AUTOMATION OF GARMENT ASSEMBLY PROCESSES

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Abstract

Robotic automation in apparel manufacturing is reviewed and investigated. Gripper design for separation and de-stacking of batch cut fabric components is identified as an important factor in implementing such automation and a study of existing gripper mechanisms is presented. New de-stacking gripper designs and processes are described together with experimental results. Single fabric component handling, alignment and registration techniques are investigated. Some of these techniques are integrated within a demonstrator robotic garment assembly cell automating the common edge binding process. Performance results are reported.

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Glossary of Terms

Term	Description
ACME	Application Of Computers Into Manufacturing Engineering.
BCIA	British Clothing Industries Association.
BRITE	Basic Research Into Industrial Technologies In Europe.
BTG	British Technology Group.
CAD	Computer Aided Design.
COG	Centre Of Gravity.
CP/M	Digital Research Inc. Operating system.
DEC	Digital Equipment Corporation.
DOF	Degrees of Freedom.
EXORCISOR	Motorola Microprocessor Bus Standard.
FIGARMA	Fully Integrated Garment Manufacture.
I/O	Input/Output.
ISO	International Standards Organisation.
MAP	Manufacturing Automation Protocol.
MIKBUG	Motorola Microprocessor monitor program.
MULTIBUS	Intel Bus Standard.
NC	Numerically Controlled.
PDL	Program Description Language.
PIA	Peripheral Interface Adapter.
PIP	Peripheral Interchange Program.
PLC	Programmable Logic Controller.
PSI	Pounds Per Sqare Inch.

PTC	Programmable Timer Counter.
PWM	Pulse Width Modulation.
RF	Radio Frequency.
SCADA	Supervisory, Control And Data Acquisition.
SERC	Science and Engineering Research Council.
SPM	Stitches Per Minute.
TDC	Top Dead Centre.

Nomenclature

Symbol	Description
x_t	Rack Displacement.
x_{rot}	Pinion Perimeter Movement.
ϕ_{pinion}	Pinion Angular Movement.
ϕ_{link1}	Link 1 Angular Movement.
ϕ_{link2}	Link 2 Angular Movement.
$\phi_{gripper}$	Gripper Angular Movement.
$\phi_{gripper\_act}$	Gripper Angular Movement Under Actuation.
R_{pinion}	Pinion Radius.
$R_{gripper}$	Gripper Radius.
R_{link1}	Link 1 Gear Radius.
R_{link2}	Link 2 Gear Radius.
ψ	Table Incline Angle.
ch	Vertical Drop From Contact Point To Clamp.
d	Horizontal Distance From Contact Point To Clamp.
ϕ1-4	Step Motor Phases 1 To 4.
α	De-stacking Reliability.
β	De-stacking Unreliability.
Θ	De-stacking Outcome Function.
i	De-stacking Attempt Index.
s	Total De-stacking Attempts.
L1	Engagement Torque Pivot To Beam End Length.
L2	Workpiece To Gripper Pivot To Contact Point Length.
L3	Pivot To Workpiece Gripper Length.

d	Beam Thickness.
b	Beam Width.
l	Beam Length.
A	Beam Area.
ρ	Beam Material Density.
p	Cantilever Beam Applied Force.
t	Workpiece To Gripper Engagement Torque.
Mr	Moment Applied To The Beam.
σ	Surface Stress.
ε	Surface Strain.
σ_{sy}	Surface Yield Stress.
Y	Beam Axis To Surface Diameter.
I	2nd Moment Of Area.
E	Youngs Modulus.
Δ	Beam End Deflection.
ω	Lowest Natural Beam Frequency.
$F1$	Load Cell 1 Applied Force.
$F2$	Load Cell 2 Applied Force.
E_o	Output Voltage.
E_i	Bridge Exitation Voltage.
Rf	Feedback Resistance.
δr	Strain Gauge Resistance Change.
Rb	Nominal Strain Gauge Resistance.
$\delta\varepsilon$	Strain Change.
G	Gauge Factor.
θ_x	Leadscrew Angle.
j	Integer Leadscrew Revs.

θ_e	Absolute Angular Encoder Return.
j_{max}	Maximum Allowable Value Of j.
x_+	Coarse Encoder Positive Accuracy Bound.
x_-	Coarse Encoder Negative Accuracy Bound
B	Binary Code Bit
g	Gray Scale Code Bit.
n	Code Size.
k	Bit Element.
θ	Alignment Table Rotary Axis.
A_m	Exhaust Area.
A_j	Nozzle Area.
A_e	Inlet Cone Area.
V_m	Exhaust Velocity.
V_j	Nozzle Velocity.
V_e	Inlet Velocity.
P_e	Inlet Cone Pressure.
P_m	Final Exhaust Pressure -- Atmospheric.
P_s	Air Supply Pressure.
P_c	Vacuum Pressure.
P_j	Nozzle Pressure.

Declaration

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

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To Tracey.

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CHAPTER 1

INTRODUCTION

1.1 AUTOMATION IN GARMENT ASSEMBLY

Large volume garment manufacturers use production line techniques based upon batch processing for economic manufacture. Within garment production lines, manufacturing systems often rely upon skilled operators assisted by mechanical assembly aids to perform sub-assembly operations upon the product. These making up operations are highly labour intensive. Typical mechanical aids are high quality industrial sewing machines adapted as required with ancillary guide, cut and feed devices. Control and the necessary handling skills are provided by the operator.

In assembly, the operator is required to perform high speed repetitive operations upon supple and delicate fabric workpieces demanding considerable manual dexterity combined with tactile and visual coordination.

Thus the assembly process remains reliant upon skill. Automation of the human element is important to allow competition with overseas producers and presents many interesting problems ranging from handling techniques to sensory based real time computer control applications.

This thesis addresses specific problems associated with automation in garment assembly. Handling and control techniques suited to computer supervised automation are identified and experimentally evaluated. In collaboration with a large volume garment manufacturer and SERC (research grant GR/B/97022), demonstration automata were developed to investigate computer supervised assembly and are reported in this thesis with experimental results. The work is continuing and is supported by a research grant awarded under the SERC Applications of Computers to Manufacturing and Engineering (ACME) initiative.

1.2 A BACKGROUND TO GARMENT ASSEMBLY AUTOMATION

Automated textile production began with the invention of mechanised weaving looms. An early example was the Hargreaves Spinning Jenny in 1767 [39]. The first needle with an eye in the centre was invented by Wisenthal [55] in 1775. Later the sewing machine was developed by Thimonier in 1830 [61], followed by the lockstitch machine in 1846 by Howe and the chainstitch machine by Gibbs in 1856. Subsequently, thousands of patents covering improvements to the sewing machine have been awarded, but few fundamental changes have been made in the way stitches are formed since then. Motive power changed from hand or foot power to shaft power developed by water or electrical supplies, then to individual electric motors in the 1930's. In the previous 75 years, machine productivity has improved. By 1930, machines were available capable of operation at 3000 stitches per minute (SPM), increasing to 5000 SPM with the introduction of automatic lubrication. From 1962, with improvements in metallurgy, a maximum of 6000 SPM has been obtained for lockstitch machines and 8000 SPM for chainstitch machines.

In the last 75 years thousands of minor work aids have been developed. Examples include attachments, folders and guides to assist the operator in producing a variety of seams. Specific examples are hemming folders, binding attachments and edge guides.

The first automatic cycling machines were developed in 1900. This allowed the construction of machines such as the bartacker, the buttonhole machine and the buttonsew machine. Needle positioners were incorporated into sewing machines from 1960 onwards. These devices allowed the setting of the needle to an up or down position by the operator independently of the machine handwheel, making possible underbed thread trimmers with associated productivity improvements. From 1960 mechanism development proceeded rapidly and numerous disposal and stacking devices were produced.

Development accent moved from concentration on stitching speeds, feeding mechanisms and stitch formation to thread trimming, guidance mechanisms and disposal devices. Further automatic cycling machines were developed to include patch pocket setting machines and welt pocket machines, these systems initially being cam controlled and later moving to electronic control.

During the 1960's, two major research projects were undertaken. The first, funded by a German machine manufacturer was called the "Transfer Street". Intended to perform all required assembly operations on a shirt front, the system was large and complex. Capabilities of the machine included pocket setting, front edge folding, buttonholing and buttonsewing. The project was not considered successful, but it broadly improved technology leading to automatic pocket setters, automatic underfront machines, sequential buttonsew machines, pick-up devices and disposal devices now used on numerous other assembly mechanisms.

The second project was supported by the US government and a number of US apparel manufacturers. An experimental system termed the "RINK" and an accompanying report followed as a result of this development. This system was intended to test technologies associated with pick-up, alignment, orientation and disposal of limp fabric workpieces. The project was not a commercial venture and it stimulated thinking amongst apparel manufacturers.

Significant developments were made in pattern making and cutting processes in the early 1970's. Pantographic pattern reducers and cutters as well as cameras and other reproduction equipment were designed to improve the marker making function and to provide an improved technology for the control of material waste. Numerically controlled (NC) laser cutters were added simultaneously to cutter technology. Today this is aided by integrated computer design support to reduce materials wastage.

Single ply cutting by laser did not meet with significant commercial success but is now used by a few tailored clothing companies. Its adaption to cut patterns has been more successful.

Presently, clothing manufacturing and distribution has grown to the fifth largest industry in Britain employing nearly half a million people [40].

Before 1968, control of textile machinery was carried out by mechanisms deriving control information from cam based or punched card information stores, using considerable mechanism technology. These high speed mechanical selection systems are detailed by Grosberg [36]. Examples of machinery controlled by such means are flat bed knitting machines and Jacquard looms. An account of the mechanisms employed in knitting machines is also given in Nissan [71], by Grosberg.

Computers are now being introduced into the industry for use as controllers. Initial applications relate to the most immediate area of economic benefit. In the US much of the success of the K-L manufacturing company has been attributed by Bruess [10], to the introduction of computer based facilities into its production process.

Within the Finnish company Turo of Kuopio, manufacturing 2300 suits per day from an automated production line, computers have been introduced for cloth grading and automation of cutting lines [97].

There are now some well established computer software products aimed at the fully fashioned garment industry, Coles [22]. a detailed knitting statement for a fully fashioned garment may be calculated by the HATRA Computer Aided Design of Knitwear system (CADNIT). The WTCAL system (a fully fashioned garment weight calculator), used when a knitting statement has been established, calculates the yarn content (for costing) and the garment weights (for quality control checking). Both programs were produced in the late 1970's. These programs have allowed tight control over yarn useage.

Further programs were developed from 1980. The resulting GRADER programs form a fully fashioned garment grading system. These are used to develop the base-size knitting statements for a new garment style from information on an existing garment, and to produce a set of fully graded garment statements from the base size and finished garment size specifications. Interactive on screen modification of both the base garment and the graded set can be undertaken, and data filing facilities allow storage within a microcomputer of records of garment specification, knitting statements and size charts.

Another HATRA product is the MICROKNIT package. This system can compute knitting statements, grade a range of statements from an existing base size statement, analyse yarn requirements and compute costings.

Computers are also being introduced in other areas of garment and fabric production, such as dying processes. The Donisthorpe company [97], manufactures sewing yarn and uses automated colour stores, microcomputer controlled dying machines, radio frequency (RF) drying and a computer controlled colour matching system. Substrate and dyestuff weighing has been automated and automatic winding and finishing equipment has been introduced.

In 1975 Stoll introduced the first microprocessor controlled knitting machine, the ANV Selectanit. Other knitting machine builders have subsequently launched a variety of microcomputer controlled machines including Monarch, Dubied, Universal, Bentley Alemamia and several other firms. Bentley and Nagata Seiki have produced half hose machines. In 1981 Karl Mayer introduced their microcomputer controlled Lace Jacquard Rachel machine. Gerber have recently introduced low cost automation for the pattern making field based upon digitising apparatus, a microcomputer and a cutter/plotter. The system is called the Gradamatic 5 [125].

A survey of the uses of microcomputers in the textile industry is given in Happey [39], and an account of automation in fully fashioned knitwear machinery is given by Vitols and Wray [39], pp 405-407.

1.3 GARMENT ASSEMBLY RESEARCH

With the UK, garment assembly research is being undertaken at several commercial and academic establishments.

At the University of Durham, previous automation work includes the development of a microprocessor controlled elastic tensioning device by Burdess [12], for use in elastic insertion into edge binding. This device has proved very successful and has been in industrial use for several years. Other work has been carried out relating to quality control in circular knitting machines, Burdess [11]. Presently, work at Durham includes research into robotic vision based discrimination in leather components for the shoe manufacturing industry, and a collaborative project with Rockwell Rimoldi under the European Economic Community (EEC) Basic Research into Industrial Technologies in Europe (BRITE) scheme for investigation of quality monitoring techniques in sewing.

At the University of Hull, work has begun by P and G Taylor [113, 122] on the automation of shirt collar inspection and assembly. Development of an edge binding attachment workstation has been additionally proposed by Taylor [111], incorporating earlier work in robotic fabric ply separation from fabric batches [52, 112]. The de-stacking system forming this work was based upon air turbulence and has been patented by the British Technology Group (BTG). [110, 114, 115, 117, 120]. Some aspects of the use of sensory robots in flexible workstations are described by Taylor and Stubbings [119]. Robotic vision applied to the orientation of embroidered motifs in the textile industry has been investigated by G.E. Taylor et al [53, 109]. The Hull Robotic research program is described by Pugh [84].

At the Shirley Institute and Salford Industrial Centre, general studies of automation in the garment industry are being carried out. Work has begun by Vitols and Wray [131] at Loughbrough into handling electromechanics relating to the high speed sensing and manipulation of knitted fabrics.

Investigation of sewing machine monitoring is being conducted at SATRA. Shirt front assembly techniques at the Cranfield Institute of Technology are under investigation. Courtaulds textile research centre at Coventry is now collaborating with GEC Automation in a large EEC BRITE supported garment assembly automation project. The general state of robotic research in the UK is reviewed by Davies [25].

Sensory feedback from robotic vision systems is anticipated to become important in commercial automation and work has been carried out in textile quality control with vision by Hashim et al [41]. Low cost vision based means to locate fabric workpiece edges or corners have been investigated by Taylor and Bowden, this technique being employed in visual servoing applications [116, 121, 135]. Work has also been carried out by Vitols et al [130] using vision to identify individual loops of yarn in knitted fabric to facilitate joining for assembly. Additional work into sock pairing has been carried out by Hashim [42].

Recently a commercial vision system has been announced by the Linsey & Company Inc. for quality control in narrow fabrics, and claims a capability to inspect 225 m/minute of fabric for flaws [141]. However the large data processing requirement associated with vision systems presents operating time obstacles. Contemporary developments in optical image processing offer alternatives to these systems. Holographic spatial filters described by Liu [62], and Trabka [127], may find application in garment quality control. Hybrid optical/electronic processors, described in work carried out by Gara [33], Dandliker [24], and Thompson [126], resulting in protoype high speed pattern recognition systems, may find more immediate application. The use of robotic vision is considered by Pugh [83].

In Europe, the TNO organisation is engaged in fabric handling research whilst the Fully Integrated Garment Manufacture (FIGARMA) project is relevant to garment assembly automation.

Elsewhere, at the Charles Stark Draper Laboratory in the US, work is proceeding upon tailored clothing. At the Clemson University, some aspects of fabric handling are receiving attention. A Ministry for International Trade in Industry (MITI) project is concerned with complete garment assembly automation and is supervised by machinery manufacturers JUKI. Kawachi [51], has announced the project will incorporate automation of manufacture, management systems and computer aided design and manufacture. The project is scheduled for completion in 1989 and will incorporate large amounts of robotic electromechanics, termed mecha-electronics [70]. A brief description is given by Ogawa [73].

Attempts to implement single ply processing have been made by Toyota [98, 143, 147], with a production line system called the Toyota Sewing Management System, but these have not seriously challenged established production techniques.

More conventional uses can be found for robotic automation in garment production, such as the transfer of batches between operators. A robot, termed "Earnest One", has been applied to transfer wound packages to a creel [149]. Robot usage is anticipated to increase in the future [124]. Alternative approaches to garment making up processes are considered by Vitols and Wray [132].

A commercial stacking device now exists. Developed by the Austrian manufacturer Stahl, and described in the press as a robot, the Stahl Stacker has received a great deal of press attention [65]. Several of these devices are in use within the industry. It does not produce a neat enough stack for open loop onward mechanical processing and is directed only towards a limited range of workpieces.

A treatment on mechanical transporters is given by Gillespie [32]. Automated handling and seaming techniques for knitware are considered by Atkinson [2].

1.4 THE GARMENT ASSEMBLY PROCESS

To investigate the role of automation within garment manufacture, an example of a typical assembly process is considered. The example is taken as the manufacture of the Y-Front type of men's brief, produced by the collaborating industrial partner.

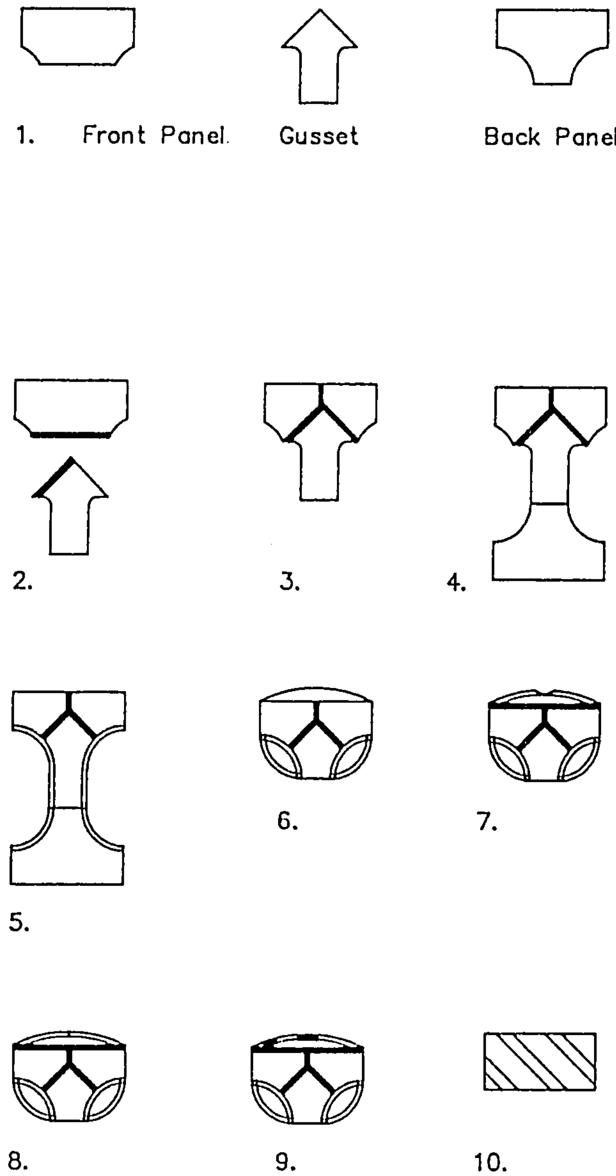
This garment is simple in design yet uses many of the basic operations required to form more complicated garments. Moreover, its design does not change rapidly with fashion. In these respects its assembly may be a good candidate for automation. However, the labour content of the finished product comprises less than 20% of its total cost. An automated system must be able to compete with the low labour content of the cost to justify financial investment. It must also save on the material wastage of conventional assembly and improve product quality. Some relationships in automation between speed, quality and cost are outlined by Lord [63]. As background, a generalised outline of the construction of garment items is given in Mills [67].

The example assembly process contains the following fundamental operations demanding practical solutions for success in a fully automated manufacturing system:

i. Fabric cutting.
ii. De-stacking of cut fabric batches.
iii. Limp material handling.
iv. Sewing operations on straight, angled or contoured seams.
v. Joining operations on side by side and overlaid workpieces.
vi. Three dimensional sewing operations.
vii. Application of binding and elastic materials.
viii. Attachment of motifs and labels.
ix. Constant supervision of assembly operations.
x. Packaging.

The assembly process is based on batch manufacture where sub-assemblies for the garment are processed in groups of approximately 4 dozen per batch. This quantity has been found of practical size, both for manual transportation of the batch between processes and for bulk cutting of the batch components. Contemporary equipment allows the component (or workpiece) cutting with laid up sheets of fabric of typical size 30 x 5 m by an NC cutter. In one cutting cycle, many different sizes and shapes of components are cut from the fabric under the direction of a CAD layout optimising program reducing fabric wastage. The Gerber S91 cutting system is an example of such a unit. Several batch cutting systems now use the SCARA robot arm principle to articulate the cutting head, an example being the EASI Auto Arm Cutter.

The assembly of the Y-Front garment is now described in detail and is illustrated in figure 1.4. The major components of the Y-Front garment comprise front, back and gusset panels (1). At the first stage in the assembly of the garment attachment of edge binding to the gusset component occurs, and is followed by similar attachment of edge binding to the front panel (2). Next, the edge bound front and back panel are attached at a stage termed "Assemble Front" (3). The back panel is then joined to the front sub-assembly (4). Edge binding and elastic are inserted at the legs (5) and the sides are sewn together (6), forming a three dimensional shape. Attachment of the waistband is then carried out (7) and the waistband is joined at the back of the garment (8). This is followed by the attachment of a trade label (9), and the finished assembly is finally inspected and packed (10).



Key:

1. Cutting.
2. Bind Front.
3. Assemble Front.
4. Close Crutch.
5. Bind Leg.
6. Seam sides.
7. Elasticate waistband.
8. Elastic Join.
9. Labelling.
10. Pack and Distribute.

Figure 1.4 Stages In The Manufacture Of The Y–Front Garment.

To assemble these components the above operations are partitioned into the stages listed as follows:

i. Attach edge binding to the front panel.

ii. Attach edge binding to the gusset panel.

iii. Assemble gusset panel to the front panel.

iv. Close crutch.

v. Bind leg.

vi. Intermediate examination.

vii. Form one side seam.

viii. Form the opposing side seam.

ix. Edge bind and insert elastic to both legs.

x. Attach waistband.

xi. Complete waistband with a final joint.

xii. Attach trade label.

xiii. Final examination.

xiv. Pack the finished garment.

xv. Apply adhesive to the pack and seal.

In the above process, studies have shown handling to comprise 70% to 85% of the operators time. Introduction of handling automation may thus save a high proportion of manual labour.

1.5 RESEARCH OBJECTIVES

Automation of the entire process described in section 1.4 would present an immense task. The experience of other research workers has shown the success of such attempts unlikely [55]. A better approach to this problem would be to identify critical and labour intensive components of this work and then design automated sub-assembly systems to perform these tasks. Full automation would only succeed if the constituent components were proven to operate efficiently and reliably in an industrial context.

With modern engineering techniques, achievement of a degree of automation in this area is possible. Automation of cutting and packaging has been very successful and has been used by many manufacturers. Semi-automated mechanical work aids, such as controllers for direction of sewing, position of workpiece etc, have saved handling times and reduced labour costs. Also, microprocessor based sub-assembly systems have improved garment quality and reduced operation times.

Any serious attempt at full automation of batch organised garment manufacturing would have to offer a credible practical solution to the major obstacle of ply separation from batch cut fabric stacks and fabric manipulation. Of course, ply removal may be avoided by reorganising the entire assembly operation on single ply processing [88]. However, because of heavy investments in the traditional assembly operations, batch organised manufacturing is likely to remain the principal production method until impact of computer controlled automation in the industry is made.

Thus initial research objectives for this work are best suited to the automation of critical and labour intensive handling and sewing elements of manufacture. Activity sampling, carried out on sewing machinists at 13 factories comprising 659 workstations [34] has indicated the average time spent by operatives on sewing was 20.2% and 44.4% in necessary work handling. Thus robotisation of handling is of importance to reduce the labour content of these tasks.

1.6 THE DE-STACKING PROBLEM

A major obstacle to the automation of the garment assembly process has been identified as the de-stacking operation. Based upon the singulation of fabric plies following the batch cutting process, a de-stacking system is required to receive a batch of fabric plies at its inlet and repeatedly remove one ply at a time, either from the top or base of the fabric stack, reliably presenting the removed ply to the downstream process at the outlet in a mechanically registered condition.

The requirements for complete automation of this operation include high reliability for the ply separation operation and the incorporation of error detection [55]. To meet the demands of practical garment manufacturers, the system should be fast in relation to the equivalent manual process, eg able to de-stack one ply in less than 6 s. Several properties of the batch cut fabric stack present obstacles for automation. These are described below.

Contemporary fabrics are made by knitting or binding processes and the material is typically a composite of cotton mixed with thermoplastic fibres. During the batch cutting process, heat generated by the cutting knife or saw tends to fuse adjacent plies within the stack together [149]. Mechanical disturbance caused by motion of the cutting tool further interlocks fibres of adjacent plies and the resulting bond is termed edge fusing. This occurs in many types of fabric and allied with the natural clinging behavior of fabric makes manual separation a difficult manipulative process.

Numerous attempts have been made in the past to automate de-stacking and none are regarded as wholly successful, either on a reliability or speed basis. Existing de-stacking systems are described in chapter 2.

1.7 THESIS SUMMARY

A summary of theoretical and experimental elements of this thesis is given below.

In chapter 1, a general introduction to garment assembly is given and its state of automation is described. The relevance of automation to garment assembly is discussed and contemporary work investigating garment assembly automation outlined. Areas of automated garment assembly able to benefit from research are identified and specific research objectives are formed from these. The initial research area was determined as the de-stacking of fabric from batch cut components for assembly.

Chapter 2 covers theoretical aspects of fabric de-stacking automation and proposes a new robotic de-stacking gripper, subsequently designed for experimental evaluation and documented in chapter 3. Results from the evaluation are reported in chapter 4 and improvements are made to the system from these results. Extensions to the gripper system are proposed to enhance reliability of the de-stacking process and these are detailed in chapter 5. The enhancements are next evaluated experimentally, chapter 6 describing the resulting gripper unit, its performance being reported in chapter 7.

At this point, detailed investigation of the de-stacking process is concluded. Other fabric handling and assembly techniques are of interest in addition to the de-stacking process, and following chapter 7, several of these are investigated. A key sub-assembly operation is identified within the manufacture of a typical garment. Automation of this sub-assembly operation is investigated, and automata based upon the new de-stacking device and other novel handling equipment are proposed and described in chapter 8. The automata are then constructed and evaluated experimentally, chapter 9 reporting experimental findings. Final discussion of the preceding work and results are presented in chapter 10 and conclusions are derived with suggestions for further work.

CHAPTER 2

FABRIC DE-STACKING

2.1 INTRODUCTION

Robotisation of the batch cut fabric de-stacking process was chosen for investigation and is now treated in the following chapters 2 to 7. Experimental techniques and results are documented in chapters 3 to 7, this chapter outlining engineering considerations in de-stacking.

Reliability and rapid operation of the de-stacking system is required by garment manufacturers for acceptance as plant, as cost effectiveness is attached to their criteria for introducing automation.

It was intended to develop automation for this application by integrating either successful features from existing techniques or wholly new gripper designs, with sensory devices and real time computer control techniques.

2.2 MATERIALS CONSIDERATIONS

In attempting to engineer handling equipment for a robotic de-stacking system, quantitative knowledge of fabric behaviour is required. The handling systems must cater for the properties of the fabrics used, possibility of fabric creasing and fabric surface damage. Mechanical frailty of the fabric should also be considered in the control processes involved.

Fabrics are produced by two processes, weaving and knitting. The majority of fabric production is based on weaving, but fabric used in Y-Front garment production is produced by a knitting process, generally upon a circular knitting machine. Therefore, this application is concerned with knitted fabric. Fabrics possess distinctive properties, and the nature of these are the cause of some handling difficulties encountered in implementing garment assembly automation. Some properties are described below:

Knitted fabric is limp but elastic. Its elasticity is fairly isotropic and arises from the curved paths yarn must uptake within the structure of the fabric. The makeup of yarn used in the manufacture of the fabric is of significance. Yarn smoothness is one factor determining the ability of fabric to mechanically cling to adjacent plies. Furthermore, smoothness relates to the degree of fibrous interlocking found at the edges of batch cut components.

Electrical properties of the yarn partially determine the electrostatic attraction between adjacent plies. Here, external factors contribute such as the handling history of the fabric and atmospheric conditions. The role of static electricity in fabrics has been studied by Richards [89], with reference to dissipation.

Thermoplastic constituents of yarn cause welding of the fabric edges during cutting and therefore affect the magnitude of edge fusing.

Woven types of fabric are denser and more rigid than knitted fabric. Moreover, they possess different elastic moduli in directions of weave and warp. A further elastic modulus is associated in the orthogonal direction to the plane of the fabric (in the direction of its thickness) and relates to the compressibility (resilience) of the fabric. Purely thermoplastic fabrics (such as nylon and polyester) have relatively low elastic moduli and a low mechanical cling factor, but the welding element of edge fusing is more pronounced and lower fibrous interlocking observed. Electrostatic attraction between adjacent plies is also greater. Ply thickness varies widely depending on the requirements of the fabric or type of garment manufactured.

Thus a wide variation of parameters are found within common fabric. Considerable work has been conducted into the quantification of material properties of fabrics. Studies have been carried out into the compression mechanics of fibrous assemblies by Carnaby [17], and the bending of yarns and plain woven fabrics are treated by Grosberg [35]. The deformation of dense fibre assemblies are considered by Hearle [43], whilst analyses of woven fibre tensile mechanics are given by Leaf [56]. Additionally, Shinohara [96], has carried out a theoretical study of anisotropy of bending rigidity in woven fabrics, and has derived a versatile equation to model bending. Yagamuchi et al [138], have developed a viscoelastic model of fabric to predict tensile recovery. Fabric stiffness, handle and flexion are considered by Elder [31]. Together with linear extension and bending, Leaf [57], has found the shearing behavior of woven fabric is of fundamental importance upon fabric performance when subjected to the wide variety of complex deformations encountered during use. Finite element methods have been applied to derive governing equations for Carnaby and Grosbergs continuous filament yarn model [129]. Load-elongation properties of fabrics have been studied by Nordby [72].

Using the above treatments of fabric behavior, it may be possible to model the macroscopic mechanical properties of fabric during de-stacking, with the objective of simulating the performance of fabric handling equipment. Robotic simulation packages such as GRASP, recently developed by Bonney et al [7] and others described by Dooner [29] could be combined with models of fabric behaviour, avoiding expensive research tooling to predict robotic fabric handling performance with specific end-effector schemes. Such an approach would however involve a large applied mathematics and software design effort not possible within the limitations of this project. A more conventional approach of empirical experimental evaluation for specific end-effectors with recursive refinement has therefore been adopted.

2.3 EXISTING DE-STACKING TECHNIQUES

2.3.1 Manual De-stacking Techniques

Within the industry, de-stacking is presently effected by either manual or semi-automated means. Manual techniques are outlined in this section and semi-automated means are described in section 2.3.2.

Manual ply separation is commonly performed using three techniques, outlined below:

i. The "Pinch" technique comprises the engagement of the topmost ply of a fabric stack at two points and then moving them together, introducing distortion into the fabric and subsequent buckling. The fabric ply can thus be gripped at this point and then fully separated.

ii. The "Peel" technique comprises the separation of the ply at one edge. Peeling of the topmost ply may then be carried out without difficulty. In this case reliability of edge separation is the factor determining de-stacking reliability.

iii. The "Rub" technique is based upon generation of distortion by shear between several plies. If two plies are gripped and relative movement is imposed between the pints of grip, the plies are forced to slide relative to each other, edge fusing being broken in the process.

Within the production lines of the industrial sponsor, manual fabric de-stacking is carried out by the operator gripping the fabric batch in one hand and separating the bottom ply from the stack in a pinching motion. This exposes one separated fabric edge and the gripped ply is simultaneously processed in the particular sub-assembly activity requiring the de-stacking operation. In the edge binding process, the ply is presented to a sewing machine where edge binding is carried out. Here the operator grips the fabric stack and performs both a de-stacking and edge binding operation simultaneously. This technique is considered efficient, but is only of use if the fabric stack is of dimensions and weight suitable to allow its easy manual manipulation. A component size limitation of approximately 200 x 200 mm is therefore present. The above de-stacking process is the sole process used by the collaborating industrial partner and has been optimised by time and motion studies to reduce operator handling and obtain maximum operator efficiency, but relies entirely on the manual dexterity of the operator.

2.3.2 Examination Of Existing Gripper Designs

Previous attempts at de-stacking gripper design have included a variety of means and techniques. They may be described in four different groups:

i. Use of air suction or adhesive tapes [136].

ii. Use of engagable needles; like elements alone or in combination with air pressure and/ or suction [60, 74, 136].

iii. Production of waves on the uppermost ply of the stack by mechanical or air jet means [69, 108, 123].

iv. Stretching or tightening of the uppermost ply by mechanical means [4].

Air suction used for de-stacking does not yield satisfactory results for limp, porous materials and tends to disturb the rest of the stack. However, this technique can be applied to the transfer and manipulation of the removed workpiece. With air suction and adhesive tapes, separation of two or more plies at the same time (if so desired) is not possible, nor is there any certainty about the number of plies removed [136]. Frequently, the separation is not successful and the normal automatic removal is impeded, thus reducing the efficiency of operation.

The techniques employed in the second category include mechanisms making use of metal brushes or cards. These have curved teeth attached to pressure plates or pressure wheels, with the teeth locally pressed into the uppermost ply to facilitate separation [60]. Mechanisms relying upon the exact length of needle penetration to achieve ply removal suffer from poor reliability, as the thickness of porous fabrics is very uneven. Included in this group of gripper designs are devices using the application of a number of open claw shaped grip elements upon the surface of the top ply. These close engaging the fabric. An air jet is then directed through a tubular needle under the engaged ply, creating a pocket of air under pressure between the uppermost and underlying ply [74]. In this case similar disadvantages are encountered as for the air jet suction method, as the penetration length of the hollow needle must be in exact proportion to the fabric thickness. Furthermore, removal of air pockets and subsequent removal of the workpiece can disturb the rest of the stack.

Work carried out by Littlewood [61], has resulted in a device capable of engaging the surface of limp fabric material and is called the Gepec Hand. Retractable needles are forced into the workpiece to a preset depth under pneumatic actuation to achieve surface engagement. The equipment is effective in achieving engagement of the workpiece but has no means to specifically break edge fusion. Use of this device is therefore not appropriate in the example de-stacking application but applications have been found in handling leather components.

A good example of production of localised waves on the surface on the uppermost ply of the stack is provided by the Cluett Clupicker device manufactured by Jet-Sew [69]. The complete Cluett Clupicker system is rather complicated but the pick-up device essentially consists of two rotatable, partially toothed gripping wheels used to engage the top ply under controlled pressure. Operation of the device is shown in figure 2.3.2. View (A) shows the initial state of the gripper and fabric stack with the gripper wheels suspended above the topmost ply. The wheels contact the topmost ply (B). Rotation of the wheels buckles the top ply

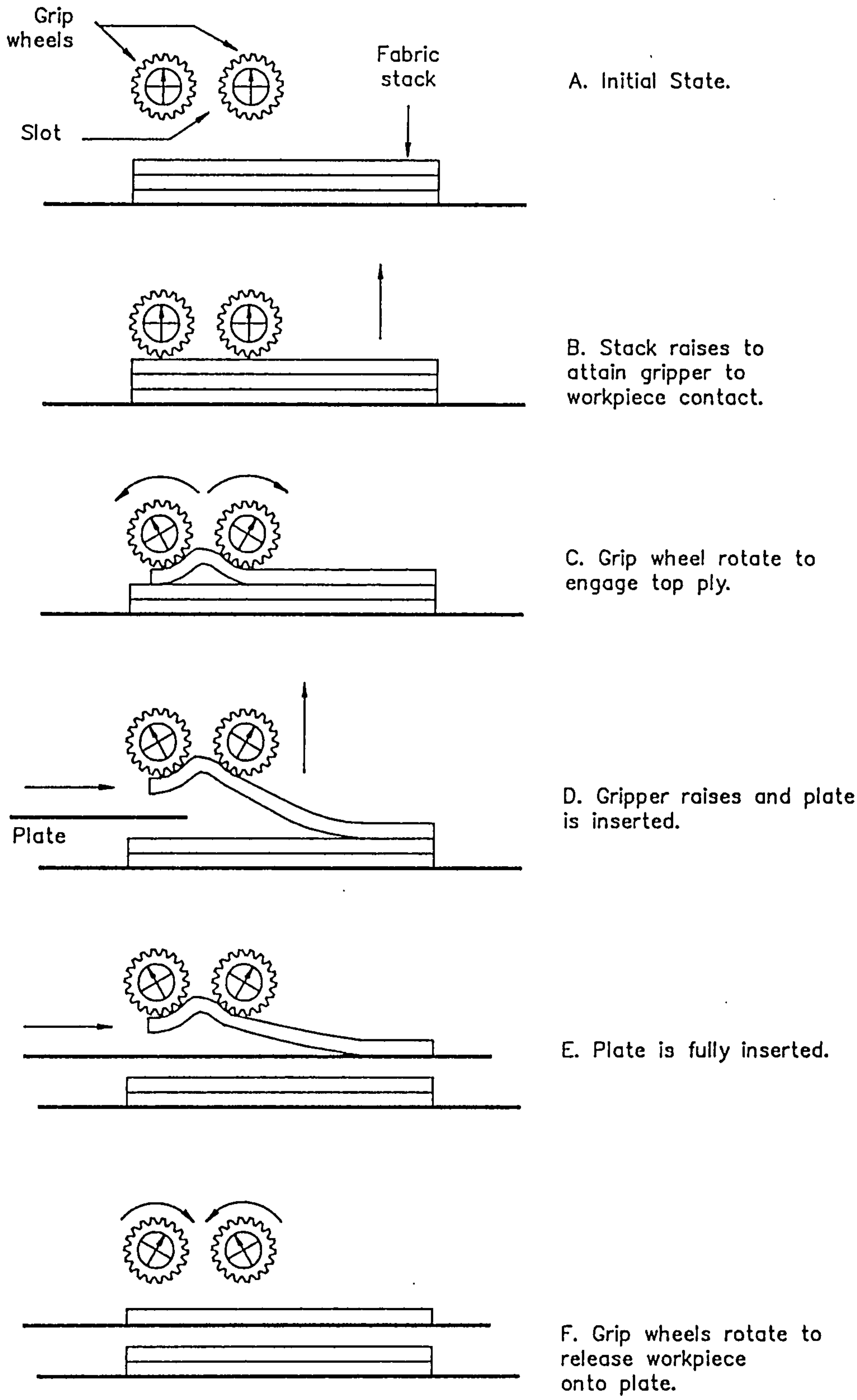


Figure 2.3.2 Clupicker Separation Process.

upwards, (C) thus creating a wave, the leading edge of the ply being drawn into a slot between the wheels. Continued rotation of the wheels accumulates enough material in the shoe slot to facilitate a localised separation, (D), whereupon the wheel assembly is raised to allow insertion of a plate. Complete ply removal is accomplished by plate insertion into the already detached region between the uppermost ply and the rest of the stack, (E). The wheel assembly then releases the ply and the metal plate is used to transport the ply to the next process, (F).

