice recognition. Ultrasonics can be further subdivided into simple ultrasonic ranging and more complex ultrasonic imaging. Ultrasonic ranging is a technique that has been used for many years and there are a variety of commercially available ultrasonic sensors, together with their associated electronic hardware. Both forms of ultrasonic techniques may be used to detect the presence of a component. Some forms of ultrasonic detectors may be used to penetrate an object to enable an internal inspection of the component.

Ultrasonic sensors may be used as simple proximity sensor. However, there have been recent developments in the field of ultrasonic phased array sensors, which can rapidly detect the position of components, with no mechanical mechanisms being utilised. This then makes it possible to measure the width and height of near components and to define their position. Unfortunately, when reconstructing a 2- or 3-dimensional image, crosstalk between array elements has been found to be a very important characteristic. This crosstalk produces great inaccuracies, which make this kind of process, at present, unacceptable for industrial use. There is at present a great deal of research [9] being carried out into these types of sensors. This indicates that in future years they will become more accurate and hence more attractive for the use in position sensing.

Another major area that utilises ultrasonic sensors, is that of non-destructive testing. The general goal of non-destructive testing we are interested in is characterising a component as thoroughly as possible without damaging it. One of these objectives is to find internal structures and analyse what they mean. Therefore this would enable the position of the components to be determined whenever direct observation is not possible, i.e. are encapsulated between substrates. If the sample is transparent, the internal structure may be tested for regions of damage etc., without sophisticated instruments, due to the interaction of visible light with locally changed optical properties.

If the sample is opaque, as in the case of skived shoe components, it may be possible to use the technique of non-destructive testing, but using a different wavelength, where penetration depth is large enough. One such method could be to utilise X-ray inspection, where it is possible to look into materials and reveal their structures. Unfortunately some structures are difficult to observe.

Electromagnetic waves are not the only waves that can be used for non-destructive imaging of hidden structures. Acoustic images obtained with elastic waves [10] show structures where local variations of certain properties are involved.

Imaging may also be achieved using thermal waves [11] where the thermal wave describes how a temperature modulation propagates in a medium. It is characterised by a highly damped scalar wave with a phase velocity that is by orders of magnitude smaller than for ultrasonic waves. The frequency dependence of phase velocity causes pulse distortion. Therefore modulated continuous wave sources are often preferred. Consequently thermal wave signals are generally characterised by their magnitude and phase shift, with respect to the temperature modulation that drives the wave. Therefore, if the temperature of the component is increased prior to the operation, then the detection of movement may be achieved using these devices.

It should be noted that the appearance of components depends to some extent on the method of thermal detection. Both the magnitude and phase angle determine the depth range. In metals a typical range is in the region of a millimetre at about 10 Hz modulation frequency.

One problem in trying to apply these technologies in an industrial environment is the amount of noise surrounding the manufacturing system, of a frequency likely to corrupt the signals. In the case of ultrasonics, one typical source of this type of noise is pneumatic equipment, which is in widespread use in industrial applications. It is however possible with techniques for coding and decoding the ultrasonic signal, to filter out the unwanted noise. This unfortunately increases cost and complexity to the system.

3.4.2 Proximity and Range Sensors

Proximity sensors are devices that indicate when one object is close to another object. How close the object must be to activate the sensor is dependent on the particular device chosen. The simplest form of proximity sensor is the magnetic/inductive pick up. The pick up is in the form of a case containing a coil that is wound round a permanent magnet. This produces an alternating magnetic field in the tip of the probe. This field induces eddy currents in any conductive body that enters the target zone. Due to the nature in which these devices identify components, it can be clearly seen that they are unsuitable for the recognition of shoe components.

3.4.3 Capacitive Sensing

Capacitive sensing may be used for detecting the proximity of non-metallic objects. Usually an oscillator-type circuit is used. Oscillation of the circuit is maintained due to the feedback compensating for losses in the coil capacitor circuit. Adjustment of the circuit is such that if a further load is experienced by the circuit the oscillation stops, hence detecting the presence of an object.

These types of sensing devices are relatively inexpensive to obtain. However any changes in humidity, temperature or vibration will reduce the operating characteristics of the devices. In addition a linear characteristic cannot be maintained for large displacements produced by the target component.

3.4.4 Radar Sensing

Radar technology is widely understood and used for long distance and especially metallic object, detection and positioning. It is also used in small area presence detection systems, which operate by the variation in standing wave patterns set up in a particular area.. The use of this method to define the position of components in a limited enclosed area is not of practical use, due to the interference from reflections within the work area. These cause the output to appear to be multi-sourced and incoherent.

3.4.5 Microwave Sensing

Microwave technology has been used to produce presence sensors. These operate on a principle of transmitting microwave signals to a given area and then receiving the reflections. By altering the sensitivity of the devices, it is possible to operate these devices across wide distance from the target and also detect through thin materials. They are not able to distinguish the position of any movement within their own target area and hence cannot be used in the detection of shoe components.

3.5 Conclusion

Sensor technology has advanced rapidly since wire strain gauges were the only forms of sensors to be used. This chapter has presented an overview and general description of a small portion of the sensors available. It also highlighted some of the sensor technologies which are currently being used or developed to provide sensing functions required in advanced electronically controlled systems.

Each of the various sensors described have their merits and disadvantages. Consequently, special attention has to be taken when choosing a sensor for a specific application, such as the positioning of components within the skiving project.

The sensor needs to have the ability of detecting the leather component, while taking into account the environment within which it is operating. These factors and the subsequent evaluation of the sensors will be analysed in chapter 4.

Chapter 4

Sensor Evaluation

4.1 Introduction

Following the completion of the evaluation into the range of sensors and their respective control products, for use in the identification process, it was necessary to carry out various tests. These tests were used to confirm the suitability of each device chosen, with respect to their integration into the skiving project.

The constraints that are placed on the sensing system include both the physical layout of the skiving process and the material being detected.

The first major area to develop was the production of a programme of tests that will be used for each of the sensors chosen. It is essential that these ensure that the sensor cannot only detect the shoe components but produce results that are both accurate and reliable.

This chapter will therefore describe the aspects of the implementation of the sensor evaluation.

4.2 Sensor Choice

The sensing devices are required to detect the movement of the components as they travel along the manufacturing system. They must first of all be capable of detecting the material, shoe components are made from, and be sufficiently close to the cutting edge so as to abort the skiving process whenever necessary. It is for this latter reason that the sensor will be placed in the gap generated by the design of the upper belt, as described in chapter 2.

This then becomes one of the major considerations when selecting a sensing device.

4.2.1 Contact Sensors

These devices enable information to be supplied digitally, however, their major disadvantage is that they all require force in order to activate them. This presents a problem with regards to the detection of shoe components, as the application of force on the leather often causes the leather component to buckle, and hence rotate about the point of contact force. A tactile sensor array may be used when the component can be compressed against the membrane, as with the transport to the skiving knife by the three layer transport system. However these devices prove to be unreliable when temperature variations are encountered, especially in manufacturing systems.

4.2.2 Non-Contact Sensor

The majority of these detect the presence of components by the reflection of light. These devices once again can supply the information in digital format. The devices may utilise either a single cell or an array of cells to form a matrix. When in an array form, the manipulation of the data produces an additional time delay that may affect the performance of the present skiving process. This factor then is particularly critical when considering this type of system for identification in this application.

Ideally, single cells placed in a row would be beneficial in the process of identifying components of the type used in the skiving project.

4.2.3 Unsuitable Sensors

The sensors that fall in this category are not suitable for this particular application. In most cases they often require some form of change in the physical attributes of the component being identified. These include such characteristics as resistance, magnetic or chemical changes. Other forms of detection include ultrasonic and thermal images. These methods may be employed, however, due to interference from the surrounding working environment, the information may be so distorted as to be meaningless.

4.3 Constraints of Skiving Process

There are two major factors that need to be considered when choosing the type of sensors that may be employed to detect any movement of the components, before entering any form of manufacturing process. These are i) the characteristics of the component to be detected, and ii) the process/environment within which the sensors are to operate.

4.3.1 Component Characteristics

The shoe upper is constructed from a number of pre-cut leather components. These leather components are manufactured using a variety of both colours and textures. The variety of colours to be tested vary from light green through to black. In addition, each of the components are shaped to relate not only to their position on the completed article, but also to take into account any stress that may be placed on them during its use. It is for these reasons that specific parts of the hide are used, which relate to these properties. It should also be noted that different thicknesses are required for different areas of the shoe upper. These range from 0.75mm to 2.17mm, with the average thickness of forty sample types of hide supplied by B.U.S.M. being 1.42mm.

Each of the shapes that are manufactured will also vary in size dependent upon the size of the shoe being manufactured.

In addition to these variations of colour and size, it should be stressed that one of the major characteristics of all these components used, is that they are manufactured from material that has a pliable nature. This property infers that not all of the pre-cut components will lie in a flat horizontal plane when placed on either a bench or transport system. This buckling effect of the components is experienced to a greater extent on the larger components, which are manufactured from the thinnest material at B.U.S.M.

4.3.2 Process/Environment

The process which is to be utilised for the development of a position sensing system within a restricted environment, is that of an automated skiving process. As mentioned in chapter 2, the research into the automation of the skiving process was undertaken by the University of Durham, on behalf of B.U.S.M.

The present operating environment of the skiving process is within the University and is therefore ideal. This implies that there is minimum dust and no need for any form of electrical screening.

The length of the conveyor system from the present recognition area to the skiving knife is dependent upon two factors. Firstly the variation in size of the leather components. Secondly the time taken for the computer, in conjunction with the recognition system, to analyse both the component type and its orientation, on the present skiving process.

Initially the three layer transport system was to be manufactured with a continuous upper belt. Unfortunately this proved to be impractical, in terms of manufacturing difficulties. The difficulty was overcome by splitting the upper belt into two distinct parts. For timing purposes these had to be driven using the same stepper motor.

The splitting of the upper belt produced a 7 mm gap, which was situated 260 mm from the skiving knife edge. This then allows brief access to the component as it is transported to the skiving mechanism head.

4.3.3 Fulfilment of Sensor Choice

Due to the constraints of the component material, in conjunction with the available space on the present system, a series of alternative considerations has been examined. The most promising of the options considered is that of reflecting light from the components to indicate their presence.

Two such devices will be analysed further, to provide statistical information on their suitability for integration within the system. Their specifications are given in the comparison table, in appendix 1.

The first device is a standard reflective opto switch, that has both the emitting diode and detector housed in a single moulded package.

The second device is an optic fibre diffuse scan, infra-red detector, which has a flexible stainless steel tubing, 2mm diameter, housing the fibre.

4.4 Determining the sample size

If a large sample of data is to be collected, in order to determine the type of distribution from which this data were chosen. A reasonable hypothesis would be to assume that a specified kind of distribution is the one from which the sample was chosen.

For the purpose of classifying the majority of statistical problems two types of hypotheses may be used, estimating and testing. In estimating we are concerned with obtaining the best possible estimate of the parameter values. Estimating encompasses the class of statistical problems in which it is inferred something about the values of a particular parameter, so that it is possible to have as precise an idea of its value.

In order to make predictions about the behaviour of the sensors, it was necessary to determine a specific type of distribution and confidence limit. The data that was collected is assumed to be of normal distribution, and that the confidence belt will be 95 % i.e. that from the series of observations taken 95 % will include the true value.

These confidence intervals or limits may be calculated and thus appear as confidence belts. In order to determine what size sample is necessary so that any estimate is within a specified tolerance from the true value of the parameter, certain assumptions must be made. It is rarely possible to guarantee these tolerances, but by introducing a suitable confidence coefficient this maybe achieved. The confidence coefficient used to predict that 95 % of the results that are obtained are correct is 1.96. This value is obtained using standard statistical text books.

To determine the sampling error that may be obtained using different sample sizes, the following formula may be used:

Number of sample errors = sample size ± sampling error

$$\text{Number of sample errors (e)} = \text{sample size (n)} \pm 1.96 * \frac{\text{standard deviation } (\sigma)}{\sqrt{\text{sample size (n)}}}$$

Assuming that the standard deviation of the sensor readings is 20 and using a sample size of 100 then:

$$e = 100 \pm 1.96 * \frac{20}{\sqrt{100}}$$

$$\therefore e = 100 \pm 4 \text{ approximately}$$

This indicates that for a sample size of 100 sensor observations, the degree of error is approximately 4, while still providing a 95 % confidence that the results obtained are correct. The smaller the value the of sampling error, then the validity of the results are enhanced.

By increasing the sample size the sampling error will be reduced i.e. 300 observations produces an error of approximately 3 readings. If the number of sampling errors is required to be reduced further, then the appropriate sample size may be obtained using the following formula:

$$\text{sample size (n)} = \left(\frac{\sigma * 1.96}{\text{sample error}} \right)^2$$

Therefore to provide a sampling error of ± 2, the sample size must be increased to 384 observations.

4.5 Simulation of Process

The research has been carried out on a part-time basis, but was to be integrated into the full-time project concerned with automating the skiving process. This combination of the two projects would have been restrictive to one another, concerning time allocation of the overall project. The alternative to this was to carry out the initial statistical analysis of the selected devices on a simulation of the process. This would enable information on the accuracy and repeatability of each sensor to be obtained before implementing them into any development for a sensing system in a restricted environment.

The simulation was predominately required for the transportation of the shoe components, from one operation to another. In order to achieve the simulation and enable the total integration into the skiving process various key properties needed to be investigated.

4.5.1 Transport System

The system to be used must emulate the conveyor system that is installed on the skiving process. These are essentially made from various substrates.

In order that the simulation may be repeated and sufficient data may be correlated, it was felt that some form of rotary device could be utilised. The rotary device should also be coated with the substrate used in the skiving process to improve the validity of any results gained.

The rotary device chosen consisted of a flat plate that is driven by a stepper motor. This motor can be connected to provide continuous running, or may be stepped using clock pulses, supplied to an additional input.

Figure 4.1 Rotary table transport system with substrate added

4.5.2 Control of Simulation

The overall control of the system was achieved using a standard computer, this was modified to enable it to produce clock pulses. These clock pulses were initially used to drive the rotary table. Following completion of the simulation of the process, the computer would then be responsible in the process of identifying any movement of the leather component. In addition it may also be used in the communication that will be necessary within the integration of the overall skiving system.

4.6 Mechanical Layout

Both sensing devices that have been chosen enable mechanical fixing to take place by the use of a simple through bolt. Therefore in order that tests may be carried out, a plain bracket was sufficient for mounting purposes. To facilitate the movement in both the vertical and horizontal planes, each of the brackets were secured to a laboratory stand, this also allowed access over the rotary table.

4.7 Electrical/Electronic Interface

This section of the system was initially required to perform the task of utilising a computer to control the rotary table and also interpret any results. It involved the implementation of the interfacing hardware and the writing of software for controlling the simulated workcell. These factors were all carried out using suitable techniques that would allow any future enhancement to be easily accommodated.

The controlling of the simulated process, and analytical analysis of the results were carried out using a standard 386-33 MHz personal computer. In addition, the computer was enhanced with added software and a system timing controller interface board.

The software which was utilised is Microsoft C/C++. This is a general purpose programming language and was chosen, due to the fact that present systems within B.U.S.M. also run on this software. Hence integration of the identification process into any present or future system would be standardised. Programs that are produced using Microsoft C/C++ also have the advantage of being easily translated into machine-coded form, that will increase their running speeds. The software program is shown in appendix 2, and controls the configuration of the system timing controller and the analysis of data obtained.

The systems timing controller has several distinctive sub-systems. These include a frequency source, tapped 16-bit counter with programmable frequency output, programmable gating functions, and programmable count/gate source functions. A high speed counting rate of 300 nS from counting internal source pulses to producing output valid data can be achieved. These characteristics enable the controller to be configured for personalised applications as well as being dynamically reconfigured under program control.

The main timing and signal pathways of the controller are illustrated in the schematic diagram, figure 4.2.

4.7.1 Interface Considerations

All the input and output signals for the system timing controller are specified with logic levels compatible with those of standard T.T.L. circuits. In addition to providing T.T.L. compatible voltage levels.

Alternative output conditions may be specified to help configure non-standard interface circuitry, whilst also taking into account the effects of variables such as temperature and processing parameters. The controller can overcome their subsequent effect on logic level thresholds.

A simple interface was also developed, which inverted signals from the sensors and amplified the trigger signal to the rotary table. In addition it provided optical isolation of the signals to and from the system timing controller.

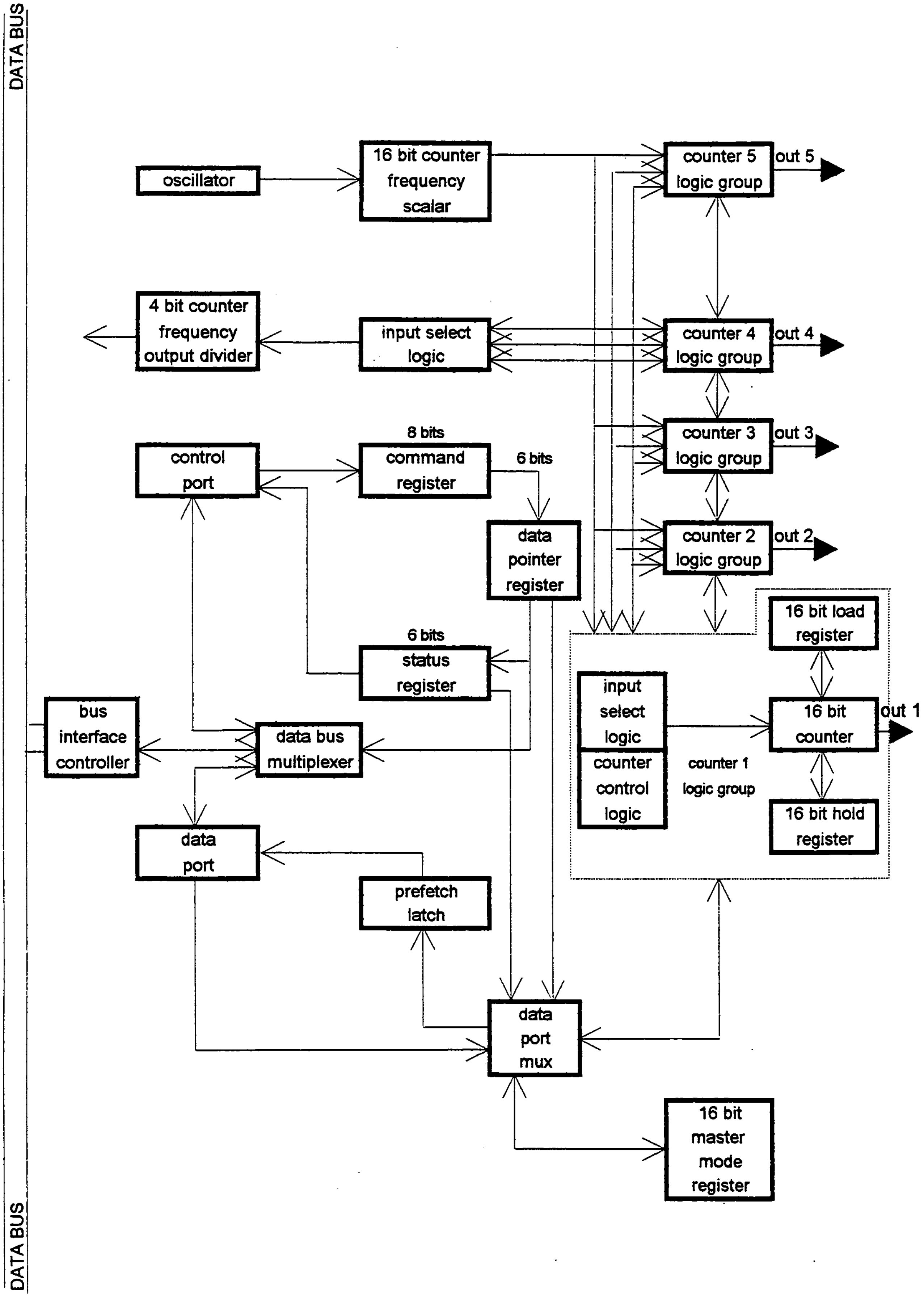


Figure 4.2 System timing controller architecture

4.8 Evaluation of Sensing Systems

As previously mentioned it was considered essential to obtain the characteristics for the various sensors chosen, when being utilised in the identification of leather components. The main functions of this was to provide standard methods of obtaining information on various sensors, and secondly to produce data that may be used in future research for comparison purposes. In addition, analysis may be carried out prior to the introduction of any sensor into a particular process.

The overall arrangement has the sensors mounted above the rotary table, with movement available in three planes, the sensors were placed at the optimum distance of 5 mm above the leather component, as it travels around on the rotary table.

4.8.1 Response Characteristic of the Sensors

An example of the results that were obtained, by simply placing a squared edged component on the rotating table is shown in figure 4.3. The graphs represent the expected change in the output, from the reflective opto switch, and the actual response obtained.

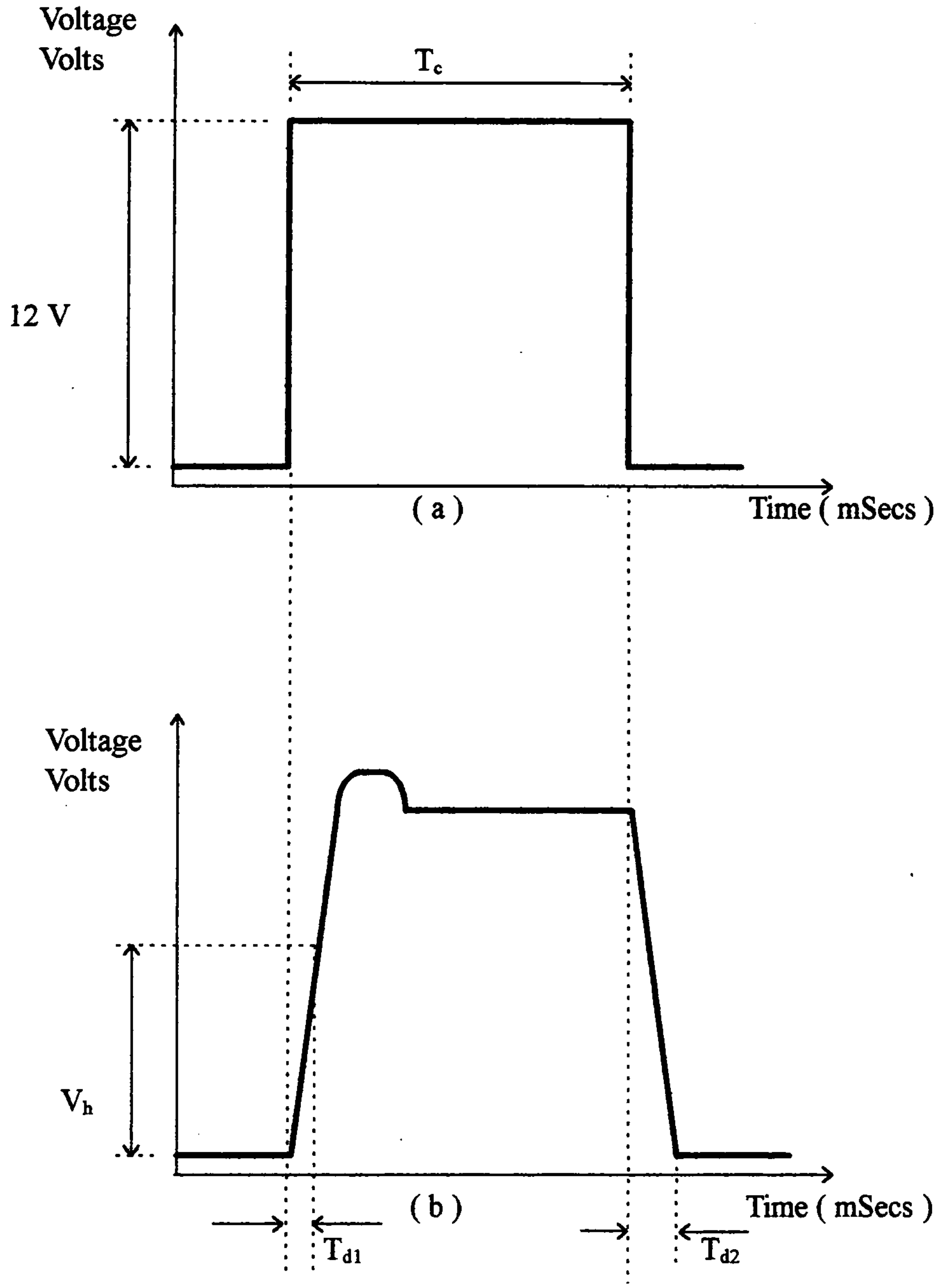


Figure 4.3 Voltage ~ Time characteristics for reflective opto detector.

(a) theoretical characteristic

(b) actual characteristic

T_c : Duration of component present.

V_h : Threshold voltage for interface board.

T_{d1} : Time difference between instantaneous input and actual input reaching threshold voltage.

T_{d2} : Time difference to return to initial state.

In order that valid conclusions for each of the devices chosen may be obtained, the responses to various rotary speeds were first obtained. These will indicate any changes in the characteristics at particular speeds on the skiving machine.

mm/sec	Rev/min	T_c	T_{d1}	T_{d2}
50.8	20	495.04	42.12	15.4
101.6	40	246.24	20.58	10.6
152.01	60	163.15	15.43	7.2
203.24	80	121.22	10.15	7.2

All time values are in mSec
Component size of 25 mm

Table 4.4 Variation in characteristics with speed for reflective opto switch

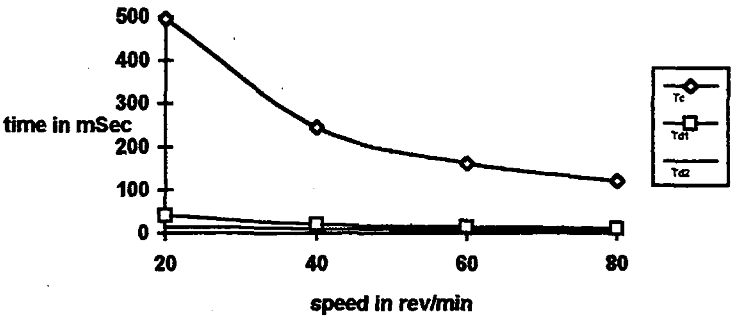


Figure 4.5 Graphical representation of opto switch characteristics

mm/sec	Rev/min	T_c	T_{d1}	T_{d2}
50.8	20	495.02	39.92	14.9
101.6	40	246.23	19.13	10.1
152.01	60	163.10	14.56	6.9
203.24	80	121.21	8.53	6.9

All time values are in mSec

Component length of 25 mm

Table 4.6 Variation in characteristics with speed for optic fibre diffuse scan

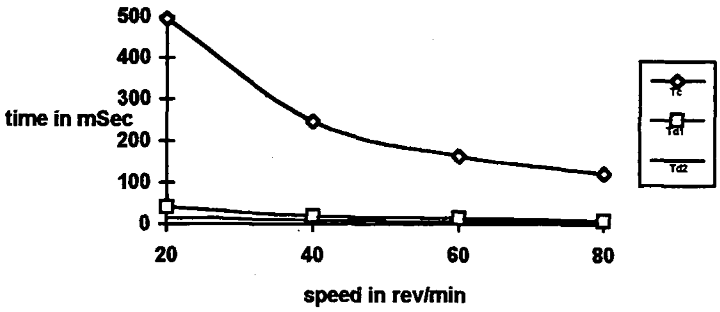


Figure 4.7 Graphical representation of optic fibre characteristics

The results shown are the mean values which were derived from a series of 60 observations, and have a deviation of ± 1.2 % of each value.