Disadvantages associated with this technique are threefold. Firstly, the initial separation is only achieved if a ply edge or, better still, a ply corner is engaged. Secondly, the efficiency of such a mechanism to remove a set multiple of fabric plies at once, which is desirable in some assembly processes, is doubtful. Thirdly, the mechanism has occasionally been known to damage the contact area. Several organisations have commercially evaluated the equipment including Courtaulds Textile Research centre (Coventry) and Dewhirst Ltd. Findings have shown unreliability in the basic separation operation. Furthermore, the equipment has not been commercially very successful. The Clupicker has also been recently evaluated in a laboratory environment at Manchester Polytechnic by Brotherton and Tyler [9]. A range of materials were used in the evaluation and a conclusion was formed that specification of the picking head to fabric contact force for different fabrics was required. The test was low volume, comprising 400 pickings per fabric type. Reliability was generally low, the best results being obtained with Poplin, Dobby and Tricot fabrics.

More recently, researchers at Hull University have developed and successfully tested a special sensory gripper device using the principle of wave generation with an air jet rather than contact by mechanical means [108, 123]. With this device, an air jet was used to vibrate the uppermost ply of the stack via turbulence whilst a fork-like gripper was inserted between the topmost ply and the underlying stack. An infra-red crossfire sensor detected when the topmost ply had "flipped" over the bottom jaw of the gripper. Once the separation had been achieved, the gripper was moved under the top layer, gripping it securely along one edge and peeling it back from the rest of the stack. Different air pressure settings were required to separate different types of material.

The main advantage of this technique is non-intrusion, as there is no mechanical penetration of the fabric. However, slow operation is inherent, with an initial separation time of 2-3 s. For single ply separation a success rate (reliability) of over 99% is reported. As with the previous technique, it is not clear how the gripper would perform for multi-layer removal.

The major commercial pick and place devices are briefly described by Walter [134], and comprise the Clupicker and other equipment commercially termed the Slickerpicker, the Polytex device and the Rimoldi Robot.

A further technique relies upon mechanically engaging the uppermost ply of the stack then tightening or stretching the workpiece, thus detaching the desired number of plies from the stack. One example of this design comprises application of sharp projections under pressure along two opposite edges, [4]. The projections are forced apart, stretching the fabric and breaking edge fusion. Finally, the gripper is lifted, removing the engaged and tightened workpiece.

No gripper system for de-stacking is presently considered satisfactory for fully unattended automation despite the continued requirement for such a system.

2.3.3 Elements Of A Robotic De-stacking System

Relevant elements of robotic gripper technology are now reviewed in general before they are applied to engineer an automatic de-stacking system.

A robotic gripper is normally attached to the end of a robotic kinematic chain and thus is termed an end-effector. Chelpanov and Kolposhnikov [18], describe the end-effector as comprising five elements, outlined below:

i. The first element is a unit effecting grip.

ii. The second element is a linkage connecting the gripping element to an executive mechanism.

iii. An executive mechanism comprises the third element.

iv. Fourthly, a transmission unit connects the executive mechanism to a drive unit.

v. The drive unit comprises the fifth element of the end-effector.

A further component is made up from sensory equipment which provides feedback of data to the end-effector controller of position, velocity and forces associated with the end-effector for control purposes.

Additional specialised sensory data may be available relating to the performance of the grip operation.

End-effectors differ widely depending upon their application. For rigid workpiece handling the mechanism may comprise levers specifically arranged to effect the required grip action. Many lever arrangements are possible, some being outlined by Chen [19]. End-effector organisation is categorised by Lhote [58] into unilateral, bilateral or multilateral means of clamping. Unilateral end-effectors clamp by attachment from one side only, such as the vacuum pad, whilst bilateral systems clamp from two sides, eg pinch type grippers and multilateral types from three or more directions. An example of a multilateral gripper is the human hand. No gripper system is presently as sophisticated as the 32 Degree of Freedom (DOF) human hand (exemplar).

In designing a gripper, correct design practice with bilateral and multilateral grippers requires the application of grip pressure by a reliable preset pressure source, such as a spring, and relaxation of pressure effected by the gripper drive system, Billingsley [5]. With this arrangement, only a predefined repeatable force is applied to the workpiece, but release is positive.

For fabric handling the end-effector must engage the workpiece either by bilateral clamping or unilateral surface attachment. Bilateral clamping may be effected by plate type sandwiching of the workpiece as in the Hull robotic fabric gripper [108], or unilateral surface attachment. Surface attachment techniques involve the adhesion of the end-effector to an area of one side of the workpiece. Devices using this technique include needle insertion and pin engagement units. Thus the de-stacking end-effector will use a unilateral or bilateral grip technique.

Manipulators are additionally described by Davies [26].

The kinematic chain is considered next. Usually the end-effector is attached to the transportation equipment causing repositioning and alignment of the workpiece for onward processing. Coordinated operation of the two elements are normally sufficient to effect ply separation, transportation and release of the workpiece. Examples of transporter systems include the multiaxis robot and the linear transporter, the latter being a simple case of a kinematic chain, having one DOF. A survey of presently available robot systems is presented in Hunt [45].

2.4 PROPOSED ROBOTIC DE-STACKING TECHNIQUE

2.4.1 Design Of A De-stacking Gripper To The Application

A new end effector based technique to de-stack fabric is presented in this section. Two functions are required of the end effector, the first being to simply grip or achieve surface attachment to the fabric workpiece. This was considered the least difficult of its functions and design of such a system could be carried out using existing robotic engineering science. However, the second function was to effect separation from the underlying fabric plies. Separation may be effected either before attachment, as in the Hull gripper [108], or after surface engagement. Adjustment and adaption of one or more of the existing gripper designs is possible to achieve a reasonable level of reliability for operations with fixed conditions. Here, conditions are fixed if a single size and shape of ply of the same material is processed at all times. However, in a more typical operation, the equipment may be called upon to handle workpieces in a variety of shapes and sizes. In Y-Front assembly, for example, the gripper is additionally sometimes required to remove a double layer of gussets for processing. Conventional gripper designs are not suited for such operation. Even when the operation involves only a single size and shape of fabric, as in shirt collar assembly, serious obstacles may be experienced in dealing with multiple fabric materials. Therefore, a gripper must be able to handle a variety of sizes, shapes, fabric materials and multiple layer workpieces to have any significant impact in automation. The transport element must include means to move the successfully separated workpieces from a pick up point to a release area in a controlled manner and without disturbance in the process. Speed of operation, simplicity of design, reliability and efficiency of the separation process are factors of great practical significance if the gripper is to compete with human operators.

2.4.2 Technique For Investigation

The proposed technique was based upon the engagement and stretching process described in section 2.3.2. Components of the system comprised a mechanical gripper capable of breaking edge fusing, and a workpiece transportation element.

The separation system provided a means to engage the surface of the topmost ply of fabric. Use of metallic pins were proposed, projecting from the surface of a drum and entering the fabric ply to a limited depth, engaging the workpiece but not the underlying fabric ply.

The separation procedure is shown in figure 2.4.2a. Initially, the drum was presented to the fabric stack, (a-i). It was then brought into contact with the uppermost ply of the stack (a-ii). Next, the drum was rotated and the "Rub" operation, described in section 2.3.1 was

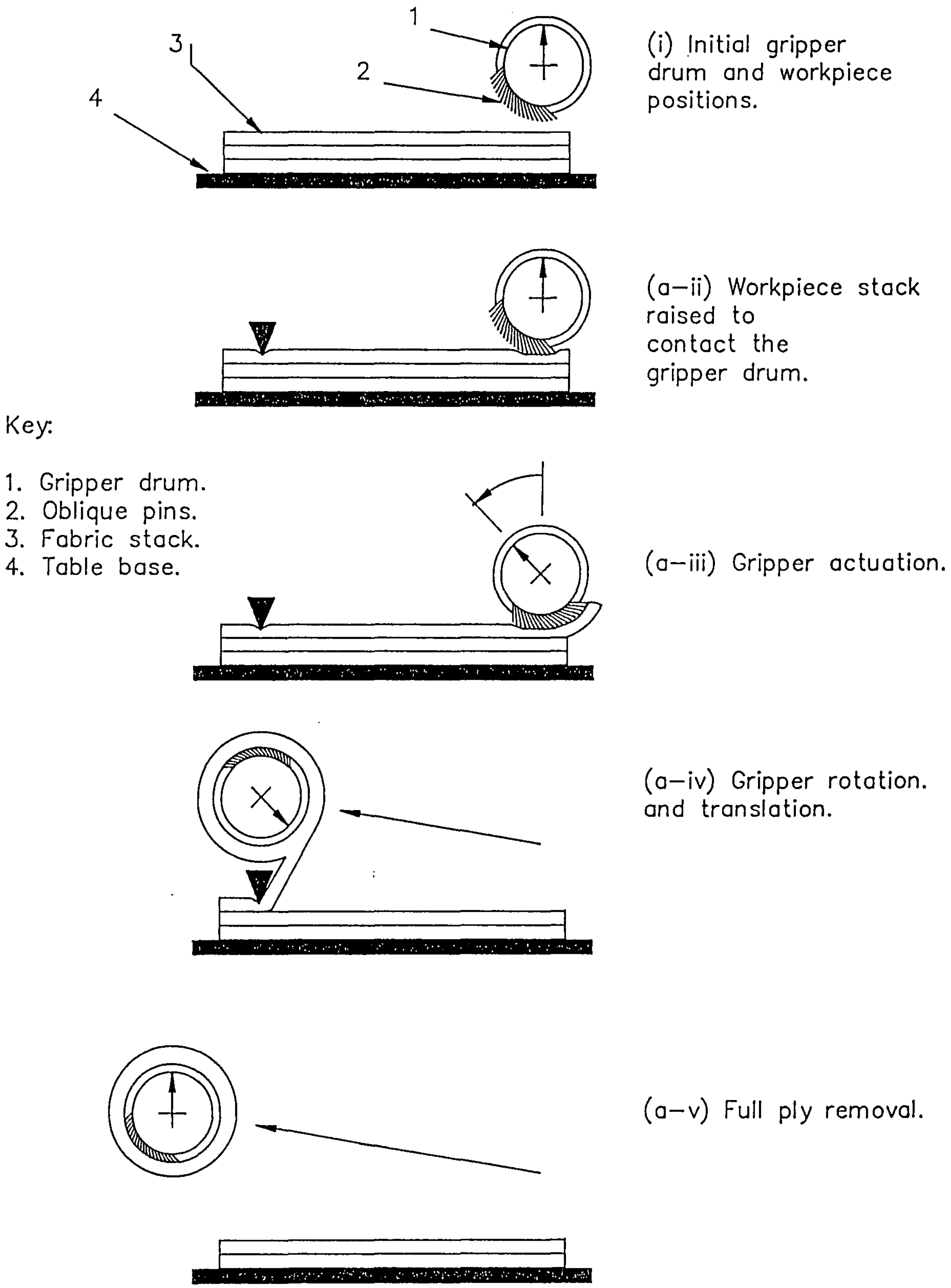


Figure 2.4.2a Oblique Pin Ply Separation Principle.

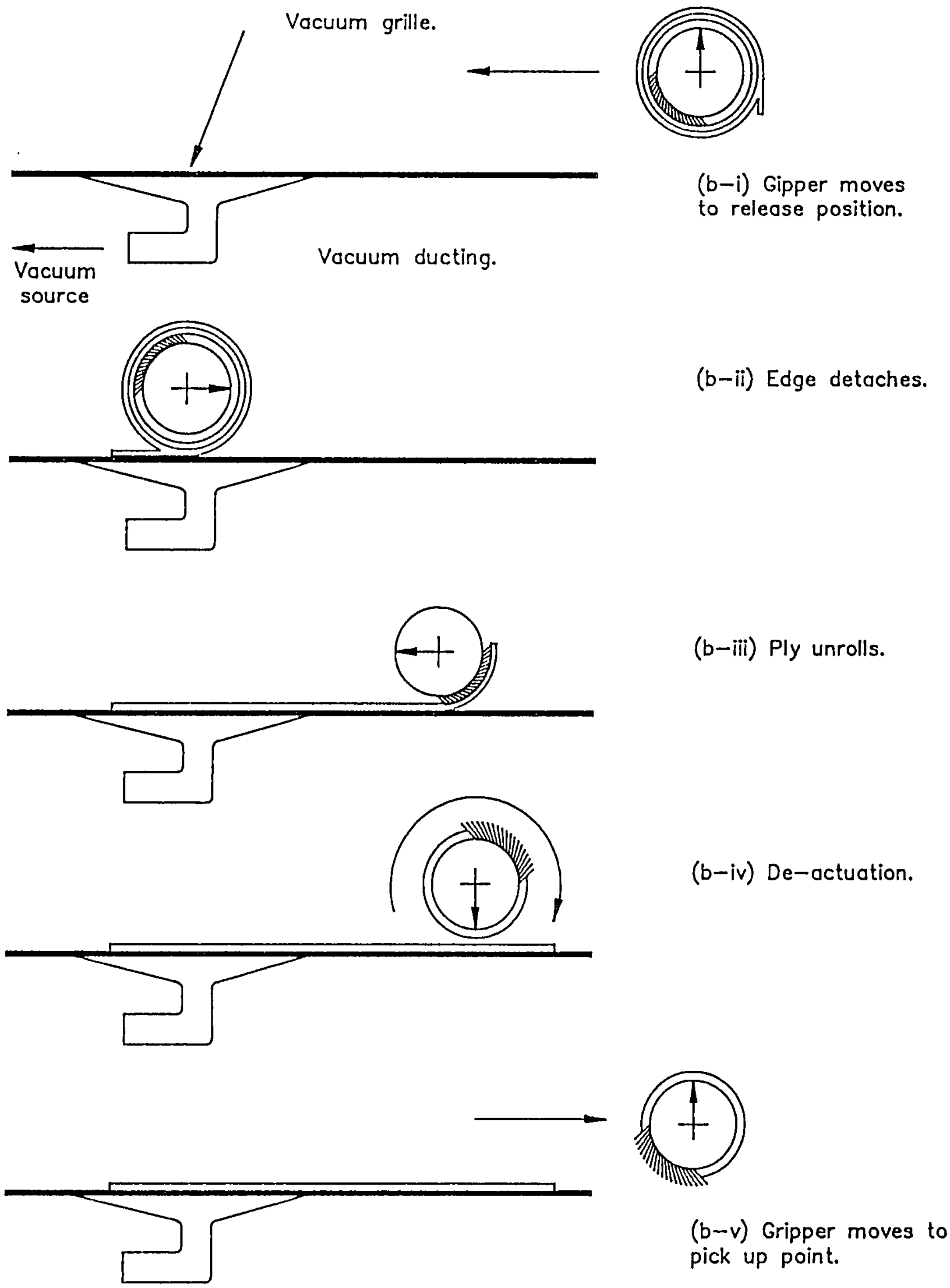


Figure 2.4.2b Oblique Pin Ply Release Principle.

effected, (a-iii). This operation was termed the actuation operation. One end of the fabric stack was clamped with a spring loaded clamp to allow the actuation process to introduce distortion (stretching) into the ply. If the workpiece to gripper contact point was set at the edge of the fabric stack, it became less difficult to break edge fusing. A variety of mechanical operations could then be carried out with the gripper to effect a "Peel" operation. A combined roll and "Peel" operation was proposed to hold the workpiece during transportation (a-iv) and (a-v). Having separated the topmost ply, the workpiece may be transported to the release position. Figure 2.4.2b illustrates the associated release operation. To release the workpiece, the ply separation procedure could now be reversed. The drum was moved to the release point (b-i and b-ii) and unrolled, (b-iii). A de-actuation motion was next issued from the gripper, (b-iv), throwing the fabric from the drum and leaving an unrolled component at the release stage, (b-v). The drum was then moved to the ply separation point to repeat the process with the next fabric ply. In its simplest form this was an open loop operation and could be controlled with a Programmable Logic Controller (PLC) or microcomputer.

Of all of the gripper mechanisms discussed, this technique was perhaps the most promising in several ways. It offered a fast method of ply separation as it relied solely upon needle penetration and subsequent stretching to effect separation. A very efficient and reliable performance was potentially available. A further advantage of the stretching action was provided in the length of needle being not a critical factor. As long as this length was less than the thickness of the workpiece, a successful separation was possible. With this principle, reliable separation of a set number of fabric plies was feasible in a single operation.

There were two main disadvantages associated with the simple technique described above. Firstly, the device relied upon stretching action alone to produce complete separation. In practice, this would not always be the case. When the fibre entanglement between adjacent plies formed very strong bonds or when significant edge fusion existed, complete ply detachment could not always be achieved. Furthermore, the addition of sensory devices to detect incorrect separation would improve reliability further.

This method of ply separation was termed oblique pin separation and its experimental evaluation is reported in later chapters.

2.4.3 Parameters Affecting Ply Separation

Parameters affecting ply separation include workpiece to gripper contact pressure, workpiece to gripper engagement torque, material properties of the fabric and edge fusing strength.

2.5 WORKPIECE TRANSPORTATION AND POSITIONING

Either a robotic or a hard automation based device could be employed to articulate the gripper assembly. The requirements for workpiece transportation and positioning for the de-stacking system outlined in section 2.4.1 could be reduced to positioning in one DOF and would therefore be satisfied with a linear transporter. With this arrangement there would be no means to automatically accommodate the decreasing height of the stack resulting from plies consumed in the course of the process. Therefore, use of a linear transporter required at least an elevating feed table to hold the stack, allowing maintenance of stack height.

In considering means to position the end effector, a robotic device would provide flexibility for research purposes and facilitate handling of variable sized workpieces for error correction. Classes of contemporary robotic articulation mechanisms are described in the literature.

Robotic electromechanics are generally driven from a controller unit. This unit supports the necessary motor drive and positional feedback circuitry. Its controller receives timing, positioning and speed commands from a system controller or derives preloaded signal internally from its own data storage.

2.6 SUMMARY

The fabric de-stacking process and its importance to batch organised apparel assembly automation has been considered. Existing de-stacking fabric grippers have been discussed with factors affecting their performance. Based upon this information, a novel de-stacking gripper and de-stacking process has been proposed for experimental evaluation in the following chapters. Auxiliary equipment necessary for operation of the gripper has also been described.

CHAPTER 3

EXPERIMENTAL EVALUATION OF A DE-STACKING PROCESS: DESIGN

3.1 INTRODUCTION

A novel de-stacking process was proposed in sub-section 2.4.2. This process was investigated in a pilot performance evaluation, described in this and the subsequent chapter. Organisation and design of the evaluation is first reported, its description being made in three parts. Firstly experimental organisation is outlined, detailing experimental objectives, methodology and preparation. These areas are covered in sections 3.2, 3.3 and 3.4 respectively. The second part consists of a description of the experimental equipment and its design in sections 3.5 to 3.9. Design of the application control software is described in section 3.10. Finally, the third part, given in section 3.11, comprises a chapter summary.

3.2 EXPERIMENTAL OBJECTIVES

The experimental objectives were threefold. Evaluation of the process operating cycle time, production throughput and process quality formed the first objective. These factors were identified in sub-section 2.3.3 as those determining the commercial viability of the process. Of these factors, quality control concerned the ability of the unit to correctly operate under computer supervised conditions, as would be required if the process were incorporated in a flexible manufacturing system.

The second objective was to gain information to indicate areas capable of refinement or areas deficient in performance requiring development or further investigation.

A final objective was to demonstrate the application of microprocessor control in high speed robotic assembly automation.

3.3 EXPERIMENTAL METHODOLOGY

Two approaches were considered to meet the above objectives. The first proposed simulation by computation. This technique was attractive as expensive research tooling would not be required and computer systems of moderate power were available. Such a route has been taken with other workers, eg Bonney et al [7], with the development of the GRASP robotic simulation package. However, the accuracy of such models must be validated before they can be used for prediction. A physical prototype de-stacking unit would in this case be required for validation. If a prototype were constructed, evaluation could proceed experimentally, allowing earlier meeting of the specific experimental objectives. Furthermore, the attainable accuracy for a fabric stack model was uncertain. The experimental method therefore chosen comprised first the construction of a prototype de-stacking unit, followed by direct performance measurement and then refinement.

3.4 EXPERIMENTAL PREPARATION

Design and construction of the de-stacking unit electromechanics were carried out. Application programs were then written, this being followed by the identification and rectification of hardware and software faults in the unit and its control system.

Batch cut fabric for preliminary and pilot trials was obtained from the collaborating industrial partner.

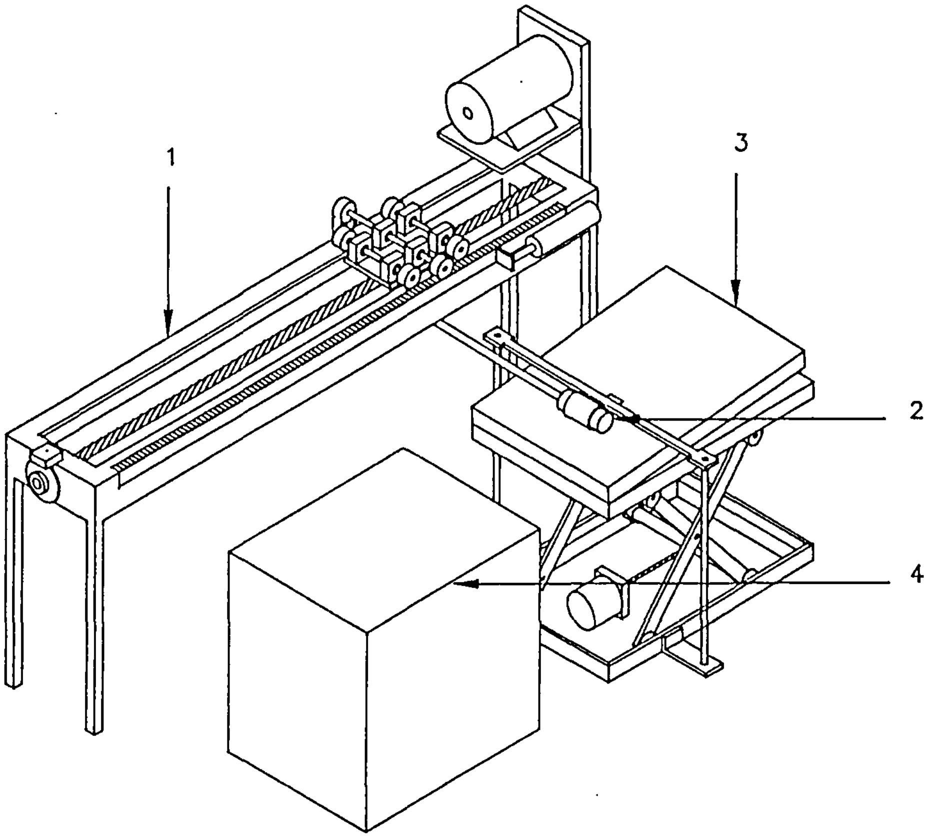
3.5 DESIGN OF THE DE-STACKING PROCESS

De-stacking was performed by the oblique pin separation technique described in sub-section 2.4.2, with several supporting electromechanical assemblies.

Figure 3.5 shows the general arrangement of the experimental de-stacking unit. A linear transporter (1) was used to mount the de-stacking gripper (2). Fabric for de-stacking was loaded onto a feed table (3) capable of maintaining the top of the fabric stack height as the gripper was articulated in the horizontal plane. Each separated ply was deposited upon a release area (4) forming a mechanical interface between the de-stacking unit and downstream handling processes. Such an interface is termed a robotic passing place. Workpiece release was accommodated by a simple plate provided with a surface vacuum grip facility.

3.6 SYSTEMS OVERVIEW

Four sub-systems were employed in the design of the de-stacking unit. The first comprised the electromechanical sub-systems, made up of the



Key:

1. Linear transporter.
2. Gripper.
3. Elevating feed table.
4. Release area.

Figure 3.5 De-stacking Unit General Arrangement.

workpiece gripper, the gripper linear transporter, the workpiece feed table and the workpiece release area. Remaining groups comprised the controller sub-system, the electronics sub-system, and the application process control programming.

3.7 ELECTROMECHANICAL SUB-SYSTEMS

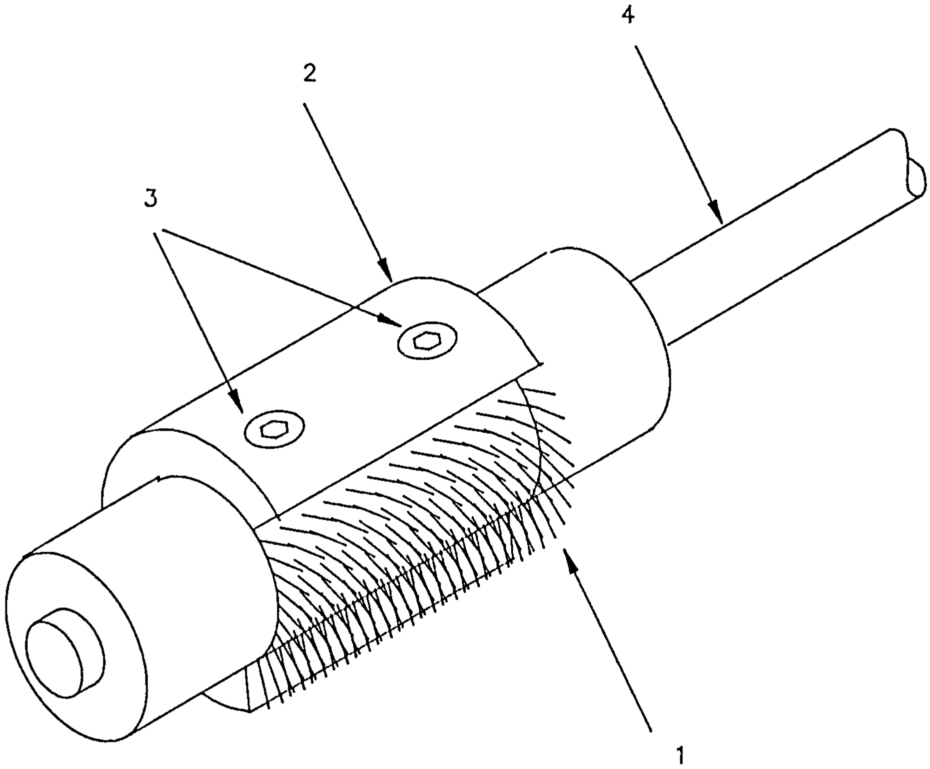
3.7.1 The Workpiece Gripper And Linear Transporter

The prototype workpiece gripper was constructed from a solid aluminium drum (ϕ 20 mm). A general arrangement is given in figure 3.7.1a.

The oblique pin array grip element (1) was mounted upon a sector of the cylinder shaped gripper body. A product known as carding cloth was employed to construct the array. Used extensively in the textile industry, carding cloth is fabricated from a matrix of stainless steel wires or pins set at an angle into a flexible backing. The cloth was clamped by the remaining segment of the gripper drum assembly (2) with allen bolts (3).

The transporter located and supported the gripper carriage within bearings in a track arrangement in the interior of the transporter frame. Support for the transporter structure was provided by legs at corners of the frame.

An ancillary mechanism was included to provide gripper rotation. This employed a rack and pinion, the rack being mounted upon the linear transporter frame and the pinion attached to the gripper carriage. Linkage was provided to cause rotation of the gripper cylinder at a rate designed to generate a synchronised rolling motion when the transporter carriage was moved. The rack was displaced by a pneumatic ram to effect



Key

1. Oblique pin area.
2. Clamp segment.
3. Clamp segment securing bolts.
4. Drive shaft.

Figure 3.7.1a Oblique Pin De–stacking Gripper.

rotation of the workpiece gripper and thus workpiece actuation. Gripper kinematics were determined by a mechanical linkage to the linear transporter. A detailed view of the linkage is given in Figure 3.7.1b.

Linkage equations are given in equations 3.7.1a to d. To attain a synchronised rolling motion, the gripper must roll a distance equivalent to the associated linear gripper motion. Equations 3.7.1e to h give the derivation of gear ratios necessary for this condition. For the timing pulley and pinion radii used in the prototype, equation 3.7.1i gives the actuation angle for a given rack displacement.

$$\phi_{pinion} = x_t \qquad \text{-- Eqn 3.7.1a}$$

$$\phi_{pinion} = \phi_{link1} \qquad \text{-- Eqn 3.7.1b}$$

$$\phi_{link1}R_{link1} = \phi_{link2}R_{link2} \qquad \text{-- Eqn 3.7.1c}$$

$$\phi_{link2} = \phi_{gripper} \qquad \text{-- Eqn 3.7.1d}$$

$$\therefore \quad \frac{x_t \cdot R_{link1}}{R_{pinion}} = \frac{x_{rot} \cdot R_{link2}}{R_{gripper}} \qquad \text{-- Eqn 3.7.1e}$$

for synchronised rolling $x_t = x_{rot}$ -- Eqn 3.7.1f

from Equation 3.7.1e and 3.7.1f;

$$\frac{R_{link1}}{R_{pinion}} = \frac{R_{link2}}{R_{gripper}} \qquad \text{-- Eqn 3.7.1g}$$

for a 1:1 linkage gearing ratio, ie

$$R_{pinion} = R_{gripper} \qquad \text{-- Eqn 3.7.1h}$$

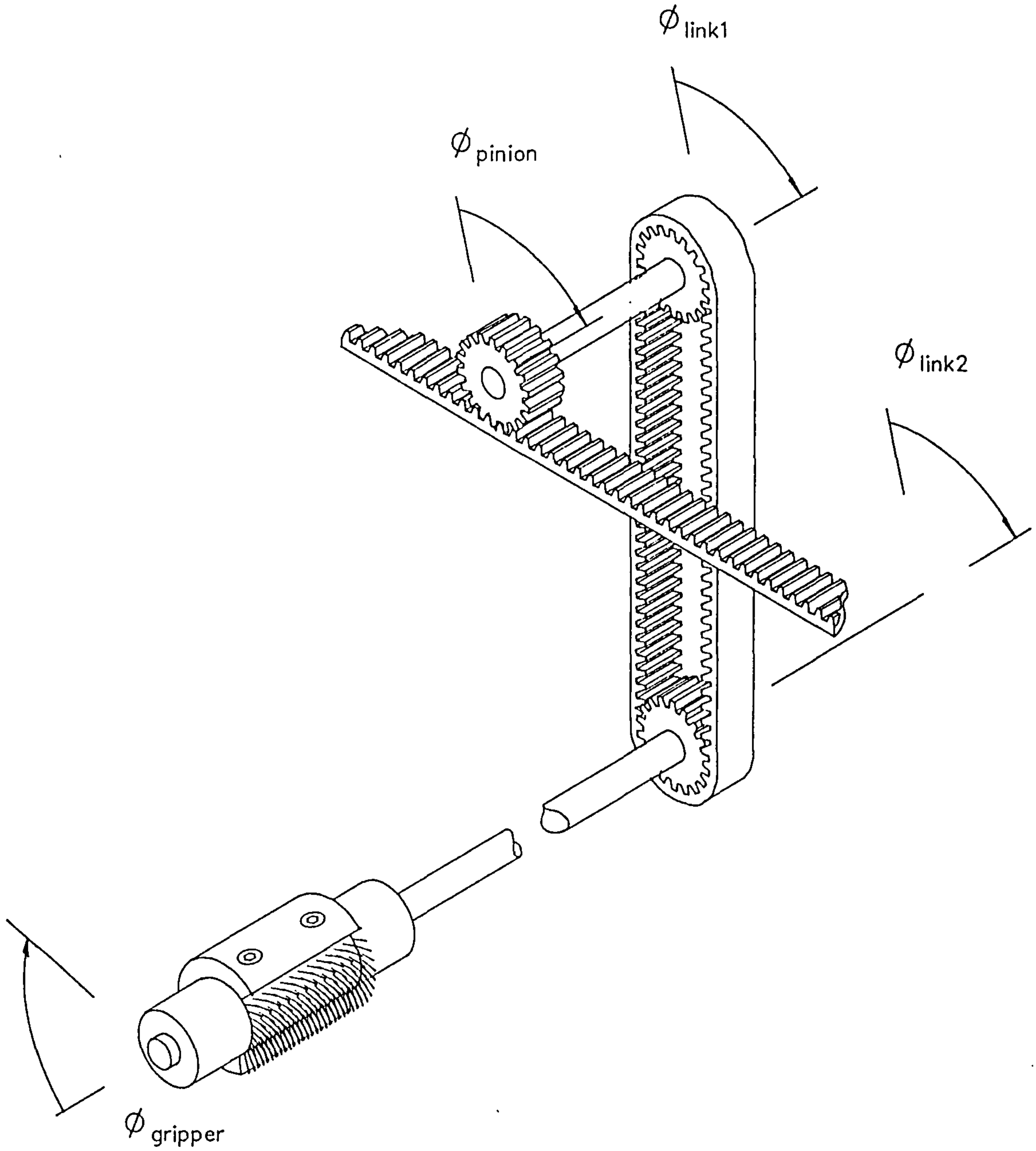


Figure 3.7.1b Gripper Mechanical Linkage.

In this case a rack movement of x_t impressed for actuation gives an angular motion $\phi_{gripper\_act}$ of;

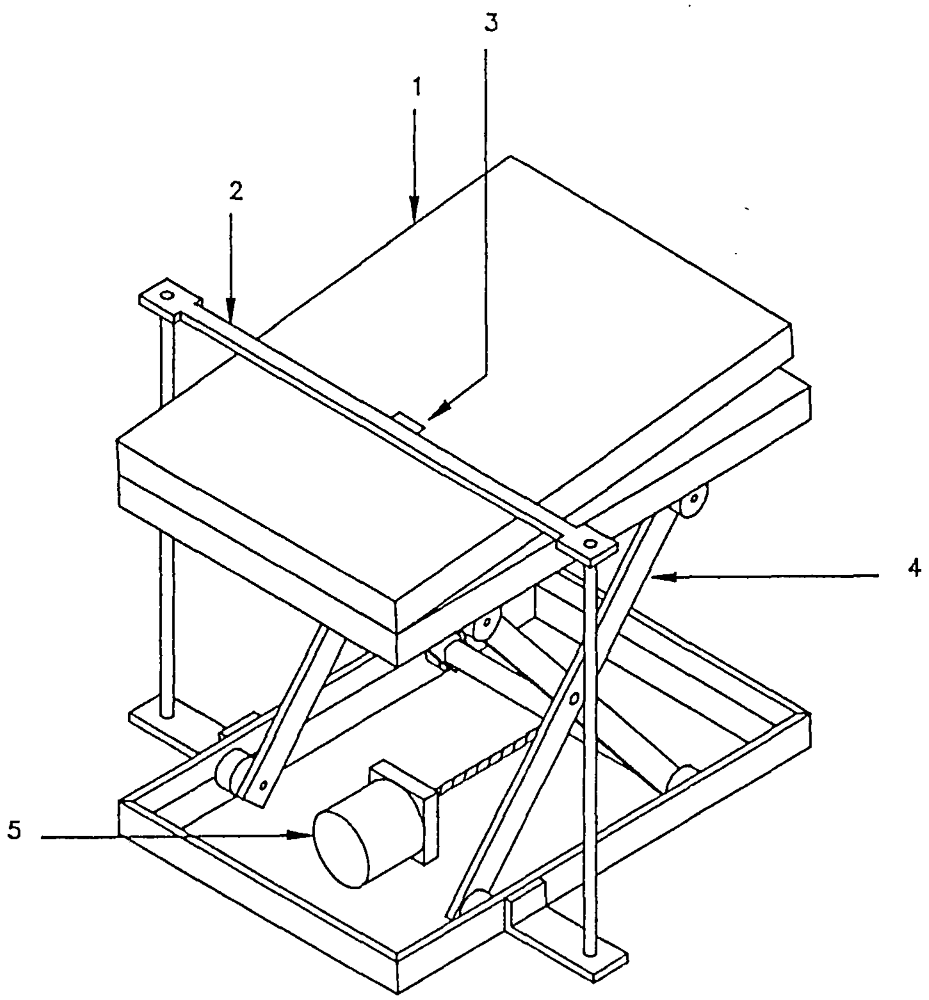
$$\phi_{gripper\_act} = x_t . \frac{R_{link1}}{R_{link2}} . \frac{1}{R_{pinion}} \qquad \text{-- Eqn 3.7.1i}$$

3.7.2 The Workpiece Feed Table

Figure 3.7.2 shows the electromechanical arrangement for the workpiece feed table. A function of the feed table was to clamp the fabric workpieces whilst the gripper separated the topmost ply of fabric. The separation procedure imparted a horizontal distortion into the topmost ply and to prevent the underlying stack shearing in an uncontrolled manner, it was necessary to clamp the rear of the stack. Therefore, a clamp was incorporated into the table, comprising a horizontal bar, supported above and across the stack on spring loaded pillars. A roughened flat surface was used (1), offset at an angle ψ to the horizontal plane to allow the gripper to clear the fabric clamp as the gripper was driven over the table surface. The condition for clearance is given in equation 3.7.2:

$$\psi \geq \sin^{-1}\frac{ch}{d} \qquad \text{-- Eqn 3.7.2}$$

This surface could be raised or lowered vertically by its support assembly, comprising four legs arranged in a laboratory jack (3) configuration whose geometry could be altered by a step motor actuated leadscrew (4).



Key:

1. Table surface.
2. Fabric clamp.
3. Fabric presence sensor.
4. Support leg.
5. Step motor.

Figure 3.7.2 Elevating Feed Table Electromechanics.

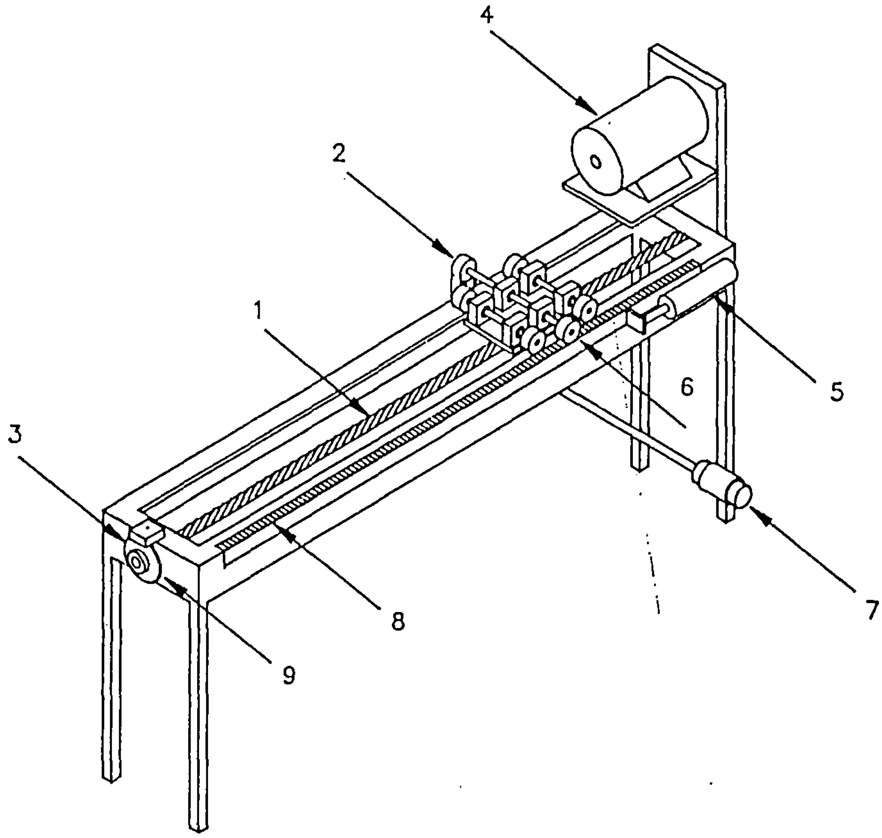
Clamp pressure was developed by raising the table and including the fabric stack between the clamp and table surface. Attainment of correct pressure was flagged by microswitches set into the spring loaded clamp mounts and control of pressure was provided by the controller, driving the table motor.