The non-linearity of the duration the component is present (T_c) may be attributed to the method for obtaining the speed of the rotary table. This was gained using a hand held tachogenerator and a friction wheel. Both the position of the friction wheel on the rotary table and the applied pressure may affect the value of the rotational speed on the analogue indicator by ± 15 %.

It can be seen from both the tables and the graphs, that the slopes of the characteristic from each of the sensors are dependent upon the time taken for the component to reach a specific point. This is the centre line of each of the devices. If the speed is increased then the delay time is reduced. This then implies that the speed at which the component passes the sensors influences the overall reaction time of the system.

In addition to varying the speed of the components passing the sensor, the thickness of the components were also varied. The results obtained for these responses, with fixed speed and sensor height, are shown in table 4.8.

Thickness in mm	T_c	T_{d1}	T_{d2}
1.07	121.58	10.93	6.85
1.46	121.22	10.15	7.21
2.01	121.14	9.85	8.13

All time values are in mSec, Component length of 25 mm,
Constant speed of 203.24 mm/sec, average thickness 1.46 mm.

Table 4.8 Variation in characteristics with thickness of component

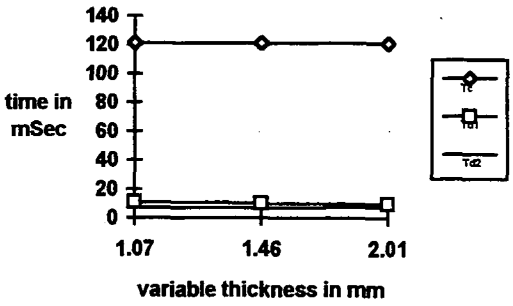


Figure 4.9 Graphical representation of varying thickness of component

From the observations, shown in figure 4.9, it can be seen that once again the characteristics of the reflective opto switch are varied, in this case when the thickness of the component is varied. As the thickness is increased it reduces the distance travelled by the reflected light and hence the time to reach the threshold voltage required for the interface board. This would also be the case, if the distance between the sensor and the target varied.

The optic fibre diffuse scan produces a similar spread of results to those shown in table 4.8. However, comparing the delay times for reaching the threshold voltage, the reflective opto switch takes 20.15 mS, as oppose to 16.53 mS for the optic fibre diffuse scan, when using the same sample and at the same speed.

4.8.2 Detection Circuit Modifications

As shown, variations in both speed and thickness of the shoe components affect the response time of each of the chosen devices. This may then lead to erroneous information being supplied to the skiving system control computer.

To reduce the problem of the delay time in reaching the threshold voltage, modifications to the detection circuitry were made. The modifications include changing the comparator in the circuit and the passive components producing its feedback.

Following these changes the delay time for each of the devices chosen, using the previous conditions, were reduced to 1.37 mS, a considerable improvement. In terms of distance, this constitutes an improvement from 2 mm of lateral movement, before the sensors detects the component, to a value of 0.27 mm.

4.9 Investigation of Sensor Parameters

In order to be able to form a valid final conclusion on the choice of which sensor should be used on the skiving process, it was essential to analyse additional characteristics that the device must posses. These characteristics will be divided into three distinct areas:

- Accuracy
- Repeatability
- Environment

4.9.1 Determination of Accuracy

To evaluate the accuracy of each device, a standard test was developed. This involved the placement of a component on the rotary table, and the utilisation of the system timing controller, integrated with a suitable software program. The software program is designed to operate on an interrupt basis. It should be noted that no hierarchical interrupt structure is to be used, thus all interrupts are constrained to a single level. Hence, no priority software complications exist, which would require extra computing time. To prevent more than one interrupt presenting itself out of step with the process, suitable software and hardware constraints have been employed.

In addition, the control software produces a fixed reference point from which measurement may be taken. When the component is revolving the reference point is redefined for each revolution.

To ensure that the time difference between the initialisation of the reference position, set by the software, and the time taken for the sensor to detect the

leading edge of the component, is within the limits of the counters being used, the rotary table is allowed to rotate before any measurements are taken. In addition this process enables the rotary table to be at a constant speed, which will prevent any inaccuracies occurring with the first measurements that are taken.
On reaching this reference point a counter is triggered within the system timing controller and timing begins. Each clock pulse represents a time of 1 mS. As the leading edge of the component passes the centre line of the sensor an interrupt is feed back to the controller. The interrupt disarms the counter and saves the information in the timing controller hold register. The program takes this information then applies mathematical manipulation to convert it to actual time. The time is stored to a file for future analysis. On completion of this process the counter is reset ready for the next reference point to trigger the counter.

Initially the sample size for this test was 100 observations, each consisting of one revolution and indicating the number of clock pulses from the reference point to the component edge.

An example of the results are shown in figure 4.10. Further samples of these results are shown in appendix 3.

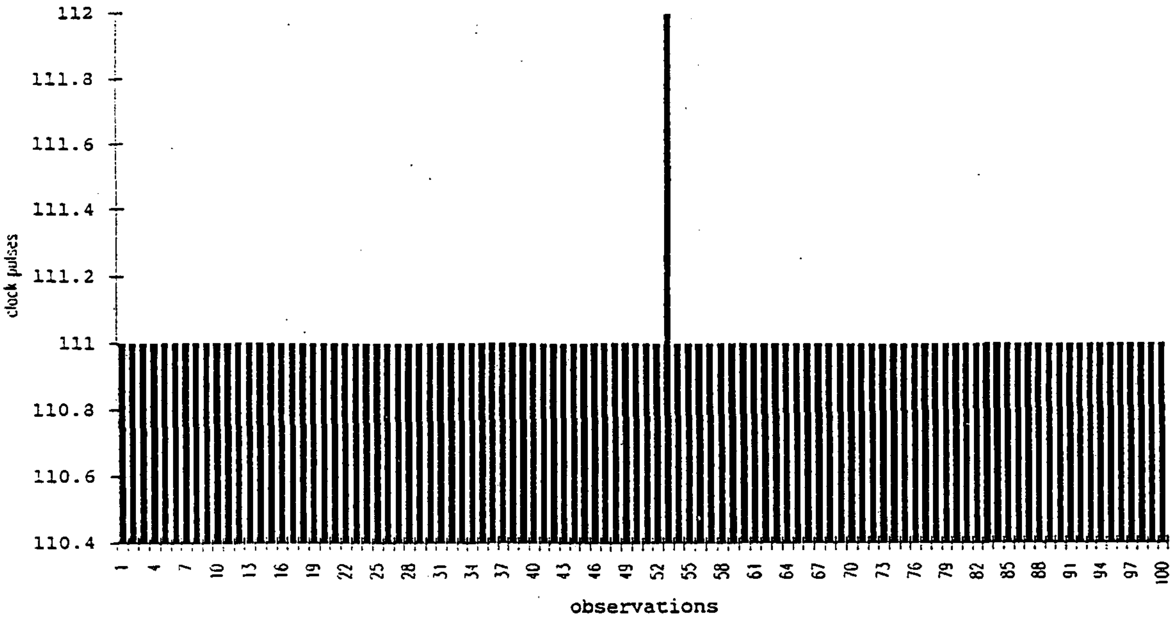


Figure 4.10 Sample of clock pulses from reference point to component.

In using this test it can be seen that a variation in the number of clock pulses from the datum to the component occurs. The position of this variation is independent of the number of observations taken.

To investigate these fluctuations further, the clock pulse rate was increased from 1 kHz to 10 kHz. Once again the results provided a random result within the sequence of observations.

The results obtained identified that within a sample of 100, that one measurement would be inaccurate. The test was repeated with a sample size of 200 and then 300, a similar pattern of inaccuracies were once again obtained. However, with the sample size of 300 the number of inaccuracies increased to an average of 4 within each sample.

The variation of the results may be attributed to the internal manufacture of the system timing controller circuit that incorporates a lumped series RC circuit. This may be producing a small impressed driving signal onto the gate of the counting circuit that will then be detected by the counters control logic.

The inaccuracies produce an error of approximately 1% of observations taken.

4.9.2 Determination of Repeatability

Another major characteristic required by any sensing system used in the identification of shoe components, is the ability to produce repeatable results. Again the rotary table with suitable software is to be utilised.

In this test two identical pieces of leather are placed on the rotary table a fixed distance apart, as shown in figure 4.11.

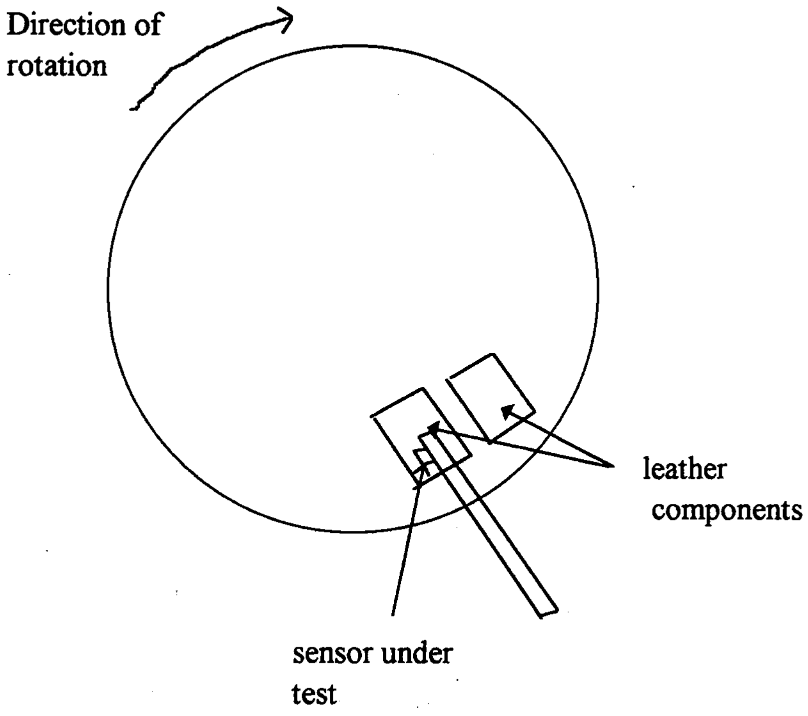


Figure 4.11 Plan view of arrangement for repeatability test

On each rotation the leading edge of the first component arms the counter within the system timing controller. As the trailing edge passes the sensors the counter's gate is activated, which commences the count. The count is disarmed when the leading edge of the second component passes the sensor. The resulting time count for the distance between the two components is then placed in a file for future analysis.

Initially the results obtained were verified using an oscilloscope, to monitor the time difference between the finish of one component and the start of the next component. The test was carried out over 300 revolutions of the table.

In addition this test not only enables the investigation into the repeatability of the sensor under test, but also its accuracy by determining the time between the trailing edge and leading edge. Each of the sensors chosen was subjected to this test. A sample of the results obtained by this test are shown in appendix 4 and verify that both sensors perform equally well.

Both sensors were tested using different coloured samples and also different thicknesses of material, while maintaining a distance from the target of 5 mm. Both sensors were able to cope with all the variations and produced the same time values.

4.9.3 Environmental Factors

During the examination of the accuracy and repeatability of each sensor, it was observed that they were influenced by the environment within which the sensors are operating.

The first key environmental condition that affected the results was that of direct sunlight onto the working area. This produced large amounts of infra-red rays that were detected by both of the chosen sensors.

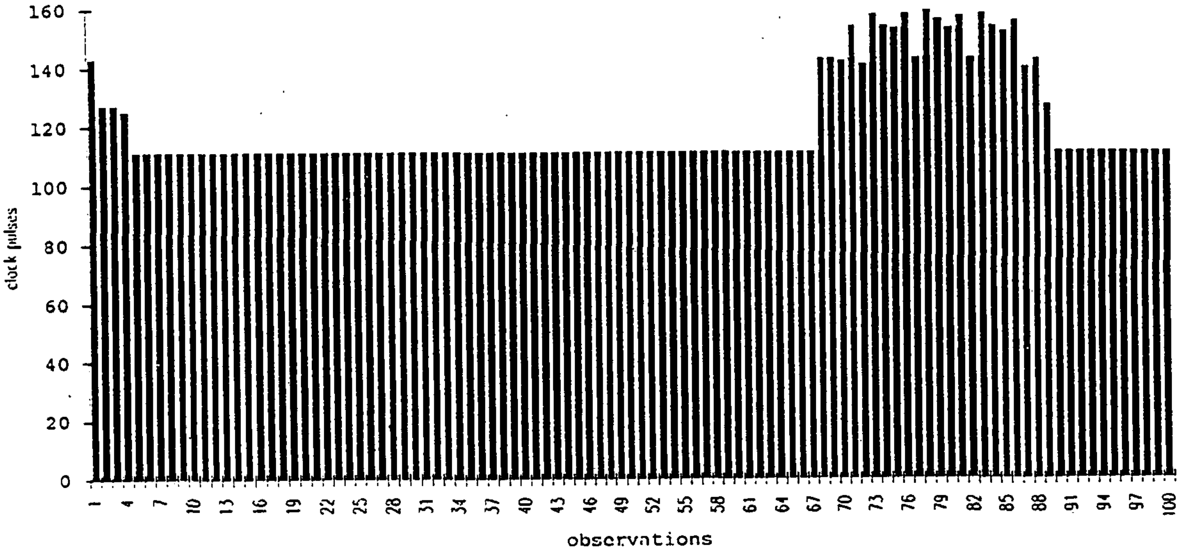


Figure 4.12 Graphical representation of the effects of direct sunlight.

It can be seen from figure 4.12 that as the direct sunlight strikes the leather component, variation in the amount of reflected infra-red signal is obtained. This effect can be reduced by placing a shield around the sensor, effectively blocking the unwanted infra-red radiation. The amount of reflected sunlight also depended upon the type of leather material being used. Black shinning leather components exhibiting the greatest affect from direct sunlight. Software interrupts were included to enable the rotary table to achieve constant velocity prior to all measurements.

The problem that arose from the interference of direct sun light was eased using a suitable screen around the sensor.

Another condition that changed their ability to detect components as they passed the sensors was that of vibration. This was encountered by the close proximity of the sensor clamping arrangement to the rotary table. This effect is shown in figure 4.13.

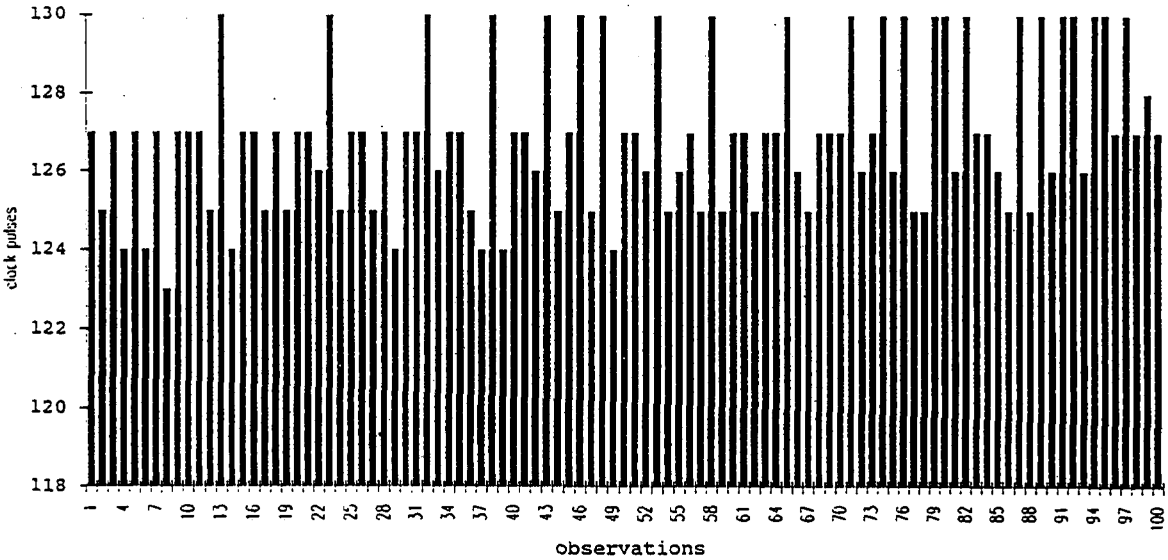


Figure 4.13 Graphical representation of the effects of vibration on sensors.

To overcome the problem of the vibration, the rotary table was placed on an absorbent rubber material, and additional weight was added to the clamping arrangement. This then alleviated the problem.

Other environmental conditions that would influence the parameters of the sensors include air conditions i.e. excessive dust. In addition, any abnormal temperature changes e.g. above 60°C and 80°C, for the fibre optic and reflective switch respectively would affect their capability to detect the leather components. The radiated ambient light from fluorescent lighting systems may also have a detrimental effect on the performance of the sensors. This affect was also reduced by the introduction of the screen around the sensors.

The sensors are to be placed in close proximity of one another, when they are mounted on the skiving project within the University. It was therefore also necessary to investigate if any interference takes place with adjacent sensors, when the sensors are placed side by side, as shown in figure 4.14.

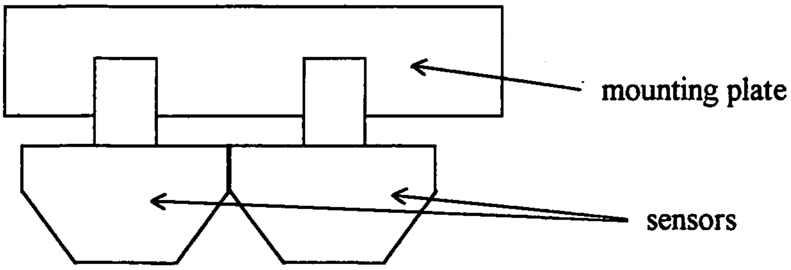


Figure 4.14 Mounting arrangement for interference test

A similar arrangement was used to that of the repeatability test, with components passing under the two sensors and their parameters checked against one another. This test established that no interference was experienced in either of the sensors tested.

4.10 Conclusion

Following an initial investigation into available sensors, in conjunction with the constraints within the skiving project, two alternatives have been proposed. In order to evaluate these devices a program for testing and estimating their parameter values were developed. To check the validity of the statements made in this chapter, tests were carried out, under varying environmental conditions, using both electronic devices and computer software.

Both sensors tested produced characteristics and parameters of similar qualities. However, the fibre optic photoelectric device was more prone to the effects of vibration, due to it long bendable stainless steel tube containing the optic fibre. It also costs ten times more in comparison to the reflective opto switch, as shown in the comparison table in appendix 1. The reflective opto switch, when tested without a shield, was more susceptible to the effects of direct sunlight.

In addition, the reflective opto switch, due to its greater surface packaging area will be affected to a greater extent by excessive dust. Within the project environment in the University, this particular problem has a minimal influence on the choice of sensor used.

From the tests carried out, the optimum distance between the target and either of the sensors was found to be 5 mm. Therefore when the sensors are integrated into the manufacturing process it will be essential to provide a 5 mm distance between the leather components and the sensor itself. This distance was maintained using standard engineering slip gauges.

Therefore, with both devices having similar characteristics and parameters, the reflective opto switch will be utilised further within the project. This decision was based on both the cost of the device and the environmental conditions in which it will operate.

Chapter 5

Integration into Skiving System

5.1 Introduction

In previous chapters there has been a description of the logical steps that have been taken in the selection of the sensors which may be integrated into any manufacturing process. The process that is of particular interest is that of skiving.

Having reached this point, it is essential that the development of an inexpensive identification system will integrate with the overall process. Therefore the integration should enhance the present system.

This chapter will deal with the combination of a cost effective sensor system into the existing skiving process. The sensor system will provide a coarse profile of the shape of the components as they pass under the developed sensing system. It will describe the main characteristics of the system and the process of acquiring information. The information may then be used in the implementation of the timing and execution of a particular shoe skiving pattern.

As discussed previously, wherever possible, all components will be of standard manufacture, to prevent rising costs. This implies that the hardware and software presented in this chapter do not represent the best, but the most cost effective at this present time. However they do provide a degree of flexibility that may accommodate different operations within manufacturing industry.

5.2.1 Integration with Skiving Process

The overall construction for the automated skiving process has been developed at the University, while taking into account the various constraints as previously mentioned. These include computation time and the use of standard components. The manufacture of the three layer transport system yielded a 7 mm gap between sections of the upper superstrate belt system. This gap is situated 260 mm from the cutting edge. A profile of the arrangement is shown in the following figure.

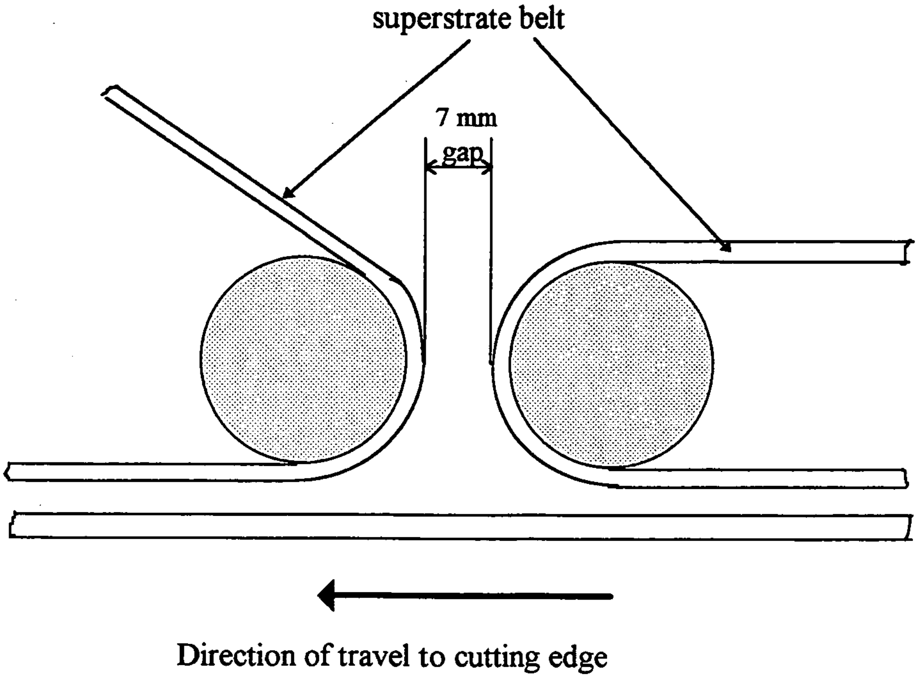


Figure 5.1 Close profile of secondary twin belt feed mechanism

As can be seen from figure 5.1, the gap enables observation of the leather component as it travels towards the cutting edge.

The selection of the reflective opto switch, in conjunction with this imposed gap, enables a single array of thirteen sensors to be placed above the component. This array enables full coverage of the conveyor belt width.

The resolution of the sensor array cannot be compared to the image produced by the line scan camera of the present component recognition system. Therefore it will be necessary to provide some form of reference. The reference image will be achieved using an additional single array of the sensors, which are placed above the conveyor feed belt system from the filling station.

The relative low cost of the sensors enhances the viability of this type of configuration.

When both sensor arrays have thirteen sensors, it enables coverage of the full width of both the feed belt systems. Hence complete coverage is achieved of all component shapes and sizes, that are used in the manufacture of shoe components.

5.2.2 Skiving System Architecture

The skiving system is designed around a set of sequential sub-systems from the moment a component is placed onto the filling station.

The first system consists of the data collection from the line scan camera and comparison of the silhouette against current shapes in the data bank.

The second system controls the stepper motors of the belt system, transporting each leather component to the work area.

The final system controls the data manipulation and execution of the skiving actuating mechanism.
A central interface board inter-connects all the sub-systems together, providing pathways for the various signals within the skiving process.

The overall hardware configuration of the skiving process is shown in figure 5.2.

The introduction of the two sensing arrays to the overall system will provide an additional control signal to the central interface board. This signal will give information on whether to continue with the actuation of the skiving process, or to abort the operation.

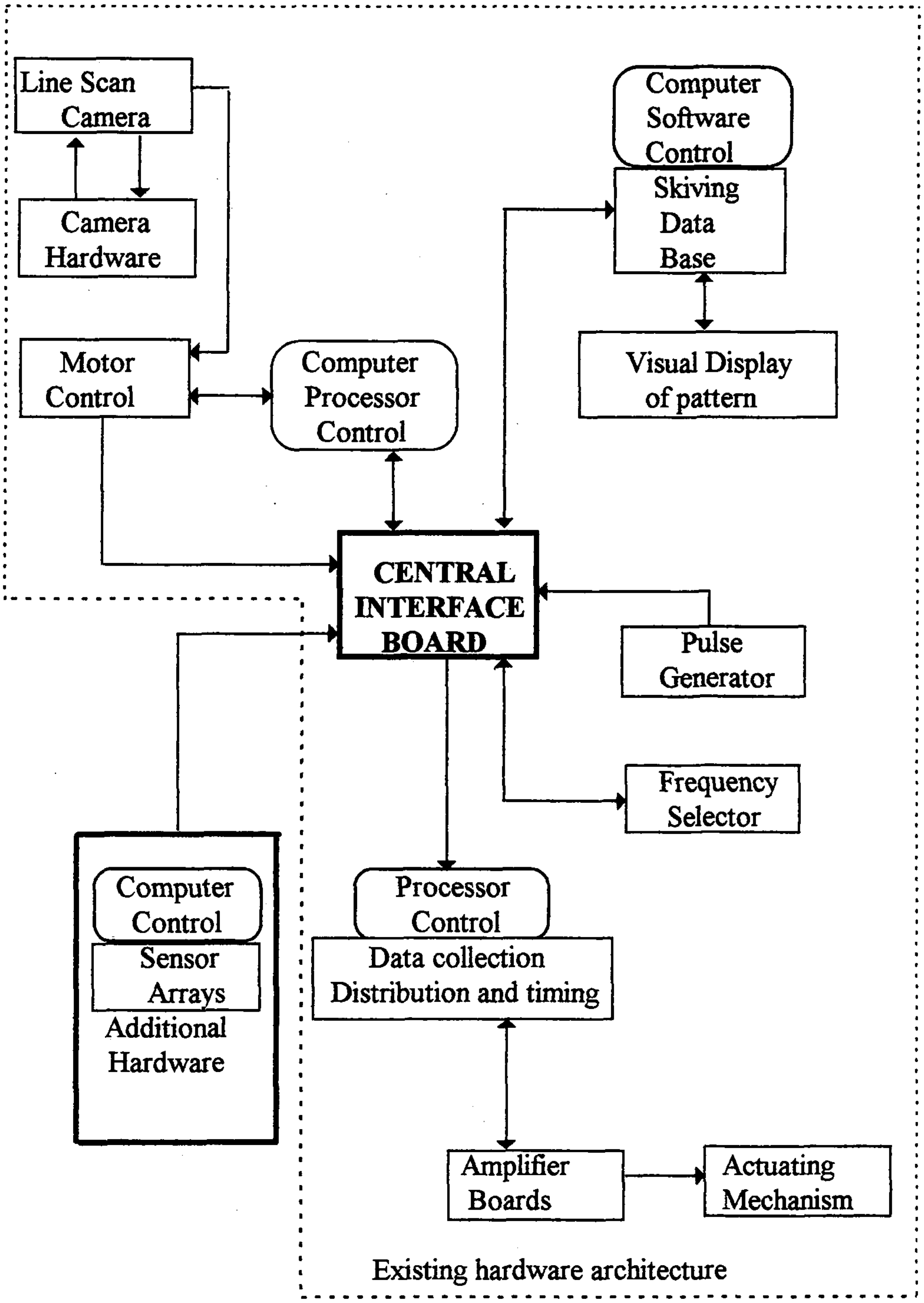


Figure 5.2 Schematic diagram of hardware architecture

5.3 Mechanical Assemblies

5.3.1 Array Assembly

Having identified the position of each of the sensing arrays on the skiving machine. An assembly had to be produced which would allow the sensor to have movement in all three planes. This allows greater flexibility when setting up the arrays into the skiving process. Each of the assemblies should have sufficient rigidity to overcome the effects of vibration. As discussed in chapter 4 the vibration may cause erroneous readings to be produced. The sensors are therefore mounted onto a 3 mm thick angle shaped bracket, which allows vertical movement of each individual sensor to be achieved.

5.3.2 Base Assemblies

To secure the mounting brackets onto the skiving process, two distinct bases were designed, one that would straddle the filling station feed belt conveyor. The second would have to be attached to the framework supporting the twin feed belt mechanism. Both of these bases should be of adequate construction, so as to absorb as much vibration as possible. In addition the design should also enable the movement of the sensor arrays in the two remaining directions i.e. horizontal and lateral movement, drawings of the assemblies are shown in appendix 5.

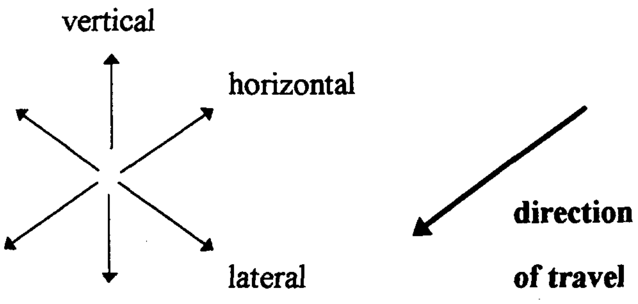


Figure 5.3 Direction of movement of sensors

5.3.3 Sensor Assembly

Prior to the assemblies being placed onto the skiving process, the individual sensors are attached to each of the angle brackets. The wire loom is also secured to the angle brackets.

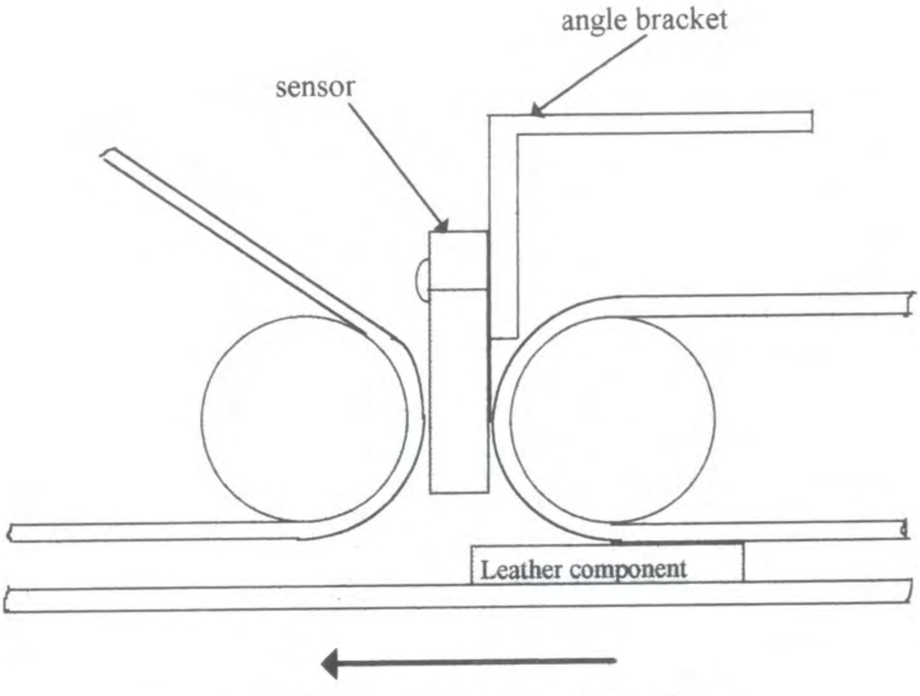
Each of the sensors are adjusted, using slip gauges, comparators and vee blocks, to achieve the optimum distance of 5 mm from the leather components, as they pass through the skiving process

5.3.4 Assembly Configuration

The complete assemblies were then secured to the skiving system in their relevant positions. The assembly that will have the least degree of flexibility is that which holds the sensor assembly between the 7 mm gap. For this reason this assembly is to be secured initially onto the skiving process. It is essential that the assembly is 90° to the travel of the components and it is centralised to the conveyor system.

The second assembly is secured to the skiving machine, using the first assembly as its reference point.

Standard engineering measuring and test equipment were used to locate each of the positions on the skiving process. The flexibility built into the assemblies enable this process to be carried out efficiently.



Direction of travel to cutting edge

Figure 5.4 Close profile of sensor and angle bracket assembly.

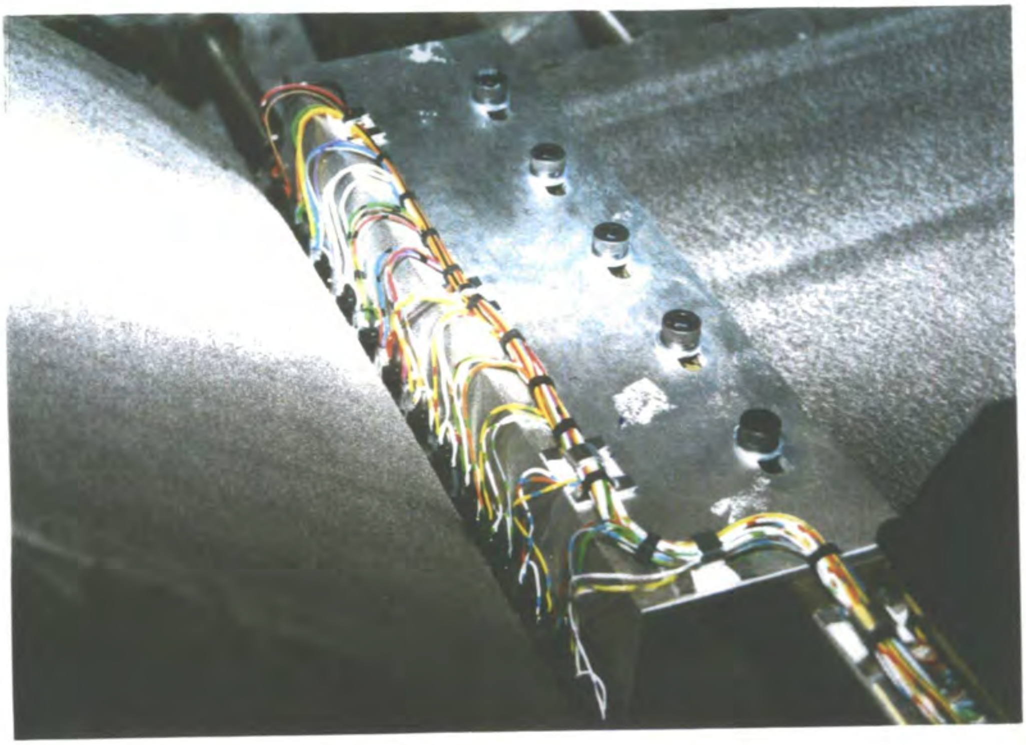


Figure 5.5 Assembly situated between 7 mm gap.

5.4 Electrical/Electronic Interface

The control of the process for producing the two profiles of the shapes will be the same as that used in the testing of the sensors. This will enable easy transfer of software and the utilisation of the system timing controller to this process.

The system timing controller has been manufactured using parallel circuitry, producing two identical configurations to that shown in figure 4.2, which provides sixteen digital inputs and outputs. Both systems are compatible at the counter and register level, providing easy manipulation of data and the use of similar software. The only major difference being their base addresses.

5.4.1 Data Capture

It is necessary that the data concerning the shape, and any movement of the leather components due to their transportation, is processed before execution of the skiving takes place. Therefore the information must be received, stored and then utilised prior to the actuation of the skiving solenoids.

The number of sensors in each array is greater than the 8-bit bus used in the computer. It is therefore necessary for some form of data manipulation to take place.

In addition each of the system timing controllers data ports are only eight bits wide, therefore both will be combined to provide one scan line of information.

The data from each of the sensors will be amplified to provide the digital information to each of the system timing controllers. This amplification is identical to that used in the process of sensor selection. The amplification circuitry is shown in appendix 6.

To remove the need of requiring a further two system timing controllers for the second array of sensors, additional signal conditioning interface circuitry was introduced. This interface circuitry included programmable 2-line to 1-line data selectors and suitable passive components.

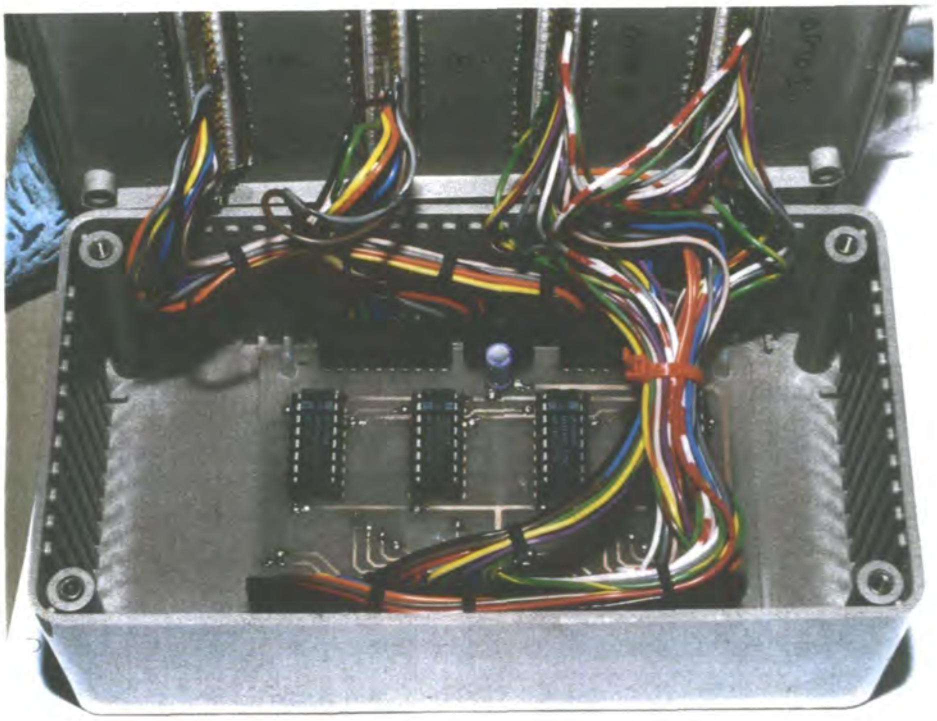


Figure 5.6 Interface circuitry

The overall process of the data capture is illustrated by means of a flow chart in appendix 7.

5.4.2 Software Considerations

As mentioned in chapter 4 the software utilised is Microsoft C/C++, that enables control of both the system timing controllers and the interface circuitry. It can be used to provide a control signal to the skiving machine central interface board. This signal information will be used to prevent the skiving of the leather component from taking place, if any movement has been detected. In addition the software package can provide an output of the information, which has previously been stored, to a visual display unit.

The overall function sequence of the software control is shown in figure 5.7. The computer is initially in an idle state, even after the user initiates the system. As the component passes the first array of sensors, it triggers an interrupt, which then allows the processors to capture the data image information. Each piece of data is temporarily stored in the computer memory. Following execution of 100 image line scans of the component shape, the identification process returns to its idle state. The leather component continues its travel towards the cutting edge. When it reaches the second array of sensors it triggers a second interrupt, which again allows data capture. Each individual line scan is combined using software techniques to produce a coarse profile of the silhouette for each leather component. The coarse profile is produced from 100 single lines of mapped data, provided by each sensor array. The two images are then compared and any movement would result in a control signal being produced.

The data is then stored to a file for use at a later date. The software programs utilised in this research are illustrated in appendix 8.

The effects of altering the time delay between each successive line scan will be discussed later in the chapter.

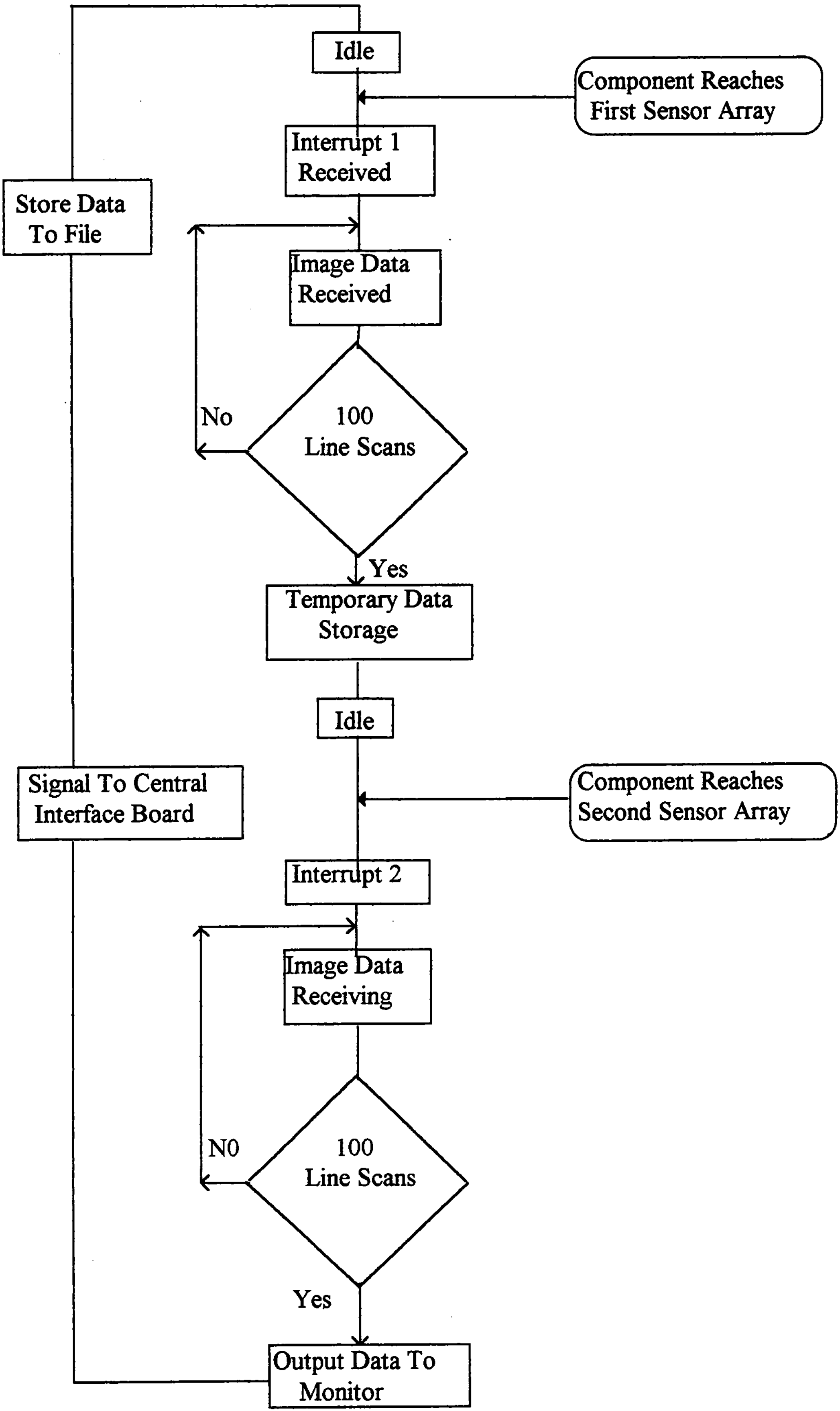


Figure 5.7 Function states of identification operation

5.5.1 System Resolution

The sensor arrays for producing the silhouette of the components are placed 5 mm above each of the conveyor belts. Due to their construction the centre lines for each sensor are 17 mm apart. As the component is transported on the conveyor systems it is scanned every 5 msecs. The scanning speed of the component is a compromise, if the scanning rate is increased, insufficient detail of the profile is obtained. This then would lead to inadequate data being obtained and reducing the accuracy of the system to detect movement. If the scanning speed is reduced, then for the smaller components, insufficient profile definition will be obtained.

The conveyor system itself has a linear speed of 180 mm/sec. Therefore the leather components are scanned at 0.9 mm of linear movement. Each sensor will produce a logic 1 when a leather component is present and a logic 0 when absent. The repetitive action of the sensors scanning the leather component yields digital information. This information results in an image being produced, that consists of a succession of strips 0.9 mm apart.

As the centres of the detection fields for each adjacent sensors are 17 mm apart, it was found by experiment, that the lateral movement which may be detected is 9 mm ± 0.3 mm. This assumes that the leather component moves totally in either of the lateral directions. However this type of movement will not be experienced by the components, within the skiving process, unless acted upon by some external force. Due to the components being totally enclosed in the three layer transport system, once past the line scan camera, then this form of movement will not be investigated further in this thesis.

In general if the components are subjected to any force, it is usually in the form of point contact. If this type of force is placed on the components then it invariably produces a rotary motion of the component. It is this rotary motion that will be investigated further.

5.5.2 Rotary Resolution

The worst possible scenario that may be encounted for this type of detection system is that of a strip of leather that is 17 mm wide, and is directly under one sensor. If this is the case and the components length was 50 mm long, then the minimum rotating angle of movement, θ_R, that may be detected would be 10°.

The table below shows the detectable change in angle with the change in length for leather components 17 mm wide.

Change in component length (Lc) mm	20	30	40	50	60	70	80	90
Change in angle (θ_R)°	24	16	12	10	8	7	6	5

Speed remains constant at 180 mm/sec and scan rate of 5 msec

Table 5.8 Detectable variation in angle with change in length

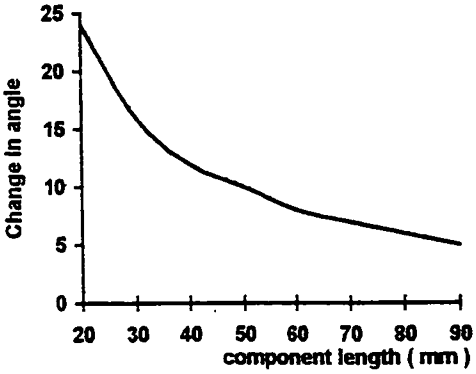


Figure 5.9 Graphical representation of angle results

If the same 50 mm strip of leather is now placed between the centre lines of two adjacent sensors, then the detectable angle of movement would be reduced to 3°. When the width of the strip is increased, then the rotational movement that may be detected is further reduced. For example, a leather component 34 mm wide, situated between the centre of three adjacent sensors would produce a detectable movement of 2°.

To obtain a relationship between all the variables that may affect the angle of rotation, experimental work was carried out. These experiments observed the response of the sensing system under varying conditions.

The variables that exist within the detection system are as follows :

- L_c : Length of the component, up to a maximum 90 mm.
- t_s : Sensor scan time between each data line in sec.
- V_c : Component velocity in mm/sec.
- W_c : Width of component under detection.

To define the resolution of the detectable rotation of a leather component using the present sensing system, the following equation may be used :

$$\theta_R = \tan^{-1}\left(\frac{V_c * t_s * 180}{W_c * L_c}\right)$$

The constant value of 180 was obtained from experiments carried out using graphical techniques and on the automated skiving process. This value represents the mean value of the test results obtained and has an error of ± 5 %. By transforming the above formula, the constant may be obtained for any piece of leather travelling at any speed on the conveyor system. The angle that may be detected is a function of the distance travelled in one line scan, to that of the overall size of the component being transported. The table below illustrates the value of the constant for variations in the angle, with all other variables remaining constant.

angle detectable (°)	constant (no units)
1.0	122
1.5	183
2.0	244
2.5	305
3.0	367
3.5	428

L_c = 90 mm W_c = 70 mm

V_c = 180 mm/sec t_s = 5 msec

Table 5.10 variation of constant with change in detectable angle

Using the previous formula, for a leather component measuring 70 mm wide and 90 mm long, then a detectable angle of 1.5° may be observed. As explained in chapter 2, when the components pass the overhead camera, a short time delay is provided for computing purposes. This time delay was utilised to provide an induced angular displacement to the test pieces, before progressing to the second sensor array. The angular displacement was obtained using a vernier protractor and manually moving the leather component. This process confirmed that by using the new sensing system integrated onto the skiving process, a detectable angle of approximately 1.5° may be achieved. This approximate value is due to the method of providing the angular displacement.

All the initial tests were carried out using a simple rectangular shape. These tests verified that it is necessary to provide some form of protection to the sensors from direct sunlight. This is particularly so for the sensing array on the filling station sub-system.

In addition the second sensing array was affected by the material used in the manufacture of the superstrate. This material had a coarse fibre coating, which aided in the transport of the leather components. However, during the initial tests carried out this fibre provided inconsistent results, due to it passing the sensors and producing an early interrupt. By modifying the software and as the system became established, i.e. no fibres protruded into the sensing field of the array, this affect was alleviated.

5.6.1 Initial System Data Collection

Following completion of the installation of the sensor arrays and the initial testing of the system had been carried out. Further investigations were carried out with regards to the integration into the complete skiving process. These tests will be performed using actual leather shoe components, a sample of which are shown below:

Figure 5.11 Typical components used to manufacture shoes

Each of the components were placed at a fixed point on the load conveyor system, prior to its transportation to the skiving head. Due to no skiving of the components taking place, only the conveyor drive mechanisms were utilised.

As previously mentioned, the program remains idle until the components leading edge reaches the sensor array. The array provides digital information that represents light and shaded areas. A similar process is used when the second sensing array detects the leather component. The results are stored and then used to display the coarse profile on the visual display unit. A sample of the display is shown in figure 5.12.

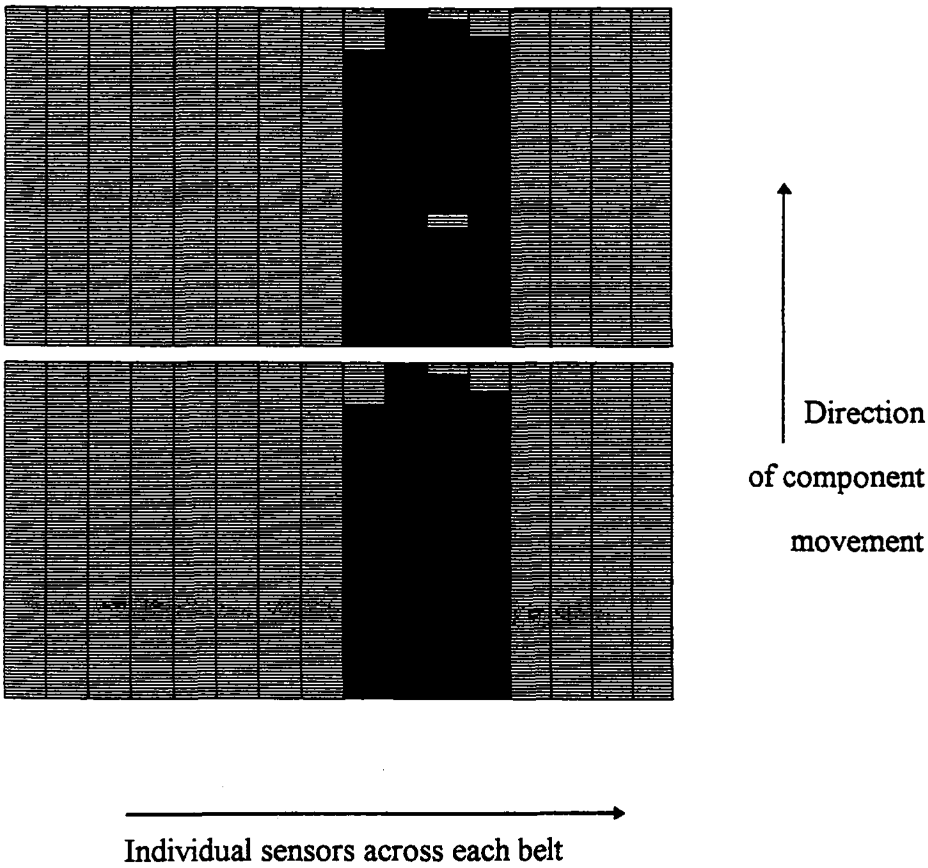


Figure 5.12 Coarse profiles of test components

The above figure illustrates 100 line scans producing two mapped silhouettes of a leather test piece as it is transported towards the skiving mechanism. The test piece had one corner removed and a small taper on the leading edge. The length of the component that is scanned is 90 mm. The upper silhouette is produced by the sensing array above the primary load conveyor. The lower silhouette is produced by the array placed in the gap of the three layer transport system.

5.6.2 Analysis of Component Data

During the initial experimentation, it became apparent that the information presented by the first array of sensors, was not what should be conventionally expected. In both figure 5.12 and appendix 9, irregular results occur on the first profile. These anomalies will be discussed later in the chapter.

Neglecting this spurious information, it can be seen that both sensing arrays produce a coarse profile of the shoe components. These can then be compared to one another for the detection of movement.

Using the data which has been collected from the sensing arrays, it was found that they enable the detection of movement of the components to within ± 1°.

If a simple rectangular shaped piece of leather is placed on the transport system. Then from a series of 100 line scans for each sensing array, only four will differ, in the worst possible case, of placement on the transport system.

As the profiles of the shoe components become more complex, then this greatly increases the number of observations that differ. Using this method of identification, and by comparing these variations, a decision can then be made on aborting the process of skiving.