3.7.3 The Gripper Linear Transporter

The purpose of the linear transporter electromechanical sub-system was to move the gripper with its attached workpiece over the working area of the de-stacking unit.

Figure 3.7.3a shows a general arrangement of the transporter and gripper. The transporter carriage was driven by a high pitch leadscrew (1), optimising transmission of rotary to linear motion for the accelerations and velocities required. Transport range of the prototype unit design was 1 m. The carriage (2) was linked to the leadscrew with an anti-backlash nut and the leadscrew was supported at its ends by thrust bearings (3). Drive power was supplied by a 200 V DC motor (4) attached to one side of the leadscrew with a timing belt and pulley arrangement.

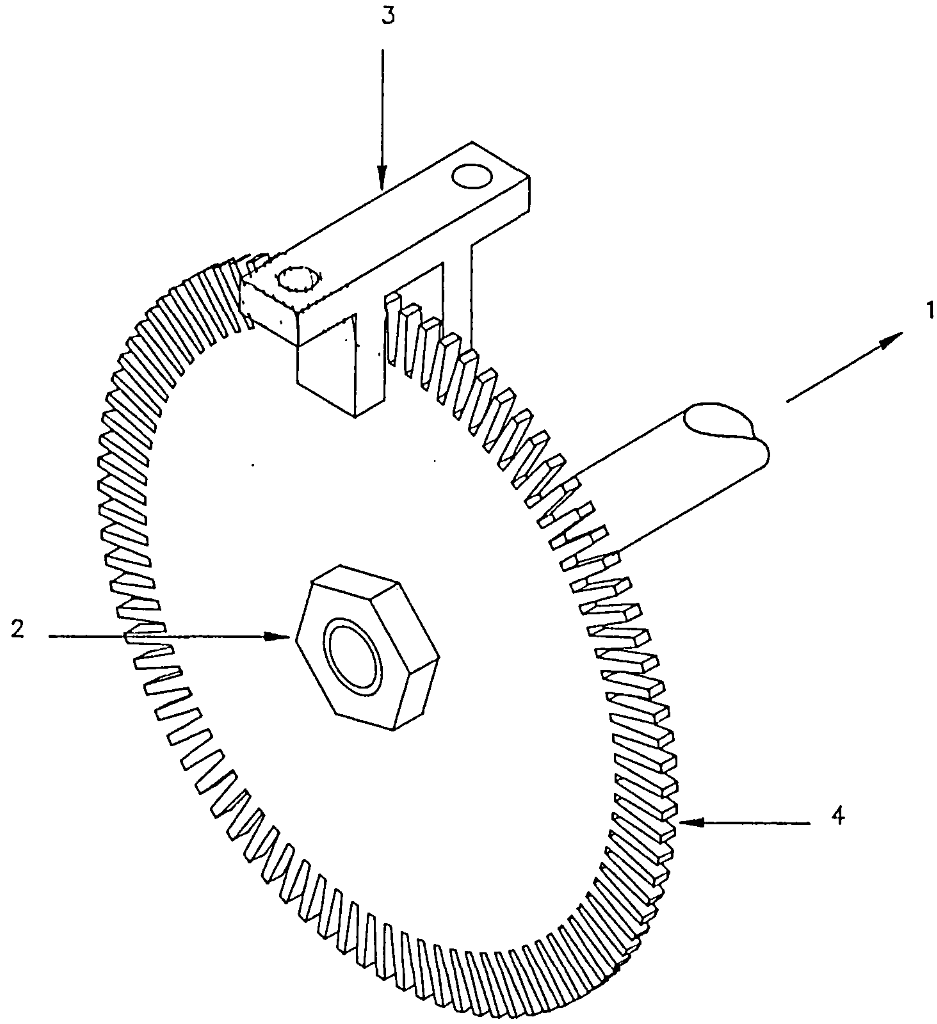
An incremental position encoder was employed by the sub-system to allow determination of carriage location. A slotted disc (9) mounted at the end of the linear transporter leadscrew formed the first of two components comprising the encoder. The second part was an infra red optical interrupter, sensing the slots on the disc (9), and was mounted on the transporter body. Figure 3.7.3b shows the incremental encoder mechanical arrangement.



Key:

1. Leadscrew.
2. Carriage assembly.
3. Leadscrew Support Bearing.
4. Drive motor.
5. Pneumatic ram.
6. Pinion.
7. Gripper.
8. Rack.
9. Encoder.

Figure 3.7.3a De-stacking Unit Linear Transporter and Gripper.



Key:

1. Coupling to leadscrew.
2. Clamp arrangement.
3. Optical interrupter.
4. Teeth.

Figure 3.7.3b Incremental Encoder Arrangement.

3.7.4 The Workpiece Release Area

The workpiece release area was provided by a flat surface. During release, to clamp the workpiece edge positively, a vacuum source, inset into the table surface was employed to assist workpiece transfer between the gripper and table. Vacuum was provided by a continuously operating exhauster unit connected to the release area via flexible wide bore tubing.

3.8 EQUIPMENT DESIGN: CONTROLLER SUB-SYSTEM

3.8.1 Control Languages And Environment

Choice of control language was first considered as language support could dictate controller choice.

For automation and robotic purposes, the language should have a connection with real time activities, for example, interrupts [100]. Real time programming is substantially less simple than conventional programming as the program must remain associated with events occurring in the real world. Three areas required in suitable languages are:

i. Multiple concurrent activities. This is mainly supported in modern systems by a multitasking environment.

ii. Support for unconventional Input/Output (I/O).

iii. Programmed contingency action.

Additionally the language must be simply modifiable, efficient, reliable and understandable [90].

There are two approaches to process control real time software; interpretive and translatory (or compiler). The interpretive approach consist of a program accepting high level language as input and gives control action as output without compilation, consolidation and execution. Proprietary examples are CONRAD (a GEC DDC package), VUPAK (Honeywell) and CONSUL (Ferranti). PLC ladder logic is normally programmed in this fashion.

A translator or compiler may either translate the real time language into another standard high level language for compilation, consolidated and running in the normal way, or may directly produce assembled coding, eg CORRAL 66 and RTL/2. Features of these and other languages are considered below:

i. CORRAL66 is a derivative of ALGOL 60 with some influence from FORTRAN and contains features to handle data representations such as bit manipulations and absolute addressing. No multiprogramming or exception handling facilities are included.

ii. RTL/2 (Real Time Language -Version 2) is a portable language incorporating limited provision for multiprogramming and unconventional I/O. The language is broadly based upon Algol 68.

iii. PASCAL. This is widely used language. Developed by Jensen and Wirth [49], Pascal is highly structured and general purpose. Extensions provided by proprietary compilers include concurrency and I/O interface procedures.

iv. MODULA. The technical parent is PASCAL, but features of PASCAL were removed to make compilation simple. Processes are incorporated into the language, these being similar to procedures, but a call to a process initiates its execution, concurrent with continued execution of the main program. Communication between tasks is carried out by signal commands, eg "WAIT", "SEND", "AWAITED". A scheme is incorporated within the language to handle unconventional I/O.

v. ADA. This is a language designed for embedded real control originating from the US Dept of Defence. Pascal provides the main technical parent. The language is highly structured and supports multiprogramming. Accompanying the language is a support environment (APSE), and the programming system is intended to compile on 32 bit micro and minicomputers.

vi. MODULA 2. This is recent language, suitable for automation purposes. Modula 2 is structured and supports multiprogramming.

vii. C. "C" is a popular structured general purpose language with novel facilities to address machine data structures by pointers.

Numerous programming languages are available to control proprietary robotic systems, eg VAL-2 for the Unimate range of robots. A language for assembly, LASCAR, has been recently produced by Taylor and Stubbings [118]. Robotic languages are reviewed by McLellan [66]. Ben-Ari [3] gives an account of concurrent programming and Hansen [38] describes concurrent programming in automation. Real time scheduling is discussed by Lumley and Phillips [64], in relation to machine control. In general scheduling may be performed sequentially (Round Robin), by task priority level, or by events such as interrupts.

In addition to the direct use of programming languages, general purpose automation software packages are becoming available. The Factorylink package of US Data [139], provides an operating environment where real time communications, control, supervisory and graphics display functions may interact. This package may execute on industrial computers such as the IBM 7531. The package employs the IBM multitasking software, TopView [146].

3.8.2 Controller Choice: Requirements

In the choice of a suitable controller, a definition of controller requirements was necessary and is outlined below.

The de-stacking system was a real time control application. Therefore, for research purposes, a computer supporting a real time operating system was preferred. An example is the DEC RSX11 operating system [23, 85], providing a multitasking environment and a versatile scheduler incorporating round robin and event driven scheduling with capability for defining task priority, dynamically or fixed. A further example is the Digital Research concurrent CP/M operating system [28]. Capacity for multiuser operation was also desirable. Flexibility should be incorporated, as the project was extensible and control requirements could become altered. The controller should possess high program execution speed to facilitate control of the high speed electromechanical kinematics under investigation. Additionally, the controller should support I/O to meet the de-stacking unit control and sensory requirement. Examples of suitable controllers are the DEC PDP 11/73 [23].

Systems as described are both conventional and expensive. They would substantially increase the cost of commercial production target systems for the size of unit envisaged.

3.8.3 Available Controller Systems

A range of controller systems are available. Some of these types are reviewed below.

The first type of controller was based upon a mainframe computer directly controlling remote powered actuators and sensors. This type is used on large process control applications, eg refinery plant, power stations etc. Supervisory, Control And Data Acquisition (SCADA) operator displays are often used. Advantages are fast processing, normally with extensive memory and storage facilities. A disadvantage arises from this equipment being more suited to larger control schemes and with the accompanying expense.

The second type of controller employs Programmable Logic Controllers (PLC units). These units are often devices using microprocessor technology and are built to emulate older relay based logic controllers. Examples are the Allen Bradley, Mitsubishi and Siemens series of PLC units. Disadvantages are expense, and to date a capacity to operate only with digital and analogue channels, limited decision making, limited memory, hardware specific programming arrangements and non standard control languages, such as ladder diagrams [1] to control program flow. A recent extensive survey of programmable controller products is available [144].

The third type of controller comprises microcomputers with directly wired I/O interfaces. This technique exploits the availability of cheap microcomputers and increasingly sophisticated VLSI I/O devices. High level languages and large memories are available. Interfacing must usually be customised, but bus standardised controller computers such as MULTIBUS, VME bus and the DEC Q-bus, support a range of commercial I/O cards. The use of multiprocessing in electromechanical control has been investigated by Mitchel [68]. The CAMAC system [13] was an attempt to standardise computer interfacing to plant but has not been widely used beyond the nuclear industry.

A fourth type is a networked system. Modern automation schemes require a rationalised way to distribute actuating control signals and recover sensory data rapidly from remote locations upon or away from the flexible manufacturing system. Networking controllers provide a solution to this obstacle. Advantages of networking are:

i. A rationalised means of distributing and collecting information to external peripherals.

ii. A means of invoking new features upon the development electromechanics without extensive rewiring of the whole unit.

iii. The ability of the main controller to delegate primitive control loops into the networked outstations. This unloads the controller and hence eases electromechanical coordination timing constraints.

iv. High data transfer rate. (eg 10 Mbytes/s with ethernet).

Disadvantages of networking are expense and time to initially design and debug accompanying application software.

The recently specified factory shop floor automation standard MAP [6, 30, 37, 54, 106] is being widely adopted for automation networking. MAP is suited to factory wide coordination functions between automation systems. This standard is outlined by Hollingum [44]. Tannenbaum [107] describes the OSI network model used by MAP, along with others such as DECnet and SNA.

Presently, means to implement networking schemes are becoming available to microcomputers by communication processor products such as the IBM Realtime Interface Coprocessor [145]. This card-level product supports its own multitasking environment and may be programmed to offload high speed concurrent multiple port communications from the controlling microcomputer.

3.8.4 Selected Controller System: Hardware

The chosen system comprised a Motorola exorcisor bus based controller as a target system and a Cifer 2684 microcomputer as a development support computer. A block diagram of the system is shown in figure 3.8.4. Construction of the target system was provided by exorcisor bus compatible cards interconnected upon an exorcisor bus backplane. The control function was provided by an MC6802 controller card. System memory was supported on a 2 Kb RAM card and the I/O section was built upon an exorcisor prototype board.

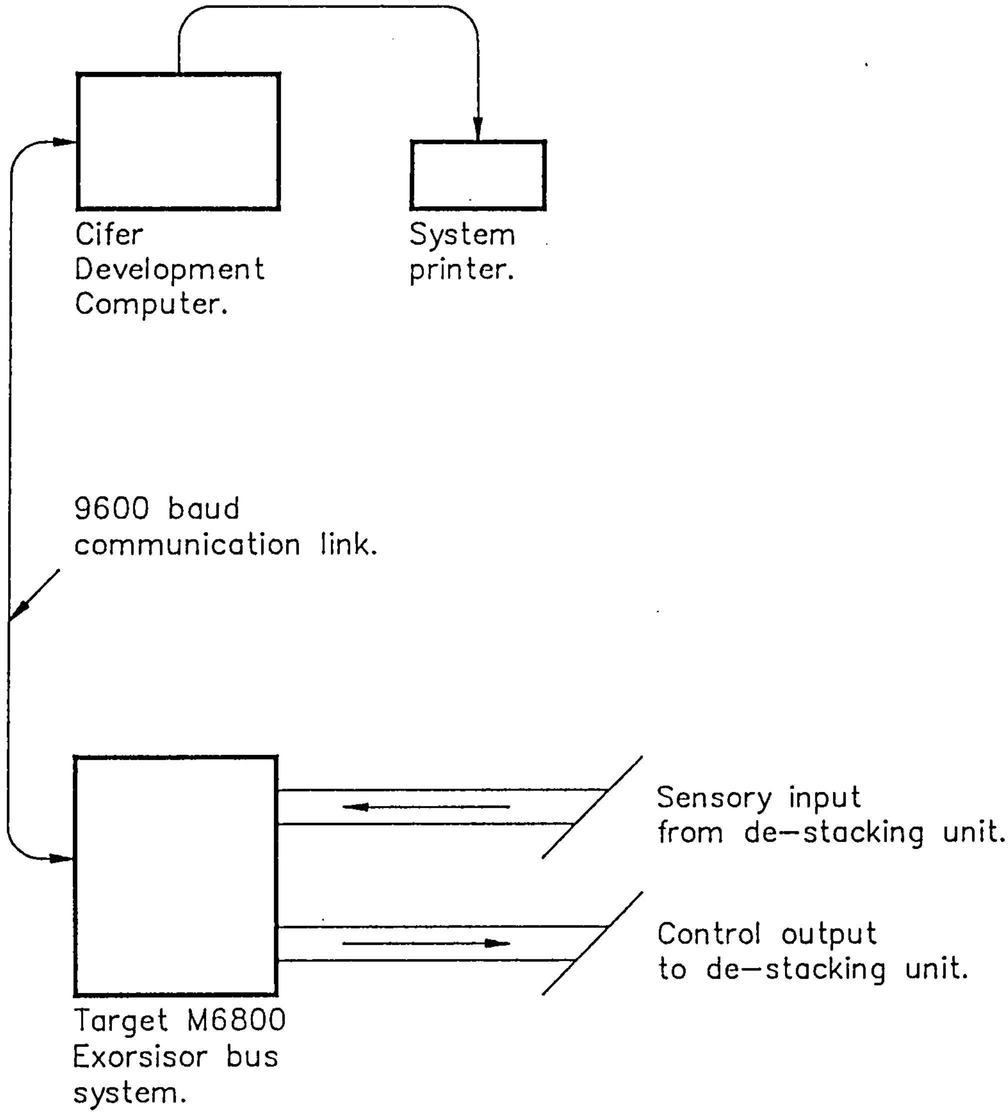


Figure 3.8.4 Prototype Controller Major Components.

Software development facilities were based on the Cifer 2684, comprising.

i. A Cifer 2684 development computer.

ii. Data storage and print facilities.

3.8.5 Selected Control Language

M6800 assembler was chosen as a control language. Its choice was determined by the small (2 Kb) memory size of the controller. Library code associated with higher level languages would require considerably more memory (typically at least 8 Kb) and thus could not be used. However, a proprietary 2 pass assembler (XASM68 [137]) was used to facilitate coding.

3.8.6 The Controller Peripheral Interface

The controller peripheral interface contained two sections. A serial communications link to the Cifer development computer provided the first section. The second comprised the I/O system necessary to interface to the electromechanical systems of the de-stacking unit. A description of this section is given below.

The I/O system was constructed using peripheral interface devices mapped into the controller memory. A separate exorcisor prototype board was employed to support these devices. Two types of peripheral device were selected for use in the interface, these being Motorola MC6840 programmable timer counter devices (PTC's) and Motorola MC6821 peripheral interface adapters (PIA's). Unlike Intel I/O architecture with partitioned I/O and memory addressing, Motorola memory addressing architecture combined I/O and memory ports. The registers of the above devices thus appeared as Read/Write locations in the memory of the controller.

3.9 EQUIPMENT DESIGN: ELECTRONIC SUB-SYSTEMS

This section describes the electronic sub-systems of the unit and their interconnection to the control computer. Their function was to provide power drive electronics for the actuators of the unit and signal conditioning for sensory elements. These were supported by a power supply sub-system and a distribution and interconnection system.

3.9.1 Linear Transporter Motor Driver

The linear transporter drive motor was electrically powered. A block diagram of the driver is shown in figure 3.9.1. Control was provided by an electronic drive package receiving its control input from the de-stacking unit controller. As no commercial driver was identified suitable for this application, the drive was fully designed at the discrete component level. Major sections of the design were firstly motor selection, secondly electronic drive package design and thirdly interface to the controller.

A 200V DC shunt configured motor (Parvalux type) was selected for use. Connection was made to the driver package by cable and a multipole connector.

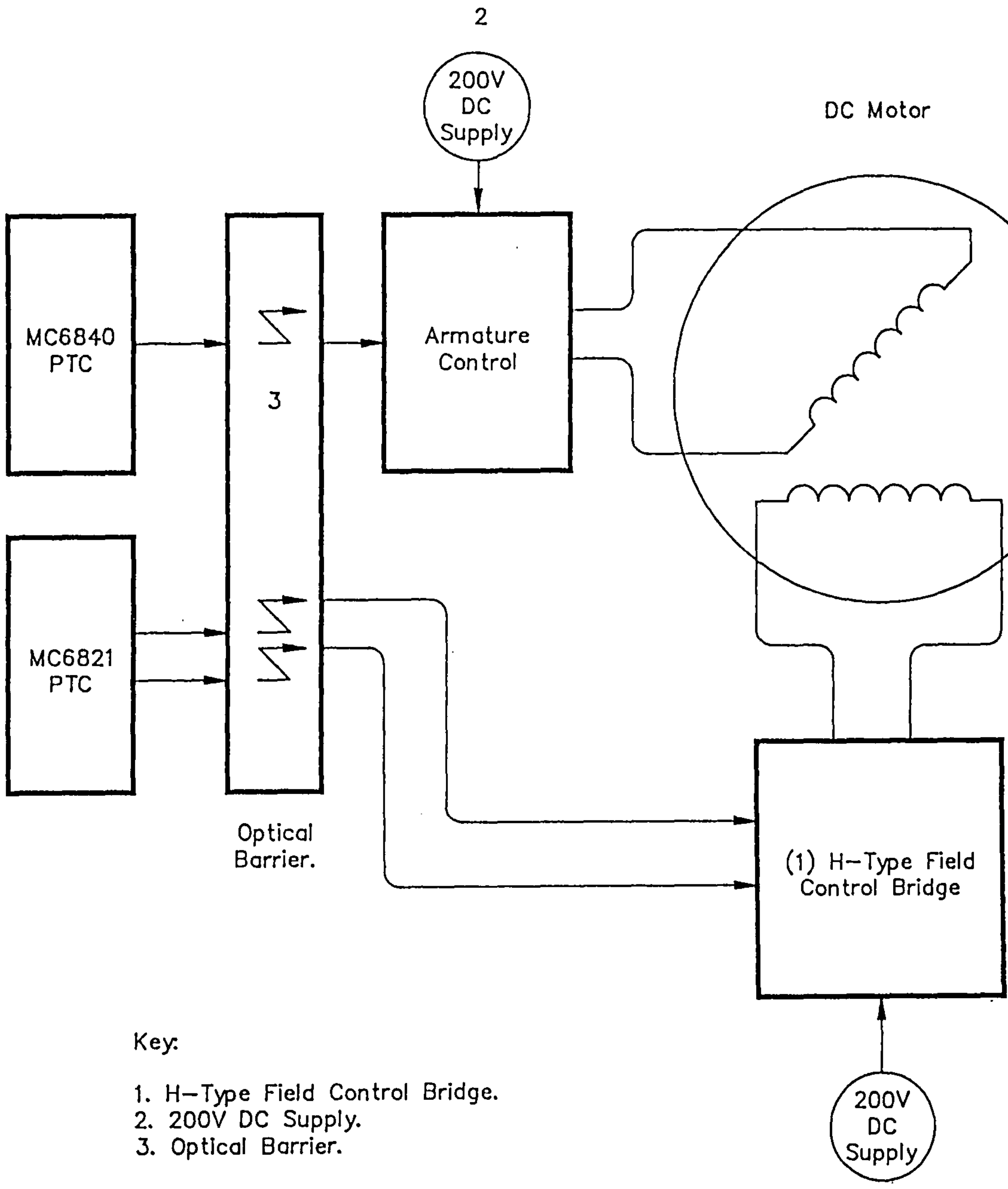


Figure 3.9.1 Linear Transporter DC Drive Elements.

In the design of the driver package, power control was achieved by regulating motor armature current with a Pulse Width Modulation (PWM) technique. Direction control was accommodated by switching the field drive current with an H-type bridge arrangement (1). The power supply for the package was provided by a laboratory 200 V DC supply (2).

The interface to the driver package supplied power and direction control. Power control was achieved by configuring a controller MC6840 PTC device as an autonomous variable width pulse generator. Its output was gated to one control line connected to the armature control circuit. Likewise, direction control employed two control lines derived from an MC6821 PIA. Each control line was routed through an optical isolator (3).

3.9.2 Linear Transporter Carriage Position Sensors

Means to determine carriage position were required for operation of the linear transporter position control system. Sensory information for this purpose was provided by an incremental encoder, coupled to the transporter leadscrew, and a datum sensor, operated by the carriage at a designated reset position. The hardware interface for these sensors was designed at the discrete component level.

In the design of the incremental position encoder support electronics, a means to accumulate encoder pulses was required. This removed the need for the controller to handle each incoming encoder pulse and the necessary interrupt routine. To provide this an MC6840 PTC was configured as a counter. The counter input was connected to the encoder output allowing encoder pulses to increment the value in the PTC counter register. Software based register initialisation was performed at the carriage reset position.

The sensor required to detect the auxiliary sensor carriage reset was designed using an infra red optical interrupter (type SPX2001). Electronic support was simple, the sensor requiring only a 5V logic supply and a current source for its IR emitter. Output from the sensor was connected to a controller interface MC6821 PIA port bit configured as an input.

3.9.3 Linear Transporter Pneumatics Driver

Electronic control of the pneumatic circuit driving the linear transporter gripper actuator was implemented with a solenoid spool valve. Figure 3.9.3 shows the circuit schematic of the valve driver. In operation, a control signal originated from an MC6821 output port of the controller (A). To decouple and protect the controller, the signal was relayed through an optical barrier (B), to the driver circuitry enabling energisation of the valve solenoid (12V 6W) at a power output stage. To support organisation of the electronic grounding scheme, ground return to a star point was used. Fail-to-safe signal processing was adopted in the design for safety purposes. Failure of any equipment power supply or control line becoming open circuit would not result in the energisation of the valve.

3.9.4 Feed Table Step Motor Driver

A four phase step motor (M061 frame size) was used to power the workpiece feed table lifting mechanism. Torque requirements for the lifting mechanics fell below the level available from the motor and thus an Inductive-Resistive (LR) driver could be used rather than a high

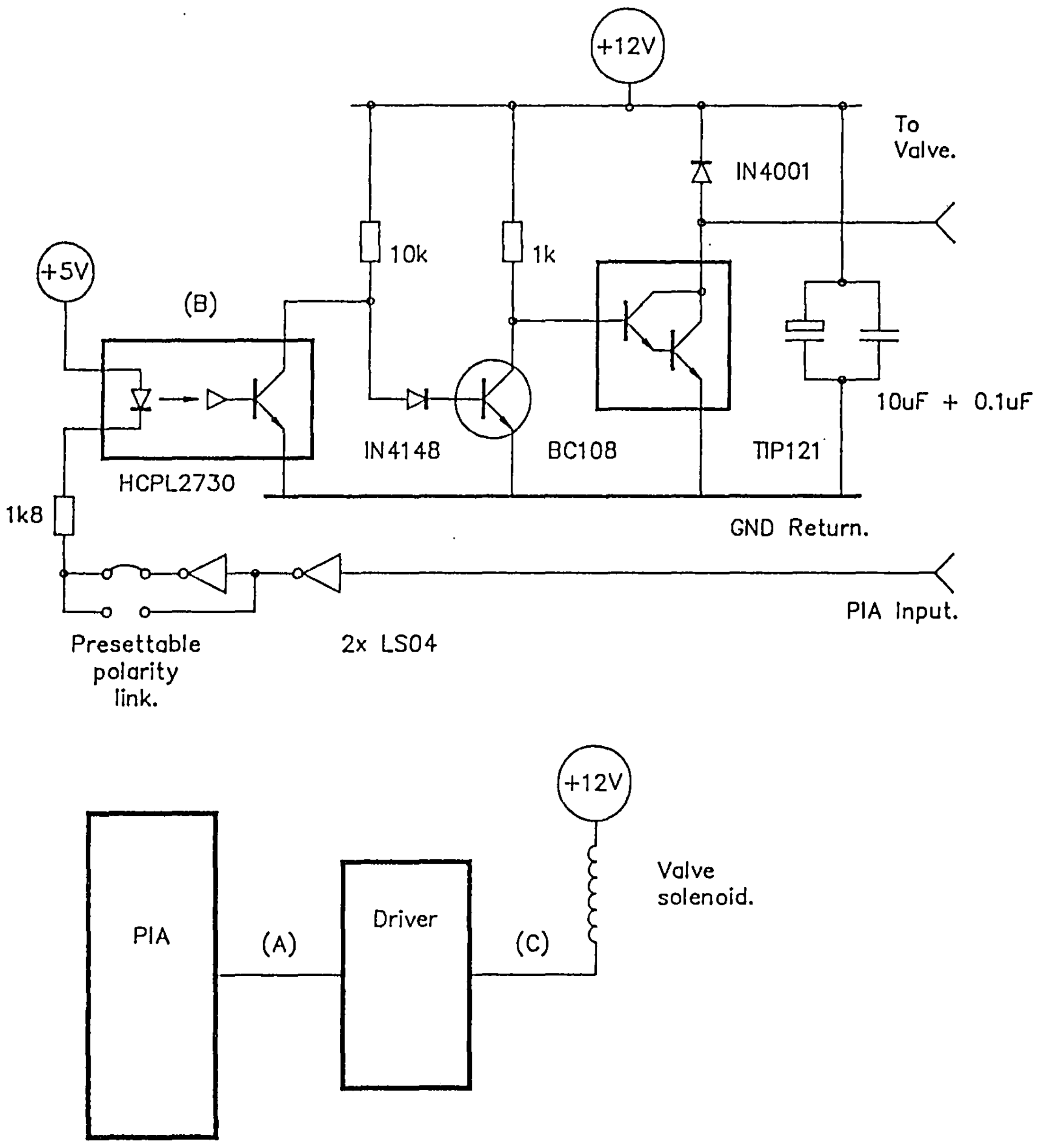


Figure 3.9.3 Pneumatic Valve Driver Schematic.

voltage current regulated unit. Figure 3.9.4a shows a block diagram of the feed table electronics included in the motor drive. Each motor phase was separately controlled by a digital control line, ϕ1-4, enabling the controller to sequence the motor phases. This allowed handling of motor speed ramping and deramping by the application software. The four digital control lines were provided by the controller from a MC6821 PIA device port, in output configuration.

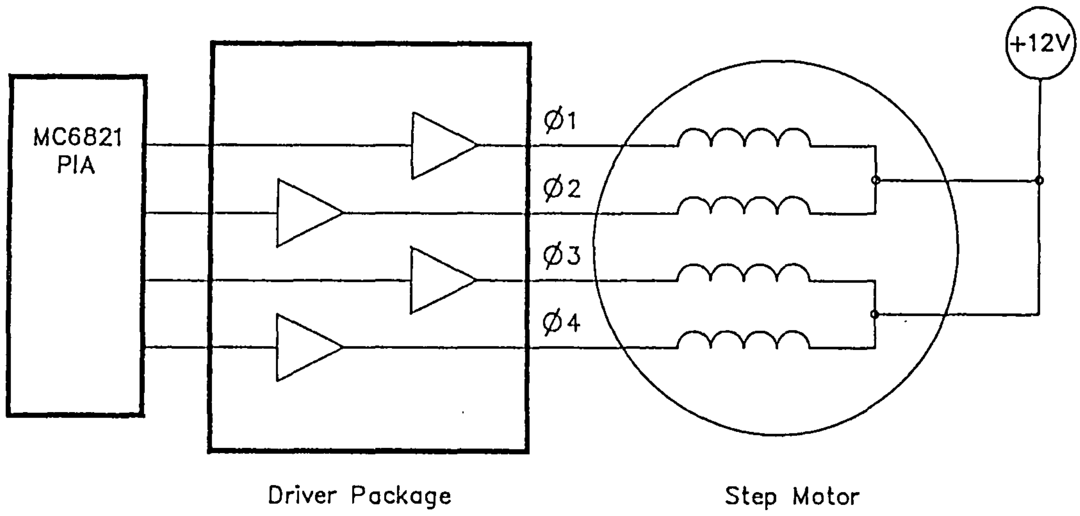
3.9.5 Feed Table Sensor Sub-system

Sensors in the elevating feed table were employed to detect two parameters. These were attainment of fabric clamp pressure and fabric presence on the table. A block diagram of the sensor electronics is shown in figure 3.9.4b.

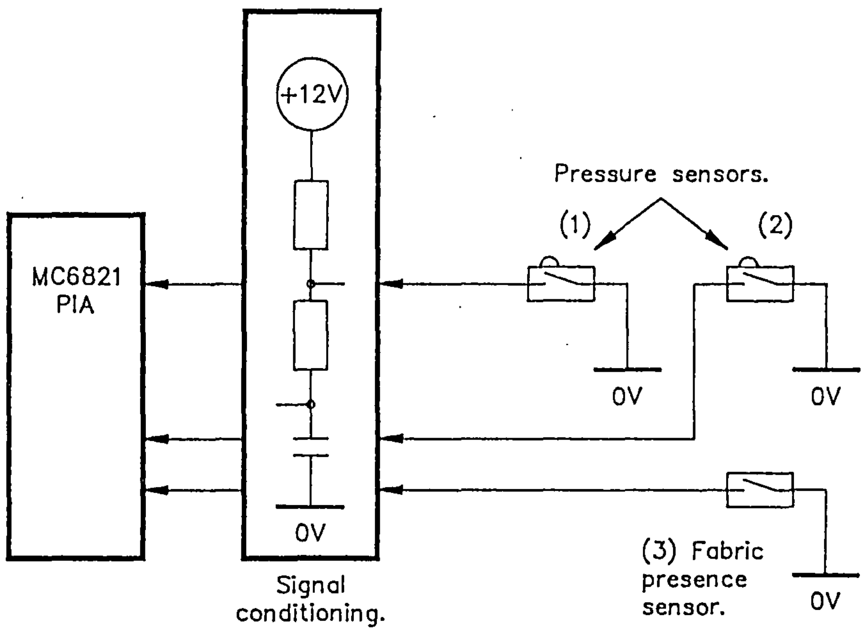
Fabric clamp pressure was detected by microswitches bearing upon the spring loaded clamp bar, figure 3.9.4b (1) and (2). Two microswitches were used, one sited at either end of the bar. When a preset upward thrust was developed against the clamp bar (attainment of clamp pressure), the bar would move and operate the microswitches.

Fabric presence was determined by a sensor (3) based upon an electrical contact system. A contact was mounted on the table underneath the fabric clamp. When the controller attempted to establish clamp pressure, if no fabric was included between the table and the clamp, an electrical connection would be made between the clamp and the contact.

For the above sensors, change of state was read by the controller via MC6821 PIA inputs, connected to each switch element. Pull up resistors and signal conditioning were included in the sensor circuits.



A. Step motor driver.



B. Sensor Arrangement.

Figure 3.9.4 Feed Table Electronics.

3.10 EQUIPMENT DESIGN: APPLICATION PROGRAMMING

3.10.1 Program Operation And Structure

The control program was organised as a group of modules, termed program components. Each provided a distinct function required by the control scheme. These components comprised a Main (root) Module, Operator Interface, Feed Table Control, Linear Transporter Unit Control and Initialisation Processor. Procedures from each were called from the Main module as required in the operation of the program. In describing the application programming Design Structure Diagrams, described initially by Rothon [91] and later in B.S. 6244, [140] were adopted and used throughout this work.

The process used in developing the control software is shown in figure 3.10.1. Three stages were employed, described below:

Firstly editing of assembler source code by a suitable editor such as Wordstar or the Digital Research ED was carried out, source code storage and backup being provided by 5¼" floppy disc. Next production of executable code was performed by assembly with the XASM68 assembler. A list file was generated and directed to the printer to aid development. An object module in Motorola MIKBUG format was additionally produced to allow task image loading and execution on the target system. Thirdly, the object module was loaded onto the target system comprised the third stage. The CP/M Peripheral Interchange Program (PIP) was employed to manage transfer of this code. PIP executed on the development computer, and a communication link was provided by a 9600 baud serial line interconnecting the Cifer 2684 and the M6800 system. The communication server running upon the target system was provided by the firmware based

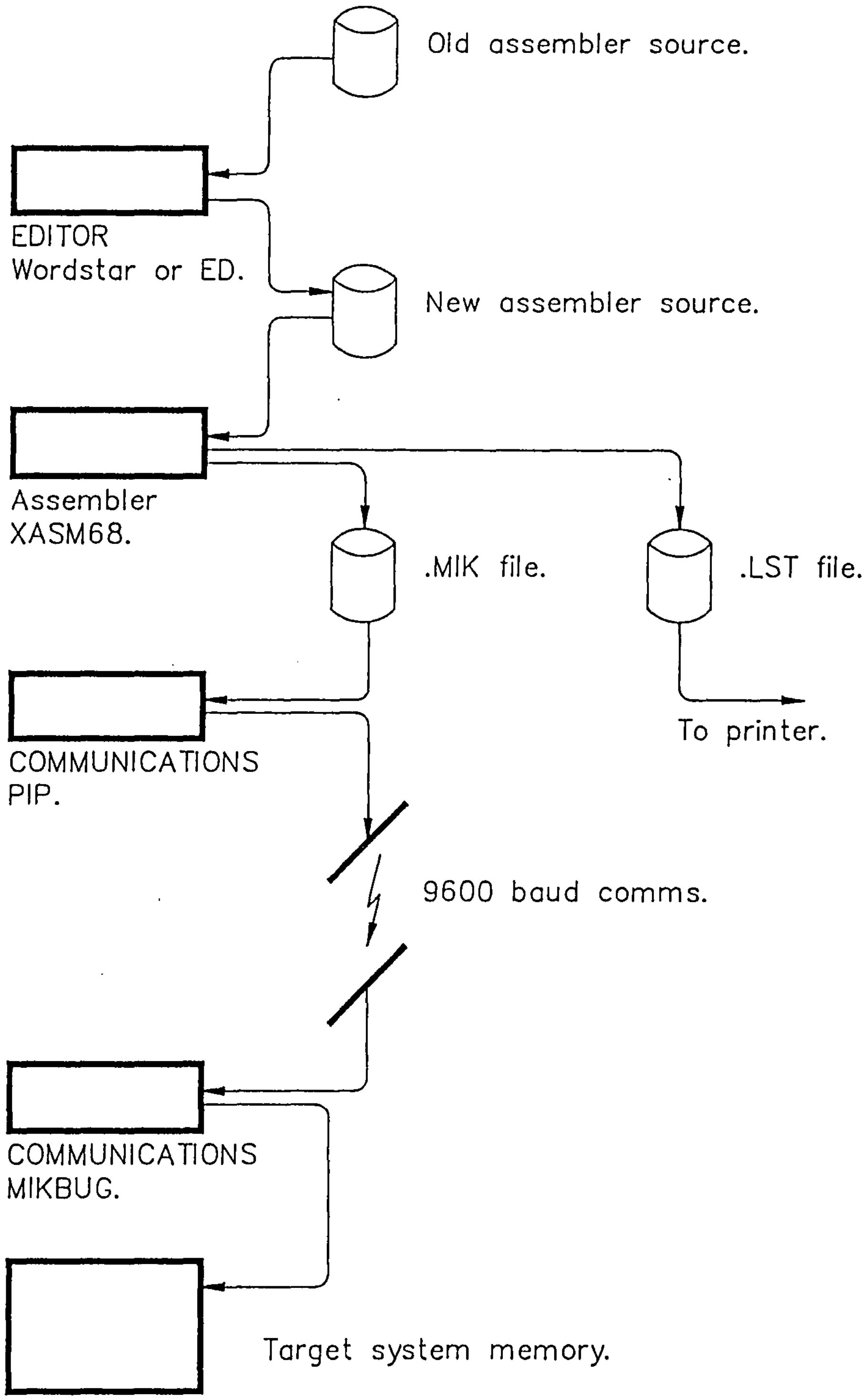


Figure 3.10.1 Controller Software Development Path.

MIKBUG monitor.

To download the object module the M6800 controller working memory range was set using MIKBUG. Operator communication to the target system was carried out with the Cifer placed in its terminal mode. Next, the MIKBUG memory loader was invoked. At this point, the M6800 system awaited input of Exorcisor format records. PIP was then run with the required object file specified in the invoking CP/M command line. Data transmission proceeded automatically. Finally, the target program could be run with the MIKBUG "GO" command.