The coarse profile, of a rectangular shaped piece of leather, for the detection of movement is shown in figure 5.13. The axes are the same as shown in figure 5.12.

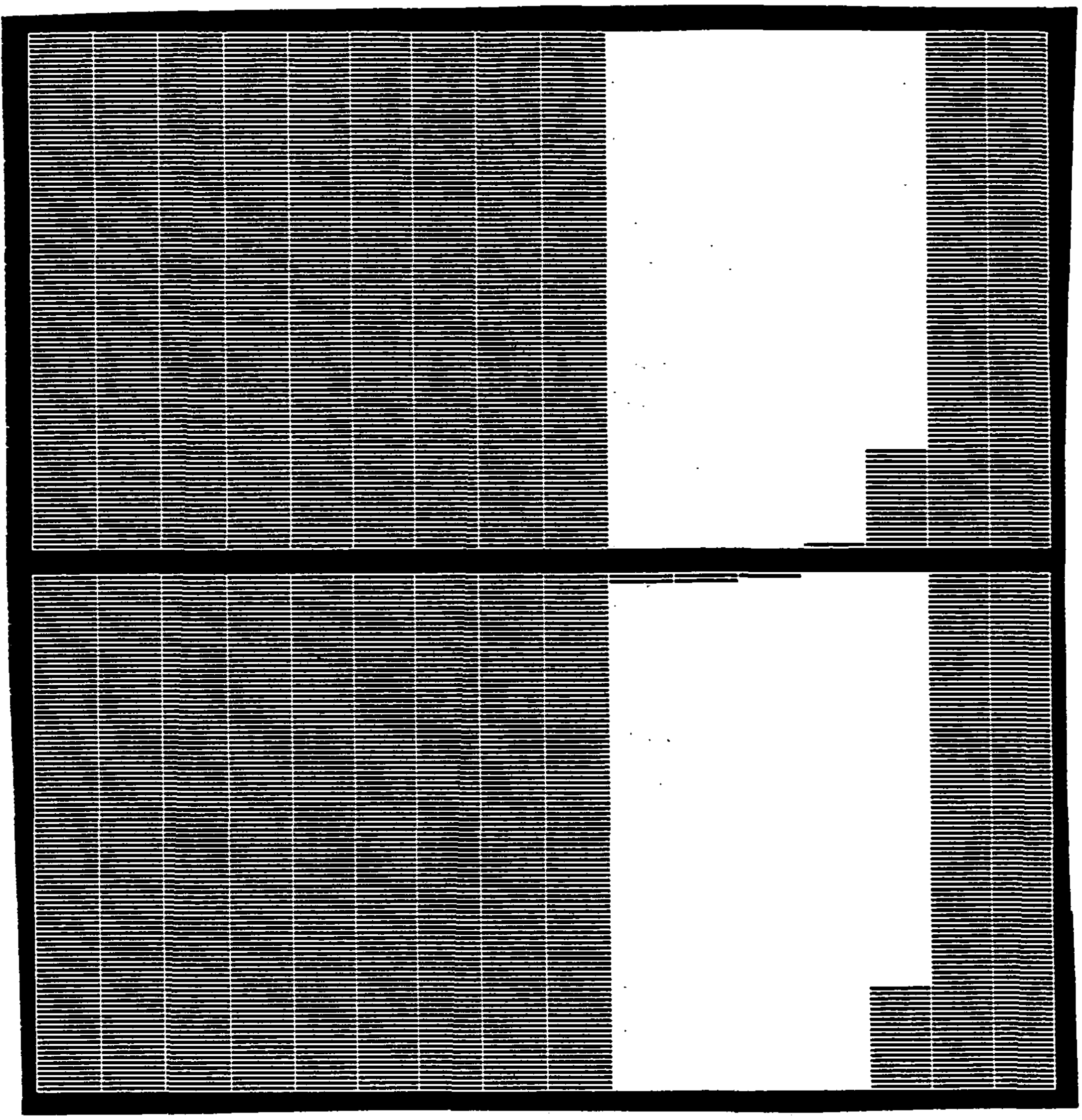
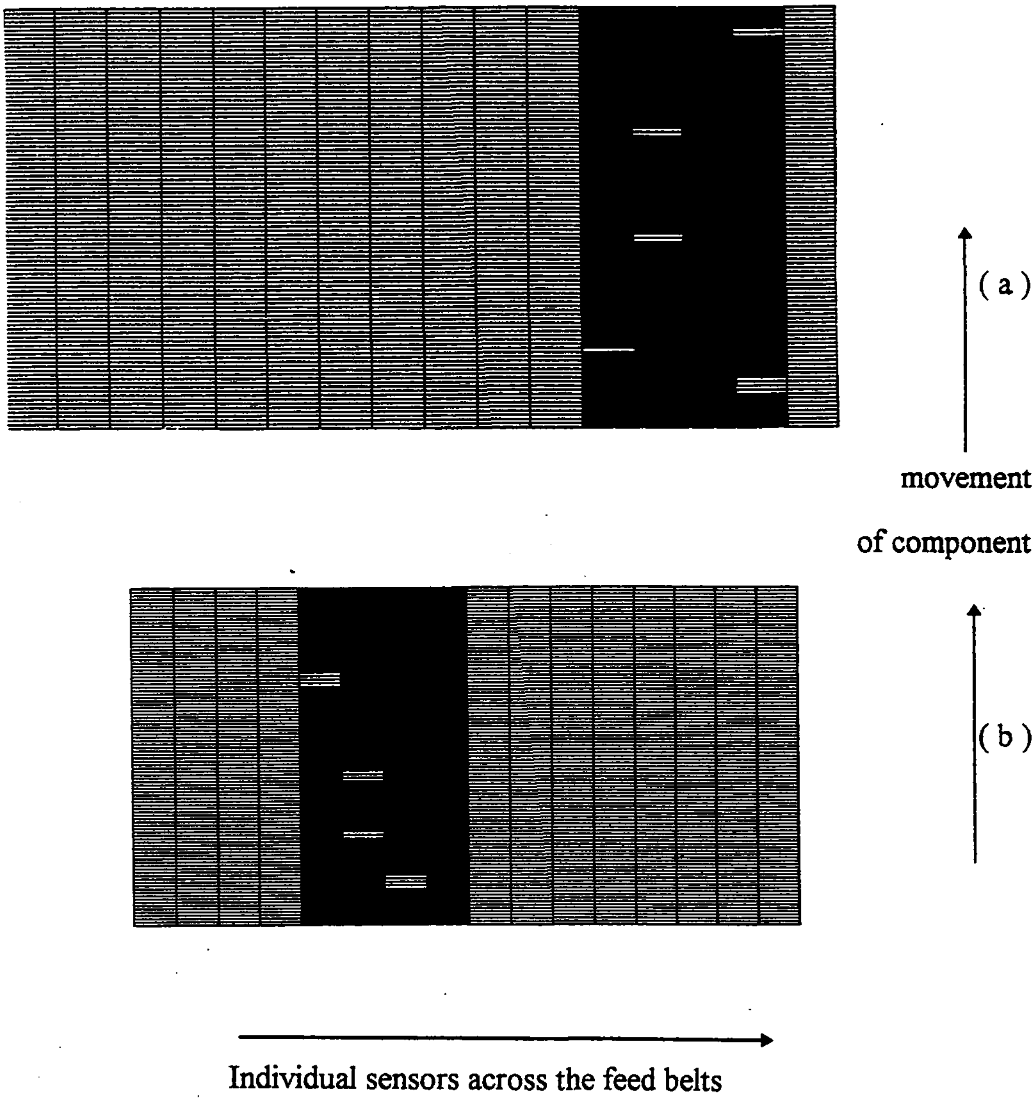


Figure 5.13 Illustration of profile with movement of 1°.

5.7 Investigation into Profile Error

Having obtained a coarse profile for the various shoe components available, using the line scanning process, each exhibited variations in the data obtained from the first sensing array. Initially to investigate these effects a long rectangular shape of leather was placed on the feed conveyor. For this particular investigation a slower sensor scan rate was applied from the control software. This enables a greater length of the component to be investigated. The resultant profiles for the first sensor array are shown in figure 5.14.



(a) right-hand side of conveyor system.
(b) left-hand side of conveyor system.
Figure 5.14 Filling sensor station coarse profile of rectangular leather.

The variations, displayed in figure 5.14, have a random nature and may be caused by various aspects within the sensing array environment:

- Faulty sensor
- Amplification circuitry
- Sensor distance from target

All sensors were checked and the connections to each tested, to ascertain whether the joints had broken due to the vibration on the skiving process rig. Following this inspection process, the first sensing system sensors were found to be functioning correctly.

Each of the sensors amplification circuits were tested to ensure that the vibration of the skiving machine had not disrupted any of the adjustment sensitivity settings. As with the previous tests, these were found to be functioning correctly and no movement had taken place.

This finally left the only possible cause of the error, to be attributed to the vertical distance varying between the sensor and the target. The variation of the distance may be due to either the movement of the sensors, or a vertical movement within the transport system itself. The effects of the variation in distance from the sensors to the target were discussed in chapter 4.

It was therefore necessary to investigate if the mechanical assembly, previously mentioned, was flexing due to vibration within the skiving process. When observing the process, it was noted that there was a certain degree of height variation between the sensors to the top of the input conveyor feed belt system. This was not due to the movement of the assembly, and therefore lead to the examination of the input feed belt.

Using a fixed datum point, and height measurement equipment, the variations in the height of the belt was examined at intervals of 50 mm along its length and at three points. These three points include its centre line and at 60 mm either side. The process then produced a grid of 3 by 28 height observations. Appendix 10 illustrates how these height measurements were obtained. As can be seen from figure 5.15, the lateral movement was restricted to 60 mm, as the conveyor belt buckles considerable at its outer edges.

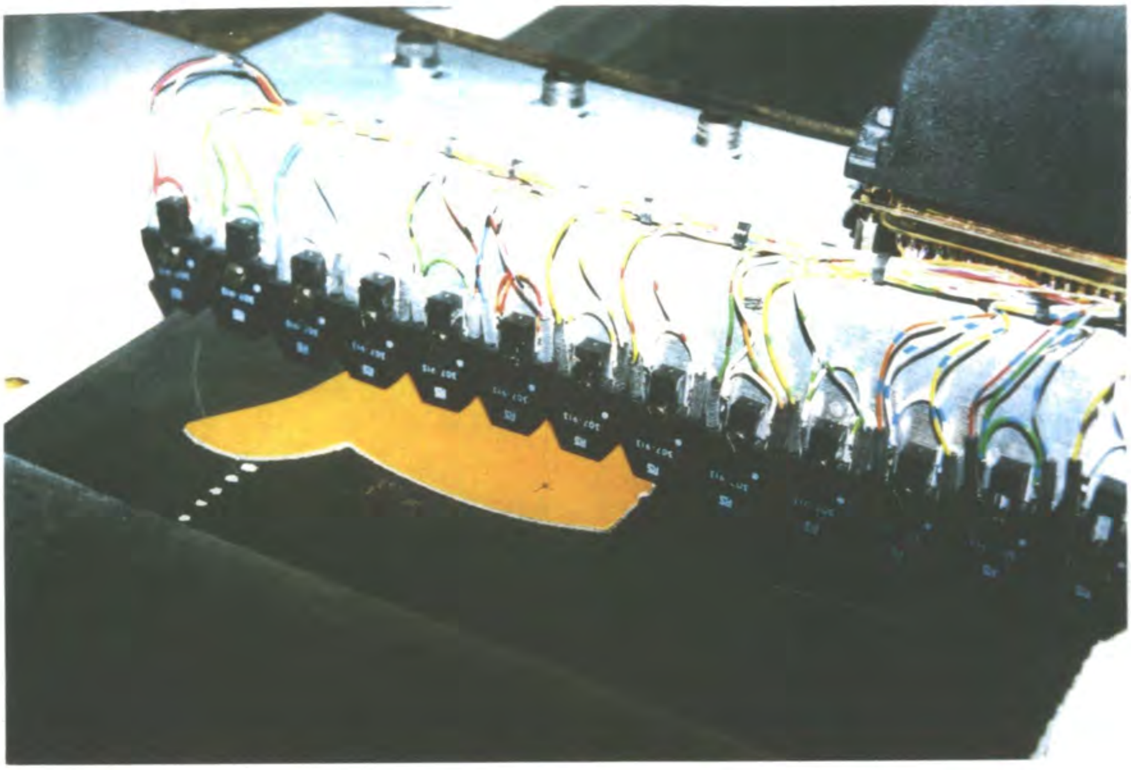


Figure 5.15 Close up view of filling station sensor array.

This buckling is due to its construction, of two single timing drive belts, with the substrate attached directly to them.

The belt height measurements taken indicated that there was large variations both across the belt and along its length. In the tests carried out, the belt was found to undulate along its length by 1.1 mm and across each grid by 1.5 mm. This undulation is shown graphically in figure 5.16. It represents how the feed belt would appear if it had been cut and placed on a horizontal surface.

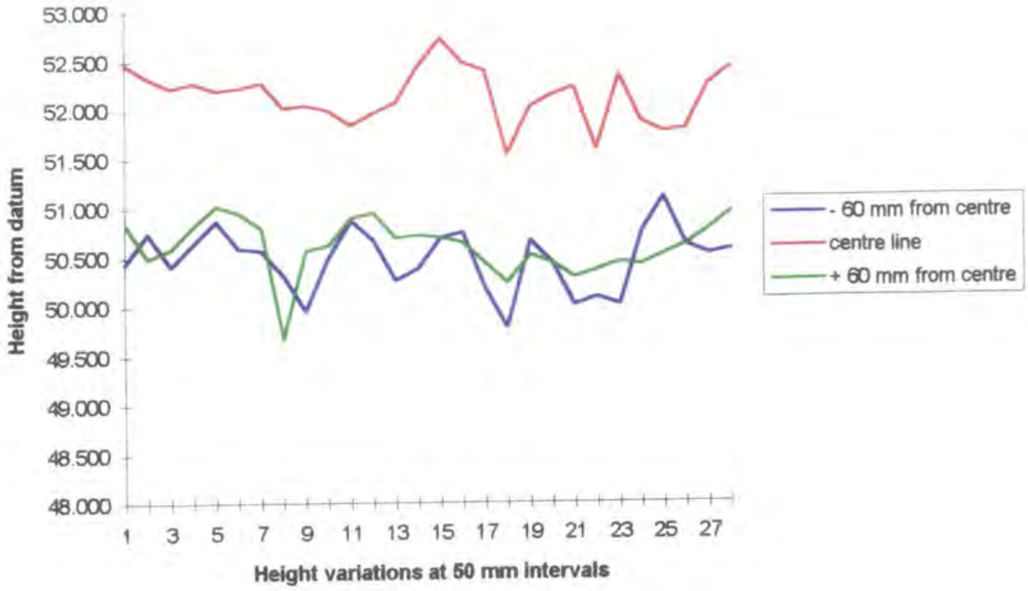


Figure 5.16 Belt height variation from fixed datum.

As both the horizontal and lateral planes had large variations in their heights, then this effect on the sensor system was investigated further.

In order to establish the effects of the vertical movement of the belt, a strip of leather 120 mm wide and 20 mm long, was firmly secured to the input conveyor belt. The length was restricted by the necessity for the leather to be able to rotate completely around each end drum. This process enabled the repeatability of the test, which was being implemented, to be confirmed. The leather strip was placed on the belt where minimum distortion was found. The actual process of securing the leather also provided a level portion of the conveyor belt. This also improved the validity of the test.

To carry out the test into the effect of varying the height, firstly all the sensors were placed at the same distance from the target strip. All sensors provided evidence that they were performing equally.

The height of one sensors was then varied, initially by ± 0.3 mm. This did not produce any variation in the performance of identifying the strip. The deviation in the height was increased to 0.5 mm, this produced an effect on the ability of the sensor to detect the leading edge of the leather strip. If the deviation to the height of the sensor is varied further, to provide a variation of 1 mm, then the effect is intensified.

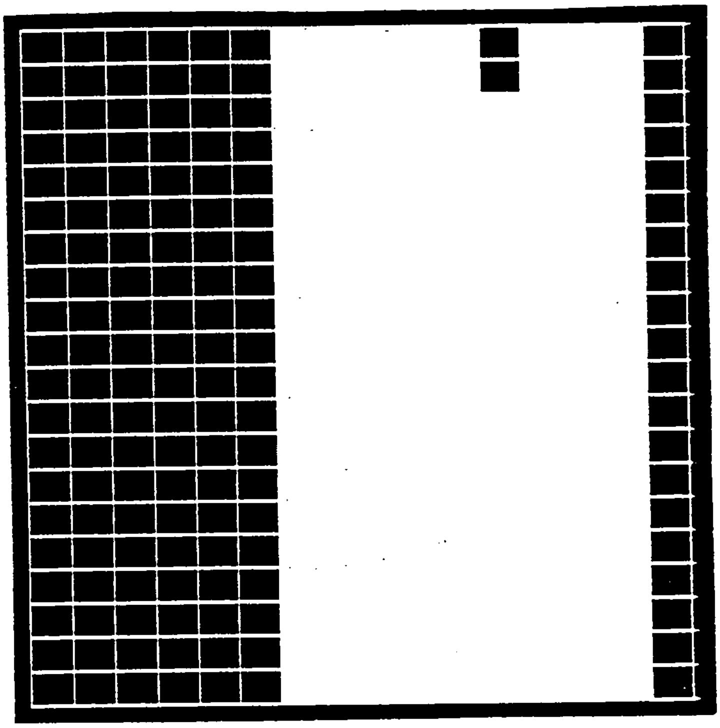


Figure 5.17 Detection of plain strip varying height of one sensor by 1mm.

Figure 5.17 illustrates the effects of varying the height of one sensor and the delayed property of its detection of the leather strip. This time delay may be attributed to the time taken for the silicon phototransistor to respond to the reflective infra-red source from the object. For example, a greater reflective pathway from the transmitter to receiver, than that of the remaining bank of sensors.

Therefore any variation in the distance, between the sensor and the object being identified, greater than ± 0.3 mm, from its optimum height of 5mm, produces variations in the digital information supplied by the sensors.

5.8 Effects of Software Parameters to the Identification Process

The major software parameter associated with the sensing array identification is that of the scanning time delay. It is this delay that provides a pre-determined time between successive line scans as the component travels towards the skiving mechanism.

The sensor scan time in conjunction with the conveyor speed influences the length of the component that may be detected, using the present 100 lines to produce the coarse profile. Assuming the speed of the conveyor system remains constant, then by varying the scan time, the distance measured between each line scan will be increased or decreased.

Increasing the time delay, while retaining 100 lines, will produce a coarse profile of the component whose length is greater than 90 mm. This increase will also reduce the resolution of the system in the horizontal direction of travel.

Decreasing the time delay would reduce the length of the component that will be detected by the sensing system. However, it would increase the resolution in the horizontal direction.

As mentioned previously in the chapter, the present line scan time delay provides a compromise between the resolution required and the length of component which may be detected.

To improve the resolution of the coarse profile silhouette and also maintain a detectable component length of 90 mm, then the number of line scans will have to be increased. The number of line scans may be determined as follows:

$$\frac{90}{\text{speed of conveyor } (W_T) * \text{line scan time } (L_{ST})} = \text{number of line scans } (N_s)$$

If speed of conveyor = 180 mm/sec

and line scan time = 1 msec

$$\text{then } Ns = \frac{90}{W_T * L_{ST}} = \frac{90}{180 * 0.001}$$

$$\therefore\ Ns = 500 \text{ lines}$$

5.9 Conclusion

The development of a sensing system onto the present skiving process, involved the implementation of four key stages. These stages included the integration within the present system, the design of suitable assembly units, the electronic requirements for both systems and their interface software requirements. The most demanding of these has been the integration within the present skiving process. This placed demands on both the type of sensor to be used, and its physical size.

The use of standard electronic equipment and materials have prevented the cost of the sensing arrays, discussed in this chapter, from escalating. It has also enabled the development of an integrated system, instead of a stand alone system, providing a means of interrupting the skiving process, if movement is detected.

Due to the relative low resolution of the sensing system, only coarse profiles of the shoe components may be obtained. This prevents comparison with present vision system. Therefore the problem of providing a reference was alleviated by using two identical sensing arrays.

The use of the coarse profiles has enabled a system to be produced, which dependent upon the shape and size of the leather components, can detect a minimum angular movement of 1°.

It has been shown that the detection of components, using the infra-red sensors, may be influenced by the environment within which they operate. These conditions include ambient light, vibration and variations in height from sensor to target.

Another key area, which has not been addressed in this research, is that of maintaining a clean conveyor surface, especially within the three layer transportation system. This may be necessary to prevent leather dust or small component shavings corrupting the sensor array placed within the small gap between the upper superstrate belt.

The overall construction of the skiving process, is not that of a commercial product. Hence problems arose in the data supplied by the sensing arrays, especially above the load conveyor. The undulations caused by the movement of this belt produced erroneous information. It is anticipated that if this belt is replaced by a commercially manufactured equivalent, then this problem would be removed.

Chapter 6

Suggestions for Future Development

6.1 Introduction

The integration of a low cost detection system has been proven to be a viable addition to the present skiving process. The overall characteristics of the product are unaffected. However, the speed of its operation within the present system, the type of sensors utilised and their position will require further investigation.

The position of the sensing arrays could be varied by modifications to the construction of the three layer conveyor transport system. In addition changing the method of displacing the leather above the cutting edge may alleviate the problems of the leather buckling, as described in chapter 2. Hence removing the need of the superstrate belt between the actuator and the leather component. In doing so it would allow the second sensing array to be placed closer to the skiving mechanism.

An additional benefit that may be obtained is an increase in the system resolution. From experiments carried out [1], it was concluded that a skiving pin resolution of 2 mm would produce adequate quality.

The investigations suggested in this chapter will enable new technologies to be assessed against the present system and hence possibly produce a variation in the design of the sensing arrays, conveyor transport systems and actuator pin mechanism.

If the additional sensing systems are utilised within a manufactured skiving process, then the influences of the environment need to be further analysed. The integration of the control signal from the sensing system to the central interface board will also require further investigation.

This chapter is to outline some of the possible solutions, which meet the above requirements. The information gathered may be used in future developments by B.U.S.M. as feasible production alternatives.

6.2 Alternative Options for Sensing Array Configuration

The overall configuration of the skiving process prototype machine presents unique problems when selecting sensors. These include the resolution of the sensing system, the encapsulation of the components and the gap that has fortunately been produced. The following discussions suggest alternatives to the present system which could improve or rectify the problems encounted within this project. These include:

- additional sensors
- modification to conveyor system
- secondary conveyor base plate

6.2.1 Additional Sensors

The present sensing array consists of 13 sensors that are spaced 17 mm apart. To reduce this spacing, especially within the centre region of the conveyor systems, additional sensors may be introduced. These sensors will require smaller axial bodies than those used in the present array, to allow them to be located between adjacent devices.

A sensor that may be employed is the fibre optic photoelectric discussed in chapter 4. The 1 mm bendable optic fibre will allow access between each of the present sensors.

The introduction of these sensors would initially present software and hardware problems when integrating them with the sensor arrays. In addition the close proximity to the skiving mechanism could produce excessive vibration. This vibration would then lead to erroneous results being obtained, from the movement of the optic fibre.

6.2.2 Modifications to Conveyor System

The supporting mechanical framework for the three layer conveyor system could be adjusted. The frame is used to hold each of the conveyor belts, while providing adequate tension. By reducing the belt length of either of the upper belts, would produce a gap larger than the present 7 mm.

If suitable timing belts are obtained, to produce a gap of 17 mm, then the present reflective opto switches may be rotated through 90°. By rotating the sensors it would then allow each sensor array to contain 44 similar devices.

An array containing 44 sensors would increase the resolution of the system and improve the detectable angle of rotation. However, the time to process the information, especially using an 8-bit bus computer system, would be increased.

In addition, set up problems would be magnified with respect to achieving a single centre line through all the sensors. Therefore adjacent sensors may detect the presence of the leather component at different times. This would once again produce erroneous information.

6.2.3 Changes to Base Plate

To prevent distortion of the three layer conveyor system, a base plate has been inserted under the lower belt. This plate counteracts the downward forces. These forces are induced into the conveyor system by the tension of the upper belt and the components, as they travel towards the skiving mechanism. By inserting slots into this base plate it would allow a pressure sensitive device to be utilised for the detection of the position of the components. The types of devices that could be used are tactile sensors or compact line and edge orientation detection sensors[12].

The edge orientation detection sensor uses four position-sensitive devices. Each device detects the centre of gravity and by a combination of the positions obtained, the orientation can be calculated. However, further developments are still being carried out as an error of 5° occurs.

6.3 Alternative forms of Conveyor System

To facilitate either the movement of the line scan camera or the sensing arrays proposed in this thesis, alternative forms of transport systems may be investigated.

6.3.1 Split Belt

The present system has a complete upper superstrate belt that has been specifically manufactured. If the short upper secondary conveyor belt, illustrated in chapter 2, were removed and replaced with a split belt. The access to the component as it travelled towards the cutting edge would be improved. This would allow many other forms of sensors to be utilised, in addition to those used in the sensor system proposed in this thesis.

6.3.2 Variation in Material

An alternative to splitting the upper belt, would be to replace the present belt. The replacement belt will require the material to have the same properties to that of the present belt, as mentioned in chapter 2, while also being transparent. This would then allow the present sensing array to be utilised, but closer to the actual skiving process.

Alternatively, a line scan vision system may be mounted in a similar position. This vision system would provide a similar raster scan image to the present camera. The image would then be directly compared to the one used in the skiving process. Comparing the two images will detect any movement that has been caused by the transportation process.

The disadvantages of these processes may be that defraction of the components outline could be experienced, due to the material being used. In addition, the requirement of a light source to be directly beneath the camera lens may not be achieved.

6.4 Alternative Forms of Actuation

Rather than modifying the transportation system, alternative forms of motive force for the actuator pins were considered. This would then remove the need for the upper belt and hence a greater choice of sensors to be considered for the detection of movement.

The alternative forms of motive force considered were Hydraulic/Pneumatic, Microactuators and Piezo-Electric.

6.4.1 Hydraulic/Pneumatic Operation

Hydraulics and pneumatic powered systems both utilise the same principle i.e., pressurising a fluid and delivering it to where it can do work.

One device that has been developed is a micro-machined electrohydrodynamic (E.H.D.) injection pump [13] . The pump mainly consists of two facing grids, which are micro-machined from single-crystal silicon and bonded together anodically. Pumping and static generation is achieved with different polar fluids such as ethanol, propanol, acetone or de-ionised water. In addition most organic solvents may also be pumped. When using ethanol a maximum static pressure of 2.5 kPa may be achieved i.e., 32 cm pumping head, and with a pumping rate of 14 ml/min at a pressure of 420 kPa having also been achieved. For the realised pump the grid area measures 3 mm by 3 mm with a grid separation of 350 μM.

Pumping starts at d.c. voltages as low as 40 Volts, whereas 700 Volts are needed for maximum throughput. Pumping is also observed with an a.c. driving voltage. To increase the pressure several of the devices can be stacked. This opens new applications, such as micro-machined cooling systems or microhydraulic actuators.

Using air as the compressive medium, Hoerbiger [14] , a pneumatics company, have developed a Piezo-Electric valve actuator that uses very little energy. The device is 30 mm diameter by 8 mm thick and is manufactured using ceramic technology for dimensional stability. Inside, the operating element is cantilevered by one end, while the free end can move between inlet and outlet parts. This basic design produces an on/off operation, while the simple addition of a third part will produce two air routes thus allowing full servo or proportional functioning, with the element acting as a baffle or throttle proportional to the applied signal voltage. The valve actuator is voltage-controlled rather than current controlled as solenoid valves are, hence its bistability and low energy consumption.

Due to the electric currents to be processed being small it has been possible to miniaturise the electronic control system and integrate it into the valve body. These electronic circuits may be customised to give various voltage levels of operation. This includes such power sources as solar cells, ratio signals, direct connection to a programmable logic controller and finger pads.

One successful application of this device has been its use on a shoe leather press. The original design had 300 pneumatic cylinders and consumed 9 kW of power in its thirty minutes operating cycle. The introduction of this device has reduced the energy requirements to approximately 0.3 W, whilst also eliminating heat build up in the valves, slashed the investment needed for the control system, reduced overall size and simplified the design for easier maintenance.

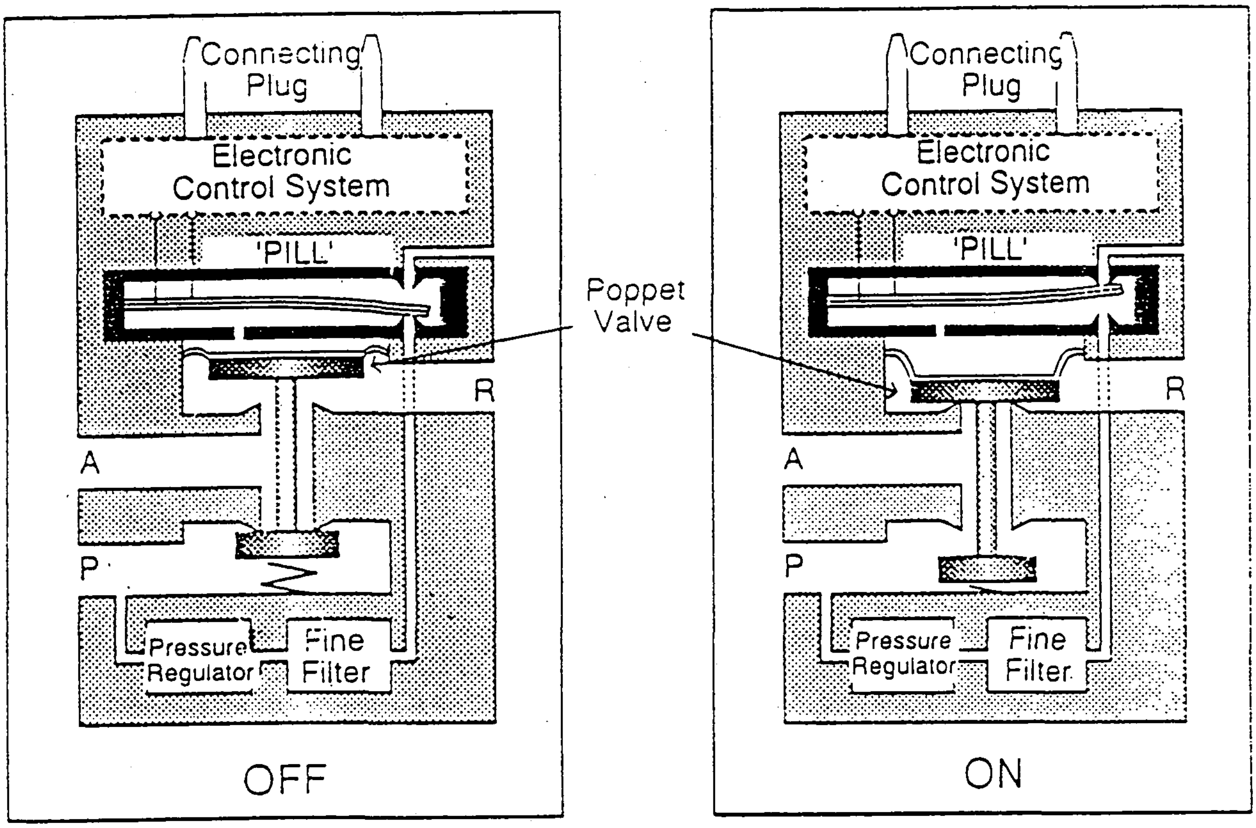


Figure 6.1 Piezo 2000 electro-valve

6.4.2 Microactuators

These devices are used to change one form of energy to another, with the majority converting electrical energy to movement. The advantage of using this form of conversion over others is that they are fast and accurate and may also be easily adapted to operate using sophisticated control techniques. One such device that could be considered for future development, was a proposal for electrically levitating micromotors [15] . The driving force for this device is obtained by an electric field that is generated between the stationary and moving parts. The biggest advantage of using an electric force, compared to electromagnetic forces, is that a very high energy density can be achieved in the very small scale involved. One such device is a variable-capacitance linear microactuator. This device is capable of moving a slider, which is a thin plate, to move along one axis. The driving force is obtained by applying a voltage between sets of conducting plates that are etched on the slider and on the stator above it. Continuous motion is obtained by phasing i.e., by suitably changing the distance between the set of plates and applying voltages to each set in sequence.

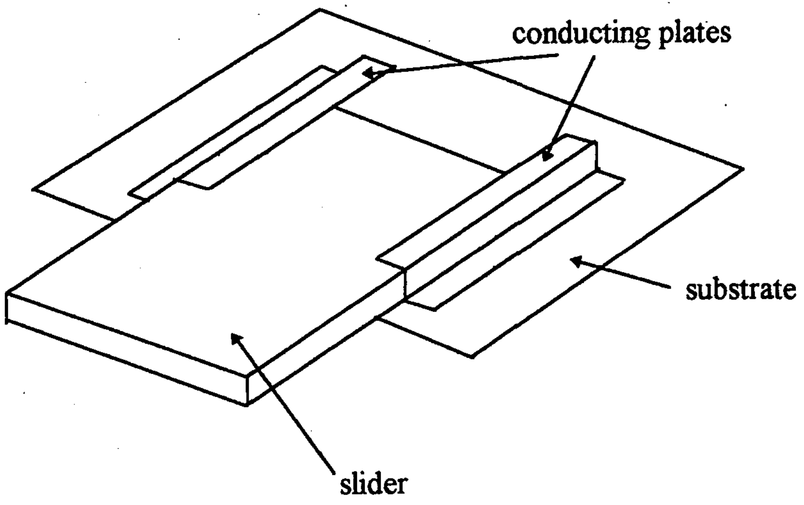


Figure 6.2 variable-capacitance linear microactuator

Another form of microactuator may be manufactured using spring translation mechanisms driven by electromagnetic force actuators, which are often used to produce controllable motions. Although various translation techniques have been developed, for example Piezo-Electric, hydrostatic and mechanical linkages, they all exhibit inherent limitations such as non-linearity, hysteresis or vacuum incompatibility. Using x-ray interferometry it can be shown that monolithic linear spring manufactured from single crystal silicon and driven by a magnet-coil force transducer has excellent linearity characteristics with a corresponding low hysteresis.

Elastic displacement mechanisms are usually used because of their smooth, wear free and linear operation over small displacements. Two types of linear springs are commonly encountered in many designs. These are the leaf spring, figure 6.3, and notch-type spring, figure 6.4. In both these types the linear motion of the platform is achieved by distorting the support legs using co-linearly applied force. Accurate, smooth and co-linear application of the driving force is essential for rectilinear motion of the platform. Piezo-Electric, feedscrew and hydraulic driven mechanisms can be employed, but electromagnetic force actuators have distinct advantages for applications involving small displacements. These include linear operation, low hysteresis, direct electrical control and the absence of mechanical linkage between the actuator and the platform[16].

In order to increase the dynamic response of the system, by increasing the driving force, the spring stiffness must also be increased, but may only be achieved if the elastic behaviour of the material used is maintained. The steel materials used, which show the best characteristics, for this particular application are Invar and Elinvar. Both are iron alloys with high Nickel content.

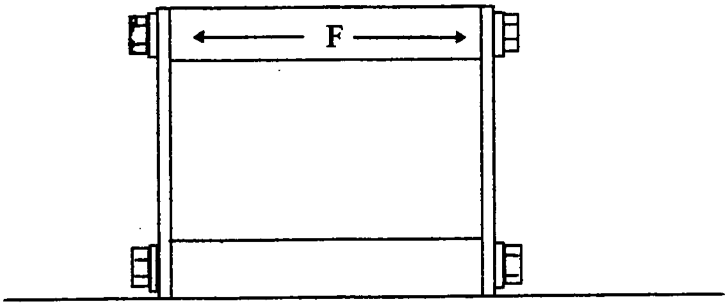


Figure 6.3 Leaf-type spring translation mechanism

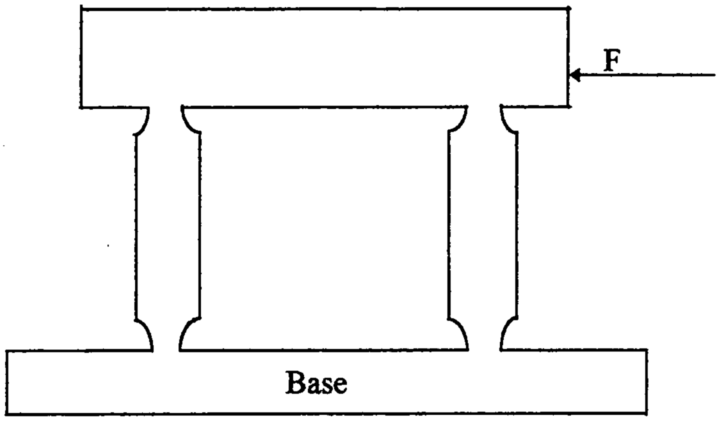


Figure 6.4 Notch-type spring translation mechanism

6.4.3 Piezo-Electric devices

Another method that may be used to increase the system resolution could be to use devices that are manufactured using Piezo-Electric ceramics. The basic principle for any Piezo-Electric device is that on the application of a force a current is generated with any circuit connected to it. However, the operation may be reversed so that an application of a voltage will produce a controlled motion. Unfortunately the displacements produced are very small for a single device and therefore a composite construction is necessary. Recent developments have produced an impact actuator[17] that uses multilayer Piezo-Electric ceramic technology.

The actuator itself includes a multilayer Piezo-Electric element, an impact hammer and a solid waveguide interposed between the Piezo-Electric element and the hammer. The principle of the design is the use of stress wave that is generated by a prestressed Piezo-Electric element, when an electric pulse is applied. The waveguide transmits the stress wave to the impact hammer at a high initial velocity. The design utilises a multilayer Piezo-Electric element 2 mm by 3 mm in cross-section and 18 mm in length, which can launch a 0.15g hammer to achieve a velocity of 263 cm/s, this is equivalent to a kinetic energy of 0.52 mJ, the device can also operate at 2.8 kHz repetition rate.

6.5 Conclusion

Following the successful integration of a sensing system, for the detection of movement in a manufacturing process. It was felt that although the overall process provided satisfactory information, to integrate the process into an industrial machine further research should be directed towards enhancing the present system.

In this chapter it explains that this enhancement could be achieved using several methods. These include increasing the number of sensors and modifying the mechanical layout of the prototype skiving machine. Improvements in the actuator mechanism could also remove the need for the upper conveyor belt and provide access to the components closer to the skiving head.

Increasing the gap size or varying the conveyor layout would allow alternate forms of sensors, as described in chapter 3, to be utilised. In addition the number of sensors on each of the sensing arrays could be increased. This would improve the coarse profile definition, and reduce the minimum angle of detection.

The material used for the superstrate conveyor belt presents its own problems when trying to identify the movement of leather components as they travel through the process, i.e. obstruction in the view of the component.

Conveyor belt material and configurations have been proposed which could allow a line scan camera to be placed closer to the skiving head. This would then allow direct comparison with the present identification process. However, it also assumes that the computing time required for comparing the large number of image bits can be reduced.

Alternative forms of actuation have been discussed which may be used as a reference for future developments. The two most promising avenues that appear to require further research are i) Hydraulic/pneumatic operation and ii) Piezo-Electric actuators.

Further examination into both the behaviour of the sensing systems and the automated skiving process may be required to be undertaken by B.U.S.M., prior to manufacturing an industrial prototype automated skiving machine.

CHAPTER 7

Conclusion

7.1 Introduction

As explained, the main aim of the project was to investigate the viability of producing a low cost means of detecting components, within manufacturing industry, especially in restricted environments. The specific intention of the project was to identify angular movement of leather components. The components were transported towards a cutting edge of an automated skiving machine, and were generally obscured from normal vision.

The overall conclusion is that the sensing array system developed successfully produces a coarse profile of the leather components as they are transported through the skiving machine, and also fulfils the main aim of the project. The system has been designed with adequate flexibility and adaptability to be utilised on similar processes, if their configuration differs slightly.

The sensing arrays have been successfully integrated into the existing automated skiving process, without the need of extensive alterations to its configuration.

7.2 The Automated Skiving Process

The overall construction of the skiving process consists of three distinct elements. These are the shape recognition system, the transport system and the automated skiving mechanism. The latter two elements produce their own restrictions in the choice of sensors to be integrated within the system.

The problems that arose from the integration of the three elements, and the introduction of the twin belt mechanism, fortunately provided a small gap. This gap allows access as the components are transported towards the skiving head.

The examination of the skiving process enabled key areas to be identified, where additional sensors may be situated. One of these areas included the generated gap, while the other was situated above the primary conveyor. The sensor chosen must be capable of identifying the leather components. In addition, dimensional constraints are placed on the sensors, for use within the gap.

7.3 Sensor Technology

Due to the rapid advancement in the development of new types of sensors and manufacturing techniques, a wide range of sensors are now available. Sensor technology has become highly diversified and fragmented. This is clearly demonstrated by the wide range of sensor types, the number of manufactures and the multiplicity of application.

The thesis has presented some of the major forms of sensing devices, while highlighting some of their advantages and disadvantages, for use in identifying leather components.

As one of the main characteristics of the leather components is to bend easily under direct pressure, some form of non-contact sensor must be used. A variety of non-contact sensors have been investigated. However, due to the space restrictions and the environmental conditions within which they are to operate, very few may be utilised.

7.4 Sensor Selection

Both the characteristics of the components and the skiving process, place constraints on the selection of sensor to be utilised. The sensor investigation carried out indicated that by reflecting light from the components, it would provide a means of overcoming these constraints.

Two devices which reflected infra-red light were chosen and subjected to further analysis. The analysis was carried out on a simulation of the process, while allowing direct access to the leather components.

The examination of their characteristics indicated that they are dependent upon:
(i) the speed at which the component passes the sensor and
(ii) the distance from, or thickness of, the component being detected.

Initially it may appear that these issues would not affect the device characteristics. However, it was established that variations do occur in the time taken to reach the threshold voltage of the detection circuitry. The above factors therefore influence the design of any sensor supporting framework. The framework would be required to maintain sensors at right angles to the process flow, and maintain the sensor height from the components.

Prior to any device being integrated into any manufacturing process, various sensor qualities need to be investigated, these include:

- accuracy
- repeatability of results and
- environmental conditions.

Tests and specific software were developed to investigate the above qualities. These were carried out on both of the chosen sensors. The error obtained during the tests was found to be 1% of each set of samples taken. The distance variation associated with these errors constituted 0.127 mm of linear movement.

Both sensors performed equally, however their characteristics did vary under the influence of the environmental conditions. The conditions which provided the greatest changes, were that of ambient light and vibration.

Having proved that these types of sensors may be utilised to provide a means of detecting movement of the leather components, a choice had to be made to build a prototype. The infra-red reflective opto switch was chosen due to its lower cost per unit.

7.5 Fulfilment of Integrated Sensing Arrays

The positioning of the sensing arrays has previously been discussed. In addition a sensor had also been identified which may be utilised and which also conforms to the constraints placed on its physical size. It was therefore necessary to provide assemblies which would secure the sensors into their pre-defined positions. The assemblies were designed to allow flexibility of movement, with a certain degree of rigidity.

The sensing arrays attached to their assemblies produce a silhouette of the components as they pass through the process. The coarse profiles are developed from a series of line scans which are taken. The line scans are then manipulated by the software to provide the silhouette of the component. The developed system resolution of the coarse profiles was fixed by the distance between the sensors, the component size and shape and the speed at which the components are travelling.

Each of the sensing arrays provide their own coarse profiles. The comparison of the two coarse profiles, using suitable software techniques on each line of data, enables the system to detect the movement of the components as they are transported to the skiving mechanism. The present design can detect a minimum angular movement of 1°, dependent upon component type.

Coarse profiles of samples of leather pieces are shown in appendix 11 and 12. They illustrate the full size silhouette of the component, with the subsequent figures showing the coarse profiles obtained. Initially no induced angle is applied to the components and no variation occurs in the line scans for the two sensing arrays. On applying an induced angular movement, the line scans vary. The lower set of line scans represents the coarse profile for the sensing array situated in the gap.

By placing the leather components in certain positions on the primary conveyor, an error in the profile generated by the sensing array was experienced. This error in the profile information was found to be caused by variation in height which the components experienced as they were on the transport system. Experiments that were carried out into varying the sensors height from the leather components indicated that a variation of ± 0.3 mm from their operating height, produces erroneous information.

The current sensing system contains the following properties:

- It can detect the presence of the leather components irrespective of their colour, shape or size.
- The system that has been implemented does not in any way disturb, or deform the leather components, as they flow through the process.
- The sensing array produces coarse profiles, which may be compared, to decide if movement has occurred.
- The system which has been implemented in this research can detect the movement of components to a minimum angle of 1°. This is performed without causing damage to the component texture.

7.6 Systems for Future Research

The resolution of the system is dependent upon the number of sensors in each array, the speed of the transport system, and the scanning speed of each line scan. The spacing between each of the sensors has also placed limitations on the relative angle which may be detected.

In order to reduce this angle, additional sensors will be required. Sensors with a relatively smaller work area may be installed between each of the sensors on the present arrays, or may be used on their own to produce new arrays. However the present technologies used to manufacture such devices make them very expensive.

The alternative option is to investigate the method of transporting the components from the camera recognition system to the skiving mechanism. This may include such areas as the material used for the upper conveyor belt, alterations to the framework, or changes to the actuator mechanism.

By modifying the framework it could be possible to increase the present size of the gap in the conveyor system belts. This would then enable the sensors utilised in this project to be rotated through 90°, thereby increasing the resolution. Alternatively other types of sensors discussed in this thesis may be utilised.

Implementing any of these suggestions would require the new system to provide a better resolution and greater detailed coarse profiles than the present system. Therefore tests will have to be carried out into their accuracy and repeatability. Depending upon the outcome of these investigations, the process of detecting angular movement may have to be developed further.

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Appendix 1

SENSOR	ELECTRICAL PROPERTIES	MECHANICAL PROPERTIES	COST	ADDITIONAL EQUIPMENT	COMMENTS
Standard make or break position switch	Switching capcity 500 v operating frequency 400Hz change over time 2 mS	mechanical $5 * 10^6$ operations	14.49		repetition accuracy ± 0.001 mm actuating force 8 N
Reflective opto switch	maximum power 50mW output voltage 5 V		3.57	Standard electronic equipment e.g. op-amps diodes and transistors	Uses Gallium Arsenide infra-red emitting diodes and matched detectors. Maximum output current occurs at reflective distance of 5 mm
Sub minature opto-switch. Micro switch style package	power 75 mW output voltage 5 V input voltage 1.3 V		2.89	Designed for p.c.b. mounting	Infra red source and opto-electronic receiving operated by lever. Used when opto-reflectve switch may be effected by dust/dirt.
Needle scanner	Supply voltage 15–30 V Output voltage 24 Vdc cable type connection	Mounted at 30–60° of needle		Requires control amplifier with up to 4 channels and counting card.	Scanning distance 15 mm ± 1mm maximum needle frequency 3000/s average service life 100,000 h detects defect needle
Photoelectric fibre-optic switch	NPN swiched output supply voltage 10–30 V infra-red light		24.10	Requires switching amplifier with response time of 15 mS	scanning range 0.5 to 20 mm switching frequency 1000/s accuracy dependent upon distance from object
Photoelectric sensor fibre optic type	NPN/PNP output supply voltage 10–30 V max load 100mA/30V			Optical fibres and amplifiers for modulated red light with power supply and relay o/p	response time < 1 mS delay time 100 mS maximum sensing frequency 500 Hz
Bar code reader	supply voltage 220V/50Hz			Serial ASCII RS 232 C, RS 422 or 20 mA current loop	Scan rate 500 scans/sec programmable to customer requirements
High precision C.C.D. line camera	Analogue output 0–5V 0–10V 4–20mA Operating freq up to 5 KHz			RS 232 C, RS422 or ASCII interfaces	Mainly used for edge, centre & width measurement interchangeable lens can measure up to 20 edges. Accuracy 1/1000
Linear variable differential transformer	input voltage 10–24 V		95.00		Non-linearity 0.3% stroke length ± 5 mm response time 1.5 mS
Linear position sensor	5 KΩ linear resistance electrical travel 10 mm	Mechanical life $5 * 10^6$ cycles	8.50	Best results obtained when used as a potential divider and not as a variable resistor	Tolerance ± 20% Linearity ± 2% Operating force 2 to 7.5N
Ultrasonic transducer	Directional angle 20° resonant frequency 40 ± 1 KHz		6.98	Standard electronic equipment	Typical operating distance 5m
Precision position switch	Maximum voltage 24V switching current 50mA transistorised outputs	Mechanical life $1 * 10^7$ steel/stone stylus	77.47	Relays etc	Acuating force 75g necessary displacement 0.001mm reproducibility ± 0.001mm

Figure A1 Sensor comparison table

Appendix 2

Program 1

The program provides a pre-determined clock pulse from the system timing controller. The clock pulse is utilised to provide rotational motion through a rotary table. An internal counter then counts the pulses and produces a fixed datum point, every revolution. Using one of the remaining counters within the system timing controller, the number of pulses are counted from the datum to the component edge being detected. The time variation between the datum and the detected edge is then stored to a file for future analysis.

A description of each section is given below:

section	description
A	Header files and definitions of specific memory addresses for use in the system timing controller.
B	Set global variable types for use within the program. In addition the test values are made void at the beginning of their function and when the program returns from testing.
C	Configures system timing controller. Produces clock pulse from frequency generator and sets values within each of the counters being utilised.
D	Tests carried out to the digital input port of the system timing controller. This indicates when the table has reached its fixed datum and the component edge has passed the detector.
E	Utilisation of counter register within the system timing controller to provide elapsed time from datum to the detection of the component edge.
F	Section (E) is repeated until a key is pressed. This enables the rotary table to stabilise itself at a fixed rotational speed.
G	This is identical program to section (E), however the time data is stored in a file for future analysis. The loop is repeated 100 times. Following completion the file is then closed.

PROGRAM 1

This program provides the clock pulses for the rotary table, and counts them in counter 3. Frequency to operate rotary table derived from counter 4. The program enables the rotary table to reach a stable speed before commencing counting to a file. This is initiated by pressing a key.

```
 /* This program is kept at b:\acc3.c          */
 /* It is to be developed for finding accuracy */
 /* of the sensors. Counter 3 will be used to  */
 /* count the number of pulses per revolution  */
 /* of the index table.                        */                          sections
                                                                           --------------
# include <stdio.h>
# include <conio.h>
/* set up addresses for system timing controller */
# define base 0x0300  /* base address */
# define data base    /* data address for/from  controller */
# define cmds base+1  /* commands to and status of  controller*/               A
# define dinp base+2  /* address of digital input port */
# define dotp base+3  /* address of digital output port */
# define mask 0x0001  /* mask to test for input change       */
# define mask1 0x0002 /* mask to test for sensor edge */
# define mask2 0x00FF /* mask to change count value to integer */
                                                                           --------------
config_sys( );        /* declaration of the function used */
void test(void);
void test1(void);
   FILE *fp;                                                                   B
   int old,new;
   int sen,seneg;
/* configure the data ports in control board */                            -------------
config_sys( )
{
   printf(" The program is now running");

  _outp(cmds, 0x17) ;  /* set control to access master mode reg */
  _outp(data, 0xE0) ;  /* low byte of MMR to output F4 */
  _outp(data, 0xC1) ;  /* high byte of MMR */
  _outp(cmds, 0x03) ;  /* set up program counter mode reg 3 */
  _outp(data, 0x21) ;  /* low byte of counter mode reg to give freq
                          from F4 on counter 3.  */
  _outp(data, 0x1E) ;  /* high byte of counter mode register */
  _outp(cmds, 0x0B) ;  /* set load reg of counter 3 with next bytes */
  _outp(data, 0xA0) ;  /* low byte of load reg */                              C
```

```
   _outp(data, 0x05) ;   /* high byte of load reg for counter 3
                         to count down from 1440 */
   _outp(cmds, 0x64) ;  /* arm counter 3 to operate */
   _outp(cmds, 0x04) ;  /* set up program counter mode reg 4 */
   _outp(data, 0x11) ;   /* low byte of reg to utilise freq from
                         F4 on counter 4 */
   _outp(data, 0x9D) ;  /* counts on falling edge */
   _outp(cmds, 0x0C) ; /* set load reg of counter 4 with next bytes */
   _outp(data, 0xFF) ;   /* place maxm value in load reg 4 */
   _outp(data, 0xFF) ;   /* load reg 4 complete with all ones */
   _outp(cmds, 0x48);   /* load counter 4 */
   _outp(cmds, 0x28);   /* arm counter 4 */
}
                                                          --------------
void test( )
{
   old = _inp(dinp);        /* place value on inputs in old */
         if ( old & mask ) new = 1;    /* set new if mask and inp same */
  else new = 0;
}
                                                              D
void test1( )
{
   sen = _inp(dinp);        /* place value on digital inputs in sen */
         if ( sen & mask1 ) seneg = 1;  /* set seneg if mask and inp same */
  else seneg = 0;
}
                                                          --------------
main( )
{
   int time,i;
   config_sys( ); /* configure system */
   test( ); /* start initial test for component */

  fp = fopen ("b:test18.XLS","w");      /* open file for writing to */
                                                          --------------

   do{
         if ( new == 1 ){

            test1( ); /* need to identify when sensors detects edge & JK reset */
              while (seneg == 1) {
              _outp(cmds, 0x88); /* saves count to hold reg */
              _outp(cmds, 0x14); /* hold reg accessed for reading to file */
                time= _inp(data); /* contents of hold reg put in low byte of time */
                 time ^= mask2 ; /* exor data to return original value */
```

```
              printf( "The value of time is %d\n",time); /* print value of time */
             seneg = 0;                                                E
            new = 0;
           _outp(cmds, 0x48); /* load counter 4 */
                                   }
                           }
        else                                                      --------------
        test( );
                                                                       F
   }while (!_kbhit( ));
  i = 0;                                                          --------------
  do{
        if ( new == 1 ){
         test1( ); /* need to identify when sensors detects edge & JK reset */
         while (seneg == 1) {
         _outp(cmds, 0x88); /* saves count to hold reg */
          _outp(cmds, 0x14); /* hold reg accessed for reading to file */
            time= _inp(data); /* contents of hold reg put in low byte of time */
           time ^= mask2 ; /* exor data to return original value */

          fprintf( fp, "%d\n", time ); /* place value of time in file */
         printf( "The value of time is %d\n",time); /* print value of time */
        i = i + 1;
        printf (" the value of i is %d\n", i);
         seneg = 0;                                                    G
         new = 0;
          _outp(cmds, 0x48); /* load counter 4 */
          _outp(cmds, 0x28); /* arm counter 4 */
                             }
                         }
        else
               test( );
      }while ( i < 100);                                          ---------------
           fclose(fp); /* close file before ending program */

}
```

Program 2

The program provides a clock pulse, from the internal frequency generator, to drive the rotary table. In addition a counter is utilised to monitor the time delay from one component edge to the detection of the next edge.