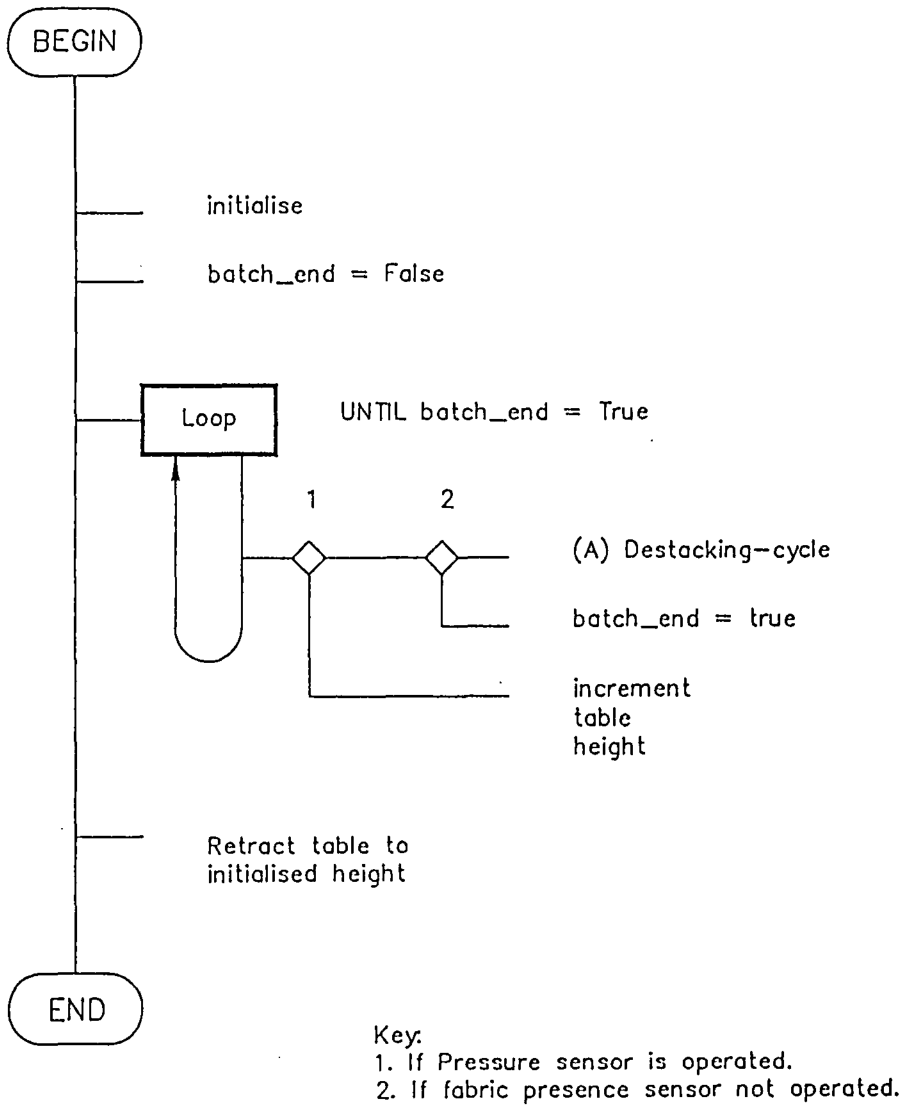
3.10.2 Program Components -- The Main Module

The main module effected overall control and coordination of the de-stacking unit. A flow diagram of the main module root segment is given in flow diagram 3.10.2. Execution of the main module began with a call to an initialisation processor used to perform the start up initialisation functions for the control program. This included batch loading and electromechanical initialisation of the de-stacking linear transporter.

The main de-stacking cycle was then entered and a ply was de-stacked. The cycle repeated, unless the end of the batch was detected by the fabric detection sensor. In this case, the elevating feed table lowered to accept another batch, awaited batch load, raised the table and re-entered the main cycle.

3.10.3 Program Components -- Feed Table Unit Control

The elevating feed table program component contained necessary



Flow Diagram 3.10.3 De-stacking Program Root Segment.

procedures to operate and control the elevating feed table. Its purpose was to initialise the feed table, return the state of the feed table sensors, and elevate the table to feed single workpieces.

Table retraction was effected by issuing successive calls to a feed table step motor control procedure. This procedure issued a group of four motor steps, in a downward direction, at a predefined rate. Table elevation was effected by a call to a corresponding motor advance procedure. A basic output procedure was used to set the four step motor phase control lines ϕ1-4, their state being assigned via a controller MC6821 output port. A four step sequence was necessary to cycle or advance the motor shaft, the required sequence being shown in table 3.10.3. Two subroutines were used to control the motor, one advancing the motor in a clockwise direction and the second in an anticlockwise direction. As the motor was not driven near its torque limits, ramping and deramping motor speed was not necessary.

Table 3.10.3 Step motor Phase Sequencing.

Step	ϕ1	ϕ2	ϕ3	ϕ4
1	+	.	+	.
2	+	.	.	+
3	.	+	.	+
4	.	+	+	.

+ = Energised state
. = Unenergised state

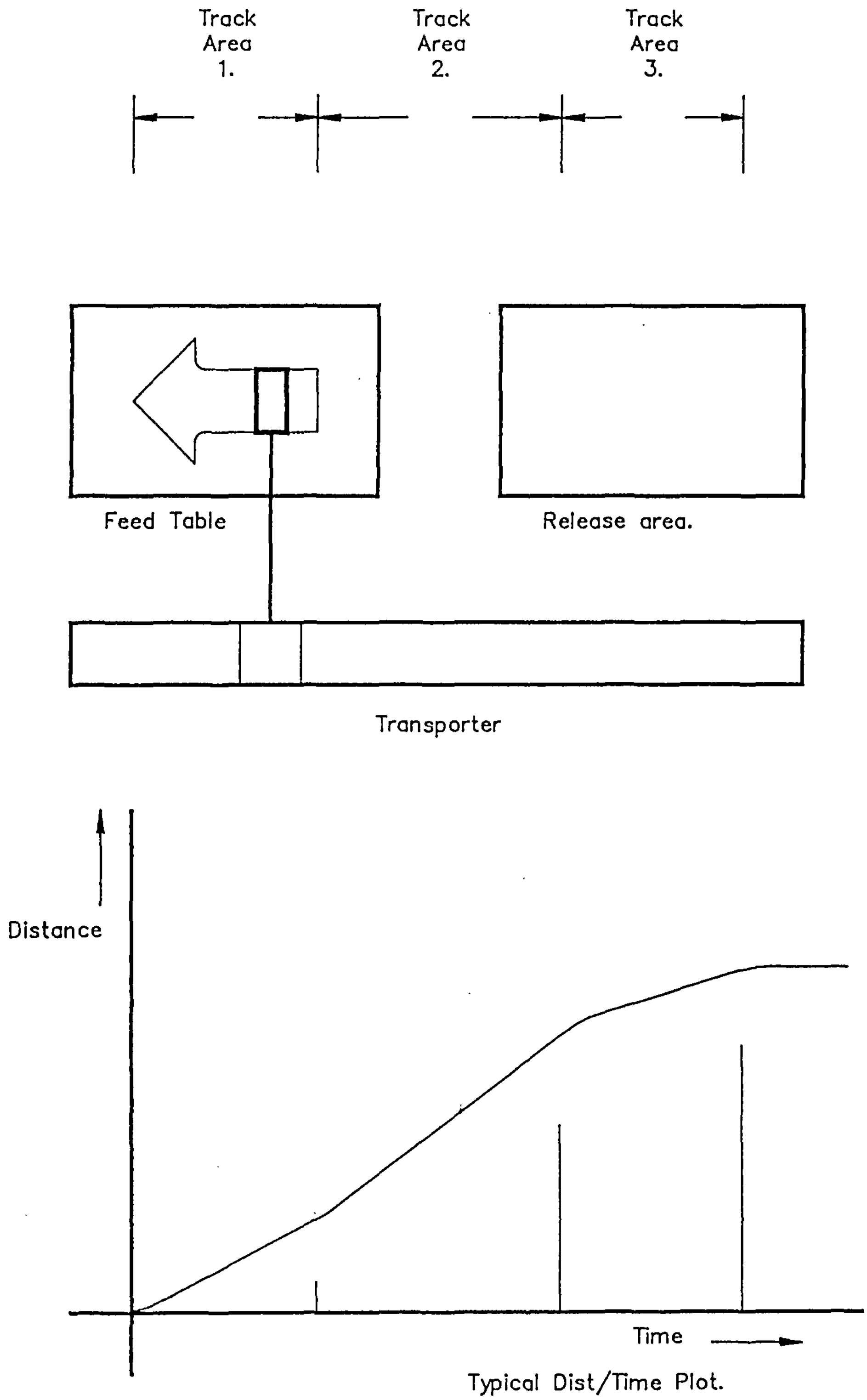
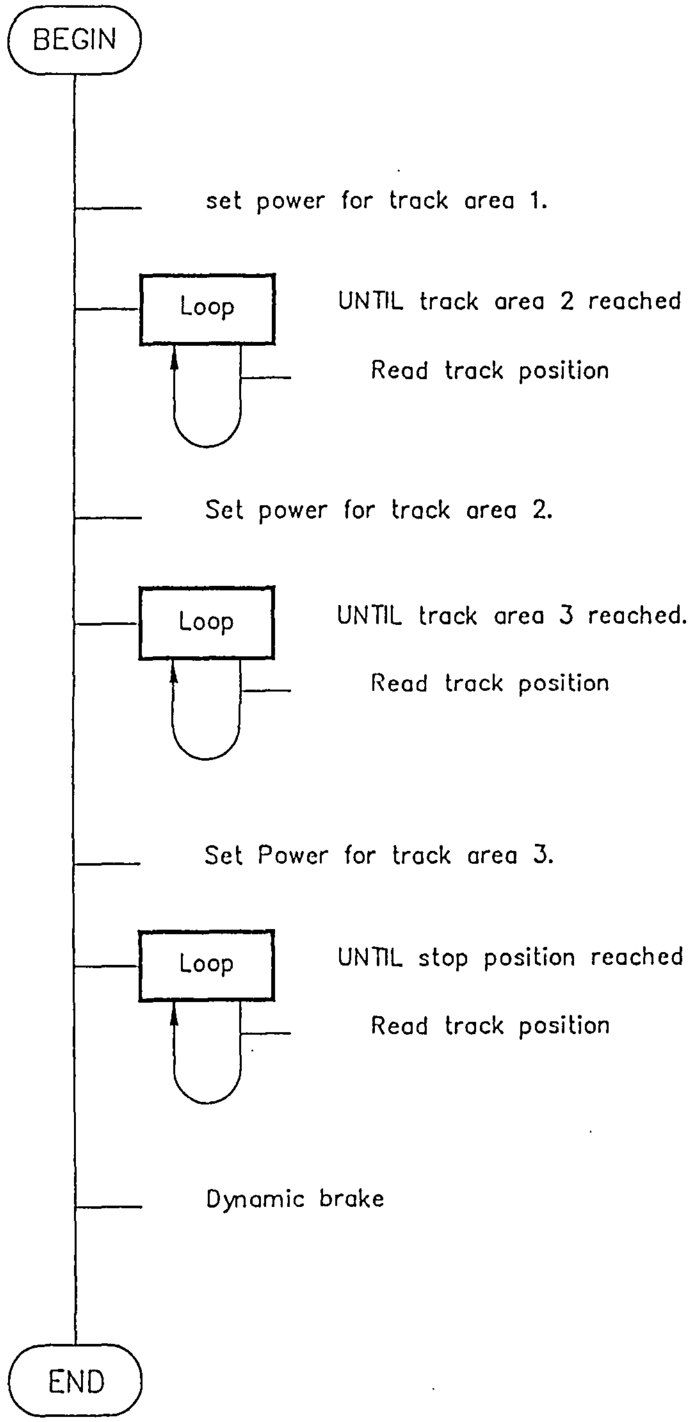
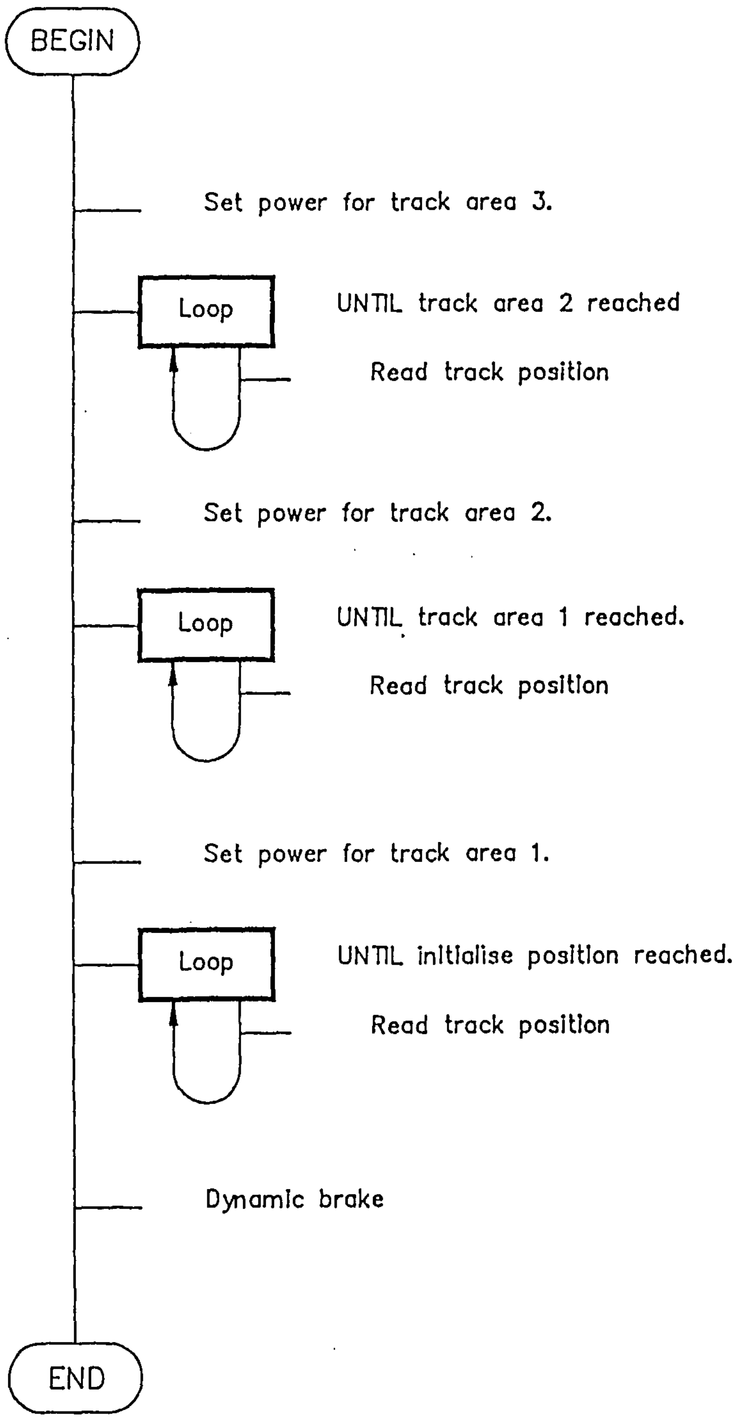


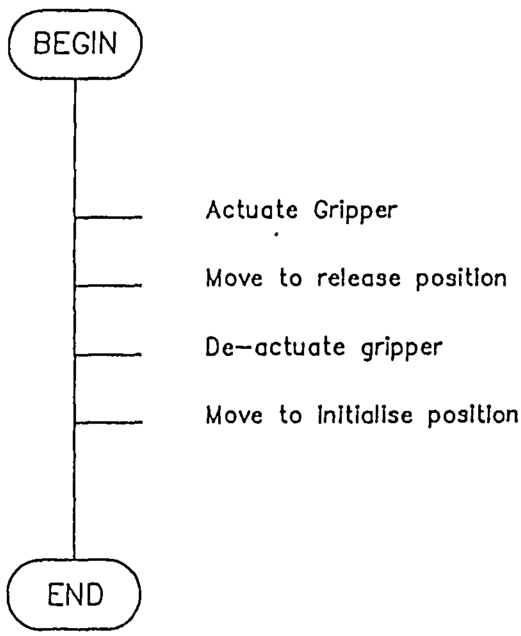
Figure 3.10.4 Linear Transporter Positioning Scheme.



Flow Diagram 3.10.4a Move Linear Transporter To Release Position.



Flow Diagram 3.10.4b Move Linear Transporter To Initialise position.



Flow Diagram 3.10.4c De-stacking Cycle.

initialisation functions for the control program. This included batch loading and electromechanical initialisation for the de-stacking linear transporter.

To initialise the de-stacking electromechanics, the workpiece presence on the feed table was first sensed. Should one or more workpieces be present, the gripper was initialised and the table elevated until workpiece to gripper contact was achieved. If fabric was not present, the table was raised until the workpiece to gripper contact sensor became tripped. In this case, the table surface and the gripper had been brought into contact. The table was thus placed in a known position, and therefore the feed table could retract for a preset number of steps to achieve a reset position to await a new batch of fabric.

3.11 SUMMARY

The preceding sections have described experimental objectives, experimental procedure and the experimental preparation. Additionally, experimental design was described with associated electronic and electromechanical hardware. The following chapter describes construction and evaluation of the experimental equipment. Results from the evaluation and in situ refinements made during the evaluation are also described.

CHAPTER 4

EXPERIMENTAL EVALUATION OF A DE-STACKING PROCESS: RESULTS

4.1 INTRODUCTION

The design of the experimental de-stacking unit was described in chapter 3. Construction and evaluation of the unit was carried out according to the methodology and schedule given. Experimental results are now reported in this chapter, results obtained during commissioning being reported first in section 4.2. Performance deficiencies and potential refinements are noted. Modifications were then effected to improve the performance of the unit and these are described in section 4.3. Full pilot trials were conducted next and reported in section 4.4. Further developments were then carried out and described in section 4.5. A large volume trial was next run and results are given in section 4.6. Finally, results are summarised and conclusions are drawn in sections 4.7 and 4.8 respectively. For all trials reported in this chapter, new batches of gusset components were obtained from the collaborating industrial partner in an edge fused condition.

rack. Should skipping occur, the gripper lost angular registration with its linear position, resulting in ineffective ply actuation.

4.2.2 Gripper Carriage Positioning Accuracy

Gripper carriage positioning accuracy was investigated. The gripper positioning system was found to develop a positively biased position error during operation. Error parameters are summarised in Table 4.2.2. The magnitude of this error was evaluated at 2 mm per cycle. This was unacceptable as the 4 dozen components comprising each batch provided a final error of 96 mm from the datum position. Whilst the initialisation routine at the commencement of the cycle would remove this error by synchronising to the initialisation datum absolute position encoder, those cycles towards the end of a batch would be performed with excessive position errors.

The error was found to arise from two sources. Firstly, the incremental encoder code wheel was found to slip on its mounting shaft as it was clamped without a locating pin, introducing additional code pulses. A temporary remedy was effected by periodically tightening the code wheel clamp. Electrical noise injected into the incremental counter input formed the second source. The wiring scheme associated with this input required screening and improvement in the grounding arrangement. Additionally, the provision of a line driver and receiver was found to reduce noise.

On effecting these changes, the error was observed to reduce to 3 mm per 48 component batch, sufficiently low to allow further evaluation to proceed.

Table 4.2.2. Gripper Carriage Position Accuracy.

Workpiece components per batch:	48
Initial Results	Distance (mm)
Position error per cycle:	+2.00
Cumulative error per batch:	+96.00
Following line noise reduction:	
Position error per cycle:	+0.06
Cumulative error per batch:	+3.00

4.2.3 Elevating Feed Table Commissioning

The elevating feed table electromechanical sub-system was found to operate as anticipated. Table 4.2.3 summarises performance results. Observed initialisation time, excluding manual load time was 26.8 s. As this timing component would add to batch cycle time, means to effect its reduction were considered. Increase in retraction speed could be obtained by increasing drive motor power, either by replacement of the drive system with a switched mode current regulated step motor or by a DC motor. For either case implementation would be appropriate at a commercial development stage and was therefore omitted for the following work.

Table 4.2.3. Elevating Feed Table Performance.	
Manual load time:	4.80 s
Retraction depth:	11.00 cm
Retraction time:	21.15 s
Derived retraction speed:	0.52 cm/s
Average batch height:	7.20 cm
Preset after load wait time:	0.00 s
Elevate to initialised position time:	5.66 s
Total initialise time:	26.81 s

4.2.4 Operating Cycle Time

Components of the operating cycle time were recorded and are given in table 4.2.4a. The major component of operating cycle time was found to comprise linear transporter transfer time. Transfer time was determined by the control algorithm of section 3.10.4, whose parameters are summarised in table 4.2.4b.

Table 4.2.4a Linear Transporter Cycle Component Times.

Component	Time (s)
Actuate time:	0.4
Transport to release area:	4.1
Return to pick up area:	3.3
Feed new workpiece:	0.8
Total cycle time:	8.6

Table 4.2.4b Linear Transporter Control Algorithm Parameters.

Track Section	Assigned Drive Power (%)
1	20
2	90
3	20

4.2.5 Process Quality

Process quality was gauged by the state of the delivered workpiece at the release area. State was assessed by the following parameters.

i. Presence or non-presence of the workpiece.

ii. Mechanical condition of the workpiece.

iii. Angular displacement of the workpiece.

iv. Absolute displacement of the workpiece from the required delivery point.

Process quality results are summarised in table 4.2.5. In the commissioning trial, the workpiece was not delivered in 20% of the attempts. Of the remaining cases, angular displacement was well maintained, with a maximum deviation of ±4°. Absolute displacement was found to lie within ±2 mm in the Y direction (orthogonal to to the transporter direction of travel) but ±20 mm in the X direction. 35% of attempts were incorrectly separated and comprised double workpiece layers. In 25% of attempts crumpled components were delivered.

Table 4.2.5 Commissioning Process Quality

Delivery results.	Percentage of total attempts (%)
Correct delivery:	25
double component workpieces:	35
crumpled workpieces:	20
No delivery:	20
Delivery Accuracy.	**Error**
In transport direction:	±20 mm
In orthogonal to transport direction:	±2 mm
Angular accuracy:	±4°

4.2.6 Identified Refinements And Modifications

The causes of low process quality were examined. A major contributor was found in the control of gripper to workpiece contact pressure. In the arrangement described, this term was controlled indirectly by the feed table fabric clamp pressure sensors. A pivot for the table surface was formed around one pair of support legs and pressure developing between the fabric and clamp created a moment about the pivot. As a result, under sufficient pressure, the table surface tilted, raising the stack towards the gripper. The above mechanism thus caused simultaneous contact between the gripper and the fabric stack, developing clamp pressure. This arrangement was not ideal, as gripper pressure was also determined in this process. Parameters such as point of pivot and pressure sensor actuating force were not easily adjusted. As a result indeterminate gripper pressure was applied to the stack and indeterminate clamp force was developed. Excessive gripper pressure led to shearing of indeterminate numbers of fabric components, disturbing the stack. Excessive clamp pressure led to displacing the stack when the end of the ply was removed from the clamp. Once a disturbed stack had been created, subsequent separation attempts produced lower quality results.

4.3 EFFECTED REFINEMENTS AND MODIFICATIONS

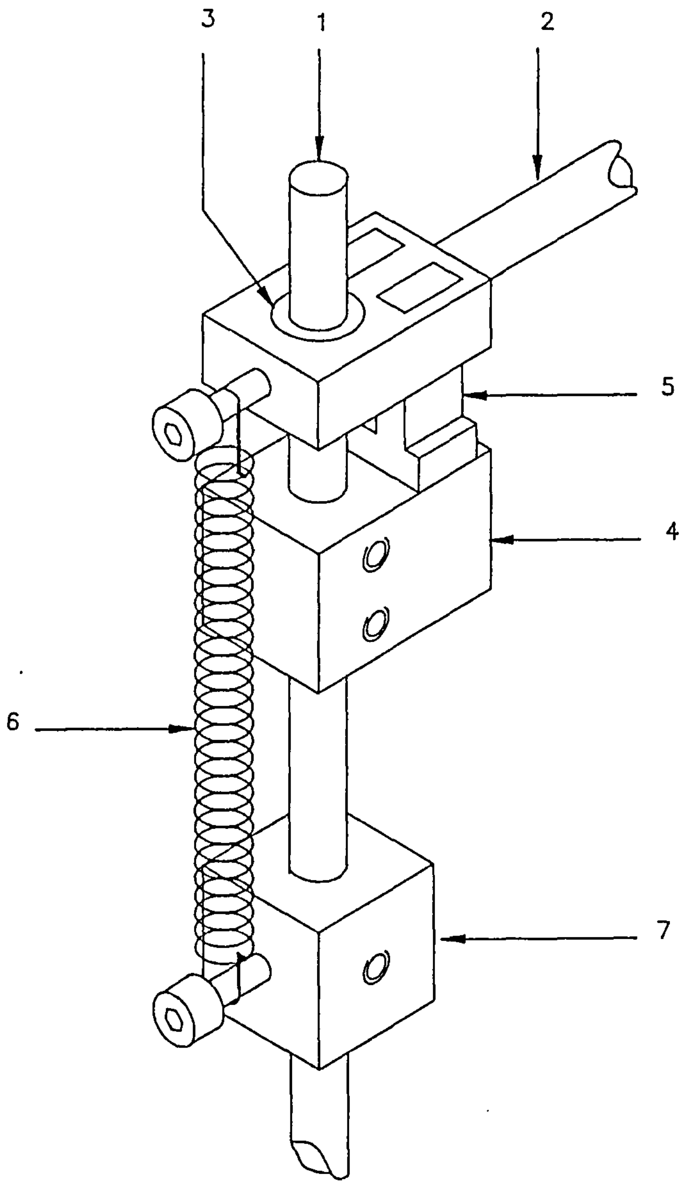
The control system element determining gripper to workpiece and workpiece to clamp contact pressure was modified. To improve pressure regulation, a spring based clamping bar arrangement was designed and the microswitch based actuators were replaced with non contacting infra-red optical interrupter sensors. Figure 4.3 shows the modified elevating feed table elements.

4.4 PILOT DE-STACKING TRIALS

Following modification and refinements to the unit, pilot trials were begun. Approximately 1000 edge fused components were processed through the unit in this test.

4.4.1 A Step Motor Transporter Drive

In the previous work, carriage position was set with a closed loop control system. A final positioning error of ±1 mm was achieved. Use of step motor as a leadscrew actuator driven in an open loop mode was anticipated to offer improved positioning accuracy over the DC motor drive as movement would be quantized into fixed steps. The performance



Key:

1. Clamp support rod.
2. Clamp.
3. PTFE bush.
4. Sensor mount.
5. IR opto sensor.
6. Tension spring.
7. Spring anchor.

Figure 4.3 Modified Fabric Clamp And Pressure Sensor.

of such a drive was investigated. A step motor was installed in place of the DC motor, and an LR type driver circuit was designed and constructed to power the motor. Modification was made to the control program to drive the new motor and the de-stacking unit was retested. Table 4.4.1 summarises the results obtained. Operating cycle time was found to reduce to 8.1 s and positioning error was reduced to ±1.0 mm. Whilst performance was improved, the DC motor was retained as the final cost of a developed commercial unit using DC motors would be less.

Table 4.4.1 Step Motor Drive Cycle Times.

Component	Time (s)
Actuate time:	0.4
Transport to release area:	3.9
Return to pick up area:	3.0
Feed new workpiece:	0.8
Total cycle time:	8.1
Positioning accuracy:	±1.0 mm

4.4.2 Operating Cycle Time

Improvements were gained in operating cycle time by increasing the assigned DC motor power. The results obtained are summarised in table 4.4.2a, and control algorithm parameters in table 4.4.2b.

Table 4.4.2a Linear Transporter Cycle Component Times.

Component	Time (s)
Actuate time:	0.4
Transport to release area:	1.4
Return to pick up area:	1.2
Feed new workpiece:	0.8
Total cycle time:	3.8

Table 4.4.2b Linear Transporter Control Algorithm Parameters.

Track Section	Assigned drive power (%)
1	20
2	90
3	20

4.4.3 Process Quality

Successful delivery of workpieces to the release area improved to 96% of delivery attempts. Angular registration remained accurate to ±4°. Registration in the axis orthogonal to the direction of transport remained accurate to ±2 mm and registration in the direction of transport improved to ±10 mm. This was found due in part to improvement of stack condition, resulting in less frequent disturbances to the stack.

Table 4.4.3 Process Quality (Commissioning).	
Delivery results.	Percentage of total attempts (%)
Correct delivery:	96
double component workpieces:	2
crumpled workpieces:	1
No delivery:	1
Delivery Accuracy.	Error
In transport direction:	±10 mm
In orthogonal to transport direction:	±2 mm
Angular delivery accuracy:	±4°

4.4.4 Quantification Of Reliability

A term α was defined to represent the coefficient of reliability of the process. Its complement β represented process unreliability. If Θ_i is the outcome of separation attempt i, where

$$\Theta_i = \begin{cases} 1 : \text{successful.} \\ 0 : \text{unsuccessful.} \end{cases} \quad \text{-- Eqn 4.4.4a}$$

Then in a trial comprising s attempts:

$$\alpha = \frac{\sum_{1}^{s} \Theta_i}{s} \quad \text{-- Eqn 4.4.4b}$$

and

$$\beta = \frac{\sum_{1}^{s} (1-\Theta_i)}{s} \qquad \text{-- Eqn 4.4.4c}$$

In sub-section 4.4.3 a value of 0.96 was found for α. Several mechanisms were observed to contribute to the low level of α and these are considered in the following sub-section.

4.4.5 De-stacking Failure Mechanisms

α was found sensitive to gripper to workpiece contact pressure and could be minimised by reducing workpiece to gripper contact force.

A second failure mechanism originated at the fabric presence detection system in the feed table. The electrical contact built into the table surface for fabric prescence detection disturbed the clamping action during separation of the last three plies upon the stack.

Finally, the gripper head geometry was observed to introduce disturbance into the ply, due to the wide workpiece and low gripper width. On occasion the workpiece would not form a regular tube during the rolling element of the de-stacking process. This was exhibited by the workpiece crumpling as it was rolled. The above mechanisms of de-stacking failure are treated in the next section.

4.4.6 Identified Refinements And Modifications

The mechanisms of failure described in sub-section 4.4.5 were considered for modification. Detection of fabric by an electrical contact was intrusive to the process and a non contacting detection system was anticipated to give improved performance. Crumpling of the fabric was found due in part due to uneven rolling after ply separation. Initial tests of de-stacking equipment yielded results indicating a performance improvement was necessary before equipment could be operated in unattended fashion. De-stacking failure mechanisms were identified in sub-section 4.4.5 and the following developments were considered necessary to increase α.

i. Further improvement in gripper to fabric contact pressure regulation.

ii. Revision of the fabric clamp arrangement to minimise ply displacement during fabric removal.

iii. Replacement the fabric detection system with a non contacting system to defeat unreliability during separation of the last fabric component of the stack.

iv. Modification of the gripper to aid the workpiece rolling operation.

4.5 DEVELOPMENTS

4.5.1 Gripper To Fabric Contact Pressure Regulation

The gripper to fabric contact pressure regulation system described in section 4.2.6 was improved by de-coupling it from the clamp pressure regulation system. A pressure sensitive plate was mounted beneath the fabric stack on the table surface directly below the fabric to gripper point of contact. A spring loaded low actuation force microswitch was used in the plate to determine attainment of contact force. The sensor was operated by weight of the fabric stack added to the fabric to gripper contact pressure, allowing input to a controller based contact force pressure control algorithm.

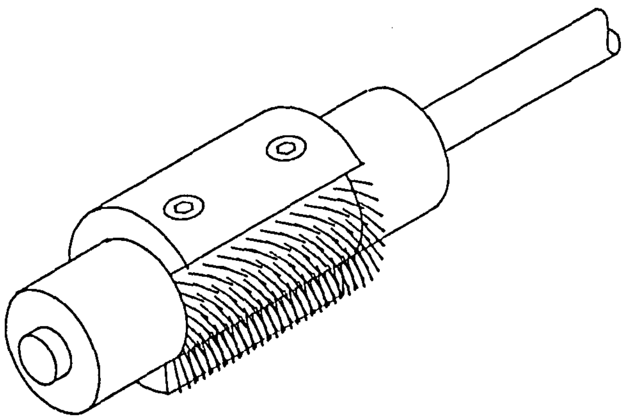
4.5.2 Gripper Improvements

Once separated, the fabric ply was rolled on to the gripper body. The grip area provided a former for rolling the workpiece. During rolling, the edges of the fabric were occasionally observed to become crumpled. This was due to the short length of carding cloth used, its dimensions creating an insufficiently long former.

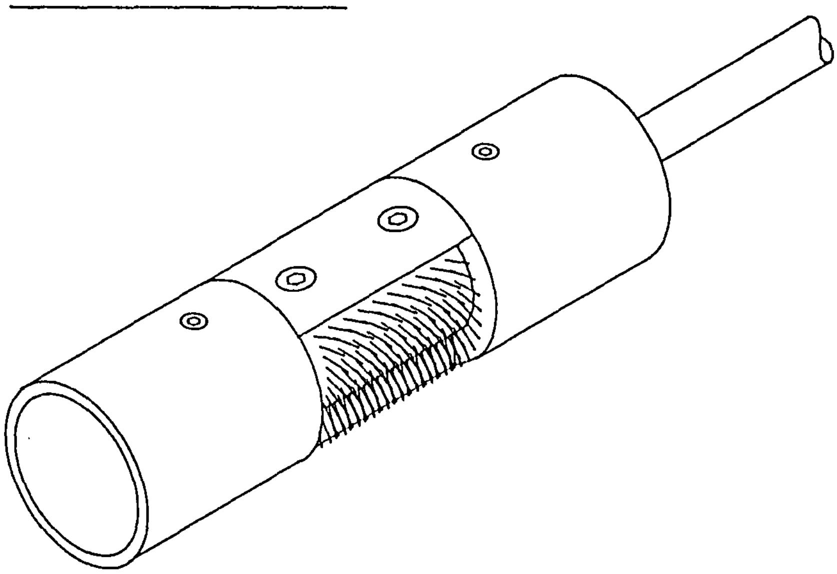
The gripper was consequently modified. By providing extension formers at either end of the grip area, an elongated former was created. These were constructed from turned aluminium tubes and locked in position with allen screws. The tube diameter was set to allow the oblique gripping pins to project from the former body to a distance of 1 mm. Cross sections of the gripper before and after modification are shown in figure 4.5.2. Table 4.5.2 summarises the effected modifications.

Table 4.5.2. Gripper Former Tube Modifications.

Roller component	Dimensions (mm)
Previous former length:	40.0
Extension tube length:	30.0
Modified former length:	100.0



Initial Gripper Arrangement.



Gripper with extension tube modifications.

Figure 4.5.2 Gripper Modifications.

4.5.3 Elevating Feed Table Fabric Detection Improvements

Redesign of the fabric presence detection system was identified as an area allowing improvement in de-stacking reliability, α. Alteration of the existing electrical contact based detection system to a non-intrusive reflex infra red based fabric detection method was investigated. The schematic diagram for the system is shown in Figure 4.5.3. A circuit capable of detecting fabric presence was designed based upon an commercial infra red reflex cell (1) comprising an emitter and receiver sensing infra red light reflected from fabric. The reflex sensor was fitted into the table surface (2), oriented upwards to detect the last ply of fabric on the table through a window of dimensions 10 x 5 mm. A digital output was provided by the sensor, indicating presence or non presence of the fabric. The new detector system was evaluated and found to operate reliably. It was therefore installed into the feed table surface, and the earlier system removed.

4.6 SECONDARY TRIALS

4.6.1 Bulk De-stacking Trial

Developments described in section 4.5 were effected on the de-stacking device and a second bulk trial conducted. A sample of one hundred batches of workpieces were provided by the industrial partner from its production lines. The group of workpieces were then de-stacked by the unit from the sample, each batch comprising four dozen plies. Table 4.6.1 summarises results.

4.7 CONCLUSIONS

The experimental de-stacking unit described in chapter 3 has been constructed and was experimentally evaluated in this chapter. A quantitative gauge of unreliability was defined and used to assess the performance of the unit. A pilot test was conducted, yielding a reliability, α, of 0.96. Unreliability was attributed to several mechanisms identified from this test. Development was then carried out to reduce the influence of these mechanisms and was followed by a large volume assessment of unreliability, yielding an α of 0.995.

Unreliability is discussed in section 4.7.1 and cycle times in section 4.7.3.

4.7.1 Criteria For Unattended Operation

Wholly automatic processing requires either complete reliability, or inbuilt means to automatically correct mishandling. Quality control feedback must thus be provided when reliability is not complete. A maximum α of 0.995 was obtained during the large volume de-stacking experiment, indicating a necessity to investigate quality control and error correction within the de-stacking process.

Provision of quality control and improved handling schemes are investigated in chapter 5.

4.7.2 Cycle Time Considerations

Cycle time of the de-stacking process relates to the economic viability of the automated process. A time of 3.8 s was recorded in the large volume de-stacking trial. Moreover, the "Bind gusset" sub-operations could be interlaced and so a cycle time of 3.8 s does not imply further time overhead for the automated process, not true in the manual process. Automation thus appears preferable to manual assembly by cycle time criteria. Transfer speed was determined by the state of development carried out upon the transport transfer control system and the above results do not indicate a limit to the reduction of cycle time. Suggestions for further reduction of transfer speed are given below:

i. Improve the transfer mechanics by reducing friction.

ii. Optimisation of the control of the linear transporter dynamics.

4.7.3 Controller Performance

At this point elements of the de-stacking unit could be individually controlled by key commands from the development system console. However, in attempting to connect all of the functions in software some shortcomings in the controller were highlighted. These were:

i. A necessity to program the controller in assembler. Use of this low level language slowed software development, and mathematical functions were not supported.

ii. Storage was limited in the prototype system to 2 Kb. This restricted the overall size of the control program and removed the possibility of adding advanced error handling procedures as the preliminary control program was itself almost 2 Kb long.

iii. It was necessary to construct a special interface employing the development system serial line to allow operator communication whilst the program was running.

4.8 SUMMARY

In this chapter, the results obtained during the trial of the de-stacking process were reported. Final results were stated in section 4.6, but intermediate results were described. Both implemented and suggested developments are reported. Refinements to the basic design of the process were reported and their treatment was covered. The above results were reported by Sterling, Sarhardi and Nicholson [55, 94, 101, 104]. The following chapter extends work with the de-stacking device directed towards achieving unattended operation.

CHAPTER 5

A FLEXIBLE DE-STACKING PROCESS

5.1 INTRODUCTION

This chapter describes an investigation into robotic means to achieve further reliability in the de-stacking process. Previous de-stacking unit reliability results, described in chapter 4, determined the reliability coefficient, α, of the pilot de-stacking process at 0.995 and improvement was therefore sought to meet the requirement of computer supervised operation.

In Section 5.2, the investigation of a flexible de-stacking system incorporating error correction is proposed. Requirements of such an improved system are described. Section 5.3 details the introduction of sensory based feedback to the process. A summary of the chapter is given in section 5.4.