A description of each section is given below:

section	description
A	Header files and definitions of specific memory addresses for use in the system timing controller.
B	Configuration of system timing controller to utilise counter 5. It counts falling edge clock pulses from a frequency counter set at 1000 Hz.
C	The counter is enabled for counting. It commences counting on obtaining active high level on its gate. The counter continues counting rising clock pulses from the selected internal counting source. When the gate level returns to zero, the counter is disarmed. Counter value is placed within a hold register. The information can then be used to display the time elapsed for the gap.
D	All variables and counter values are reset.

PROGRAM 2

```
/* This program is kept at b:\rep4.c */
 /* It was developed for finding repeatability of two components */
 /* on the index table. Counter 5 counts source edges */                    section
                                                                            -------------
# include <stdio.h>
# include <conio.h>
# define base 0x0300     /* base address of controller */
# define data base       /* data address for/from controller */
# define cmds base+1     /* commands to and status of controller */
# define dinp base+2     /* address of digital input port */                   A
# define dotp base+3     /* address of digital output port */
# define mask 0x0001     /* mask to test for input change */
# define mask1 0x0002    /* mask to test for sensor edge */
# define mask2 0x00FF    /* mask to change count value to integer */
                                                                            -------------
config_sys( );          /* declaration of the function used */
void test(void);
void test1(void);
   FILE *fp;
   int old,new,x,j;
   int sen,seneg;
                                                                            -------------
config_sys( )
{
   printf(" The program is now running");

  _outp(cmds, 0x17) ;  /* set control to access master mode reg */
  _outp(data, 0xE0) ;  /* low byte of MMR to output F4 */
  _outp(data, 0xC1) ;  /* high byte of MMR */
  _outp(cmds, 0x05) ;  /* set up program counter mode reg 5 */
  _outp(data, 0xA1) ;  /* low byte of reg to utilise freq from
                       F4 on counter 5 */                                      B
  _outp(data, 0x8E) ;  /* counts on falling edge */
  _outp(cmds, 0x0D) ;  /* set load reg of counter 5 with next bytes */
  _outp(data, 0xFF) ;  /* place maxm value in load reg 5 */
  _outp(data, 0xFF) ;  /* load reg 5 complete with all ones */
  _outp(cmds, 0x50);   /* load counter 5 */

}
                                                                            -------------
void test1( )
  {
          sen = _inp(dinp); /* place value on digital inputs in sen */
          if ( sen & mask1 ) seneg = 1; /* set seneg if mask and inp same */
```

```
          else seneg = 0;
  }
delay( )
  {
    for (x=0; x<4; x++ )
          {;
            for ( j = 65535; j--;)
                  ;
          }
  }
main( )
{
   int time,lo,i;
   config_sys( );
   test1( );
   I=0; /* initialise the counter */
    _outp(cmds, 0x30);  /* arm counter 5 */
     printf(" The counter is armed\n");
   do{
   test1( );
          if ( seneg == 1 ){
                                                                   --------------
            _outp(cmds, 0xD0); /* disarm counter 5 */
             printf("The counter is not armed");
              _outp(cmds, 0x90); /* saves count to hold reg */                C
               _outp(cmds, 0x15); /* hold reg accessed for reading to file */
                time = _inp(data); /*contents of hold reg put in low byte of time */
                 time ^= mask2 ; /* exor data to return original value */
                printf( "The value of time is %d\n",time); /* print value of time */
               i=i+1;
              printf("The value of i is %d\n", i );
             seneg = 0;                                                   ---------------
            _outp(cmds, 0x30); /* arm counter 5 */
            _outp(cmds, 0x50);  /* load counter 5 */                          D
           time=65536;
          delay( );
                                                                   --------------
                          }
     else
       test1( );

     }while (!_kbhit( ) );

}
```

Appendix 3

The graphs illustrated in appendix 3 represent results obtained using the program developed for obtaining the accuracy of the sensing system. The horizontal axis is the number of observation taken, i.e. complete revolutions of the rotary table.. The vertical axis is the time variation between the datum point and the edge of the component. These are measured in milliseconds.
The fluctuations in the results are independent of the number of observations. They occur in random positions within the 100 observed revolutions.
The final graph illustrates 300 observations of the measured distance between the datum and the component edge. The time scale of the clock pulses has been changed to 1 microsecond.

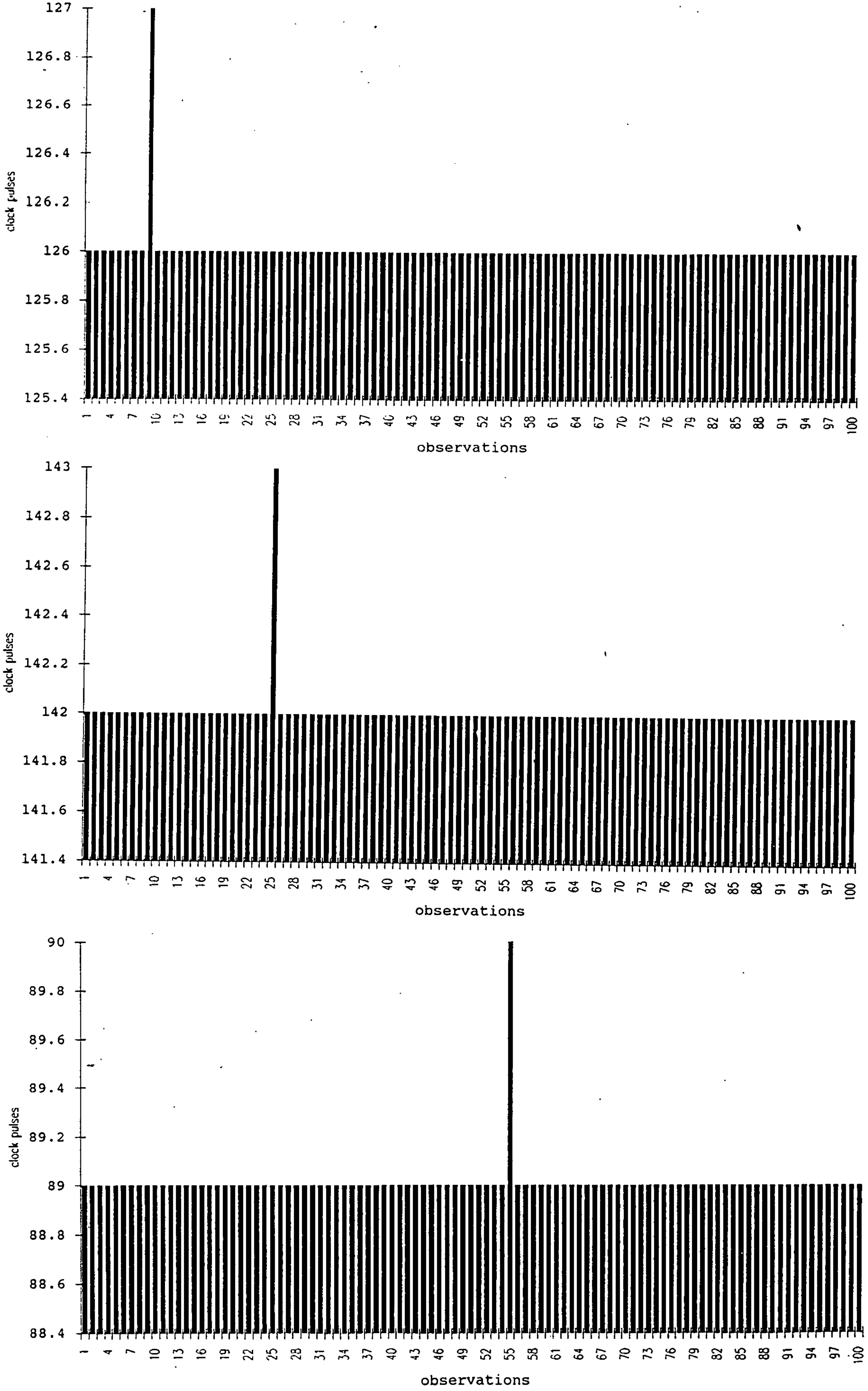


Figure A3-1 Fluctuations in accuracy tests

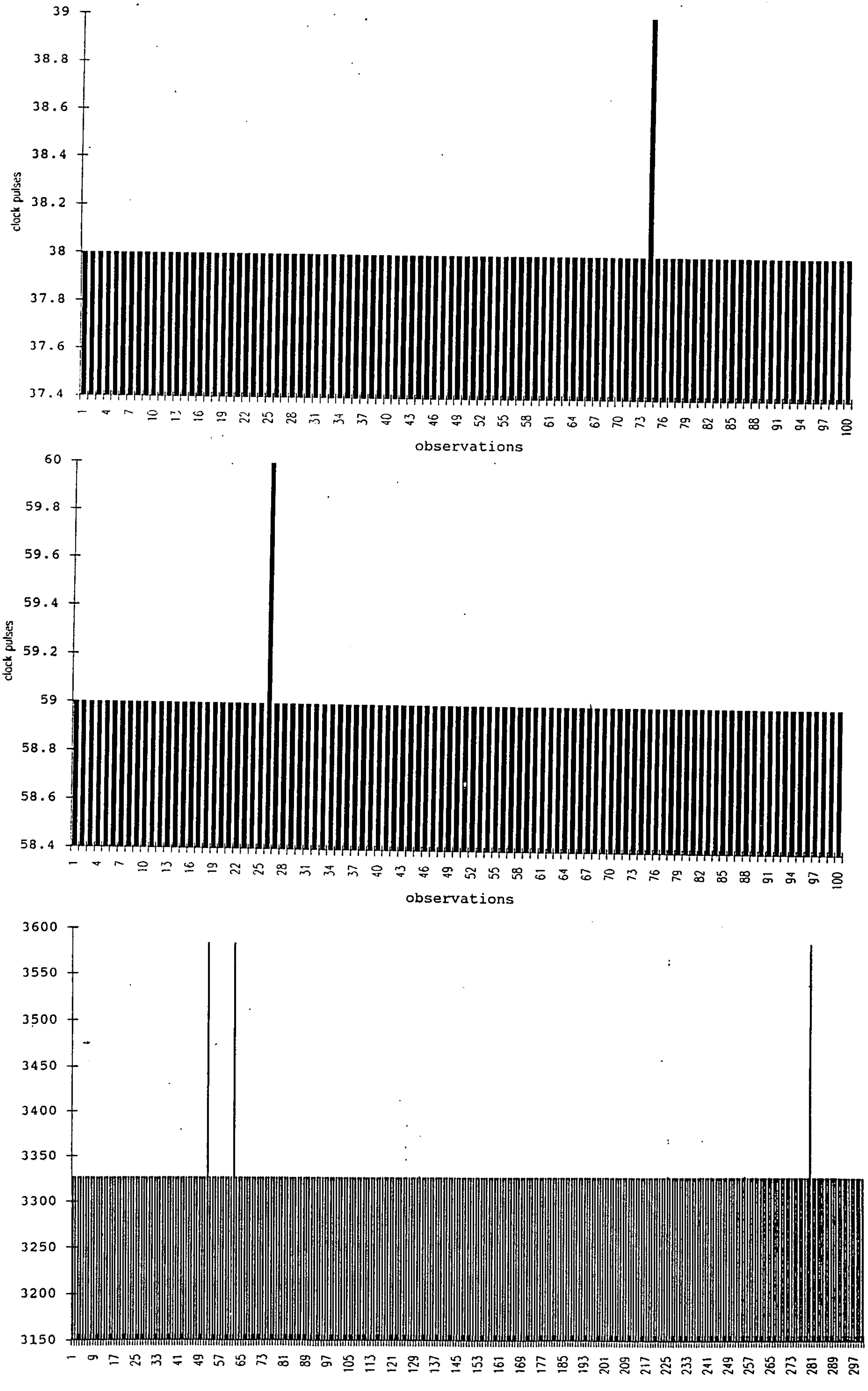
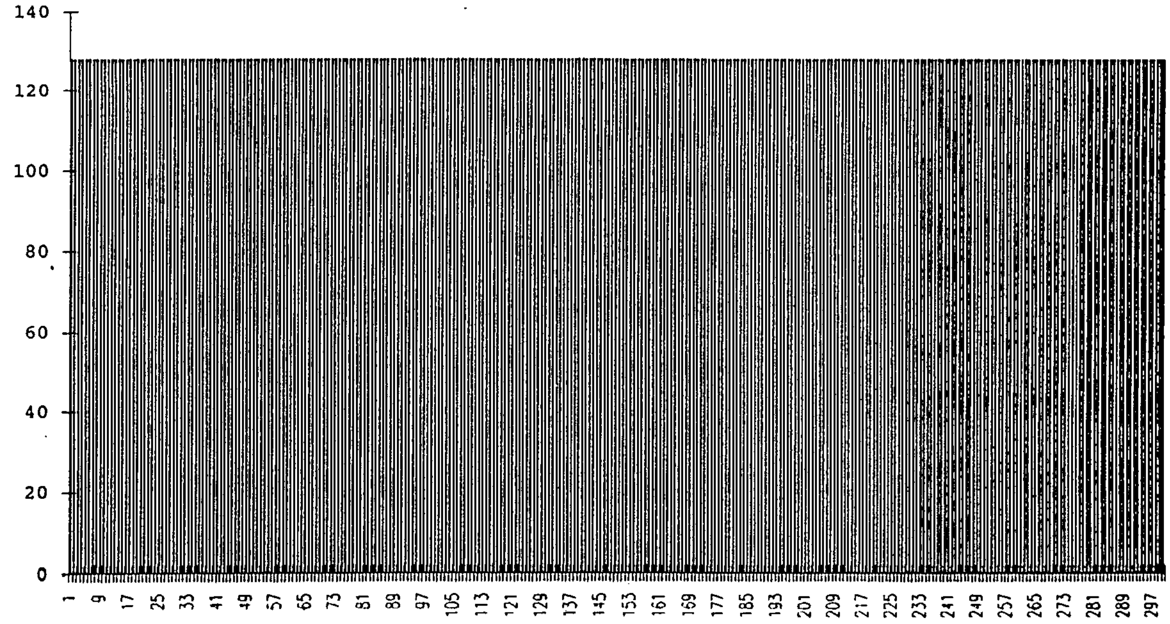


Figure A3-2 Fluctuations in accuracy test

Appendix 4

The graphs that are displayed in appendix 4 were obtained using the repeatability programme described in this thesis. The horizontal axis represents the number of rotary table revolutions. The vertical axis shows the number of clock pulses which were counted in the controller system counter. These clock pulses are the time between two components and are measured in milliseconds.



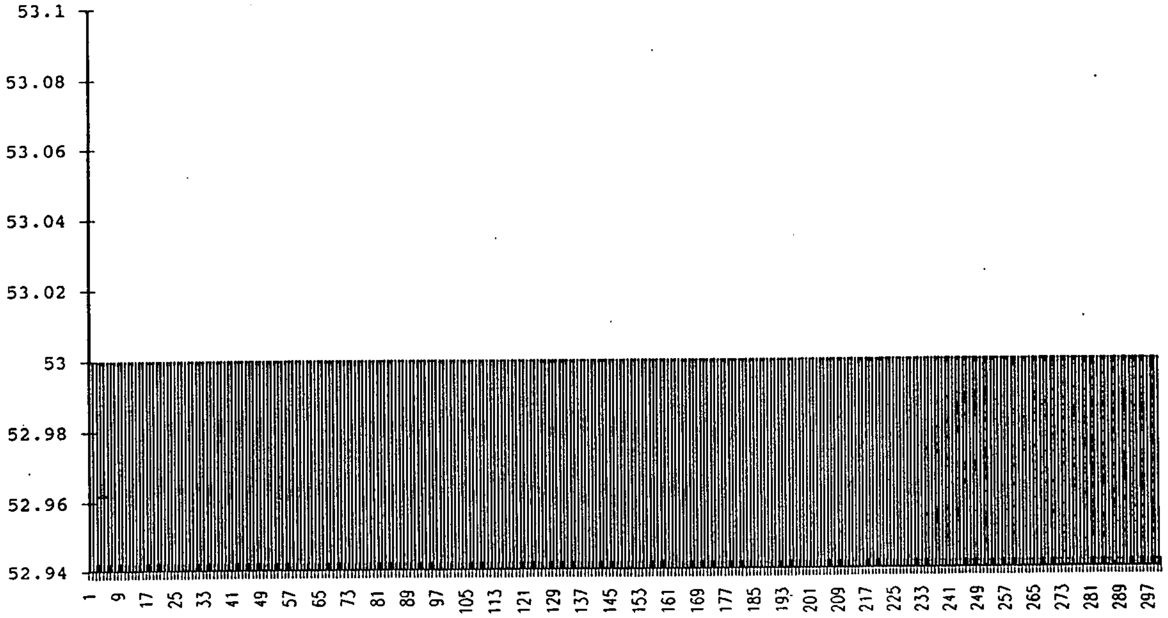


Figure A4-1 Samples of clock pulses recorded for varying gaps using the repeatability test

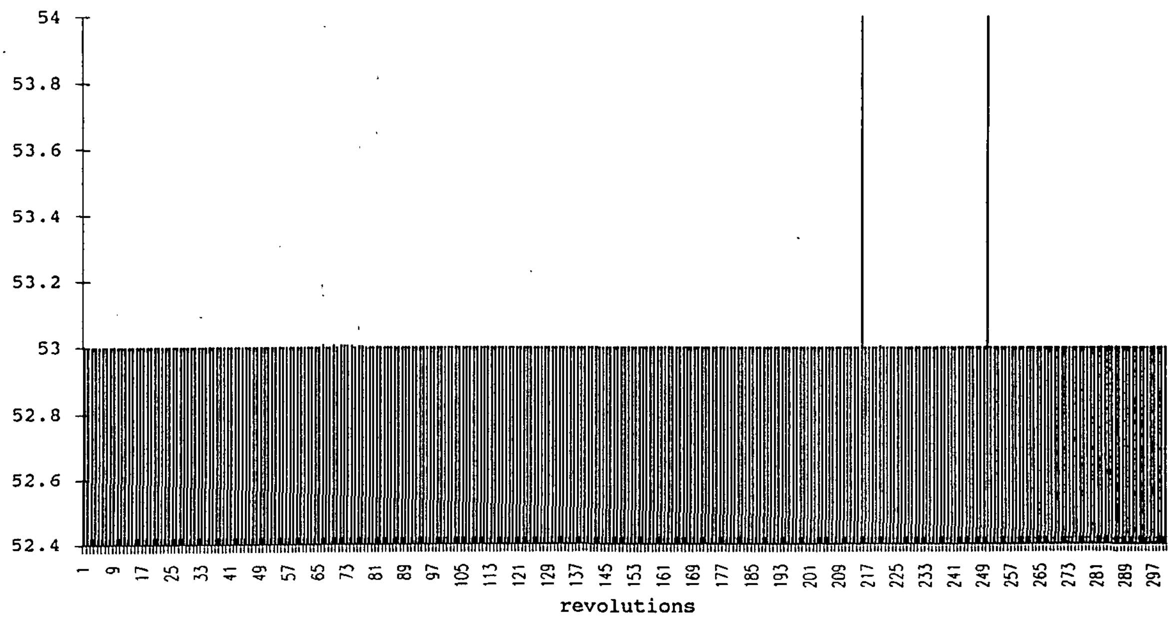
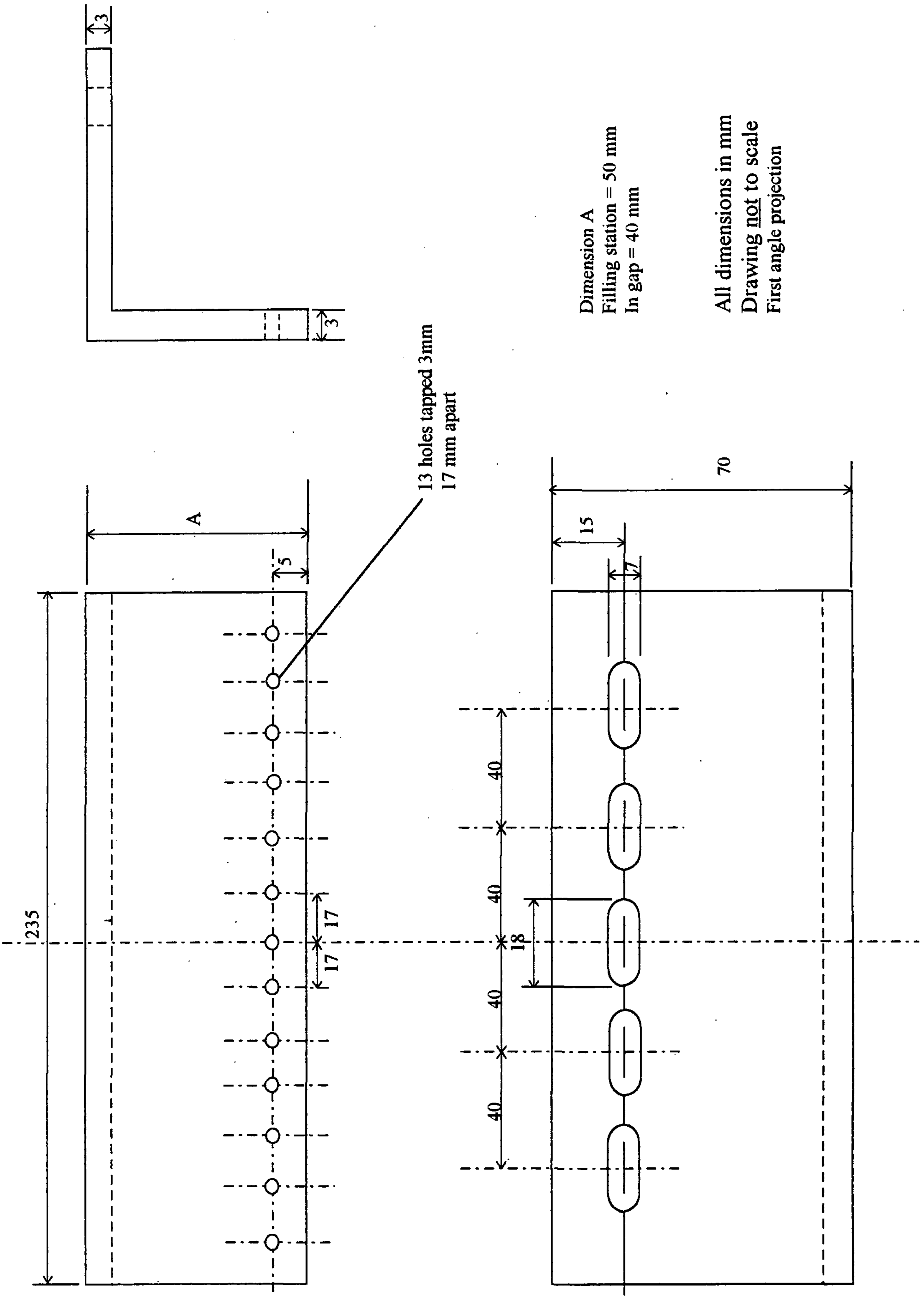


Figure A4-2 Sample for repeatability test

The above figure, illustrates the number of clock pulses recorded, between two components placed on the rotary table. However, from the 300 observations taken two varied. The variation between these values and the remaining 298 observations is only one clock pulse. This variation in time represents a distance of 0.127 mm of linear travel.

Appendix 5



Dimension A
Filling station = 50 mm
In gap = 40 mm

All dimensions in mm
Drawing not to scale
First angle projection

Figure A5-1 Angle bracket mounting for sensor arrays

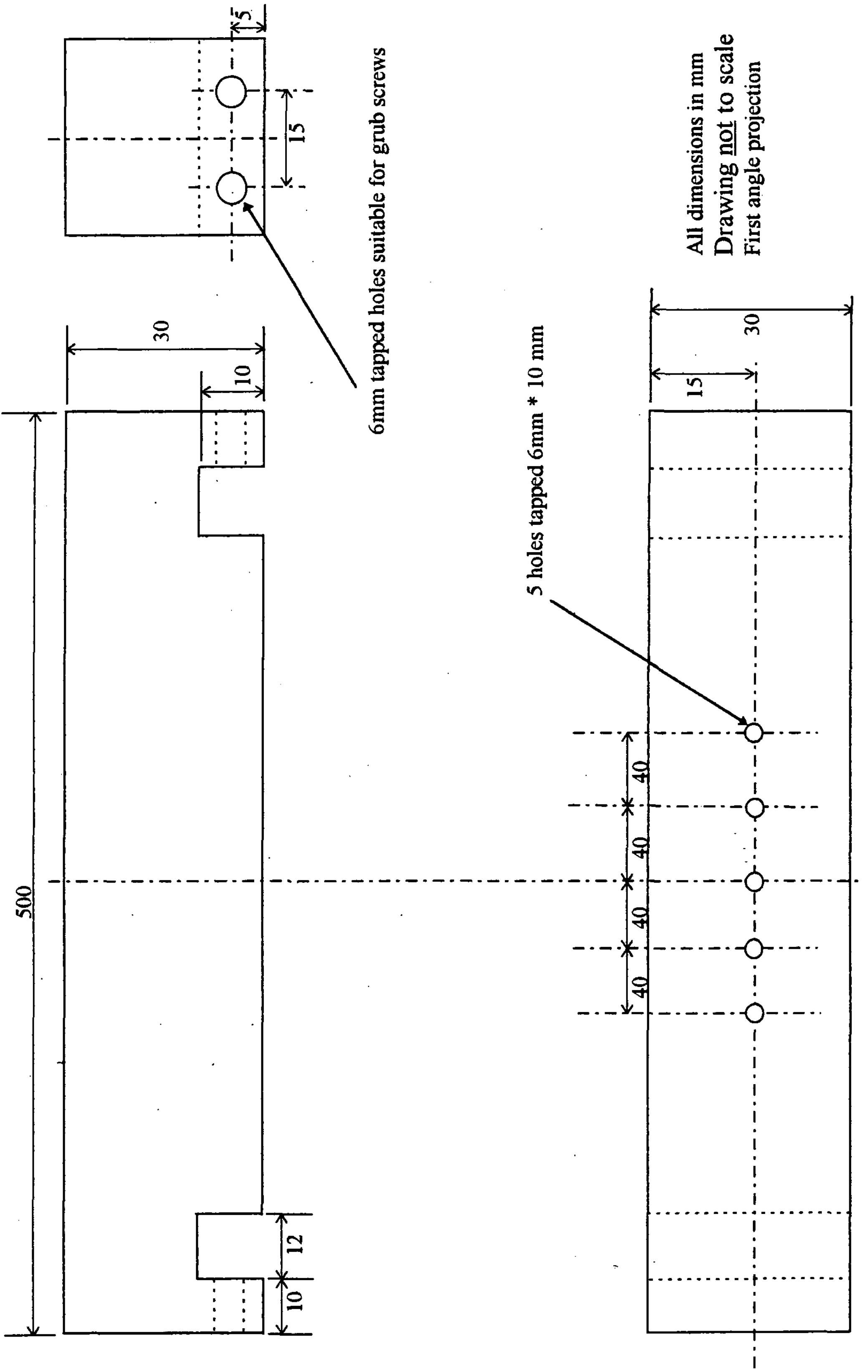


Figure A5-2 Mounting base for sensor array above 7 mm gap

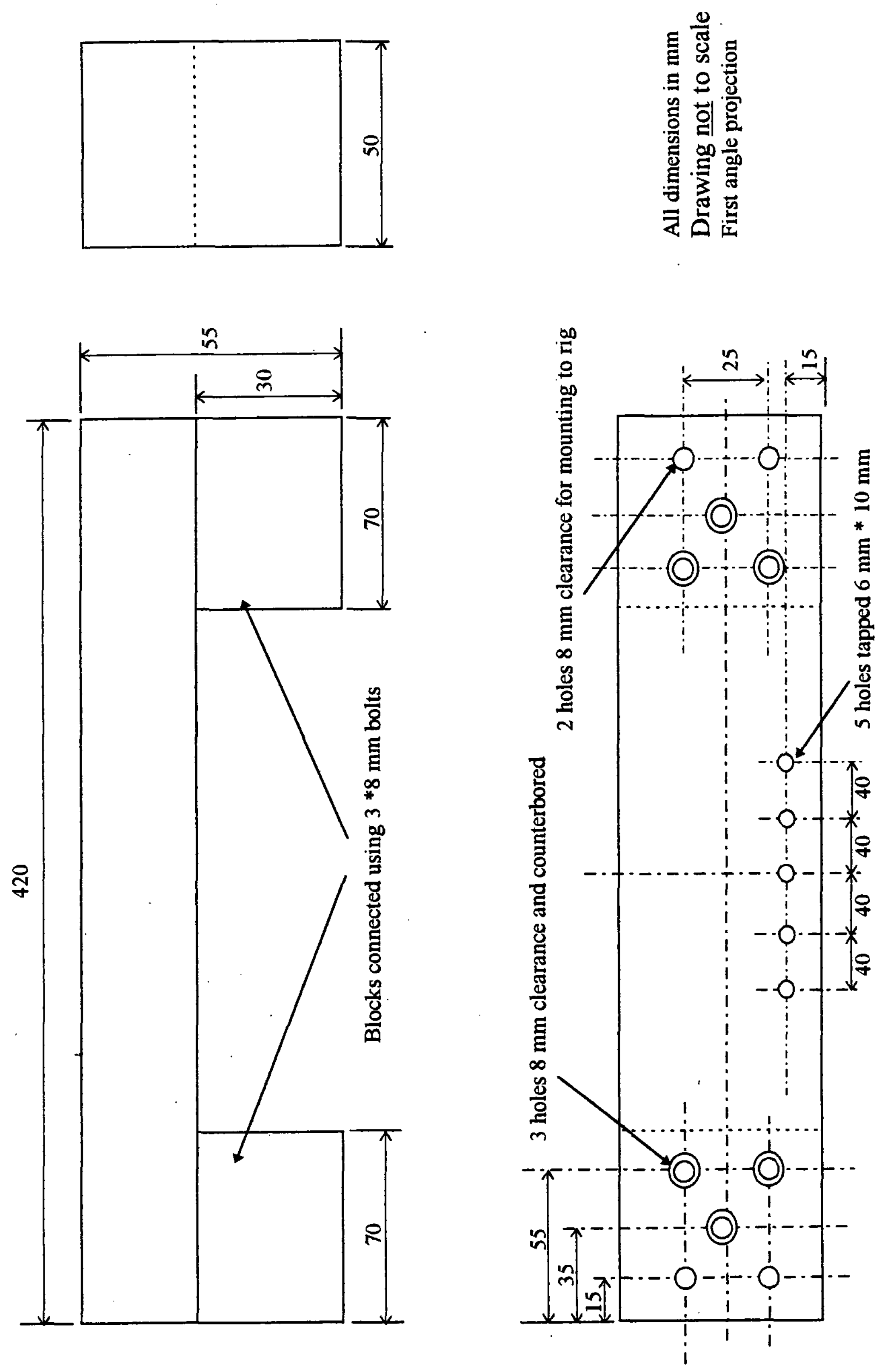


Figure A5-3 Mounting base for sensor array above filling station

Appendix 6

Figure A6-1 illustrates the amplification circuitry used for both of the sensing arrays. Each of these circuits are secured to the machine framework and is therefore susceptible to vibration.

Potential sources of malfunction could be the connector to each individual circuit and the potentiometers within the circuits.

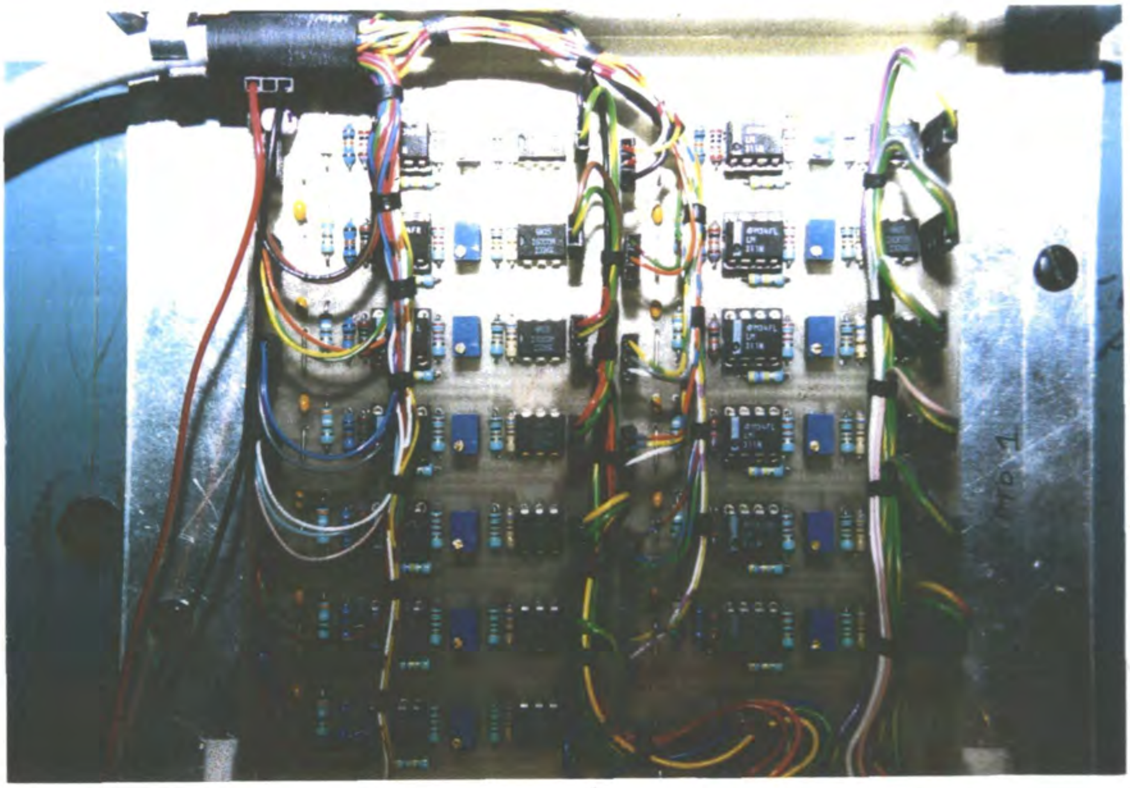


Figure A6-1 Amplification circuitry for sensor array

Appendix 7

The sensing array above the primary conveyor system is identified as row A. Row B is the sensing array situated in the gap on the three layer conveyor system.

All the sensor signals each have their individual amplification circuits, providing signal adjustment were required. The amplified signals are transferred to the 2-line to 1-line data selectors.

There are eight selectors for the lower byte and a similar configuration for the upper byte. A control signal from the system timing controller selects either of the two inputs. The software program utilises the digital 1 output port for this operation. By placing a zero on the data selector, then sensor array A is selected. A digital one selects sensor array B.

The lower byte of information is transferred to the first system timing controllers eight digital input ports. The upper byte being placed in the second system timing controllers digital input ports.

The digital information placed on both digital ports is read by the software program. The upper byte is shifted by the program and attached to the lower byte to produce one line scan of information. The coarse profiles that are produced contain 100 line scans.

Each of the sensing arrays contains thirteen sensors, therefore the upper three bits are not required (NR). These bits are masked by the software program.

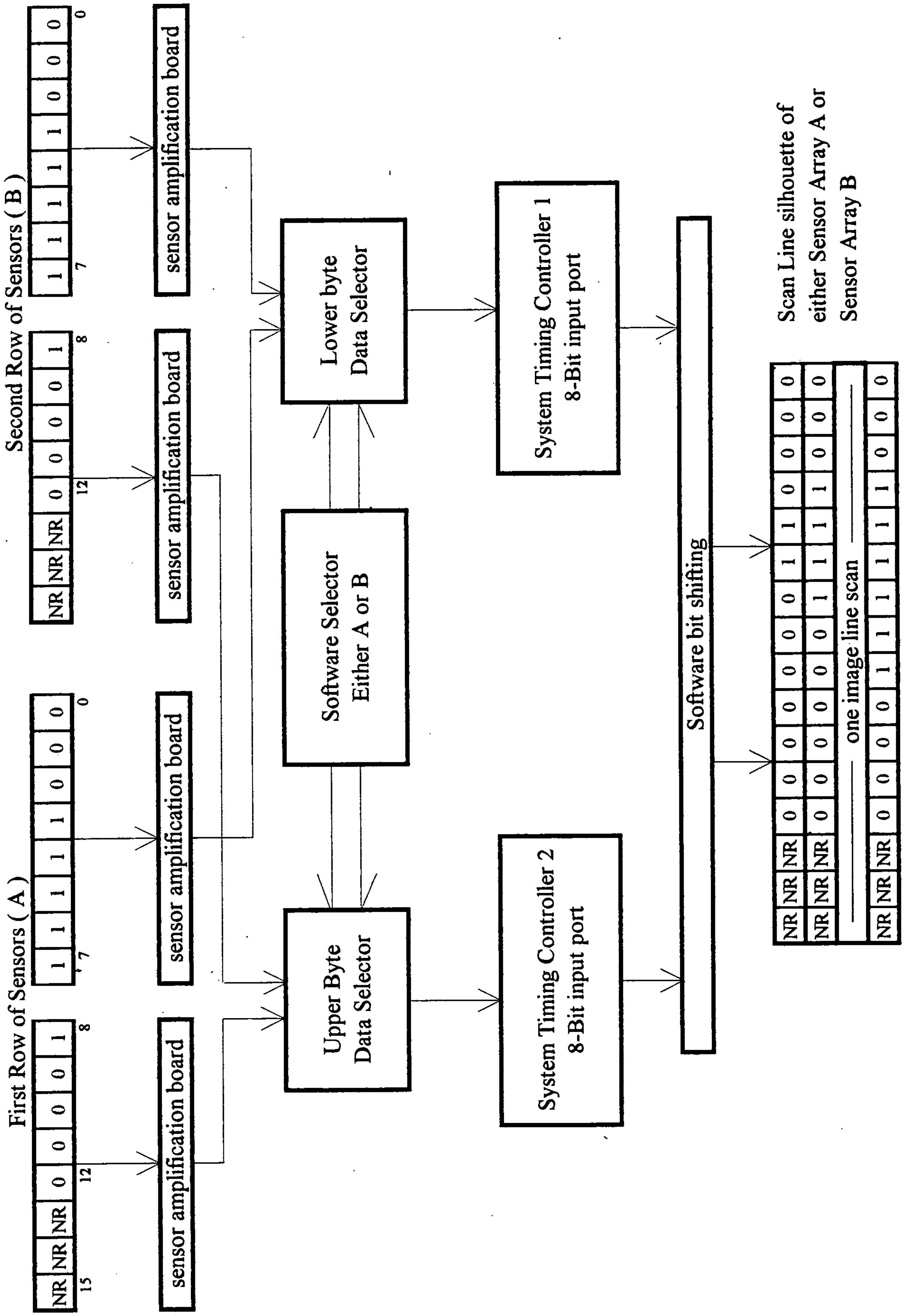


Figure A7-1 Digital information flow chart diagram

Appendix 8

Program 3

The program scans the first sensing array for the presence of a component. On detecting the component 100 line scans of information are taken. The line scans are combined to produce a coarse silhouette of the components. The program then waits until the component arrives at the second sensing array. A similar process is then carried out.

Both profiles of information are displayed on the screen within a grid matrix. The shaded areas indicate the presence of the component. Each of the silhouettes are compared and an indication is given as to whether the component has moved or not.

The various sections of the program are described below:

section	**description**
A	Header files and definitions of specific addresses for use within the two system timing controllers.
B	Test 1 and test 2 examine the first and second sensing arrays, respectively, for the presence of a component. This then produces an interrupt flag for use within the main program.
C	This section provides the time delay between each of the line scans, on either of the two sensing arrays.
D	Allocates the global variable types to be used within the main program.
E	Waits until test 1 has indicated the presence of a component. It sets digital output 1 to zero, selecting one of the 2-line to 1-line inputs. The digital information is then manipulated by the program to produce a 16-bit line scan. There are 100 individual line scans used to produce a coarse silhouette.
F	This performs the same function as section (E). However test 2 waits for the component reaching the second array. In addition the digital output is set to 1, selecting the other input to the data selector.
G	Sets the computer screen to its maximum resolution. It then produces a rectangular box containing 16 columns and 100 rows.
H	Each of the individual squares are then colour filled if a digital 1 is present in any bit of the line scan data information.
I	A similar grid is placed on the screen, under the first. This represents the information from the second sensing array.
J	Returns variables to their default mode and resets the resolution of the computer screen.
K	Tests each row of digital information from the first sensing array against the similar row from the second array. If no discrepancies are found, it indicates that no movement has occurred.

PROGRAM 3

The program contains a software interrupt, it waits until the component reaches the first bank of sensors. 100 observations are taken. The program returns to its wait state for the second interrupt. Once again 100 observations are taken. Both sets of information are placed in a file. The information is also displayed in two grids produced by the program.

```
 /* This program is kept at C:\JIM\identa5.c */
 /* It was to be developed for finding accuracy */
 /* of the component though the conveyor system. */
 /* It will display both banks of sensors on screen.  */                sections
                                                                        -------------
# include <stdio.h>
# include <conio.h>
# include <graph.h>
# define base 0x0300    /* base address of controller card */
# define data1 base     /* data address for/from controller #1*/
# define cmds1 base+1   /* commands to and status of controller #1*/
# define dinp1 base+2   /* address of digital input port #1*/
# define dotp1 base+3   /* address of digital output port #1*/
# define data2 base+4   /* data address for/from controller #2*/            A
# define cmds2 base+5   /* commands to and status of controller #2*/
# define dinp2 base+6   /* address of digital input port #2*/
# define dotp2 base+7   /* address of digital output port #2*/
# define mask 0x0000    /* mask to test for input change */
# define mask1 0x1FFF /* mask to use only 13 sensors */
# define mask2 0x0FFE  /* mask to use only 11 sensors */
                                                                        -------------

test1(void);
test2(void);
   FILE *fp;
   int old,new,a,j;
   int sen,sen1,sen2,seneg;
   int lo,snsr,snsrs,seneg2;


                                                                        -------------
test1( )
{
          _outp(dotp1, 0x00) ; /* set digital output 1 port#1 low */
             sen = _inp(dinp1); /* place value on digital inputs in sen */
               sen1=((_inp(dinp2)&0x1F)<<8) + sen; /* contents of input2 put in
                                                         high byte */
             sen2 = sen1 & mask1;
           if ( sen2 ) seneg = 1; /* set seneg if inp high */
          else seneg = 0;
}
```

```
test2( )                                                                B
{
          _outp(dotp1, 0x01) ; /* set digital output 1 port#1 high */
            sen = _inp(dinp1); /* place value on digital inputs in sen */
               sen1=((_inp(dinp2)&0x0F)<<8) + sen; /* contents of input2 put in
                                                       high byte */
            sen2 = sen1 & mask2;
           if ( sen2 ) seneg2 = 1; /* set seneg if inp high */
          else seneg2 = 0;
}
                                                                    --------------
delay1( ) /* this loop gives 1 mS pulse or frequency of 1 kHz */
  {
    for (a=0; a< 35; a++ )
          {;                                                            C
             for ( j = 325; j--;) /* delay loop*/
                      ;
          }
  }
                                                                    --------------
main( )
{
   int lo,i;
   int f,h,x,w;
   short int index3 =15; /* index value of 15 to give white */
   long int snsr, snsrs,snsrs1;
   int index,test3;                                                     D
   int bank1[100];
   int bank2[100];
   printf(" The program is now running");
   fp = fopen ("b:shp4.xls", "w"); /* open file */
while (!_kbhit( )) /* program waits for key to be pressed  */
                                                                    --------------
{

    do test1( ); while (seneg==0);
      do{
          for ( i = 0; i < 100; i++ ) /* this samples opto1 */
          {
          _outp(dotp1, 0x00) ; /* set digital output 1 port#1 low */
            lo = _inp(dinp1); /* contents of input1 put in low byte       */
             snsr=(_inp(dinp2))<<8 ; /* contents of input2 put in high byte */
               snsrs = snsr + lo;
                 snsrs1 = snsrs & mask1;,
               bank1[i] = snsrs1;
              sen1 = snsrs1;                                            E
```

```
          fprintf ( fp, "%d\n", bank1[i] );

          delay1( );

        }
        seneg = 0 ;
    }while ( seneg == 1 );
        seneg = 0;
                                                            --------------
 test2( );

do test2( );  while (seneg2==0);
   do{

        for ( i = 0; i < 100; i++ ) /* this samples opto2 */
         {
        _outp(dotp1, 0x01) ; /* set digital output 1 port#1 high */
         lo = _inp(dinp1); /* contents of input1 put in low byte       */
          snsr=(_inp(dinp2))<<8 ; /* contents of input2 put in high byte */
           snsrs = snsr + lo;
             snsrs1 = snsrs & mask1;
           bank2[i] = snsrs1;                                         F
          sen1 = snsrs1;
         fprintf ( fp, "%d\n", bank2[i] );

         delay1( );

         }
        fclose(fp); /* close file */
         _outp(dotp1, 0x00) ; /* set digital output 1 port#1 low */
        seneg2 = 0 ;

     }while ( seneg2 == 1 );
        seneg2 = 0;
                                                            --------------
/* print results to screen */

 if( _setvideomode( _MAXRESMODE ))
/* production of graph for first bank of sensors */
 {
   _setcolor ( index3 );
   _rectangle( _GBORDER, 10, 10, 410, 210 ); /* produces rectangular box */
   h = 10 ;
   for ( x = 0; x < 16; x++ )
   {
        _moveto ( h, 10 ); /* vertical line for sections*/
```

```
          _lineto ( h, 210);                                              G
        h = h + 25;
    }
    h = 10 ;
    for ( x = 0; x < 100; x ++ )
    {
        _moveto ( 10, h ); /* horizontal line for box*/
          _lineto ( 410, h );
        h = h + 2 ;
    }
                                                                   --------------
    h = 2;
    w = 25;
    for ( i = 0; i < 100 ; i++ )
      {                                                                   H
        for ( x = 0; x < 16 ; x++)
        {
            if ( bank1[i] & (0x8000 >> x )) /* fills in each square when
                                              component present */
           _floodfill( ( w * x) + 15, (h * i) + 11, index3 );
        }
      }
                                                                   --------------
/* production of graph for second bank of sensors */
    _rectangle( _GBORDER, 10, 220, 410, 420 );
    h = 10 ;
    for ( x = 0; x < 16; x++ )
    {
         _moveto ( h, 220 ); /* vertical line */
           _lineto ( h, 420);
        h = h + 25;
    }
    h = 220 ;
    for ( x = 0; x < 100; x ++ )
    {
        _moveto ( 10, h ); /* horizontal line */
          _lineto ( 410, h );
        h = h + 2 ;
    }
    h = 2;
    w = 25;
    for ( i = 0; i < 100 ; i++ )                                          I
      {
        for ( x = 0; x < 16 ; x++)
        {
           if ( bank2[i] & (0x8000 >> x ))
```

```
            _floodfill( ( w * x) + 15, (h * i) + 221, index3 );
          }
       }
                                                                          --------------
    _getch( );
    sen1 = 0x0000;
    seneg = 0;                                                               J
    _setvideomode( _DEFAULTMODE );
  }
  else _outtext( " The program requires EGA or VGA. " );
                                                                          --------------
      for ( i = 0; i < 100; i++ )
          {
            if ( bank2[i] != bank1[i] )
             { test3 = 0 ;
                 break ;
             }
          }
    if ( test3 == 0 )                                                        K
          {
            printf(" The component has moved\n");
            test3 = 1 ;
          }
    else
          printf(" The component is good\n");
    test1( );
                                                                          --------------
  }
}
```

Program 4

The program provides a means of retrieving previously stored data and displaying it on the screen. It reads the data required from storage memory. Draws the necessary grids, then places the silhouette information within each grid.

The various sections of the program are described below:

section	**description**
A	Header files for global use . Opens up a file within the program and allocates variable types.
B	Sets program variables and reads previously stored data from stated file.
C	Sets maximum resolution of the screen. Draws a grid of 16 columns and 100 rows on the screen. The file is scanned for the first 100 component line scans. It then proceeds to fill in the relevant areas, according to the digital information stored.
D	This provides a silhouette of the informaton gained from the second sensing array. It utilises the next 100 line scans.
E	The two silhouettes remain on the screen until a key is pressed. This then returns the screen to its original resolution and closes the file selected.