5.2 A MODULAR END EFFECTOR FOR DE-STACKING

In the prototype de-stacking system, the griper kinematics were determined by the mechanical linkage between the gripper and the linear transporter. The range of possible handling processes available for evaluation was thus limited by the linkage. Provision of means to mechanically decouple the gripper from the linear transporter would extend the processes available for evaluation. Within this range, more rapid and reliable de-stacking processes may exist. To evaluate this range, experimentation with such a flexible handling scheme was proposed. The system would comprise modular linear transporter and gripper units. Both units would be separately driven from the system controller unit.

5.2.1 A Proposed Decoupled Handling Process

Within the extended range of de-stacking processes available from the described de-coupled gripper system, several offered improved de-stacking quality. Of these, initially one process was considered for evaluation. This process is illustrated in figure 5.2.1 and is described below:

At commencement of the de-stacking process, the gripper approaches the workpiece stack with its oblique pin grip area inverted to avoid attachment to the stack until required, (A). Such a precaution was not possible with the mechanically coupled system. Next, the gripper is positioned above the workpiece and aligned to present its oblique pin area to the stack, (B) and (C). The elevating table is raised until contact is made between the gripper and stack, (D). Upon contact, actuation occurs, (E). Workpiece edge separation is caused by rotation of the roller through a pre-defined angle. Next, the ply is rolled up to the workpiece clamp position and withdraws the remaining clamped fabric from the stack (F), (G) and (H). The gripper is then translated to the workpiece receiving area. After ply release, the gripper

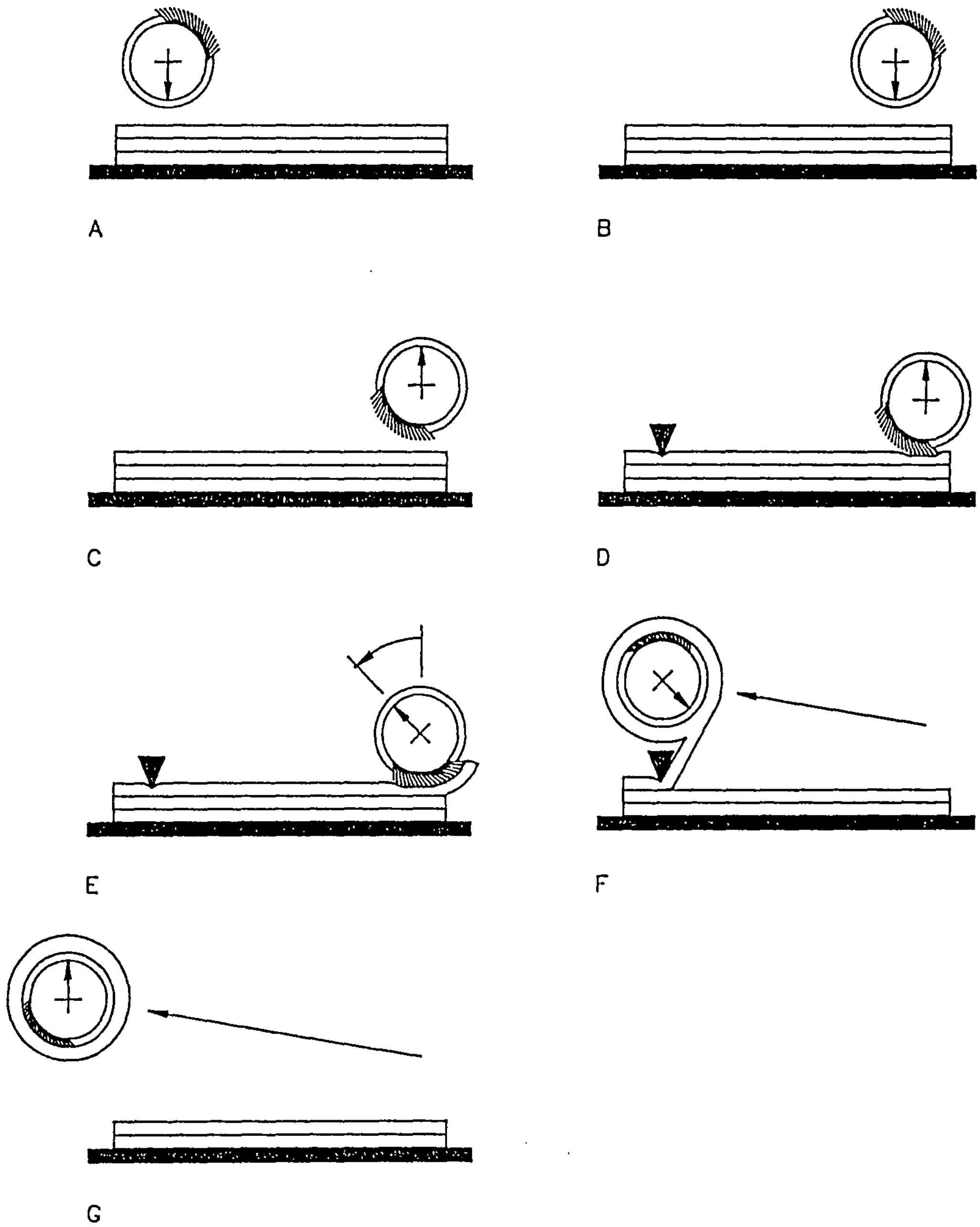


Figure 5.2.1 Initial De-coupled De-stacking Process.

alignment is set to present the oblique pin surface on the upper area of the gripper, reducing the possibility of accidental reattachment to the fabric. Next, the gripper is moved to a standby datum position, completing the cycle. Replication of the mechanically coupled process reported in chapters 2 and 4 is additionally proposed as an experimental control.

5.2.2 A Mechanically Decoupled Gripper Unit

A modular design was adopted in the implementation of the mechanically decoupled gripper unit. Such a gripper would be able to operate as a robotic end effector and thus be suited for operation with either the linear transporter reported in the previous work or with other robotic articulation devices.

To mechanically decouple the gripper, an internal power source was required to drive the gripper rotation. This could be provided by a minature geared DC motor. Additionally, gripper angle could be sensed by an angular encoder attached to the gripper shaft.

5.3 INTEGRATION OF QUALITY CONTROL INSTRUMENTATION

Quality control could be applied to detect handling errors relating to the de-stacking process. In particular, the edge separation process is subject to unreliability and performance monitoring is required. Parameters known to effect repeatability were workpiece to end effector contact pressure and engagement torque. These terms could be regulated by closed loop control with forces instrumented by force transducers. Techniques used for quality control and error detection monitoring in this application are now considered.

5.3.1 Advantages Of Quality Control Feedback

For wholly unattended operation of the unit, handling errors must be detected and action taken. Early detection of handling errors, such as ply separation errors would allow remedial action by the unit. If a ply separation error occurred, then the workpiece could either be rejected or released and separation then reattempted. Secondly, the monitoring of critical performance parameters would provide a tool to aid process refinement.

5.3.2 Optical Determination Of Correct Ply Separation

Use of optical means to determine correct ply separation were investigated. Such a system could employ the optical transmission properties of fabric to gauge the number of plies separated during one de-stacking cycle. A preliminary system based on visible light, termed a Light Locked Loop, provided results indicating separated ply number could be determined optically.

An optical ply depth detection system must allow rejection of ambient light signals and be capable of integration into the gripper unit. Infra red was used in preference to visible light to reduce the effect of variable ambient light conditions. AC modulation was employed for the same reason.

The mechanical arrangement of the sensor is shown in 5.3.2a. Figure 5.3.2b shows a block diagram of the electronic system. An infra-red emitter (1) was suspended adjacent to the gripper roller and energised by a modulator (2). The detector (3) was set into the gripper roller and AC coupled via the amplifier and DC rectification stage (4). With

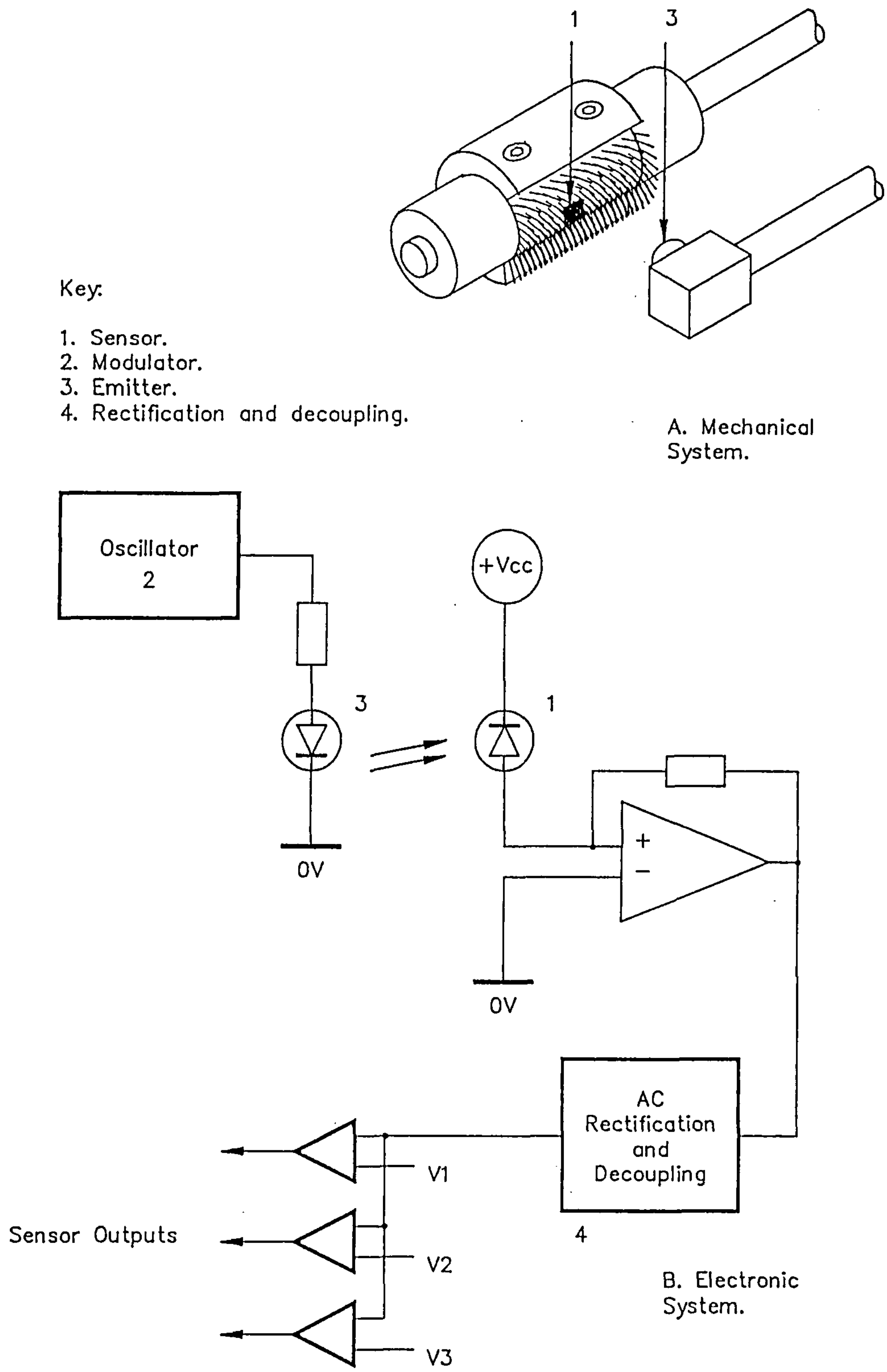
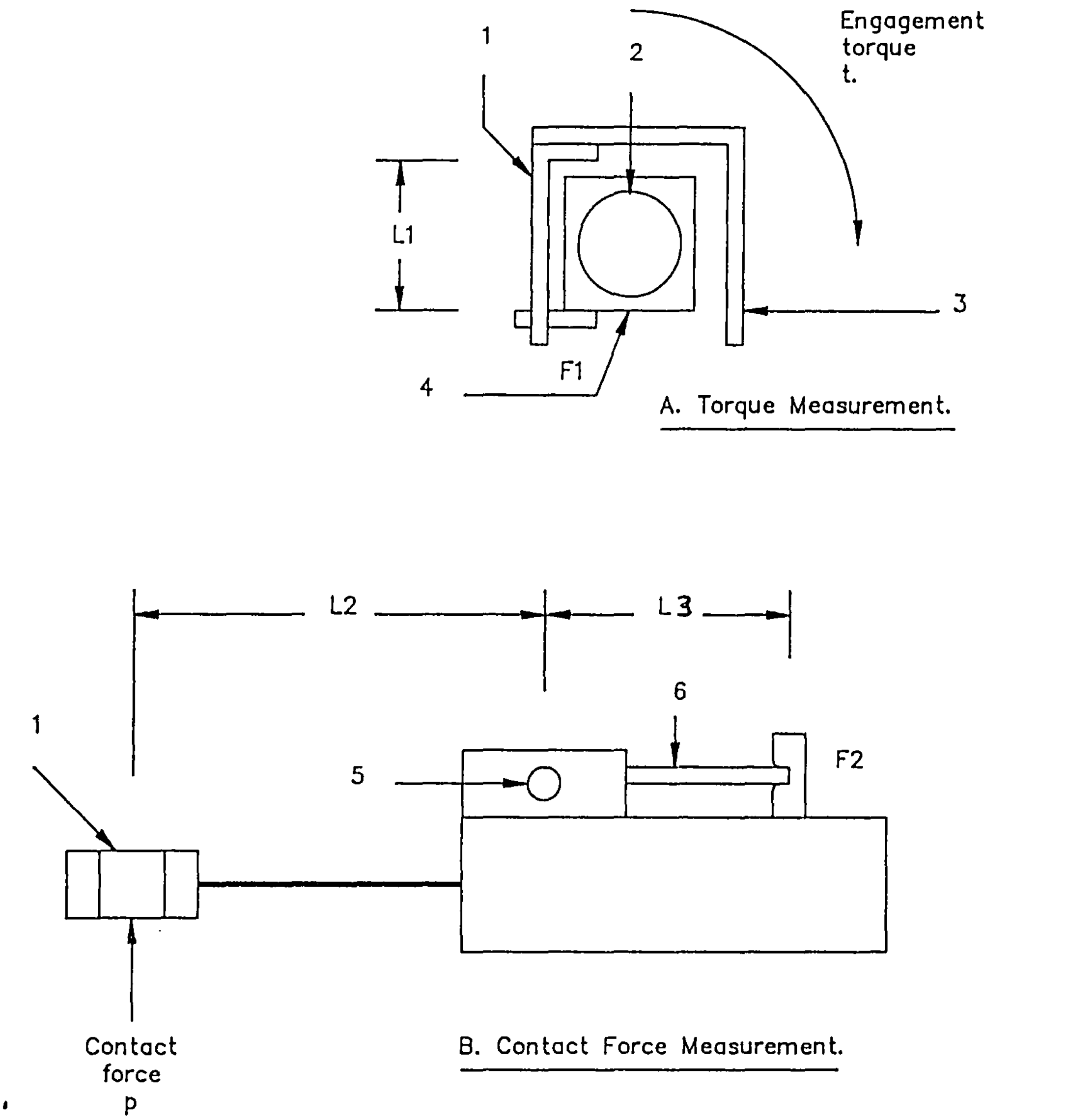


Figure 5.3.2 Ply Depth Sensor System.

the roller aligned to present the emitter to the sensor face, the output of stage (4) was a function only of the number of plies and transmission properties of the subject fabric attached to the roller. The output could be detected either by comparators with their threshold level set to detect separation of none, single or multiple plies. Alternatively, the output could be subjected to Analogue to Digital (A-D) conversion and determination of ply depth made in the application software.

5.3.3 Measurement Of Ply Separation Forces

Determination of gripper to workpiece contact force, p, and engagement torque, t, during ply separation was proposed to facilitate control of the process. Furthermore, direct measurement of separated fabric weight by the instrumentation was feasible, providing additional quality control potentially capable of discriminating the number of plies held on the gripper following separation. A force measurement system was incorporated into the decoupled gripper unit. Several techniques were considered in the force transducer design. Use of a Sting Balance support, described in Perry and Lisner [78] was investigated. The Sting Balance allows resolution of the three orthogonal forces and torques applied to a supported object. However, its use was rejected due to its complexity in manufacture, instrumentation and calibration. A more conventional approach was taken by supporting the gripper assembly to allow the unit a DOF in the plane of the force under measurement and linking the articulation to a load cell. Figure 5.3.3a shows the articulation arrangement used. To measure torque t, the gripper was suspended in a frame so it could rotate in the axis of the drive shaft and a load cell (4) linked to the gripper body to the suspension frame. Similarly p was resolved by supporting the combined assembly at its COG



Key:

1. Torque measuring beam.
2. Gripper roller.
3. Exterior frame.
4. Interior frame.
5. Pivot.
6. Contact force measuring beam.

Figure 5.3.3a Gripper Force Instrumentation Mechanics.

in an axis orthogonal to the plane of the force and linking both supports by a further load cell (6).

Forces F1 and F2 arising at the load cells may be used to determine t and p by equating moments. Thus:

$$t = L1.F1 \qquad \text{-- Eqn 5.3.3a.}$$

$$p = \frac{L3\ F2}{L2} \qquad \text{-- Eqn 5.3.3b.}$$

Load cell design is now considered. Transducers to measure forces in the equipment described were constructed, based upon cantilever beams instrumented with strain gauges. Such transducers are described in Perry and Lisner [77] and Potma [78], figure 5.3.3b showing the beam design. A full strain gauge bridge was placed at the root of the beam. The measured force p develops a moment Mr ar the root of the beam of magnitude:

$$Mr = pl \qquad \text{-- Eqn 5.3.3c.}$$

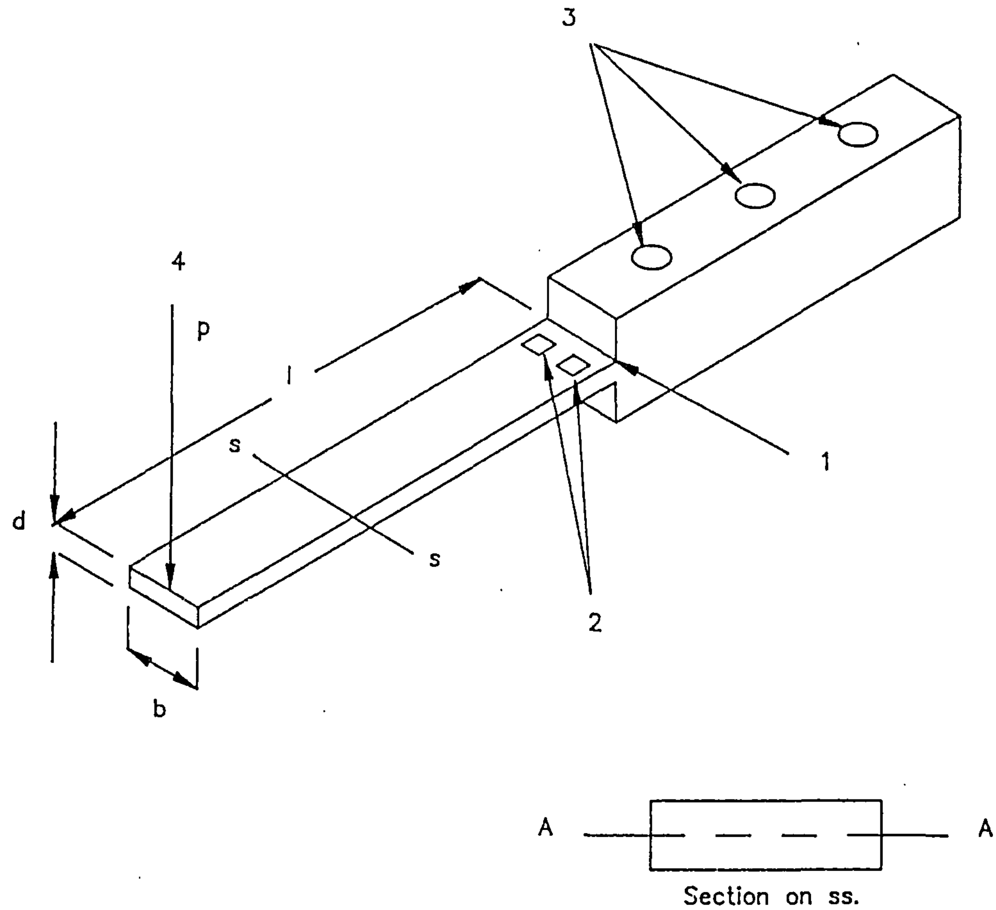
The resulting surface stress at the root is given by Stephens [99] as:

$$\sigma = \frac{Mr\ Y}{I} \qquad \text{-- Eqn 5.3.3d.}$$

where $Y = \frac{d}{2}$ -- Eqn 5.3.3e

and I is the 2nd moment of area about the beam axis AA, given by;

$$I = \frac{bd^3}{12} \qquad \text{-- Eqn 5.3.3f}$$



Key:

1. Beam root
2. Strain Gauge bridge.
3. Mounting holes.
4. Applied force p.

Figure 5.3.3b. Cantilever beam force transducer.

Strain may be determined from Hookes law:

$$E = \frac{\sigma}{\varepsilon} \qquad \text{-- Eqn 5.3.3g}$$

using equations 5.3.3c, d, e, f and g;

$$\varepsilon = \frac{6pl}{bd^2E} \qquad \text{-- Eqn 5.3.3h}$$

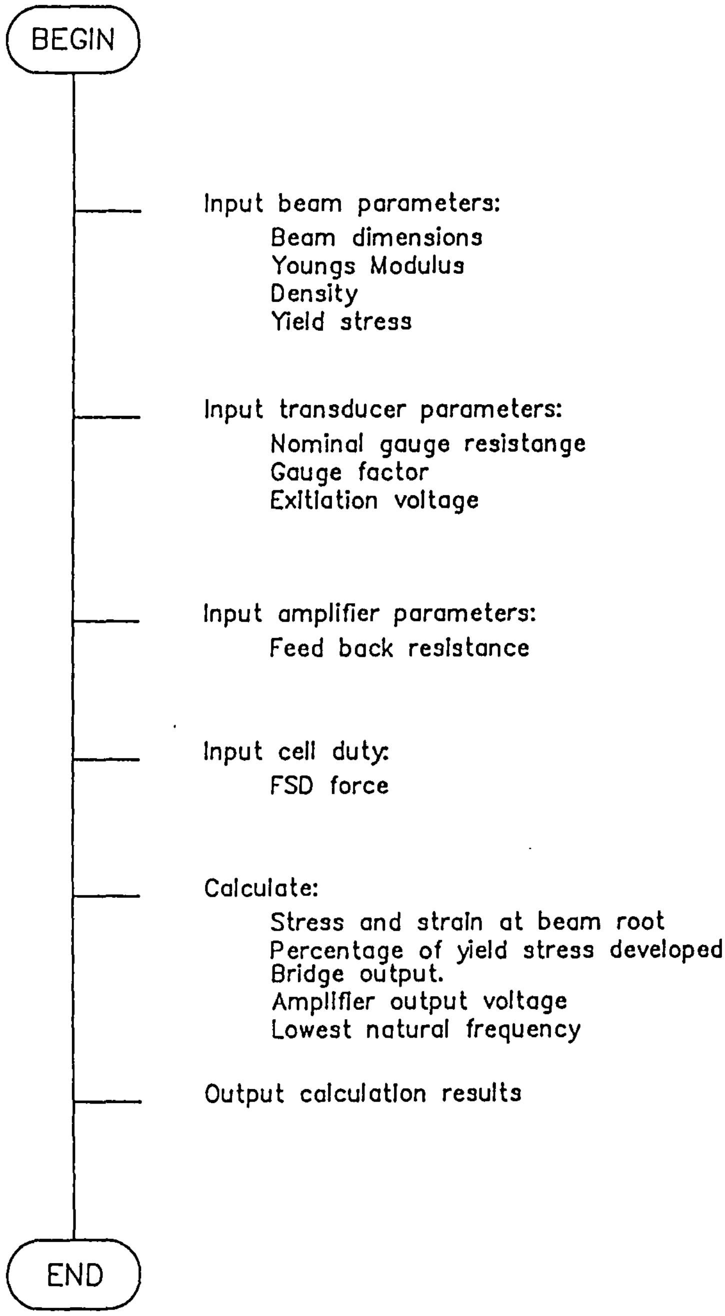
additionally, beam end deflection, Δ, is given by:

$$\Delta = \frac{pl^3}{3EI} \qquad \text{-- Eqn 5.3.3i}$$

Thus the surface strain and end deflection developed for a given applied force may be determined from equations 5.3.3h and i. To determine the dynamic response of the beam, the lowest natural frequency, ω, is given by Prentice [80], in equation 5.3.3j.

$$\omega^2 = \frac{20EI}{\rho Al^4} \qquad \text{-- Eqn 5.3.3j}$$

A computer program to facilitate the design of the transducer parameters was written, its operation being shown in flow diagram 5.3.3. Dimensions and force parameters are input. Output parameters, derived from equations 5.3.3h and i comprise developed strain and deflection of the end of the beam. Strain gauge amplifier output is also given, the analysis used being given in section 6.10.2. A check on surface stress excursion beyond surface yield stress σ_{sy} under full scale load conditions was incorporated in the program.



Flow Diagram 5.3.3 Cantilever Beam Design Program.

5.4 SUMMARY

Considerations for a mechanically de-coupled gripper unit have been given in this chapter. Use of sensor based feedback from the gripper has been discussed and several advantages have been identified.

A modular de-coupled gripper with in built optical and force measurement quality control features is proposed and its design and performance are reported in the following chapters 6 and 7.

CHAPTER 6

EXPERIMENTAL EVALUATION OF A FLEXIBLE DE-STACKING PROCESS

6.1 INTRODUCTION

This chapter describes the design of an investigation into the flexible de-stacking process proposed in chapter 5.

The structure of the chapter is as follows: Objectives of the investigation are detailed in section 6.2. Experimental methodology follows in section 6.3 and design of the flexible de-stacking process is covered in section 6.4. Section 6.5 gives the experimental schedule and preparation for the investigation is described in 6.6. An overview of the experimental systems follows in section 6.7. Next, section 6.8 details equipment design, comprising a description of the electromechanical sub-systems, the de-coupled gripper, workpiece feed table, and the workpiece release area. The controller system, electronic sub-systems and application programming are described in sections 6.9 to 6.11 respectively. Finally, the chapter is summarised in section 6.12.

6.2 EXPERIMENTAL OBJECTIVES

The investigation had two objectives. These were:

i. To identify an open loop process using a mechanically de-coupled gripper to improve upon the quality of the process of chapter 3.

ii. To increase the process reliability by the integration of sensory feed back into the de-stacking process.

6.3 EXPERIMENTAL METHODOLOGY

The experimental methodology of chapter 3 was used. This comprised the design of an experimental handling process then design of the experimental decoupled de-stacking unit. Evaluation of the process was carried out by conducting experiments described in the experimental schedule.

6.4 EXPERIMENTAL SCHEDULE

A schedule of experiments was prepared to allow evaluation of the de-stacking process. The evaluation began at the commissioning stage where a preliminary trial was conducted. At this point an experimental control was carried out with the unit programmed to replicate the mechanically coupled process. This was followed by a refinement stage where alternative processes were evaluated. A concluding high volume evaluation was finally carried out. Operational cycle time, throughput and process quality were recorded in the high volume trial section.

6.5 PROCESS DESIGN: FLEXIBLE DE-STACKING PROCESS

The basic de-stacking process used in the following work was outlined in chapter 5. Initially, the evaluation was intended for comparison as an experimental control with results obtained in chapter 4 and therefore its design was intended to simulate the kinematics of the mechanically coupled unit. This process was implemented with control programming detailed in section 6.11. Process refinements were carried out based upon preceding results obtained and evaluations of the resulting modified processes are thus reported in chapter 7.

6.6 EXPERIMENTAL PREPARATION

Detailed design and construction of the flexible de-stacking system electromechanical and electronic units were carried out. The process control software was designed, written and tested. Experimental trial samples were obtained from the industrial partner in the form of knife cut gusset component fabric stacks.

6.7 SYSTEMS OVERVIEW

The de-coupled de-stacking unit comprised sub-system elements similar to those of chapter 3 with the addition of separate electromechanical, electronic and control elements for the gripper unit. Each sub-system component is described in the following sections.

6.8 EQUIPMENT DESIGN: ELECTROMECHANICAL SUB-SYSTEMS

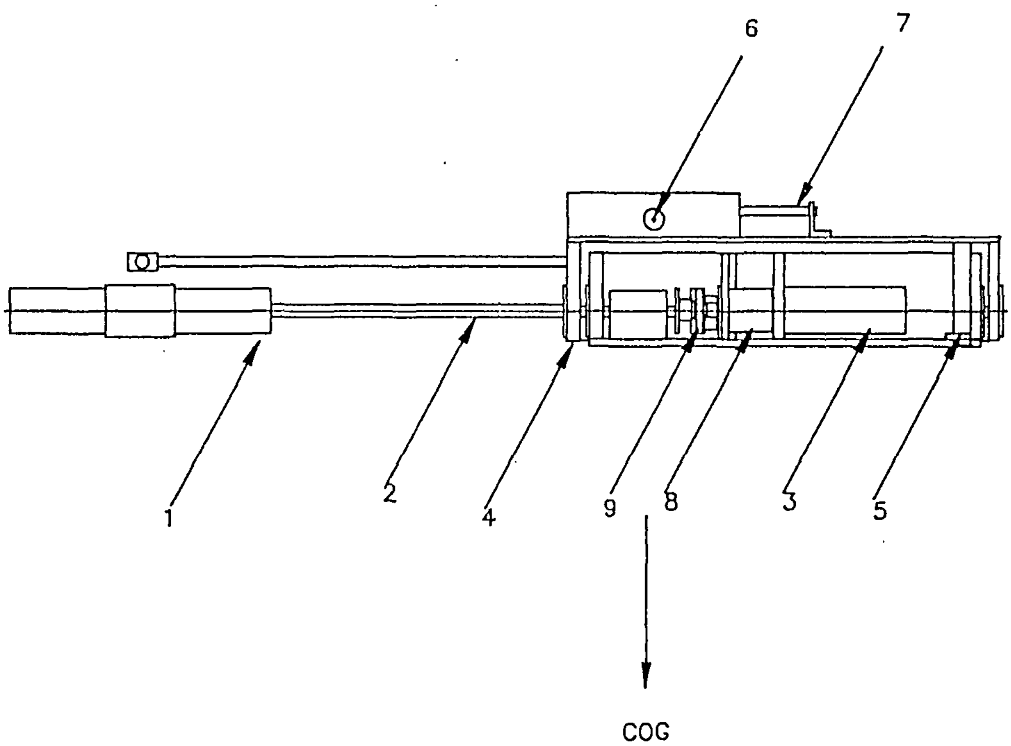
6.8.1 The Mechanically De-coupled Gripper Unit

The electromechanics of the de-coupled gripper unit outlined in chapter five were designed and constructed. Figure 6.8.1 illustrates a side elevation of the gripper general assembly and plates 6.8.1a and 6.8.1b illustrate the completed unit. The design covered electromechanics to control gripper angle and optical and force feedback electromechanics.

The gripper roller (1) was constructed from a 100 mm x ϕ 20 mm cylinder. A 40 mm strip of carding cloth was inset centrally into the roller unit, occupying a 180° segment of the roller with its pins projecting from the cylinder surface to a distance of 1 mm.

A 200 mm x ϕ 5 mm stainless steel tube was used to fabricate the drive shaft. Gripper drive power was provided by a Maxon permanent magnet DC motor type 2330 fitted with a 60:1 reduction ratio gearhead (3) linked by a flexible beam coupling to the drive shaft.

A major element of the design concerned provision for gripper force sensing. The method selected in chapter 5 required gripper articulation in DOF's coaxial with the drive shaft rotation (engagement torque sensing) and in the vertical plane passing through the drive shaft (contact force sensing). Articulation required for engagement torque sensing was accommodated by mounting the drive motor and associated shaft encoders in an internal frame by bearings supported with an external frame (4). A cantilever force sensor (5) linked both frames. Articulation required for contact force sensing was provided by a pivot (6)



Key:

1. Roller
2. Drive shaft.
3. DC Drive motor.
4. External Frame.
5. Engagement torque sensing beam.
6. Pivot Point.
7. Contact force sensing beam.
8. Encoder.
9. Pulley.

Figure 6.8.1 Mechanically Decoupled Gripper General Assembly.

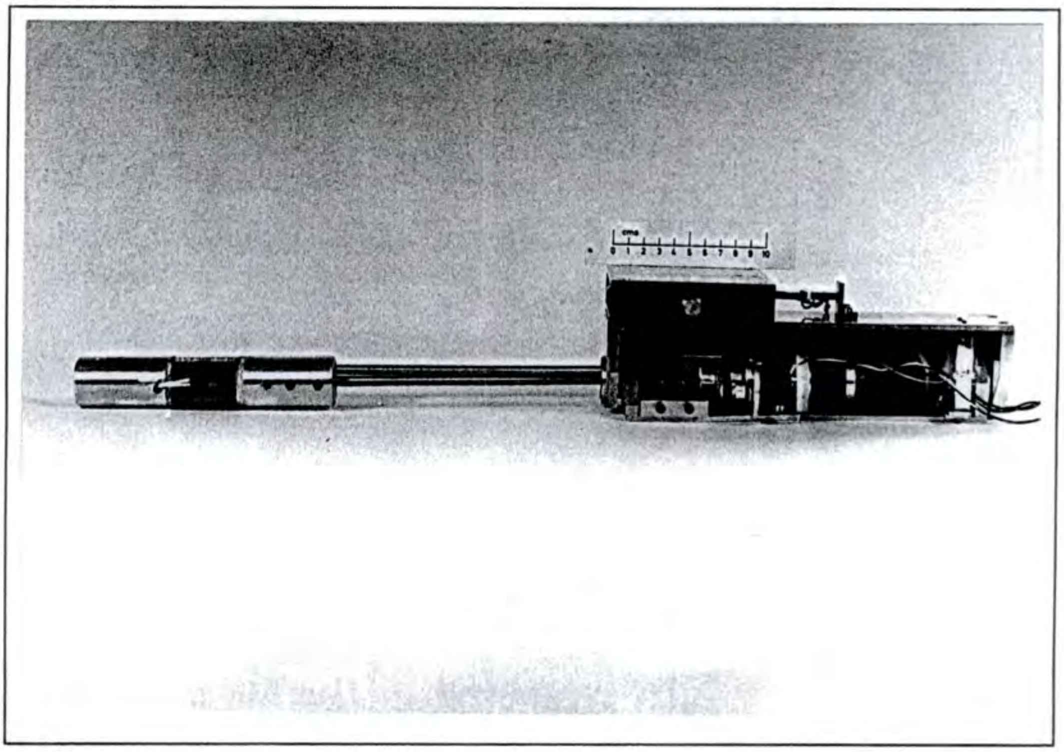


Plate 6.8.1a. The De-coupled gripper unit (Side view).

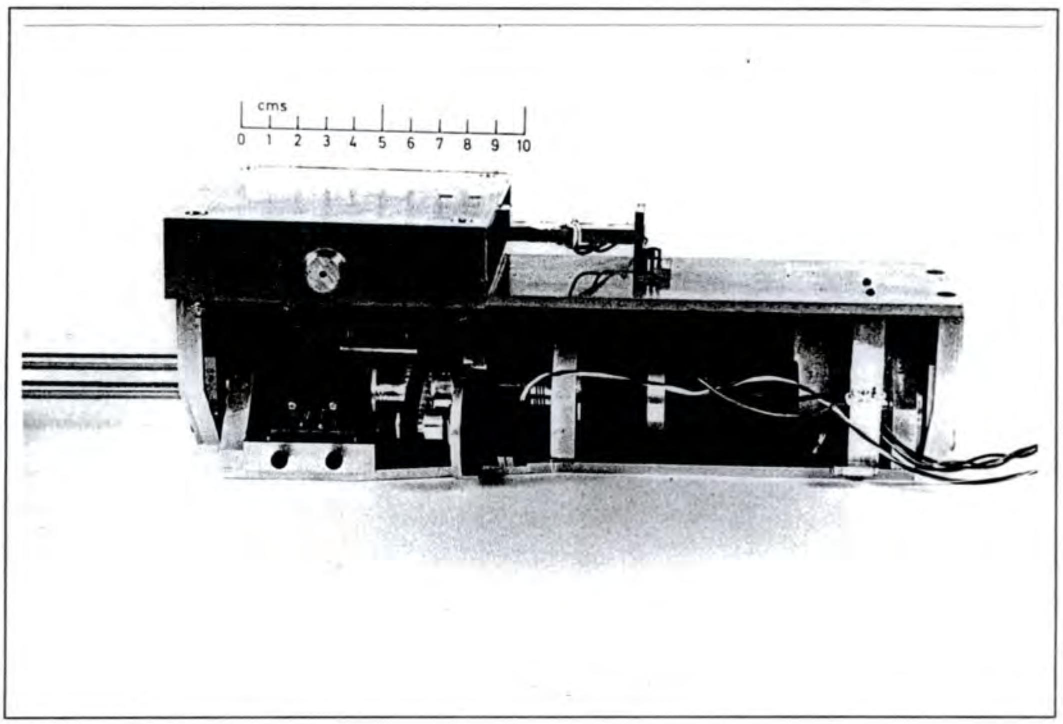


Plate 6.8.1b. The De-coupled gripper unit (Internal electromechanics).

attached to the external frame. The pivot was connected to a plate facilitating mounting to the linear transporter carriage. Pivot point location was selected vertically above the gripper unit COG to remove moment offset included in the contact force instrumentation. To instrument contact force, a further force sensing cantilever beam (7) linked the mounting plate to the external frame.

A minature low inertia incremental encoder (8) was geared to the drive shaft to instrument gripper shaft angle. Gearing was facilitated by a 4:1 ratio minature timing belt and pulley (9). To enable initialisation of gripper position to a datum, an absolute shaft position encoder was designed and coupled to the drive shaft. This unit was fabricated from an SPX2001 optical interrupter switch mounted adjacent to the drive shaft and a circular breaker plate centred on the shaft.

The gripper roller was provided with an infra red based ply depth sensor sub-system mounted in the gripper roller. A slip ring unit was thus required to provide electrical connection to the roller from the internal frame. No suitable commercial unit was found and thus a unit was designed and fabricated. In the design, phosphor bronze slip rings were mounted on the drive shaft. Brushes were constructed from graphite loaded PTFE as such brushes have been shown to possess ideal wear properties at light currents.

All electrical components of the gripper were connected to the linear transporter by a 25 way 'D type'connector mounted on the gripper unit.

6.8.2 The Workpiece Feed Table

The basic workpiece feed table employed in the experiments of chapter 3 was used with a fabric clamp arrangement modification to provide a simplified and more consistent contact pressure with the fabric stack. This was achieved by a pivoted spring loaded bar in place of the old arrangement. The bar was supported by arms allowing it to pivot from the table surface. Springs were attached to the arms to develop contact pressure. Figure 6.8.2 shows the revised arrangement.

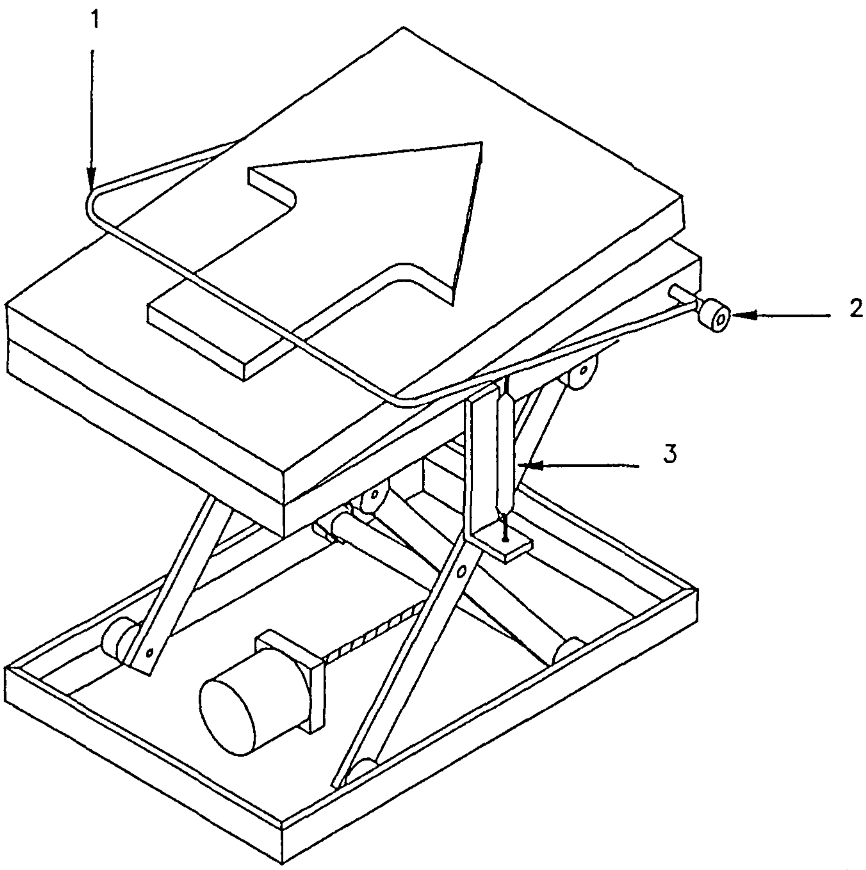
6.8.3 The Linear Transporter

Several areas for improvement were found in the previous linear transporter and therefore a new unit was designed. Figure 6.8.3 illustrates the general arrangement of the unit.

The replacement linear transporter drive and transmission was similar to that of chapter 3. However, the gripper carriage was constructed to mount upon a support plate located by dual guide rails and was supported by PTFE bearings. End blocks held the guide rails and the arrangement was strengthened by a hollow rectangular section support beam. The drive motor was mounted upon this beam and linked via a timing pulley arrangement to the leadscrew. An improved absolute position recovery system was integrated into the linear transporter requiring a coarse carriage absolute position encoder and a shaft position encoder. Data from both channels was combined in an algorithm (described in section 6.11.8) to provide high precision absolute determination of carriage position.

6.8.4 The Workpiece Release Area

The workpiece release area was formed from an aluminium plate provided with a vacuum grille in the workpiece edge release area. Vacuum was



Key:

1. Clamp bar.
2. Pivot.
3. Clamp spring.

Figure 6.8.2 The Pivoted Fabric Clamp.

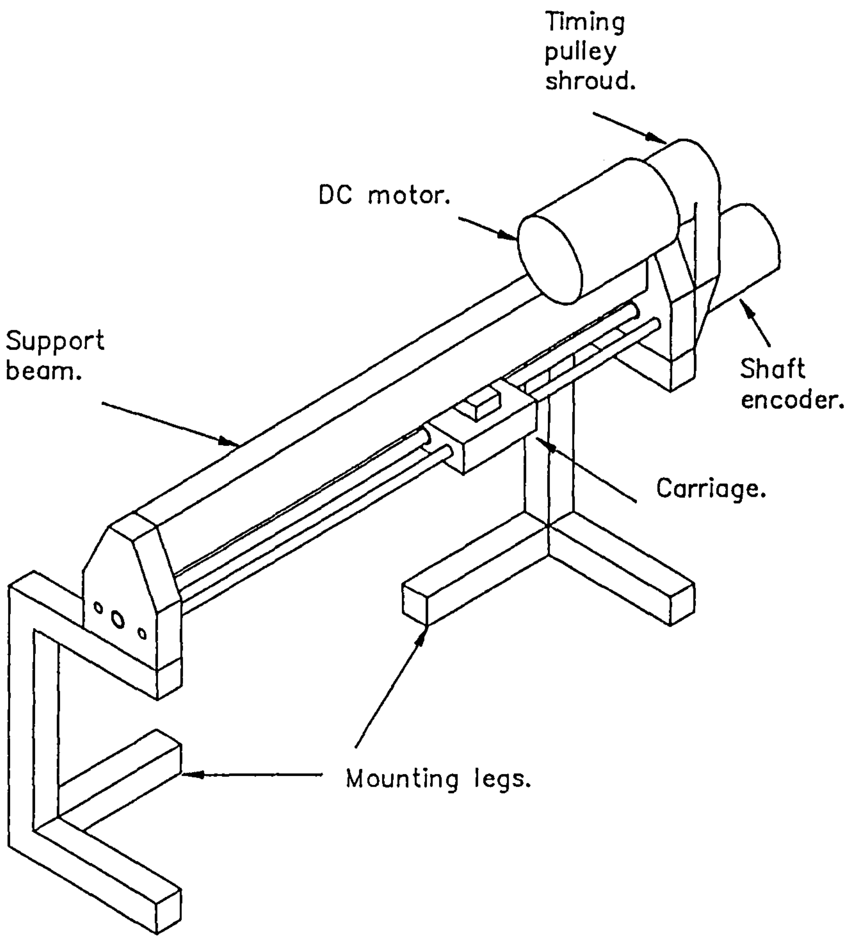


Figure 6.8.3 De–coupled De–stacking Unit Linear Transporter.

generated and switched by a high flow rate vacuum source.

6.9 EQUIPMENT DESIGN: CONTROLLER

Restrictions in performance of the M6800 system were highlighted in the experimental work described in section 4.7.3. Whilst the M6800 system provided an adequate controller for the purposes of the simple de-stacking system, a more flexible controller system was required for this work. A revised controller scheme is described in the following sub-sections.

6.9.1 Requirements

A capacity to compile and run high level languages of moderate to large code size was necessary in the controller. A flexible, extensible and large I/O capacity to support an I/O specification capable of alteration during the course of research was required thus an open architecture system was desirable. Moreover, sufficiently fast throughput was needed to facilitate real time control of the high speed electromechanics under investigation.

6.9.2 Controller Specification And Design

To meet the above requirements a bus standardised system was chosen [79]. The Intel Multibus standard was selected as it provided an asynchronous bus [47] and therefore could be used in future with memory and interfacing boards of differing speed. Furthermore, Multibus was well supported and numerous board level products existed. A Bleasdale system, type BDC600, was chosen as a Multibus controller. Figure 6.9.2 shows a system diagram overview of the designed controller.

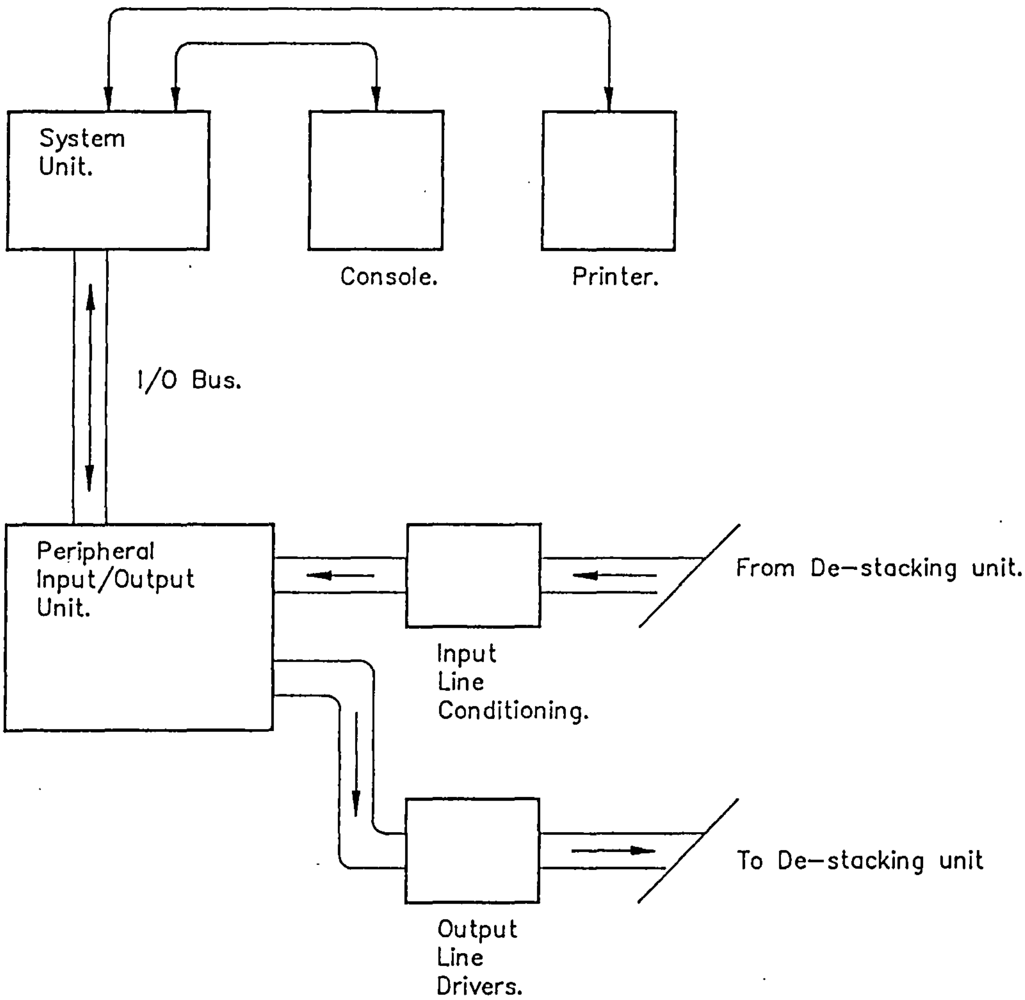


Figure 6.9.2 Multibus Controller System Interconnection.

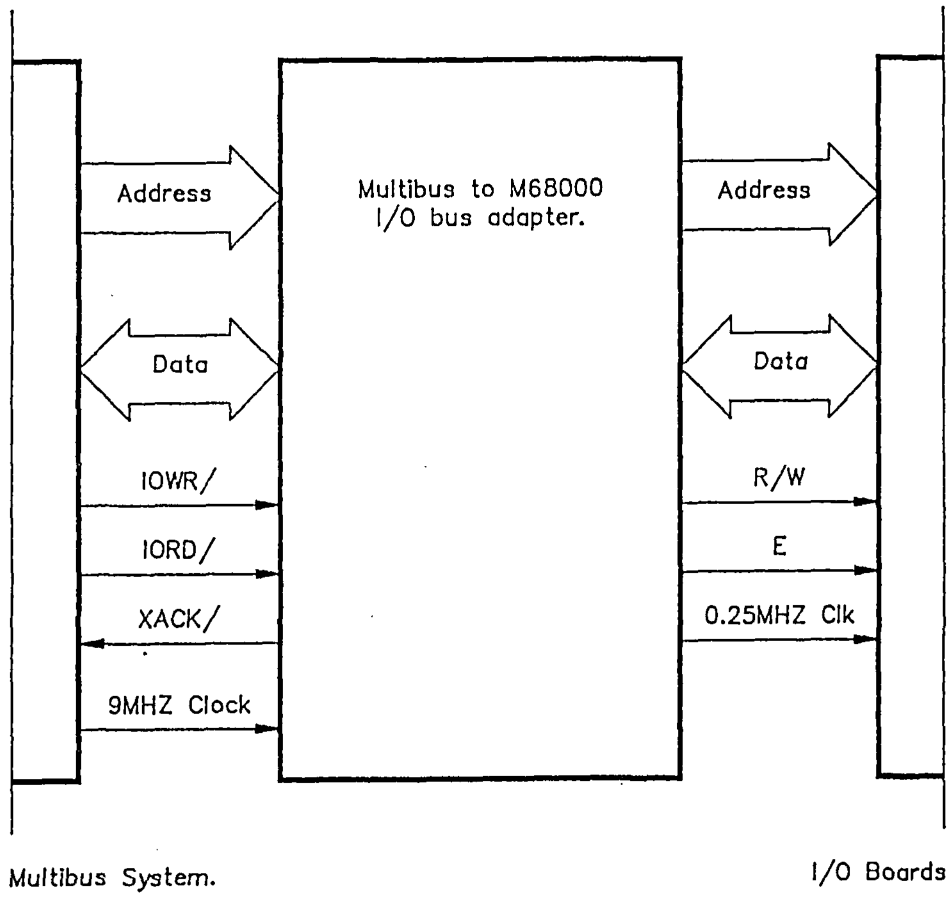
6.9.3 Input/Output Section

A purpose built I/O section was constructed for the controller. The objective in using a customised I/O area was to allow future upgrading to M68000 controller cards, under design within the Durham Engineering Department Microprocessor Centre. To interface the I/O area to the Multibus, the I/O expansion bus supported by these cards was adopted, providing a means to transfer the controller to a M68000 system in the future. Conversion of data between Multibus and the I/O bus was achieved with a purpose designed adapter unit.

6.9.4 The Multibus Adapter

This section describes the Multibus adapter arrangement designed to convert I/O transactions between the Multibus standard (defined in the Intel Multibus standard document [47]) and the I/O bus standard of the peripheral boards. Figure 6.9.4 shows a block diagram of the Multibus adapter.

The Multibus standard is asynchronous. Addressed cards resident on the bus must indicate completion of data transfer associated with the address by an exchange acknowledge flag (XACK/) to support asynchronous data transfer. However, the devices used in the peripheral boards require synchronous data transfer. Therefore the adapter generated synchronised data transfers between the Multibus system and the I/O bus. Bus clock speed was set to operate at 0.25 MHZ, a relatively slow clock speed to allow a 2 metre bus length, required to attach to the I/O board sub rack unit. Division of the 9 MHZ Multibus constant clock generated the required I/O bus clock. Synchronisation to the I/O bus clock was effected as follows:



Key:

IOWR/	Multibus write request.
IORD/	Multibus read request.
XACK/	Multibus exchange acknowledge flag.
R/W	Motorola Read/Write flag
E	Motorola enable signal.

Figure 6.9.4 Multibus Adapter Block Schematic.

An intermediate timing arrangement in the adapter board controlled data transfers. The binary division scheme generating the 0.25 MHZ clock was used to derive Multibus transfer accept and acknowledge (XACK/) timing signals at appropriate points in the cycle. If a Multibus data transfer request became active, transfer would await the accept portion of the clock cycle before being gated to the bus. Additionally, the timing arrangement indicated data transfer to the Multibus by asserting XACK/ at a further point in the clock cycle. The data transfer request flag would then be released and the timing arrangement would respond by releasing XACK/. Thus data transfer completion was indicated to the Multibus system and correctly timed data was presented to the I/O devices on the I/O boards. A wire wrapped Multibus prototype board was used to construct the adapter. Debugging was carried out using a Kikusui 100 MHZ four beam oscilloscope and a Hewlett packard 1607 logic analyser. Adapter boards were plugged into a vacant Multibus slot within the controller and the I/O bus ribbon cable fed through the controller casing to the peripheral board sub-rack.

6.9.5 Digital Input/Output Boards

Three peripheral I/O boards were constructed to fulfill the I/O requirements of the system. A block schematic diagram of a board is given in figure 6.9.5. The boards processed I/O using VLSI peripheral output devices, two types being chosen for use. Synertek SY6522 VIA units [92] formed the first type, providing 16 configurable I/O lines and two timer counter registers partially meeting the timer counter requirement. The other device type was the Motorola MC6840 unit supporting three timer counters. These units were used to generate PWM waveforms for the DC motor drives. Bus buffering was provided at the

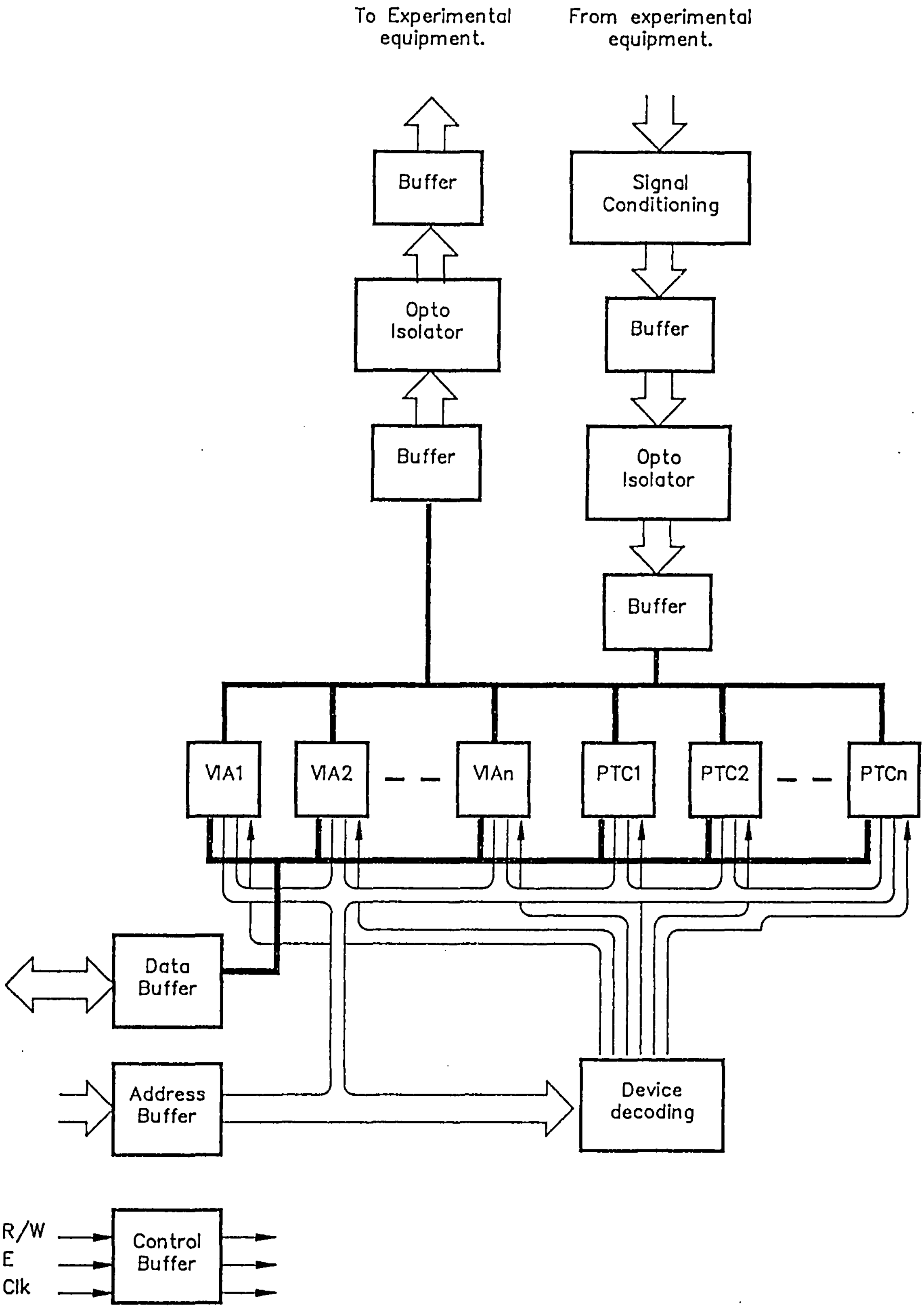


Figure 6.9.5 I/O Board Block Schematic.

I/O board to bus interface and the devices were mapped into the Multibus I/O space by decoding logic. To isolate the experimental equipment and simplify grounding scheme requirements, an optical barrier for each I/O line was included on the board. 74LS14 schmitt trigger devices were used to buffer either side of the optical barrier to aid noise immunity.

A wire wrapped 6U height prototype board was used to construct each I/O sub-system. These were mounted within a 6U height sub-rack unit. Power was distributed by a bussed supply. Connection to the I/O bus was made via a back plane terminating in a ribbon cable connection to the BDC600 Multibus conversion card.

6.9.6 Analogue Input Board

An analogue input board was incorporated onto the I/O bus to accept the de-stacking unit transducer output. The board, a product of the Durham Microprocessor Centre, provided twelve channels of multiplexed input at a conversion speed of 100 μs.

6.9.7 Terminal And Printer

A Televideo TVI920C terminal was used as a console for the BDC600 controller. The controller printer was a Smith Corona D300 attached to the printer port of the terminal unit. Listings of control software were obtained with this printer.

6.10 EQUIPMENT DESIGN: ELECTRONIC SUB-SYSTEMS

6.10.1 Overview

The electronic sub-systems interfaced the controller to the de-stacking unit electromechanics. Flexibility and adaptability were retained to allow future changes in the hard-wiring of the electronic sub-systems. At the same time, organised grounding and screening arrangements were provided. To allow the above, the electronic functions of the system were partitioned. Controller, electronic actuators and input conditioning circuitry were separated from each other by optical barriers. This demanded provision of several separate power supplies but allowed the grouping of each element into an organised racking system.

6.10.2 Ply Separation Force Instrumentation

The function of the ply separation force instrumentation was to amplify and condition output from the strain gauge bridge transducer. Components of the design comprised a transducer energisation element and an output amplification and offset element. A block diagram is shown in figure 6.10.2. The active element of the transducer was a strain gauge bridge providing a differential output related linearly to the strain developed when force was applied to the transducer. With the arrangement shown, output for an arm resistance change δr is given by Clayton [20], as:

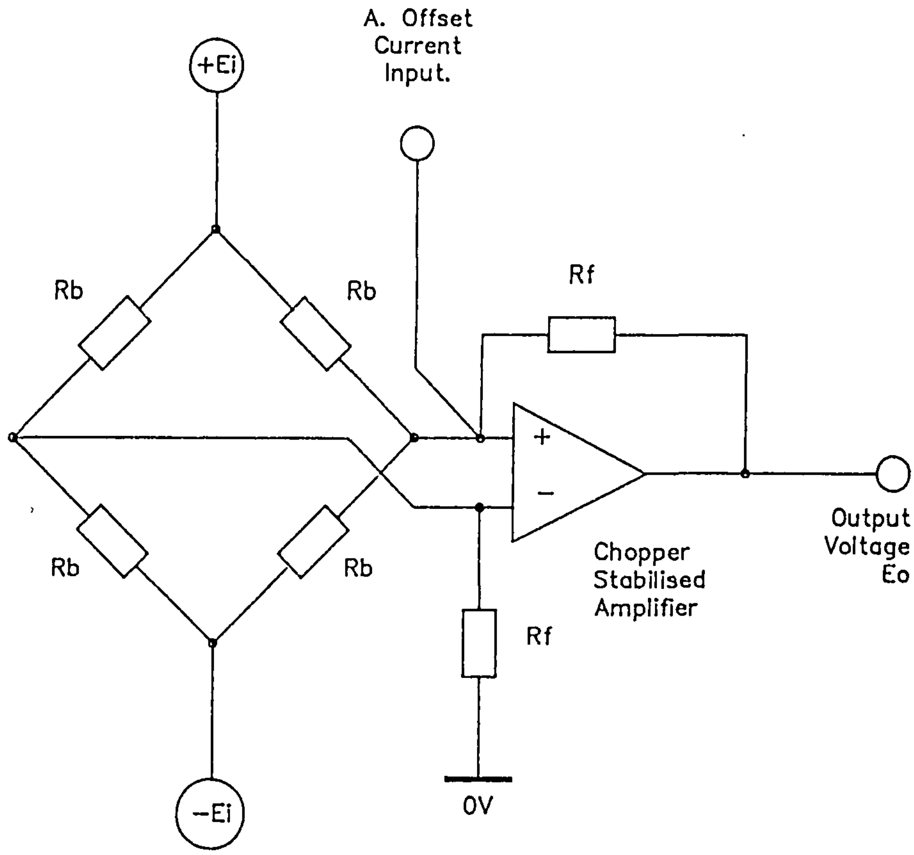


Figure 6.10.2 Basic Strain Gauge DC Bridge Amplifier.

$$E_o = E_i . \frac{Rf}{Rb} . \delta r . \frac{4}{(1 + \delta r).\left(1 + \frac{Rf}{Rb}\right) + 1}$$ -- Eqn 6.10.2a

where resistance change, δr, is related to strain change δε, by gauge factor G;

$$\delta r = G.\delta\varepsilon$$ -- Eqn 6.10.2b

Unlike conventional strain measurement instrumentation, DC exitation rather than AC exitation was used to energise the bridge. This was facilitated by the recent availability of inexpensive chopper stabilised operational amplifier integrated circuits (Intersil 7650's [48]). Such devices were employed in the instrumentation allowing DC coupling and removing the need for AC demodulation, improving the high speed frequency response of the amplifier.

A specification for the strain gauges used is given in Appendix A. The recommended drive current of the application strain gauges was 10mA. At 100 ohm nominal resistance, a 1 volt energisation drive voltage was required. Energisation voltage could be derived from a low voltage reference source (1.3V, Intersil 8069DZQ). Should resistive shunts and the 8069DZQ voltage reference be used alone to provide this, calculation showed in the case of the strain gauge being removed from the circuit current exceeding the 8069DZQ maximum rating would be passed by the reference. Better engineering practice would be to buffer the reference voltage. Thus an operational amplifier buffer was employed to generate the bridge energisation voltage, removing this contingency. The positive bridge energisation voltage was derived from low temperature coefficient (50 ppm) 8069DZQ references and buffered by an OP7 operational amplifier and BC107 combination. Thus a temperature stabilised positive voltage source was generated with an increased current drive capacity (100mA). A similar circuit was employed to generate the negative bridge energisation voltage, a PNP transistor being used in place of the BC107.

Transducer signal offset was provided by a circuit injecting current into the amplifier input junction (A). Derivation of this current was provided from the stabilised exitation source. Gain could be adjusted to allow FSD (±4V for ICL7650 amplifiers) in the working force range of the transducer.

Two separate force measuring instruments were provided: One for the gripper contact force sensor and one for the engagement torque sensor. The circuitry was constructed on a 3U height prototype eurocard with wire wrap.

6.10.3 Gripper IR Ply Depth Measurement

An experimental infra red based ply depth measurement unit was incorporated into the de-stacking gripper. Sub-section 5.3.2 outlined the purpose and operating principle of the unit. The infra-red transducer sub-system comprised an emitter and a receiver, between which the fabric was placed.

Operation of the unit was as follows: Modulation was provided by an NE555 square wave generator, [48], its output driving the IR emitter via a current limiting resistor. Reception of the transmitted IR light was facilitated by a photodiode. Signal de-modulation was carried out by a combined rectification and low pass filter circuit. The resultant DC output was compared by a group of comparators, calibrated to indicate whether none, one, or more than one ply had been separated. These digital outputs of the instrumentation could be processed by the controller.

The infra red ply depth detecting prototype was constructed on eurocard size prototype board with wire wrap.

6.10.4 Gripper Shaft Encoder

The gripper drive shaft was encoded by a minature incremental encoder. A timing belt linked the shaft to the encoder in a 4:1 gearing ratio. Two phase shifted channels were provided for determination of the gripper shaft direction of motion and were fed via the de-stacking unit wiring harness to controller signal conditioning circuitry. The 5v supply required by the shaft encoder was brought up to the encoder from a supply distribution arrangement contained in the electronic interfacing racks, broken by connectors at convenient points.

6.10.5 Shaft Datum Encoder

A gripper drive shaft datum encoder was incorporated into the gripper body. Its purpose was to facilitate reset of the gripper to a datum position, necessary as the incremental drive shaft provided indication of relative movement only. An SPX2001 infra red optical interrupter was used as a transducer element, its output being connected to the controller input conditioning circuitry via the de-stacking unit wiring harness. The 5V supply required by the SPX2001 device was brought up to the gripper in the same cable, derived from the electronic sub-system power arrangement.

6.10.6 Gripper DC Motor Drive

A block diagram of the DC motor drive is shown in figure 6.10.6a. As the motor employed a permanent magnet to generate its field, speed and direction were controlled by inserting the armature into an H-type bridge modulated with a PWM technique. Control of bridge transistors (1) was provided by logic (2) combining direction and PWM inputs (3), provided by the controller.

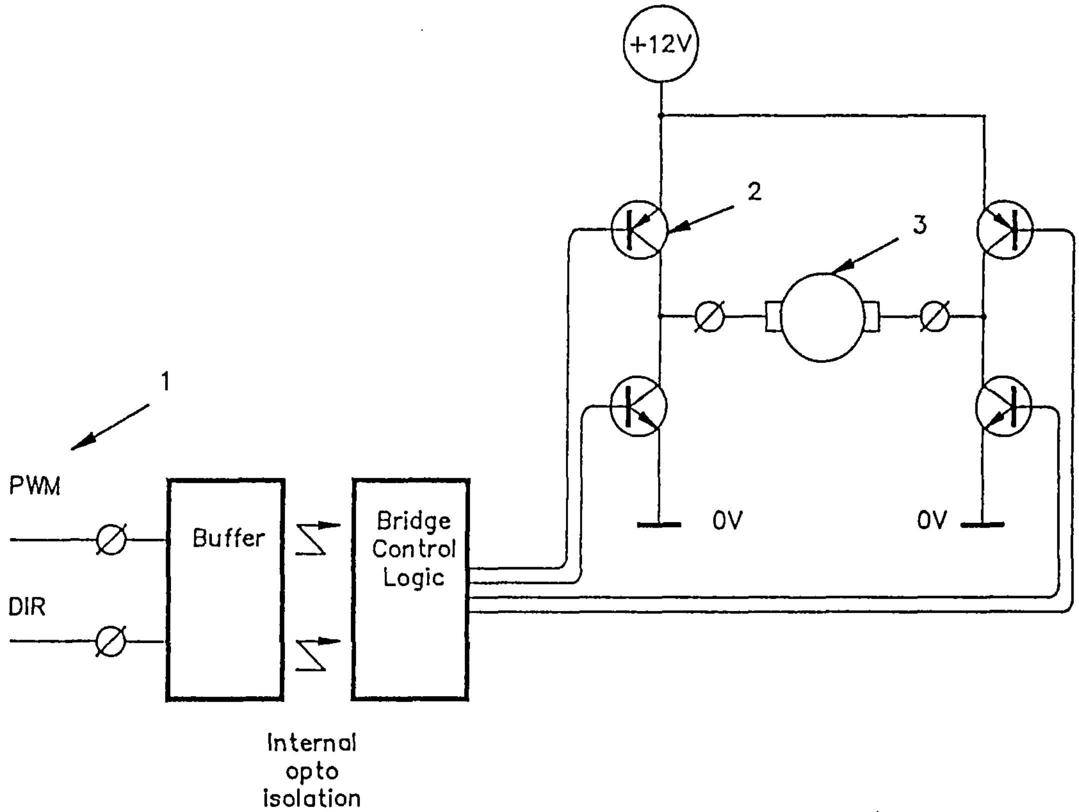
As use of other similar motor drives were anticipated in further work, this drive circuit was constructed on a purpose designed printed circuit board (PCB).

6.10.7 Feed Table Sensors

The feed table sub-system sensors described in previous work were used for these experiments. Table sensors were integrated into the de-stacking unit electronic sub-system scheme, their outputs being brought through the de-stacking unit wiring harness and to the controller signal conditioning section. Sensor supplies were provided in the same connecting cable from the electronic sub-system distribution scheme.

6.10.8 Feed Table Step Motor Drive

An LR drive to power the step motor was retained for this work, but the method of motor phase switching was revised. An encoding scheme was



Key:

1. Pulse Width Modulation and direction inputs.
2. Bridge output transistor.
3. DC motor.

Figure 6.10.6a 12V DC Motor Drive Block Schematic.

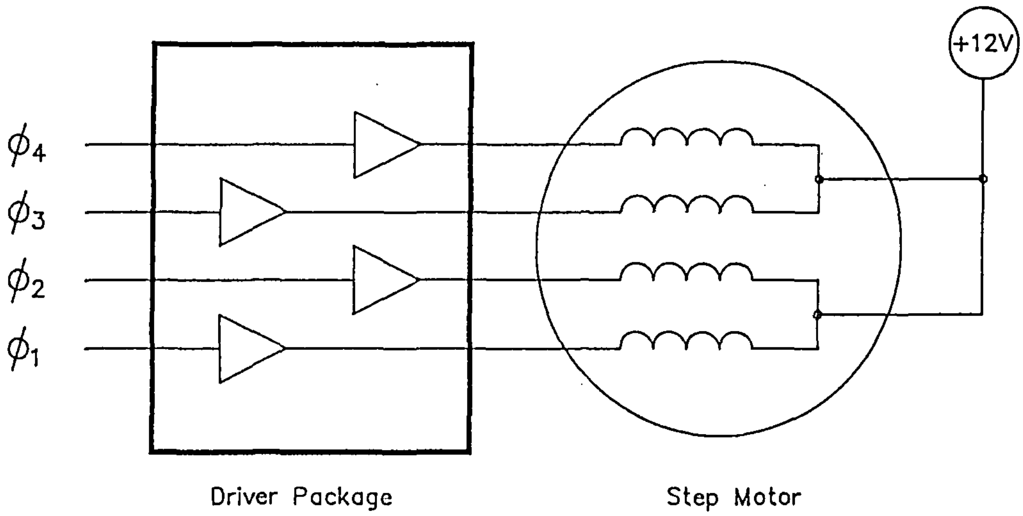
used to reduce the number of control lines and to exclude the possibility of the controller turning on all phases at once, overloading the motor drive power supply. Combinational logic was derived to encode signals from two control lines into the required phase energisation sequence. A block diagram of the step motor drive is shown in figure 6.10.6b.

6.10.9 Linear Transporter Drive

The DC motor drive was based upon the arrangement described in section 3.9.1, with the addition of optical isolation and encoding of the two direction control lines. To aid the modularity of the drive circuit, the power supply was altered from the laboratory 200V supply to a mains driven power pack. The power pack was based upon a simple full wave rectifier and capacitor smoothing arrangement.

6.10.10 Coarse Linear Transporter Carriage Displacement Encoder

To recover the absolute position of the linear transporter carriage, the position recovery scheme described in sub-section 6.8.3 required a coarse absolute position input. This comprised determination of position by sensors from a six bit gray scale marked onto the linear transporter track. The sensors were based upon reflex infra red units. A gray scale was designed and printed using the "AutoCad" drafting package then attached to the underside of the linear transporter support beam. Six infra red detectors were mounted onto the carriage with their active faces supported at a distance of 5 mm below the scale. Figure 6.10.10 shows the block diagram of the circuit used to amplify and condition the output of each detector. Each of the binary outputs



Phase Decoding Truth Table

A	B	ϕ_1	ϕ_2	ϕ_3	ϕ_4
0	0	1	0	1	0
0	1	1	0	0	1
1	0	0	1	0	1
1	1	0	1	1	0

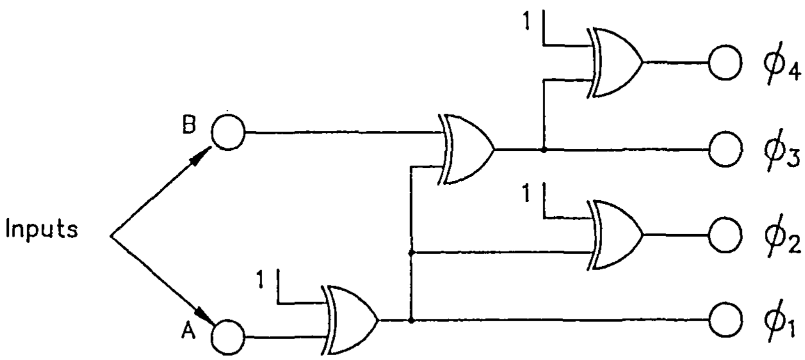


Figure 6.10.6b Step Motor Drive and Phase Encoder.

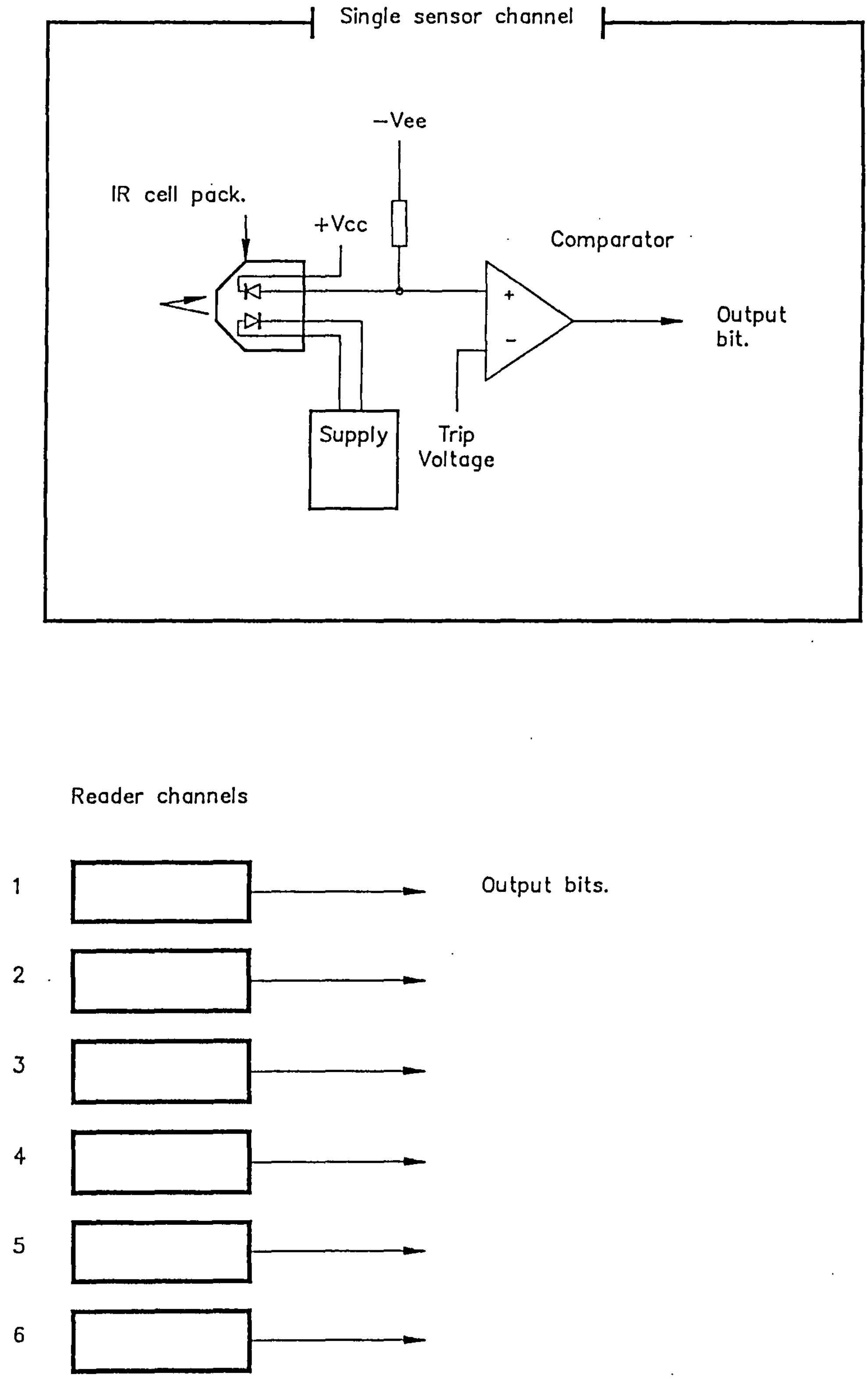


Figure 6.10.10 Gray Scale Reader Electronics Block Diagram.

provided by the circuits were presented to the controller. The detection circuitry was mounted in the electronic sub-system input circuit racks, the detector being connected to the circuitry via the de-stacking unit wiring harness.