PROGRAM 4

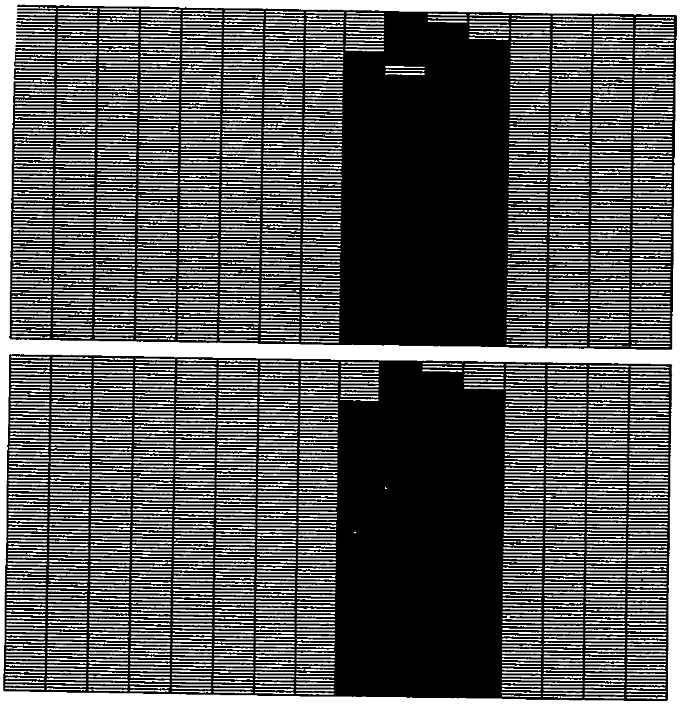
The program reads a file previously stored in memory. It then draws two grids on the screen to represent observations from both sensing arrays. Grids are filled to provide course profile of the component.

```
 /* This program is kept at b:\twosqr3.c, disk 10  */
 /* It is to be developed for reading data in */
 /* and displaying on the screen. */                          sections
                                                              --------------
# include <stdio.h>
# include <conio.h>
# include <graph.h>
# include <stdlib.h>
                                                                 A


   FILE *fp1;
   int old,new,a,j,x;

                                                              --------------
main( )
{
  char buffer[20],a;
  int f,g,h,x,w,i,k;
  short int index3 =15; /* index value of 15 to give white */
  long int old3;                                                 B
  int bank1[101];
  int bank2[101];
  fp1 = fopen ("b:shp3.xls", "r"); /* read in file name */
                                                              --------------
 /* produces first grid */
  if( _setvideomode( _MAXRESMODE ))

  {
    _setcolor ( index3 );
    _rectangle( _GBORDER, 10, 10, 410, 210);
    h = 10 ;
    for ( x = 0; x < 16; x++ )
         {
          _moveto ( h, 10 ); /* vertical line */
           _lineto ( h, 210);
          h = h + 25;
         }
    h = 10;                                                      C
    for ( x = 0; x < 100; x++ )
```

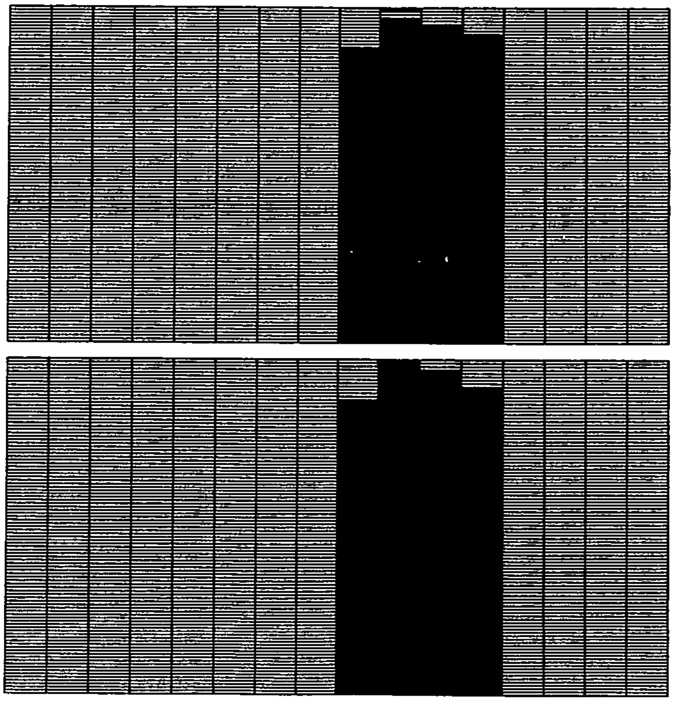
```
           {
            _moveto ( 10, h ); /* horizontal line */
              _lineto ( 410, h );
            h = h + 2;
           }
  h = 2 ;
  w = 25 ;
   for ( i = 0; i <100; i++ )
           {
            fscanf (fp1, "%d\n", &k); /* scan file for first 100 observations */
              _itoa( k, buffer, 2);
            for ( x = 0; x < 16; x++ )
           {
             if ( k & (0x8000 >> x ))
                 _floodfill ( ( w * x ) + 15, ( h * i ) + 11, index3 );
           }
           }
                                                                          -------------
/* produces second grid */
      _rectangle( _GBORDER, 10, 220, 410, 420 );
    h = 10 ;
    for ( x = 0; x < 16; x++ )
           {
            _moveto ( h, 220 ); /* vertical line */
              _lineto ( h, 420);
            h = h + 25;
           }
    h = 220;
    for ( x = 0; x < 100; x++ )
           {
            _moveto ( 10, h ); /* horizontal line */
              _lineto ( 410, h );
            h = h + 2;
           }
  h = 2 ;                                                                    D
  w = 25 ;
   for ( i = 1; i <100; i++ )
           {
            fscanf (fp1, "%d\n", &k);
              _itoa( k, buffer, 2);
            for ( x = 0; x < 16; x++ )
           {
             if ( k & (0x8000 >> x ))
                 _floodfill ( ( w * x ) + 15, ( h * i ) + 221, index3 );
           }
           }
```

```
                                                              --------------
      _getch( );
      old3 = _remappalette( index3, white );
      _getch( );
      _remappalette( index3, old3 );
      _getch( );
      _setvideomode( _DEFAULTMODE );                              E
     }

    else _outtext( " The program requires EGA or VGA. " );

      fclose (fp1);
      exit(0);
                                                              --------------
}
```

Appendix 9

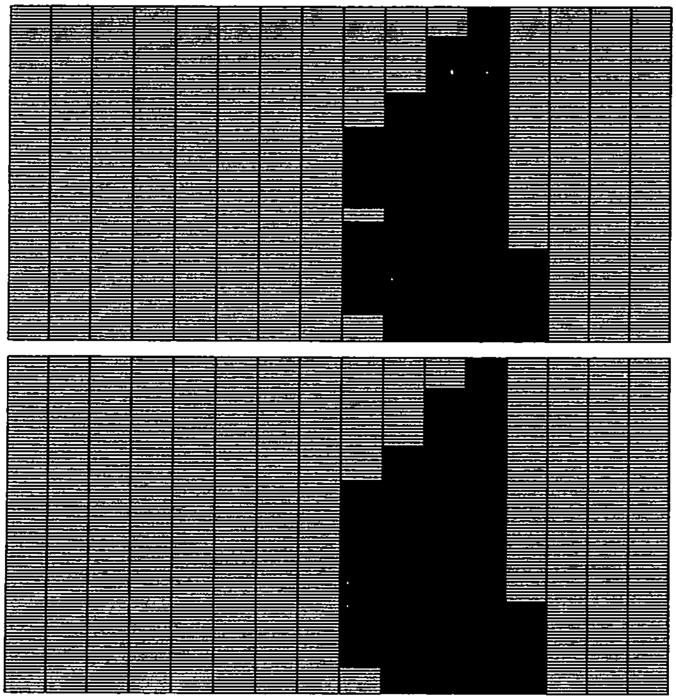


(a) Rectangular shape with tapered sides

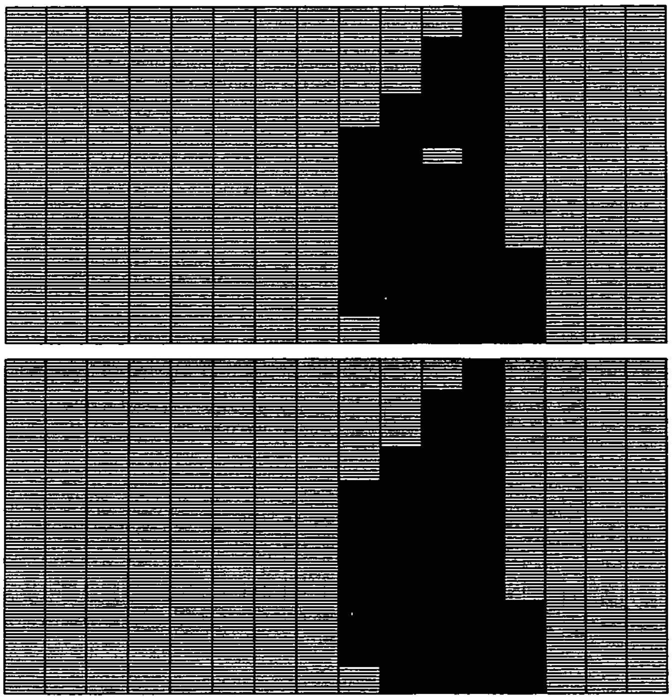


(b) rectangular shape with tapered sides

Figure A9-1 Various leather component displaying irregular results from first sensor bank



(c) curved edge leather component



(d) curved edge leather component

Figure A9-2 Leather components displaying irregular sensor bank data

Appendix 10

Figure A10-1 illustrates the arrangement for obtaining the variation in belt height from a fixed datum.

The fixed datum utilised was the mounting base for the sensor array above the conveyor. The centre of the conveyor was transferred to the support bracket. Additional centre lines were placed 60 mm either side of this centre line.

The conveyor belt itself was slowly moved at increments of 50 mm. Height measurements were taken at each increment and at the three centre lines.

This process enabled 28 increments to be made along the entire length of the conveyor, as it passed beneath the mounting base.

Therefore a grid matrix of 28 by 3 observations were obtained. These enable a profile to be made of the conveyor belt as it moves passed the datum point. It was shown that large undulations occur as the belt moves towards the skiving mechanism. These undulations are caused by the manufacture of the conveyor belt itself.

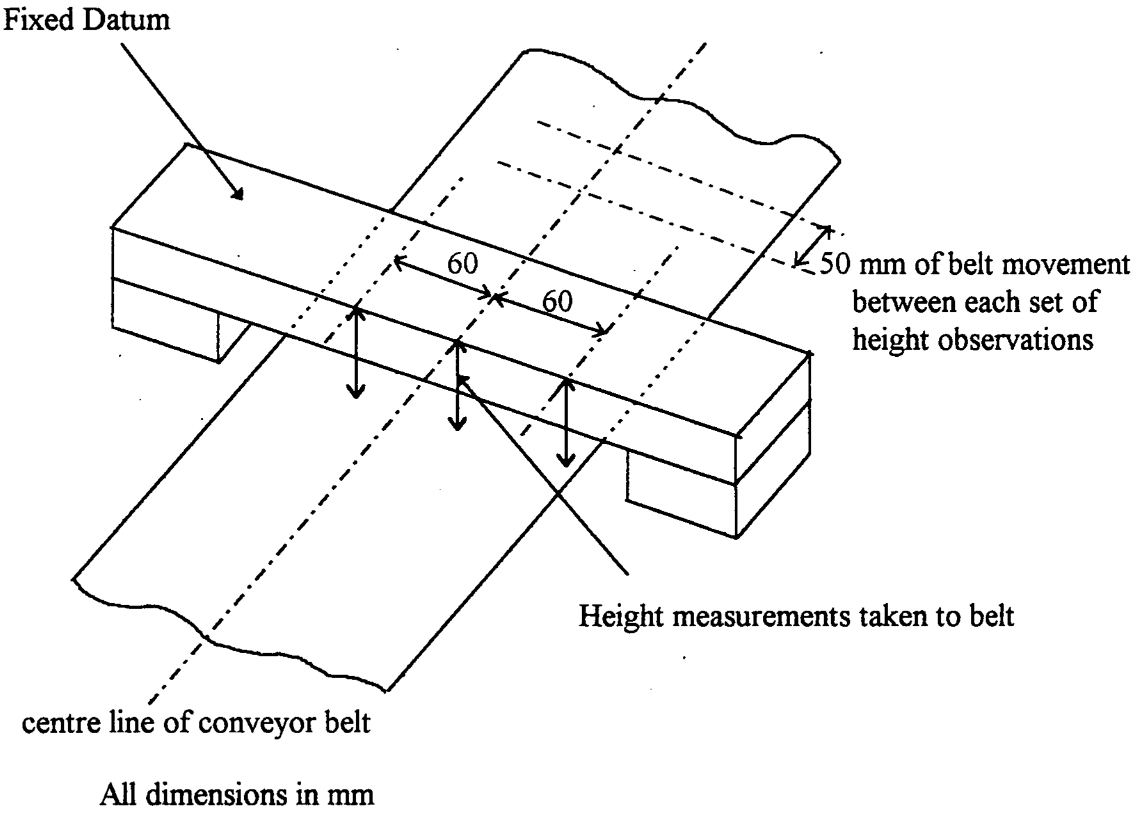


Figure A10-1 Schematic diagram to illustrate method of obtaining height measurements

Appendix 11

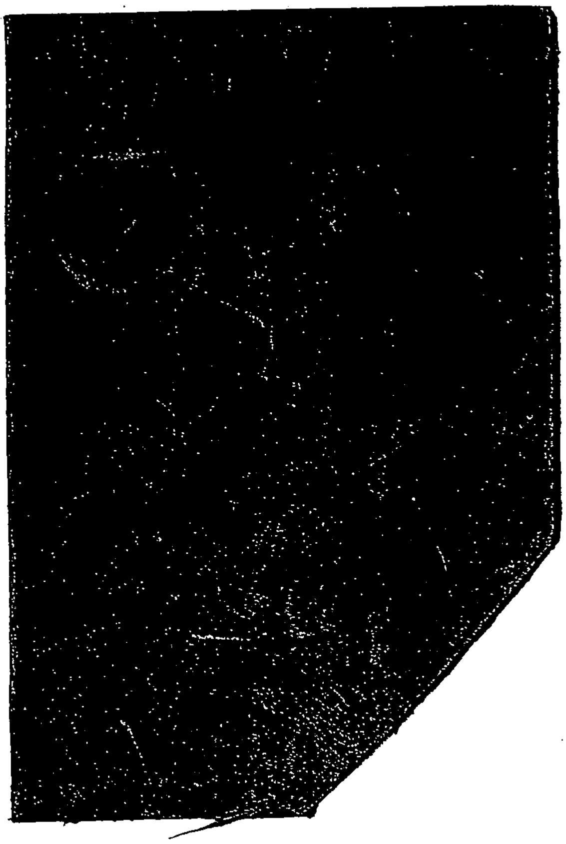


Figure A11-1 Silhouette of rectangular shaped leather

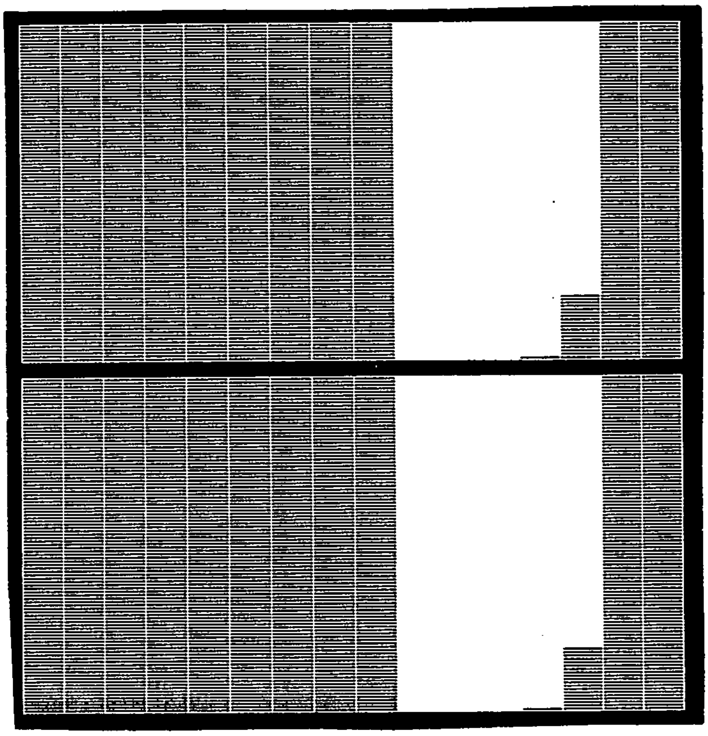


Figure A11-2 Coarse profile of rectangular leather with no movement

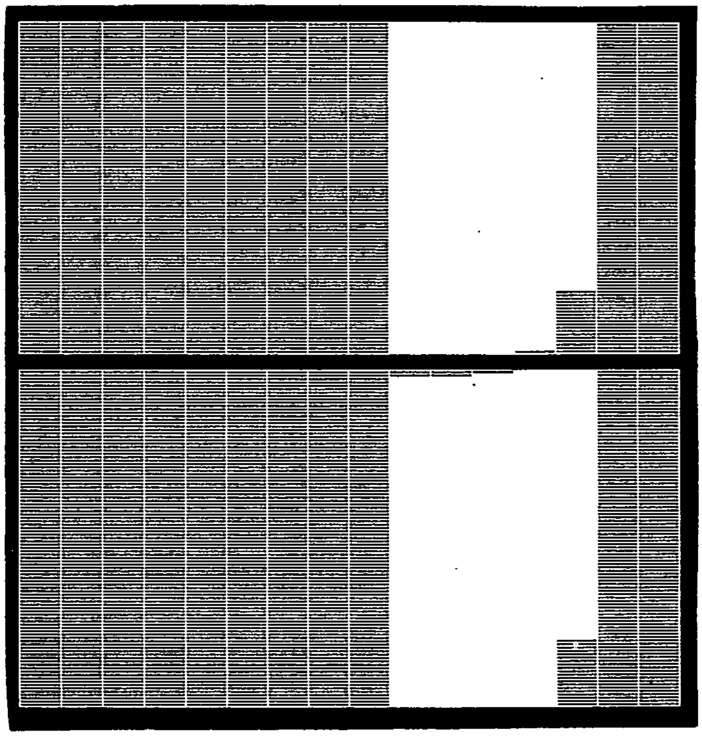


Figure A11-3 Coarse profile of rectangular leather with 1° of induced angular movement

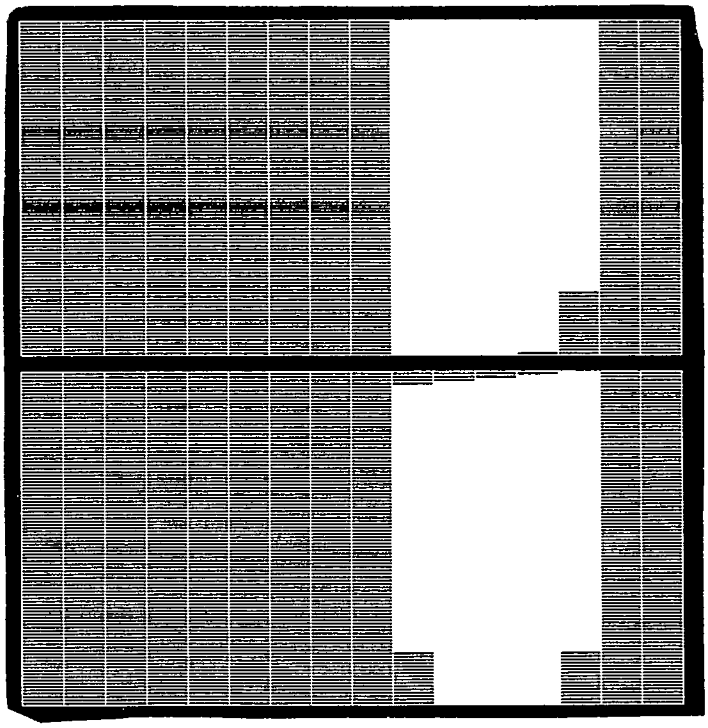


Figure A11-4 Coarse profile of rectangular leather with 2° of induced angular movement

Appendix 12

Figure A12-1 Silhouette of leather shoe component 1

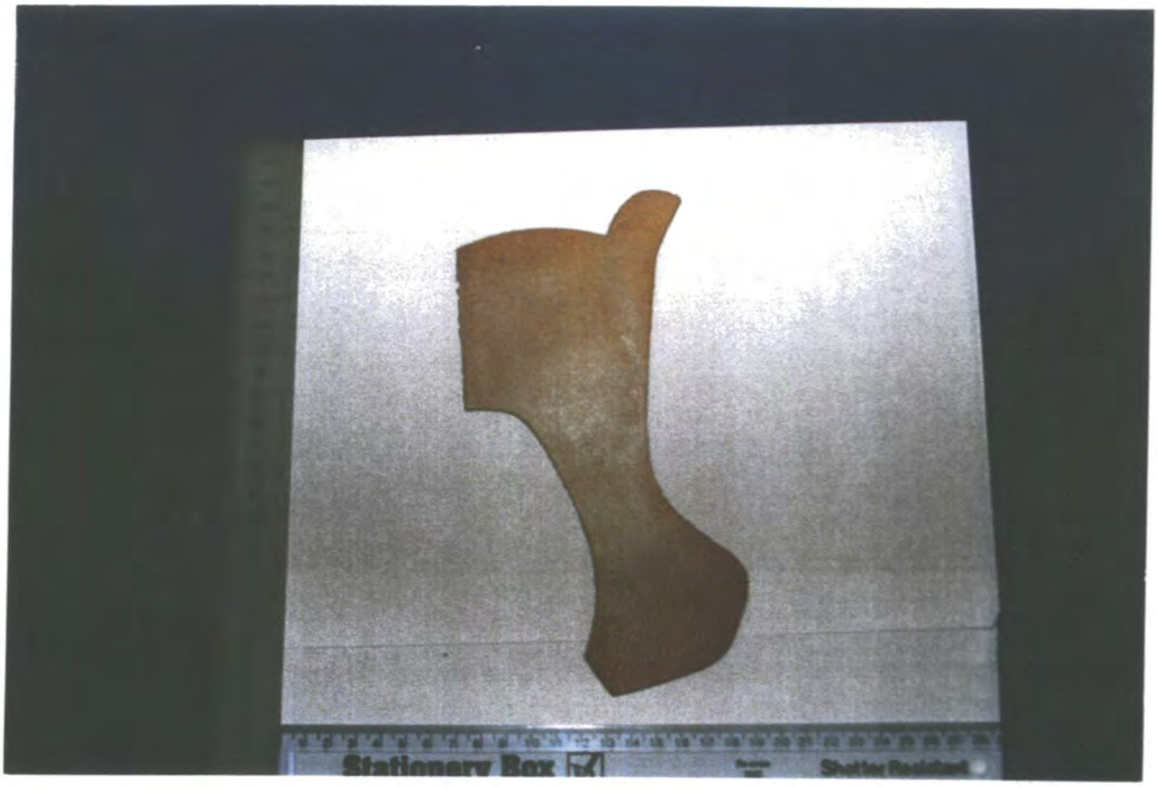


Figure A12-2 Leather shoe component 1

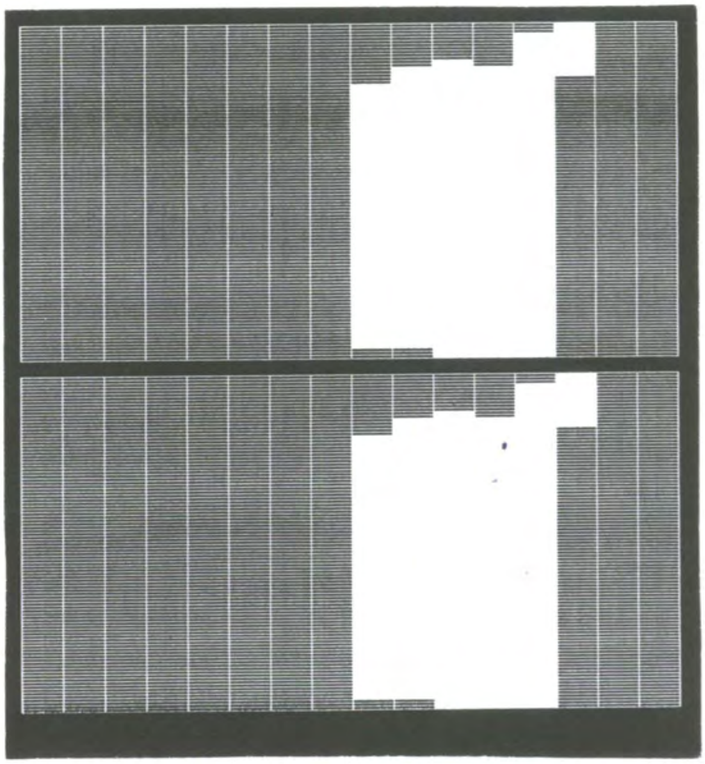


Figure A12-3 Coarse profile of component 1 with no movement

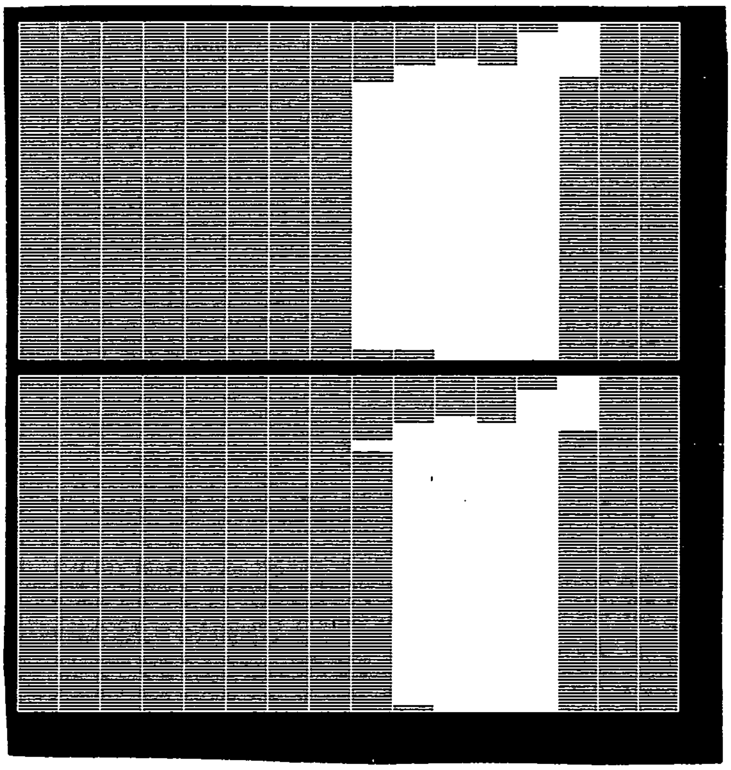


Figure A12-4 Coarse profile of component 1 with 1° of induced angular movement

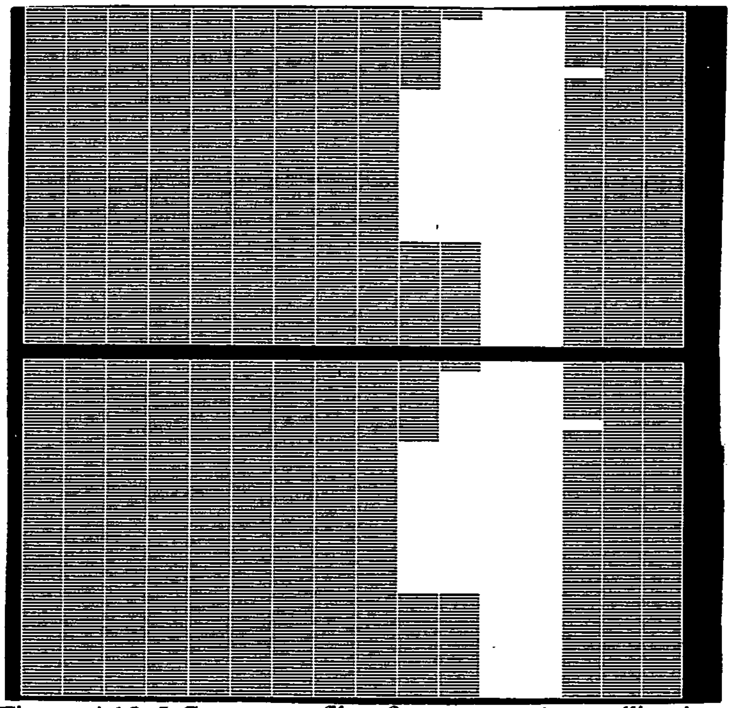


Figure A12-5 Coarse profile of componet 1 travelling in reverse direction with no movement

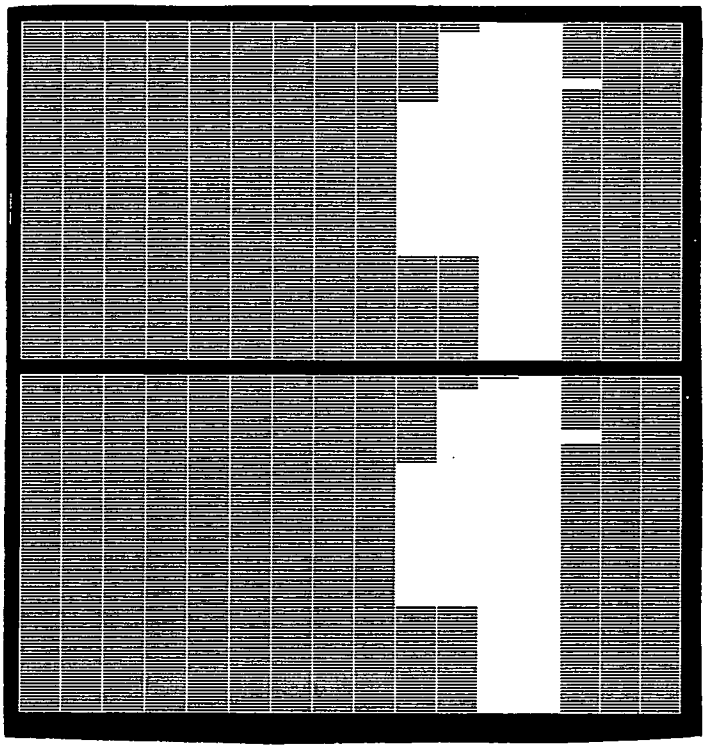


Figure A12-6 Coarse profile of componet 1 travelling in reverse direction with 1° of induced angular movement