6.10.11 Linear Transporter Drive Shaft Encoder

The linear transporter carriage position encoding scheme, required the leadscrew angle to be encoded. This was performed by an absolute shaft encoder, attached to the leadscrew by a flexible coupling. The encoder provided a ten bit output, resolving shaft angle into 1024 parts of a revolution. Each output was passed to the controller input signal conditioning section via the de-stacking unit cable harness. Power to the encoder was provided from the electronic sub-system power distribution arrangement and transmitted through heavy gauge cables, routed throughout the electronic system wiring harness to reduce voltage drop to the encoder unit.

6.11 EQUIPMENT DESIGN: APPLICATION PROGRAMMING

6.11.1 Language

Language selection for robotic controllers was discussed in sub-section 3.8.2. In control language choice, a range of proprietary languages were available for the chosen controller operating system (CP/M-86) [14, 15, 16]. Of these, Pascal was selected. Its choice was determined by its structure, self documenting style and its provision to communicate at the machine level.

Two compilers were evaluated on the controller. Initially, the Digital Research Inc. Pascal MT+86 compiler [75] was tested. This was a conventional compiler system, employing a linker and libraries. Its compilation and link speed was slow and it was necessary to edit source code by the Digital Research ED line editor. The second compiler, Turbo Pascal [128], compiled code more rapidly and supported an internal Wordstar based screen editor. Additionally, Turbo Pascal supported variable names of up to 128 characters, which allowed long self explanatory variable and procedure names. The Turbo Pascal compiler was therefore adopted for the following work. Additionally MCS-86 assembly language was used during debugging [46].

6.11.2 Program Operation And Structure

The control program was written as a group of functional modules or program components. Each provided a functionally separate set of services for the application program and aided structured programming advocated by Linger [59].

Figure 6.11.2a shows the program internal structure. Components were constructed beginning with I/O drivers for the automation electromechanics. These drivers were called by higher level procedures marshalling basic I/O data to and from more abstracted control variables. Beyond this, I/O functions were collected into groups by further procedures. These were then called by procedures implementing the logic for the electromechanical control. Higher level control was provided by a main or root component connecting separate components together. A Flow Segment Reference Tree given in Appendix B also describes this structure.

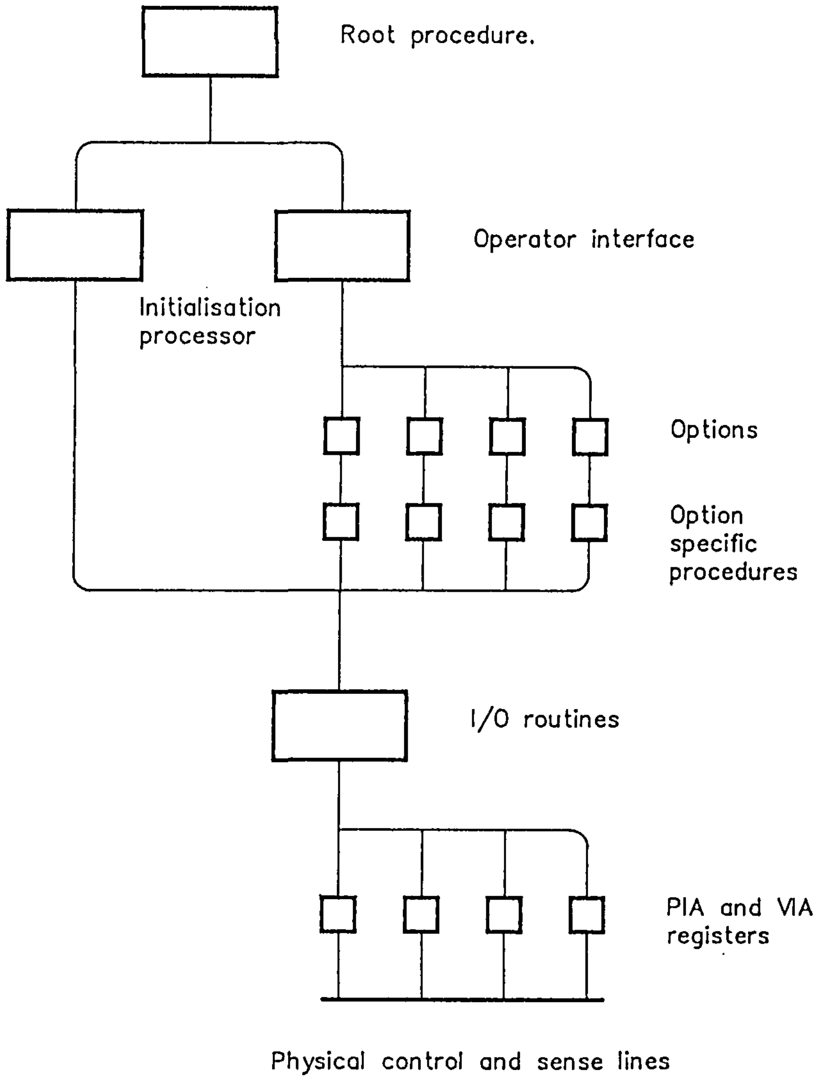


Figure 6.11.2a De-Coupled Unit Control Program Structure.

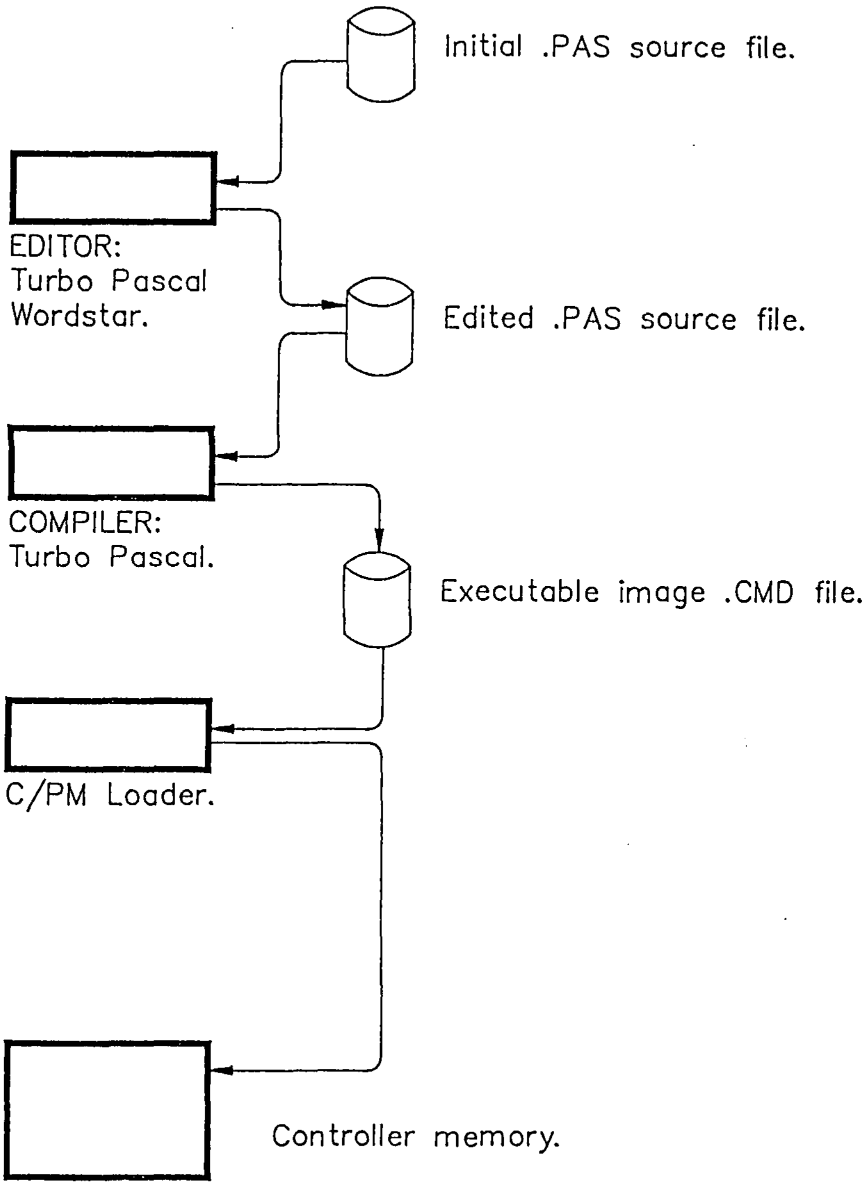


Figure 6.11.2b De-stacking Unit Software. Development Path.

When compiled and linked, the resultant task image was loaded via a CP/M-86 utility and executed as the only task present on the controller.

Program development was carried out with the controller off-line. Figure 6.11.2b showing the software development path used. In development, the source program was edited with the Turbo Pascal Wordstar editor. The resulting Pascal source file was then compiled to produce an executable image which could load and execute.

6.11.3 Software Description

Application software may be described using several techniques. These include Program Design Language (PDL) in which flow segments and data structures are detailed in Pascal-like statements. This technique is popular as software maintenance and development are facilitated, but to provide a better overview, a less detailed approach was taken in this software description. The technique adopted employs a written description overview with reference to the following documentation:

i. Flow Segment Diagrams, included within the written description. Reference to specific procedures are made within the flow diagrams, thus items ii and iii below are included.

ii. A detailed segment reference tree, given in Appendix B. From this tree the calling order and hierarchy of all procedures used may be determined. An explanatory description of the segment reference tree format is included within Appendix B.

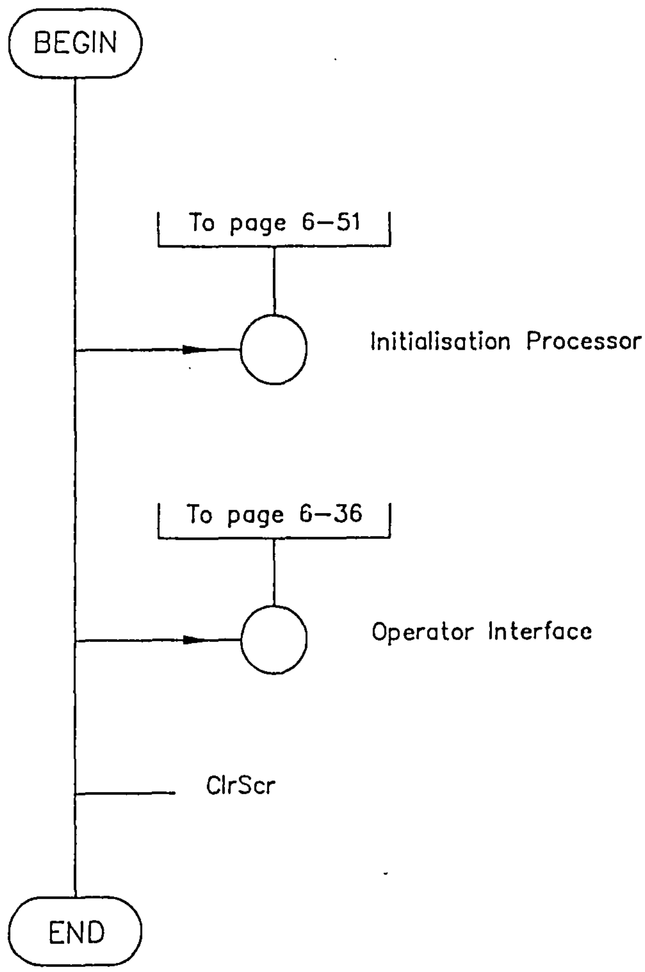
iii. A list of all procedures employed in the program and a brief functional description of each procedure, given in Appendix B.

6.11.4 Program Components -- The Main Module

The module Mainrig provided the root control function for the program. Flow diagram 6.11.4 shows the root segment for mainrig. Following entry to mainrig, program initialisation was carried out (sub-section 6.11.10) in the initialisation processor. After initialisation, control was passed to a section of code implementing the operator interface (section 6.11.5). In the operator interface an option was selected from those available in the menu screens and control returned to mainrig only if a valid option had been requested. Valid options included direct calls to basic control procedures residing inside the program components to exercise low level control functions, full invocation of program components, diagnostic procedures for electronic or software debugging purposes, or program exit. Having acquired a valid option, control was passed to a program section containing a mechanism invoking the required option. A loop was thus established allowing exit by an operator request for a program exit. A shut-down component was used, clearing the terminal screen.

6.11.5 Program Components -- The Operator Interface

Operator communication with the control program was facilitated by the operator interface component, enabling invocation of program options.



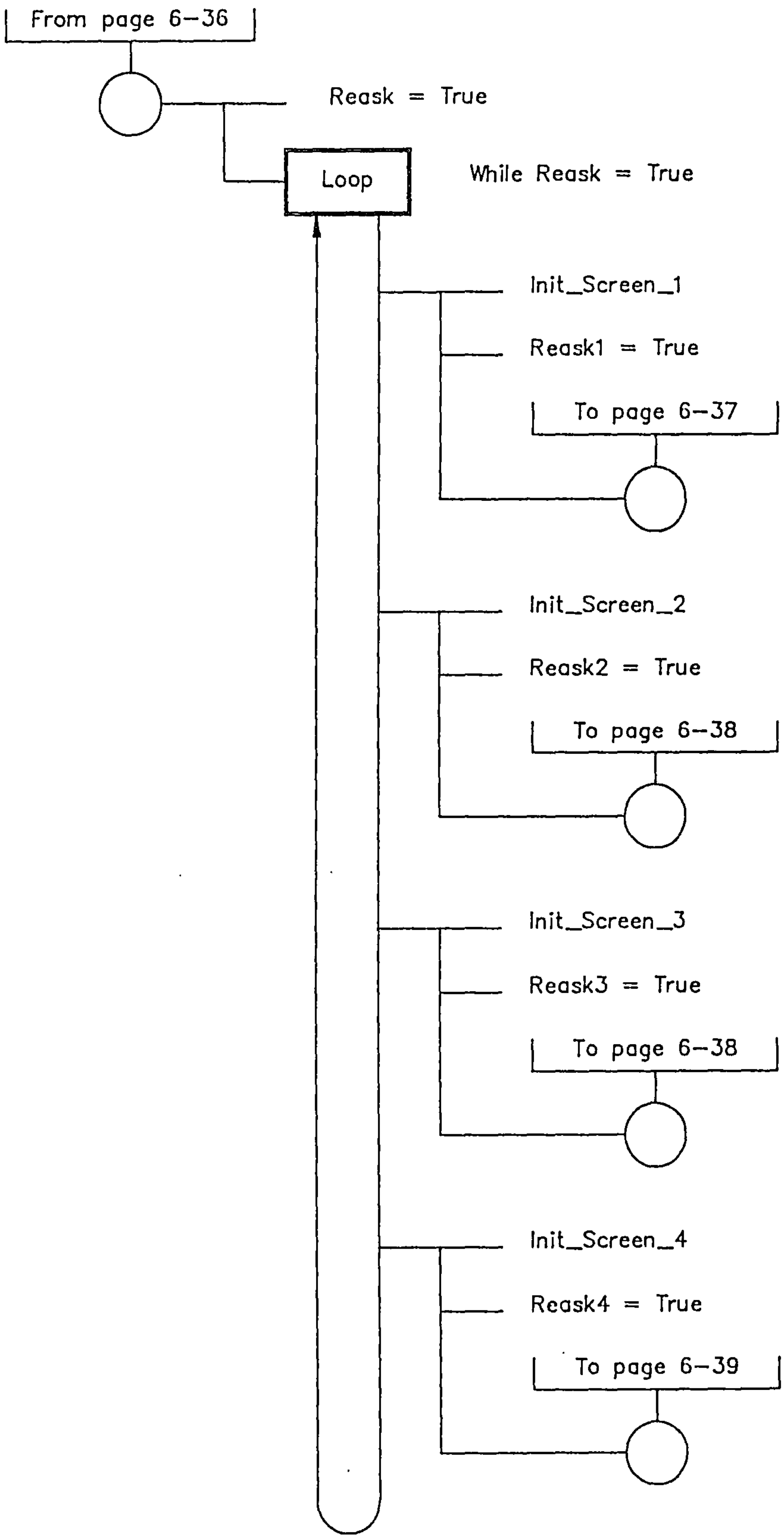
Flow Diagram 6.11.4 Control Program Root Segment.

Entry to the operator interface was effected from the root segment. Flow diagram 6.11.5a shows the root code for the component. A loop was entered controlling entry to one of the available menu screens. Four menu screens could be selected, organised into basic procedures (the default screen), multiple procedures (two screens) and diagnostic procedures (one screen). Control was initially transferred to the default screen, screen 1,its code being given in flow diagram 6.11.5b. Exit from the screen could be caused by operator selection of either "Program Exit" or "Next Screen" options. If a "Next Screen" option was selected, control returned to the operator interface root segment and a further screen flow segment was entered. A description of other screens are given in flow diagrams 6.11.5c and 6.11.5d.

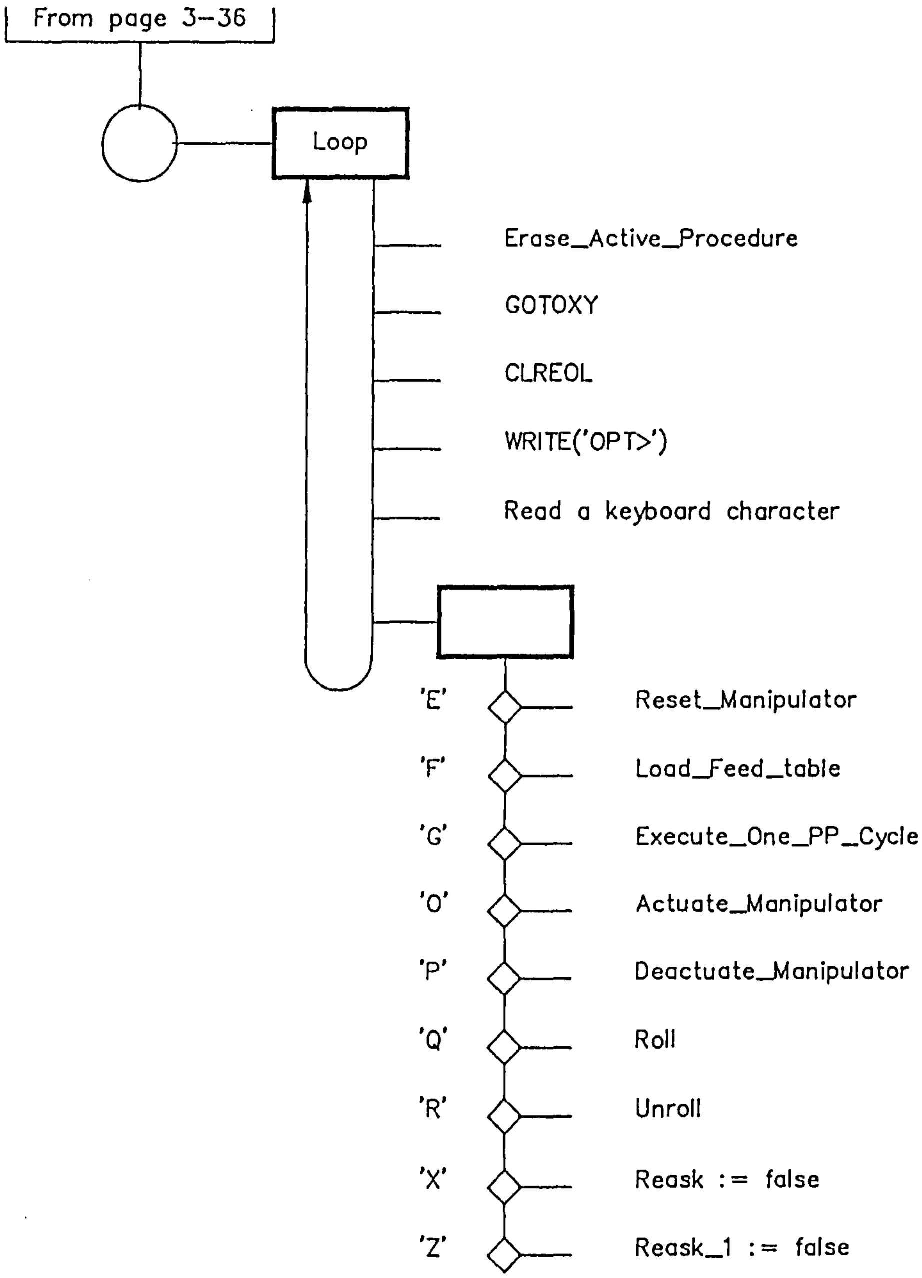
Following option selection, the option was encoded and marked active on the console screen against the associated option line. On re-entry to the operator interface, the active marker was cleared. The selection mechanism was implemented in a declaration of the Pascal CASE statement. CASE entry options were valid operator options, and their associated block contained the call to the required procedure. Thus a valid operator option was exercised and control then left the CASE statement, returning to the operator interface component.

6.11.6 Program Components -- Feed Table Control

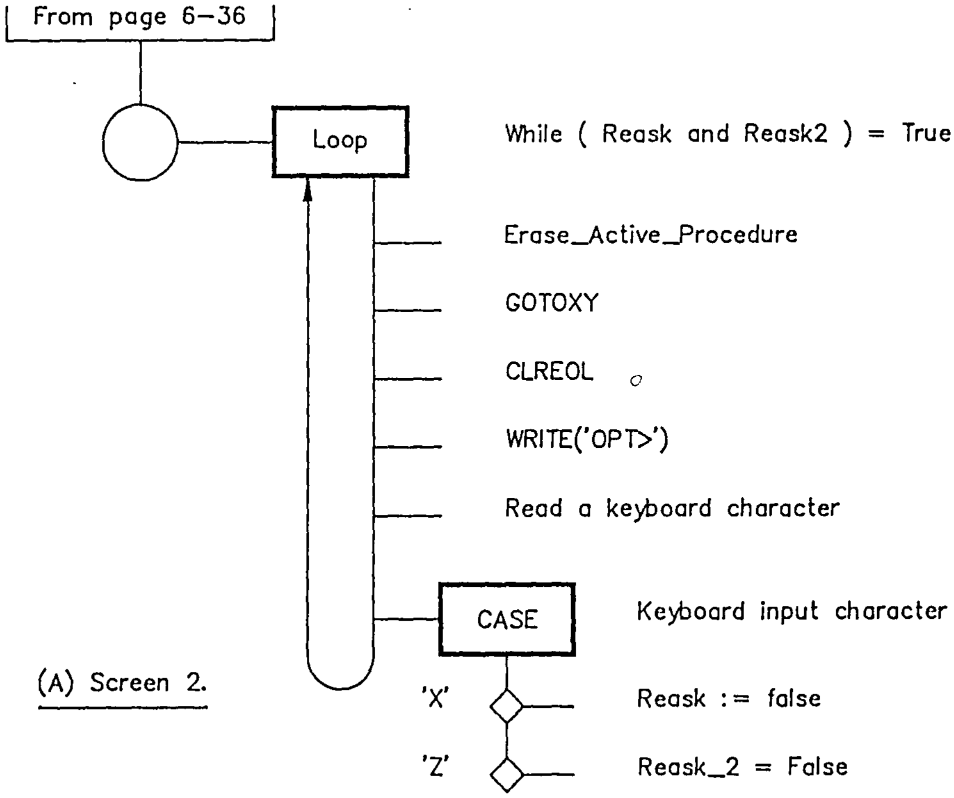
The purpose of the feed table control component was to initialise the feed table, return the state of the feed table sensors, and elevate the table to feed single workpieces.



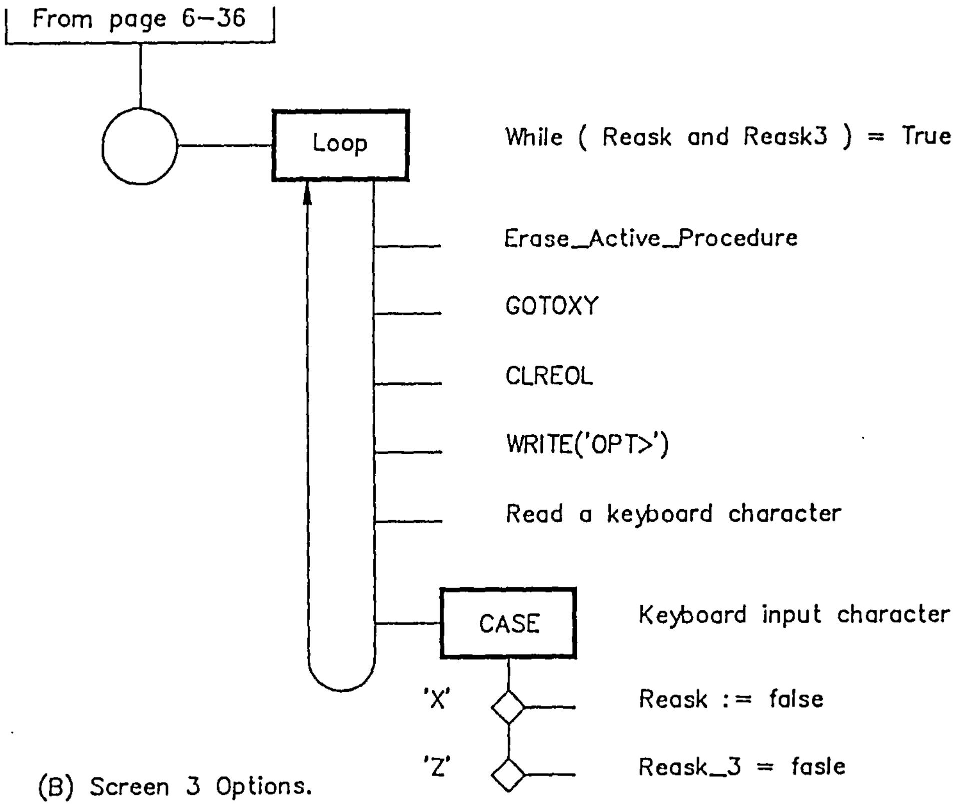
Flow Diagram 6.11.5a Operator Interface Root Segment.



Flow Diagram 6.11.5b Screen 1 Options.

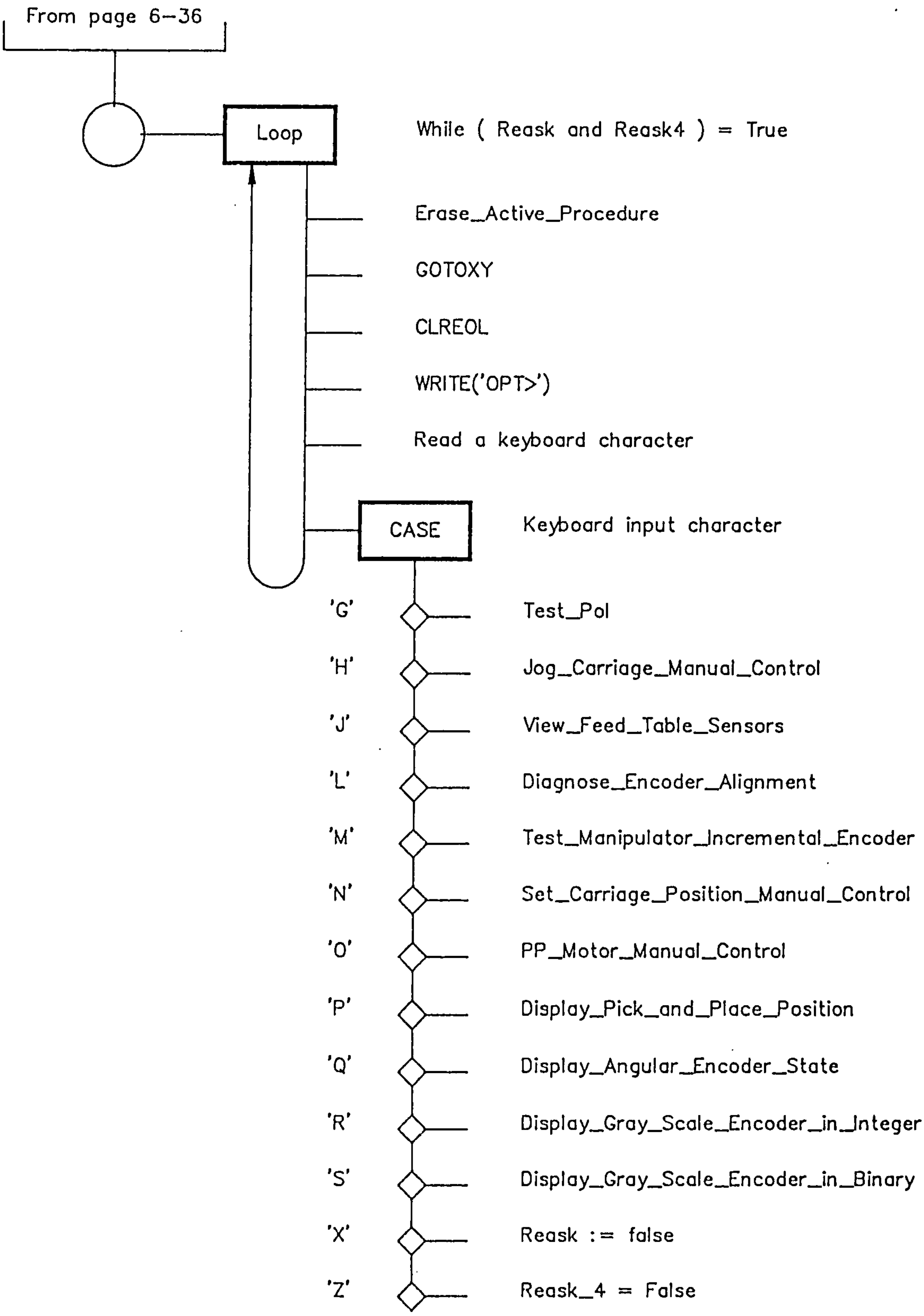


(A) Screen 2.



(B) Screen 3 Options.

Flow Diagram 6.11.5c Screen 2 and 3 Options.



Flow Diagram 6.11.5d Screen 4 Options.

Flow diagram 6.11.6 illustrates two important procedures used by the component. These were (1) Load_Feed_Table and (2) Raise_Feed_Table_To_Pressure_Limit.

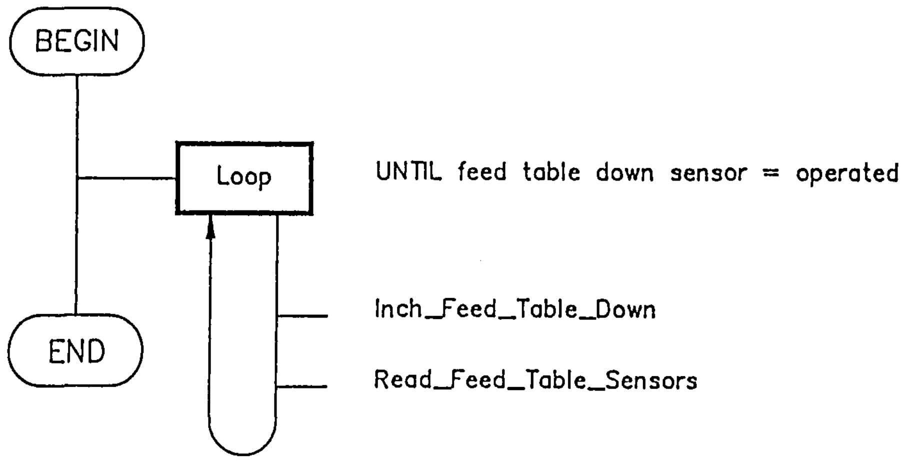
Load_Feed_Table allowed a batch of fabric to be loaded onto the table before de-stacking commenced. Here, a loop was entered causing the table to be first incrementally lowered then the retraction datum sensor tested by a call to the procedure Read_Feed_Table_Sensors. Attainment of full retraction was flagged by the datum sensor being set to its operated state. This condition caused exit from the loop, completing the procedure.

Raise_Feed_Table_To_Pressure_Limit provided means to attain workpiece to gripper contact pressure. The procedure was based upon a loop, firstly incrementing table height then testing the workpiece to gripper pressure sensor by a call to the procedure Read_Feed_Table_Sensors. Attainment of full retraction was flagged by the workpiece to gripper pressure sensor being found in its operated state. This condition caused exit from the loop, completing the procedure.

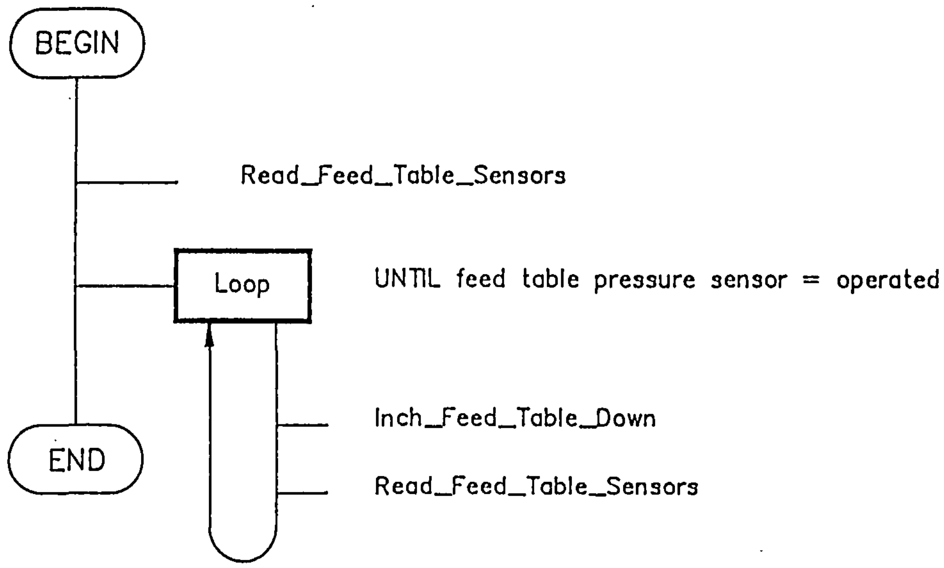
6.11.7 Program Components -- Gripper Control

The purpose of the gripper control component was to drive the gripper roller, support and read the gripper shaft angle and other gripper unit sensors.

Three functions are described. Firstly, a function to reset the gripper was required at initialisation and prior to each de-stack cycle. The procedure used, Reset_Manipulator, is shown in flow diagram 6.11.7a. Reset_Manipulator operated by applying power to the gripper by a call to

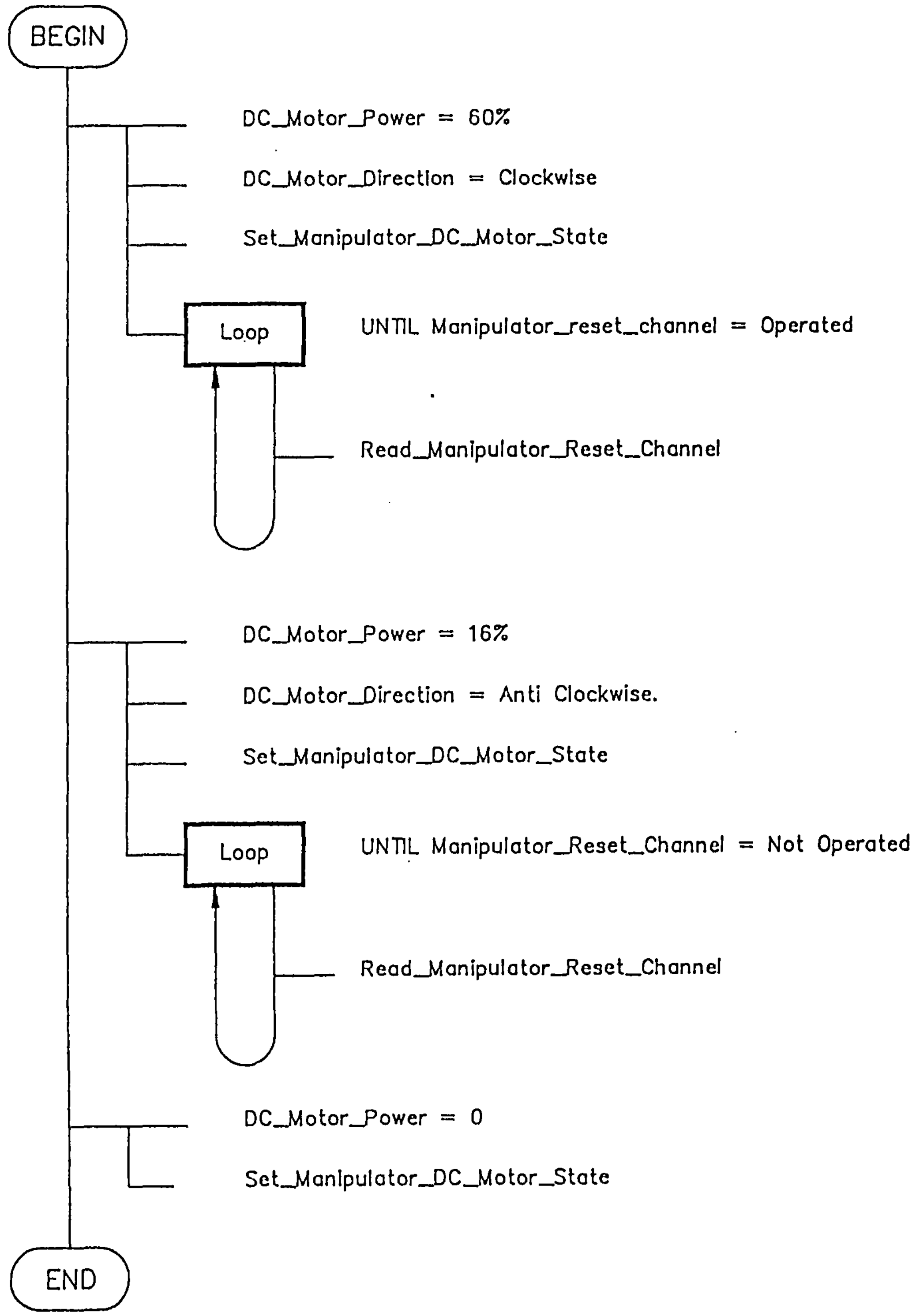


Load_Feed_Table procedure

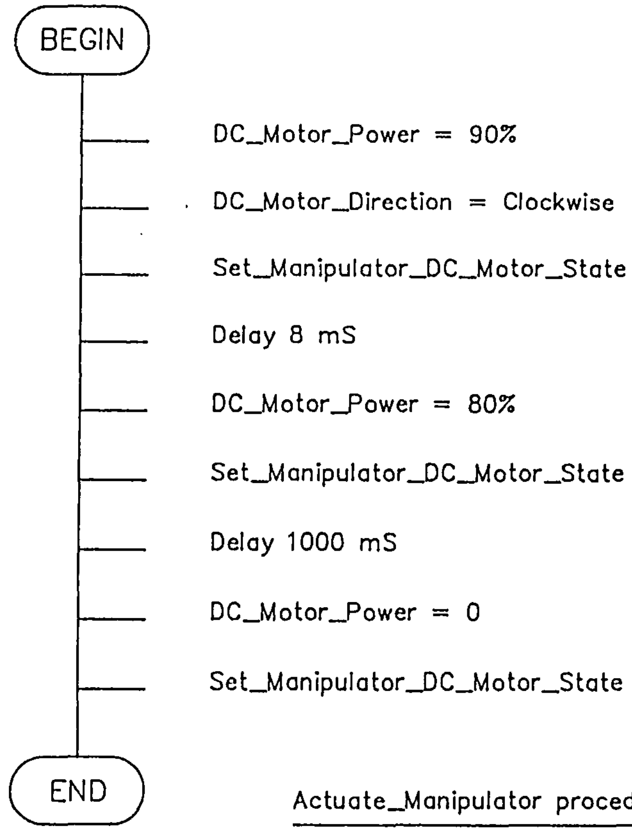


Raise_Feed_Table_to_Pressure_Limit procedure

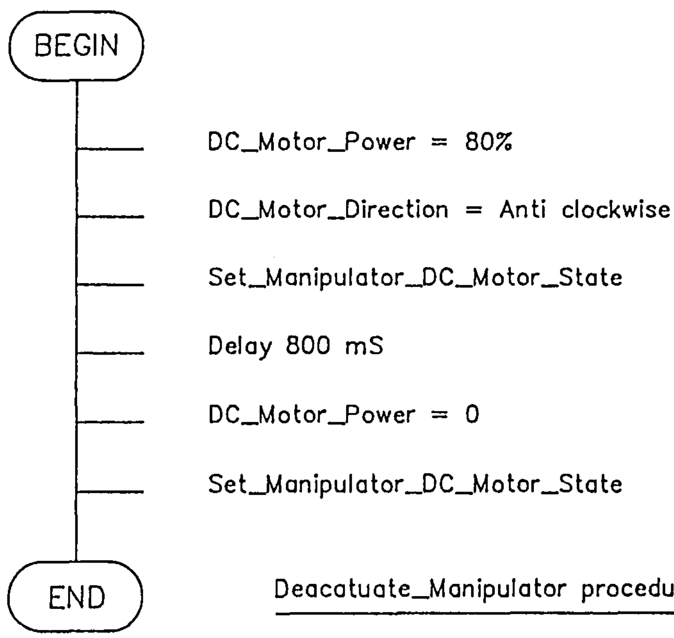
Flow Diagram 6.11.6 Feed Table Procedures



Flow Diagram 6.11.7a Manipulator Reset.



Actuate_Manipulator procedure



Deacatuate_Manipulator procedure

Flow Diagram 6.11.7b Gripper Actuation and De-actuation the procedure Set_Manipulator_DC_Motor_State, causing the gripper to begin rotation. Next a loop was entered reading the manipulator reset channel by procedure Read_Manipulator_Reset_Channel. When the channel had become operated, the gripper had crossed the reset position. To cause accurate alignment at the reset position, a process similar to the above was then invoked with the motor reversed under low power. On detection of the reset channel switching to the unoperated state, motor power was set to zero and the procedure completed.

The second function comprised gripper actuation. This was implemented with a procedure Actuate_Manipulator, its flow diagram being given in flow diagram 6.11.7b. In Actuate_Manipulator, power was applied to the gripper for a given interval, nominally 1000 mS. To overcome stiction, a high power pulse of 8 mS duration was issued to the gripper before application of standard power.

A flow diagram for the third function, de-actuation of the manipulator, is also given in flow diagram 6.11.7b. The de-actuation procedure, Deactuate_Manipulator applied power for nominally 800 mS in a direction reverse to direction of the actuation procedure. This caused the gripped component to be released from the gripper.

6.11.8 Program Components -- Linear Transporter Control

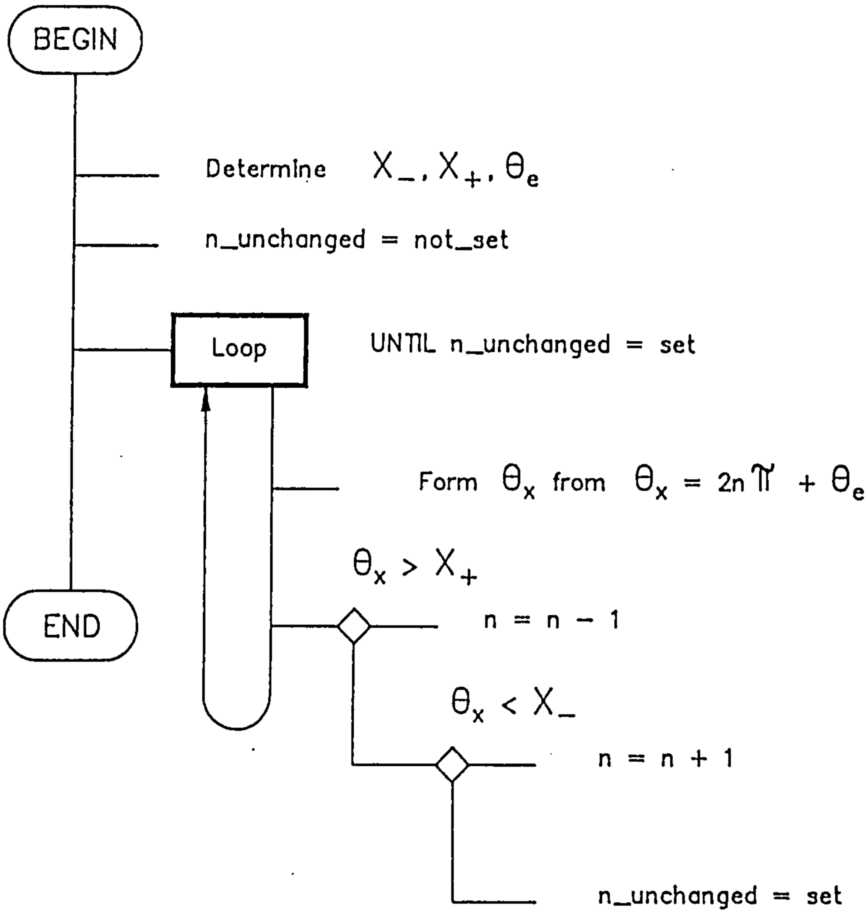
The purpose of this component was to drive the linear transporter, support and read the sensors associated with the transporter, determine and control carriage position.

Some obstacles arise in encoding absolute position accurately over the application distance (1 m). Derivation of position by incremental encoder means is most practical, but accurate commercial linear incremental encoder systems are highly expensive.

A novel algorithm to determine absolute linear position was developed to overcome the above obstacles. The technique was based upon the vernier principle. Two encoders were employed, the first being a simple coarse linear encoder to return linear position to an accuracy of 0.3" and the second a one revolution absolute angle shaft position encoder, returning shaft angle to a accuracy of 1/500 of a revolution. Flow diagram 6.11.8a illustrates the position recovery algorithm. Linear position may be represented by angular excursion θ_x from an arbitrary datum position. θ_x is determined by equation 6.8.11, given below:

$$\theta_x = 2\pi j + \theta_e \qquad \text{-- Eqn 6.8.11}$$

Where j represents integer leadscrew revolutions from the datum and θ_e the angular encoder angle. j may have the values 0,1,2, .. ,j_{max}, j_{max} being set to indicate a position beyond the travel limits of the transporter. Thus θ_x may have solutions for any of the above values of j. However, the resolution of the linear encoder was set such that no two solutions existed within the accuracy bounds x_- and x_+ for the associated coarse position returned from the linear transporter. The algorithm could thus search for the unique valid value of j, providing a correct θ_x. Procedure Determine_Carriage_Position implemented the above algorithm.



Flow Diagram 6.11.8a Linear Transporter Vernier Algorithm.

In determining the coarse linear position, it was necessary to decode the returned gray scale information. The six bit coarse position gray code was converted to binary code by the following algorithm. In general an n bit gray code produces an n bit binary code, Peatman [76]. The most significant bits are identical, thus for a given binary coded bit b and corresponding gray bit g;

$$B_{n-1} = g_{n-1} \qquad \text{-- Eqn 6.11.8a}$$

The procedure to obtain each less significant bit of the binary code is given by Peatman [76];

$$B_{k-1} = \begin{cases} g_{k-1} & \text{if } B_k = 0 \\ \overline{g_{k-1}} & \text{if } B_k = 1 \end{cases} \qquad \text{-- Eqn 6.11.8b}$$

Where $\overline{g_{k-1}}$ signifies the complement of g_{k-1}.

The resulting binary code could be directly converted to integer for further processing by standard Turbo Pascal procedures. An additional procedure was used to integrate the linear transporter shaft angle and the coarse position data to a high resolution determination of carriage position. A procedure Gray_Code_To_Binary_Algorithm was used to implement the above algorithm, and procedure Form_Gray_Scale_Data_As_Integer to convert the decoded binary information into integer format.

The linear transporter could be positioned from the operator interface or by program control. Additionally, the state of the transporter sensors could be displayed on the system console by a diagnostic routine.

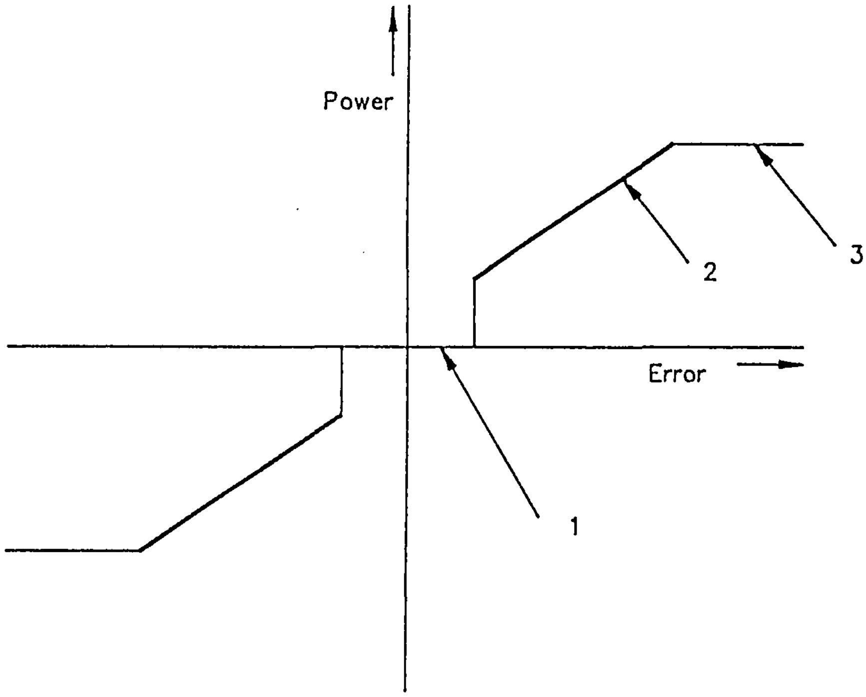
In the positioning algorithm, the output control element was provided by the procedure Set_PP_Motor_State. A variable representing a percentage of full power was passed to the procedure, with motor direction information, allowing assignment of a given power level and direction.

Flow diagram 6.11.8b shows the implementation of the positioning control scheme. A proportional control loop was used, PID control being described in Shinners [95] and Di Stefano [27]. Demanded carriage position was input and summed with its measured position to produce an error term. Assigned motor power was determined from a transfer curve (figure 6.11.8), having a proportional component (area 2) but with non-linearities in area 1 (deadband) and area 3 (power limiting).

6.11.9 Program Components -- Workpiece Release Area Control

The purpose of the module was to drive the electromechanics associated with the release area. Basic output procedures associated with the component comprise a procedure to write data to the output port controlling the air ejector vacuum unit. A further procedure was used to set the vacuum on or off.

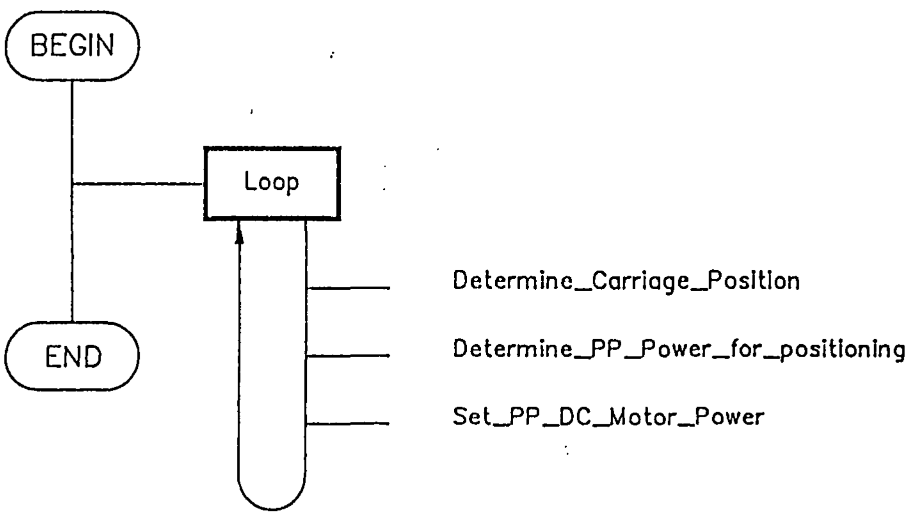
An option entered from the operator interface could be used to set the state of the air ejector for diagnostic purposes.



Key:

1. Deadband.
2. Proportional element.
3. Power Limiting.

Error/power transfer curve.



Positioning procedure.

Flow Diagram 6.11.8b Carriage Positioning Algorithm.

6.11.10 Program Components -- Initialisation Processor

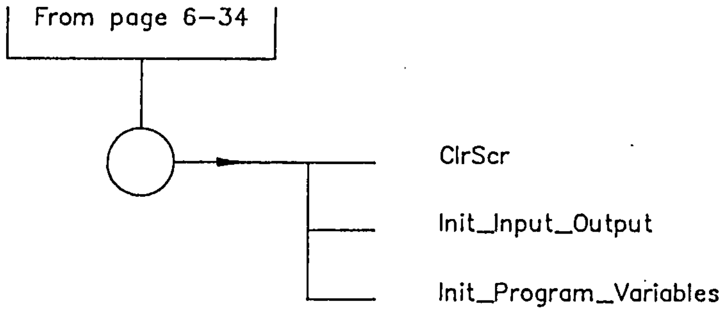
The function of the initialisation processor was to prepare the controller, its software and electronic sub-system for use in the application.

Flow diagram 6.11.10 shows the initialisation processor root segment and procedures. In procedure Init_Input_Output, initialisation of the controller I/O area was performed, as indeterminate output states assumed by the control lines before initialisation could cause unprogrammed operation of the electromechanical actuators. This initialisation was achieved by invoking initialisation procedures for each LSI interfacing device in sequence on the peripheral interface boards and loading default values into the output registers. On completion of the above, global program variables were initialised for use by procedure Init_Program_Variables. The initialisation procedure was called at the commencement of the execution of the control program.

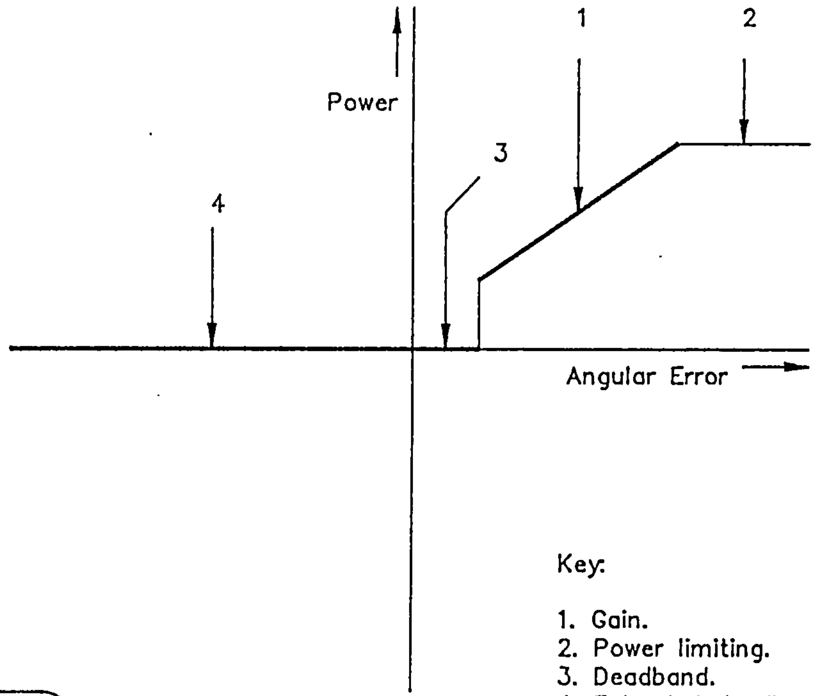
6.11.11 Program Components -- Integrated Control

The function of the integrated control component was to coordinate the electromechanical elements of the de-stacking unit to allow operation of the de-stacking function.

To achieve synchronised operation of the linear transporter and the gripper unit, a synchronised control scheme was devised. Its function in the control loop was implemented in a procedure named Roll, shown in flow diagram 6.11.11a. Procedure Roll was entered with the location for termination of rolling specified as a parameter. Within Roll, a loop was entered effecting synchronisation between the gripper and the linear



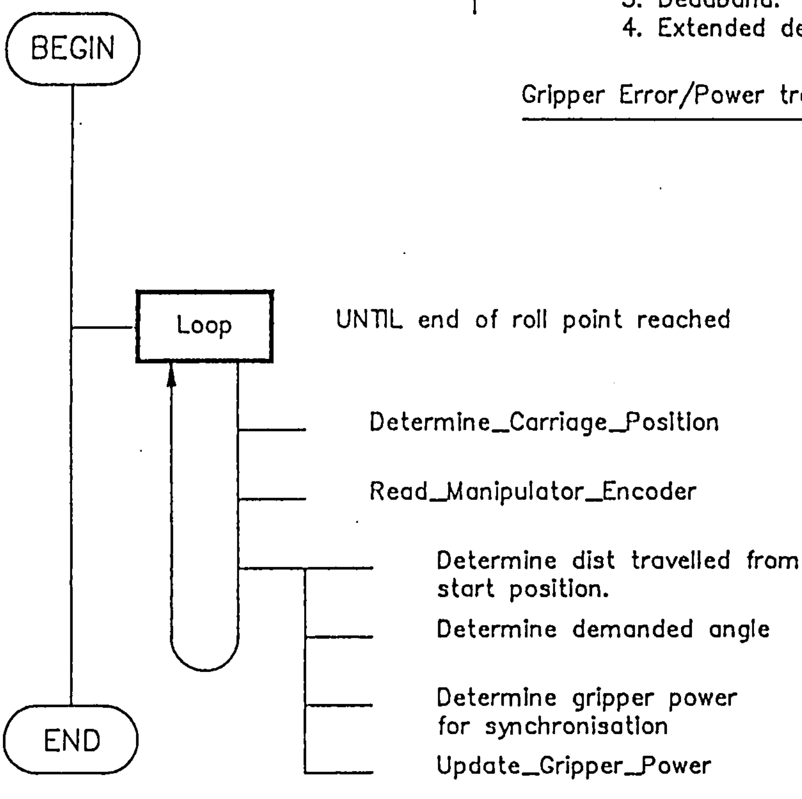
Flow Diagram 6.11.10 Initialisation Processor Root Segment.



Key:

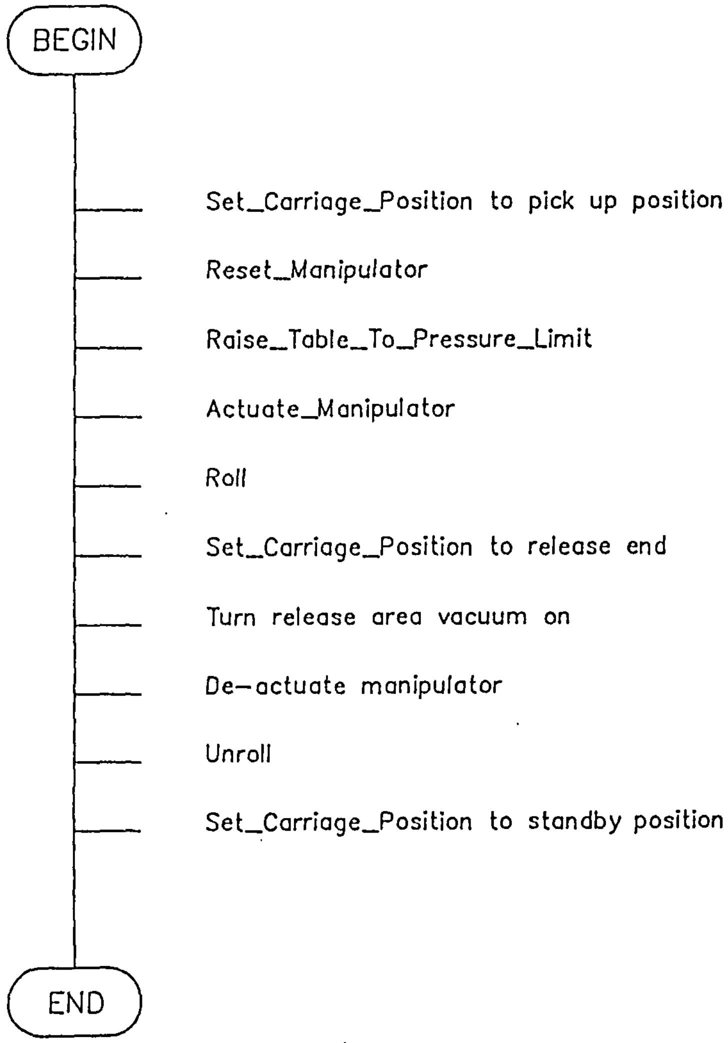
1. Gain.
2. Power limiting.
3. Deadband.
4. Extended deadband.

Gripper Error/Power transfer curve.



Roll procedure.

Flow Diagram 6.11.11a Synchronised Workpiece Roll procedure.



Flow Diagram 6.11.11b Execute one Pick and Place Cycle Procedure.

transporter position. Carriage position was first read via procedure Determine_Carriage_Position, encoder angle being read next via procedure Read_Manipulator_Encoder. Computation of gripper demanded angle was carried out from knowledge of the gripper alignment at the beginning of the rolling process and the current angle. The power needed to cause the gripper roller movement towards the demanded angle was obtained from the transfer curve shown in figure 6.11.11b. This non-linear curve was composed of four distinct areas. Area (1) represented the proportional element (gain). Power limiting was effected in area (2) and a deadband in area (3). To defeat overshoot, excursions into area (4) caused zero motor power assignment; the carriage was moving simultaneously in the Roll process and overshoot error could be removed without motion of the gripper.

Execution of a full pick and place cycle was performed by procedure Execute_One_PP_Cycle. Flow diagram 6.11.11b shows the internal operation of the procedure. The gripper was first positioned above the fabric stack by a call to procedure Set_Carriage_Position. Next the gripper was rotated to present its oblique pin area to the topmost ply via procedure Reset_Manipulator. Contact between the gripper and the fabric stack was achieved via procedure Raise_Table_To_Pressure_Limit. Gripper actuation was then called and the ply rolled. The workpiece was translated to the release area by a call to Set_Carriage_Position. Here the vacuum clamp was turned on and the workpiece unrolled onto the release area surface. Finally, the gripper was sent to a standby position, completing the cycle.

6.12 SUMMARY

The experimental design for the investigation into flexible de-stacking has been outlined in this chapter. It commenced by describing the experimental plan in sections 6.2 to 6.6, then detailed the related electronic and electromechanical hardware design in sections 6.7 to 6.10. Finally, the process application programming was described in section 6.11. Experimental results are reported in the following chapter.

CHAPTER 7

EXPERIMENTAL PERFORMANCE OF THE FLEXIBLE DE-STACKING TECHNIQUE

7.1 INTRODUCTION

This chapter presents results obtained in the investigation of the flexible de-stacking technique outlined in chapters 5 and 6.

Results obtained during commissioning of the gripper, elevating feed table and linear transporter are presented in section 7.2. Subsequent evaluations are then reported. Initially, the de-stacking unit was programmed to emulate the process of the mechanically coupled prototype of chapters 2, 3, and 4, providing an experimental control. Results are described in sub-section 7.3.1. Following the above evaluation, a group of experimental process refinements were made. These refinements, their implementation and results from subsequent experimental trials are given section 7.4, sub-sections 7.4.1 to 7.4.4.

Some mechanisms of departure from the anticipated performance are identified and discussed in section 7.5. Finally, conclusions relating to the flexible de-stacking process are drawn with suggestions for further work in section 7.6.

7.2 EXPERIMENTAL EQUIPMENT COMMISSIONING

7.2.1 Gripper Performance

Both the gripper drive and shaft position encoding scheme were found to operate correctly. Table 7.2.1 summarises the experimentally determined gripper performance results. The controller achieved reset of the gripper drive shaft to an accuracy of ±2°. A demanded gripper angle could additionally be set by the controller to an accuracy of ±2°.

Table 7.2.1 Gripper Performance.

Positioning accuracy.		Error.
Drive shaft reset to datum 0°:		±2.0°
Drive shaft set to demanded angle 0-360°:		±2.0°
Shaft Positioning Times.		Time (s).
Parameters:		
Demanded angle:	+180°	
Motor Power:	10%	1.10
	20%	0.85
	30%	0.70

Correct operation of the ply depth sensor unit was verified next. Sample fabric test cells were prepared by sandwiching single, double and triple ply depths together. Test samples were prepared from several fabric colours and styles. With the gripper shaft angle set to its ply depth measurement alignment, each sample test cell was placed in contact with the sensor receiver and the ply depth instrumentation output voltage recorded. Results are given in graph 7.2.1a. Differentiation between single and double ply depth in all test samples was observed.

The contact force and engagement torque sensors were calibrated, results being presented in graphs 7.2.1b and c respectively. Note that offset forces were electronically nulled by preset adjustment prior to recording of the above results.

It was noted the gripper drive shaft appeared frail and collision during experimentation could potentially bend the drive shaft. Thus a mechanical protection shield was constructed and fitted for the course of this work.

7.2.2 Linear Transporter Performance

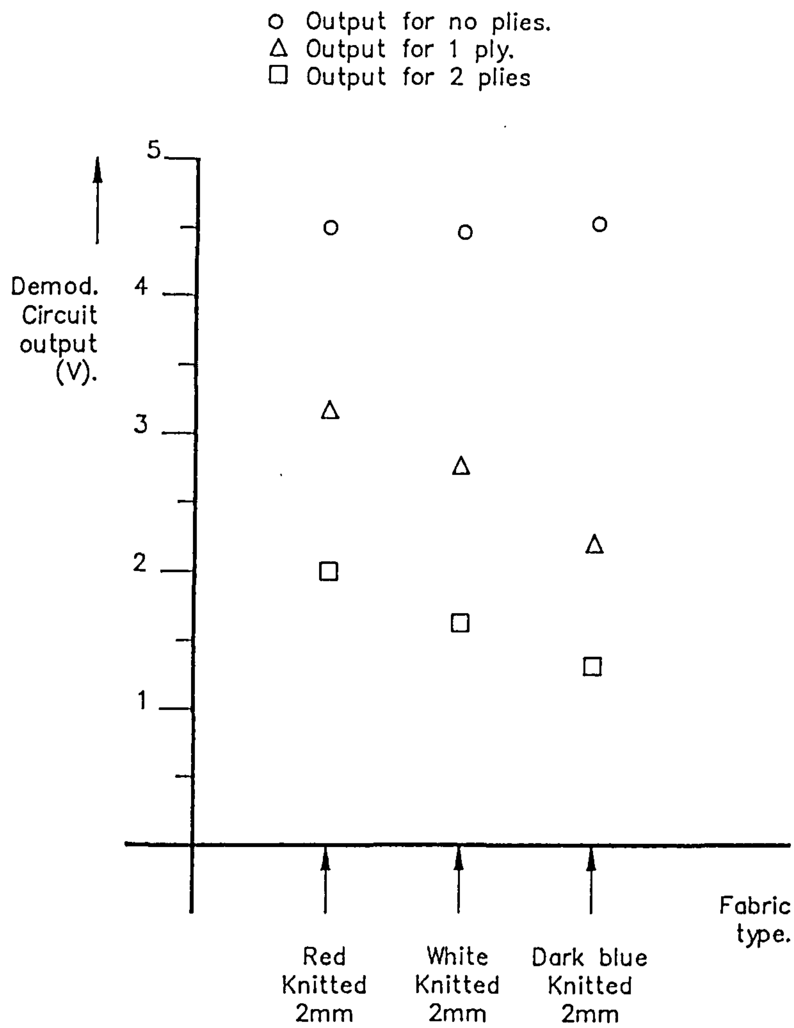
The operating performance of the linear transporter was evaluated. Results are described below with required commissioning modifications.

Initially, recovery of absolute carriage position was found unreliable due to indeterminate discrimination of the coarse position encoder gray scale by its sensors. Improvement in discrimination was effected by increasing the contrast of the encoder scale, allowing reliable recovery of position.

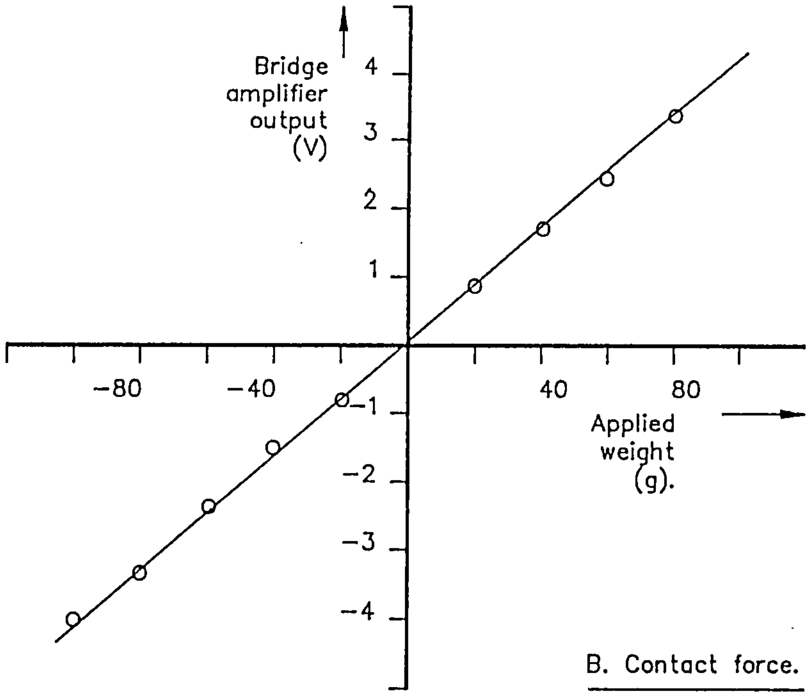
Table 7.2.2a summarises the performance results obtained from the carriage positioning control algorithm, described in section 6.11.8. Several operating deficiencies, listed below, were observed:

i. Inability to overcome stiction for small (± 5 mm) changes in demanded position.

Key:



Graph 7.2.1a Ply Depth Sensor Results.



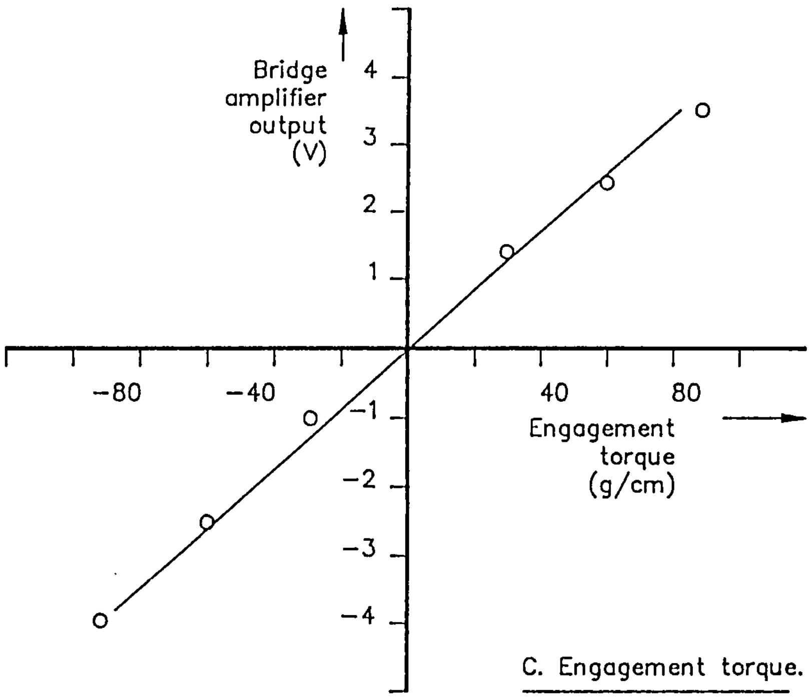
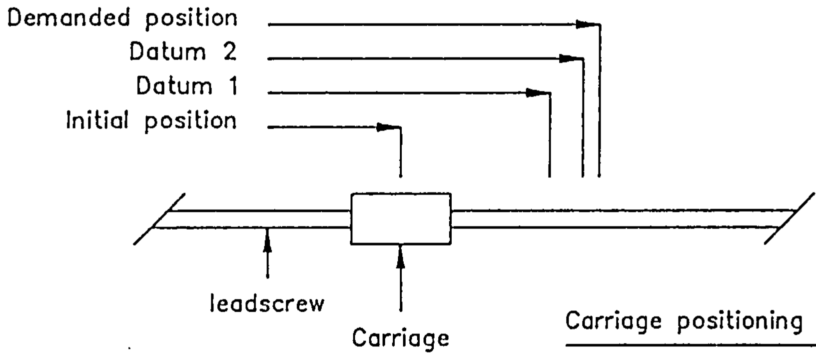


Figure 7.2.1b,c Gripper Force Sensor Calibration Results.

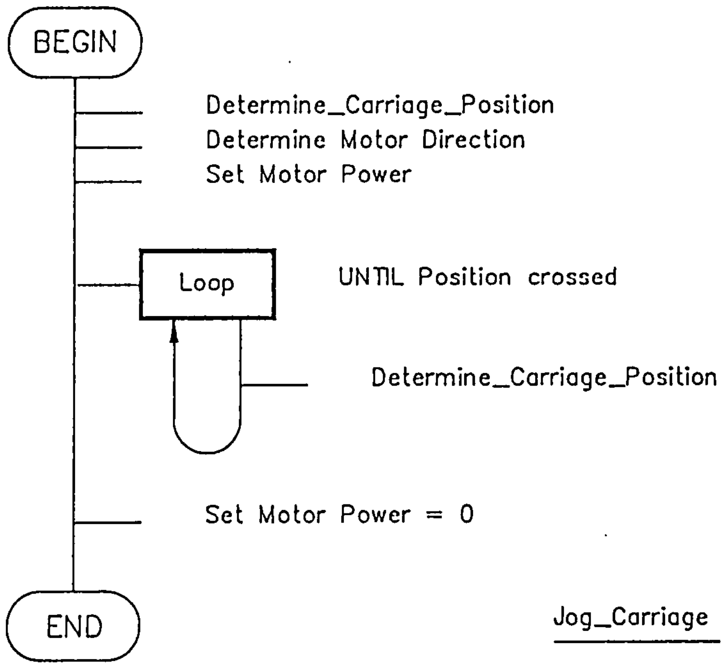
ii. Position dependent coulomb friction in the 1 m transporter working range caused large (± 7 mm) final position errors.

iii. Introduction of overshoot into positioning.

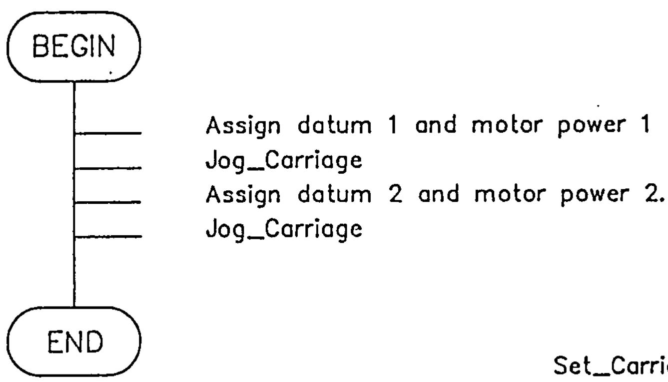
An improved algorithm was designed to overcome these deficiencies and is illustrated in flow diagram 7.2.2. Here, a service procedure, Jog_Carriage, was employed to control the transporter motor. Two parameters, Set_Position position and Motor_Power were passed to the procedure. When Jog_Carriage was invoked, the required direction of carriage motion was computed using the Determine_Carriage_Position procedure. Transporter motor direction and the passed motor power parameter were then assigned to the drive and the carriage commenced movement towards the position indicated by the Set_Position parameter. Jog_Carriage then observed the carriage position in real time using Determine_Carriage_Position and set assigned motor power to zero when the set position was crossed by the carriage. At this point Jog_Carriage_Position completed and control returned to the algorithm. A specific linear transporter transport operation could be tailored by issuing Jog_Carriage_Position two or more times with decreasing assigned power and datum positions as the demanded position was approached. The initial component of motion could be executed at high power with final positioning to the demanded position performed at reduced power. Overshoot could be eliminated by empirical assignment of motor power and use of intermediate datum positions. Performance of this algorithm was evaluated and results are summarised in table 7.2.2b.



Carriage positioning arrangement.



Jog_Carriage



Set_Carriage_Position

Flow Diagram 7.2.2 Improved Positioning Algorithm.

Table 7.2.2a	Initial Carriage Positioning Algorithm.
Algorithm Parameters:	
Power limit:	30 %
Power Gain:	5 %/cm
Deadband:	2 mm
Results:	
Trial transfer distance:	700 mm
Trial transfer time:	2.5 s
Positioning accuracy:	±7 mm

Table 7.2.2b	Improved Carriage Positioning Algorithm.
Algorithm Parameters:	
Primary applied power:	50 %
Primary transfer dist':	600 mm
Secondary (Inch) power:	7 %
Results:	
Trial transfer distance:	700 mm
Trial transfer time:	1.5 s
Positioning accuracy:	±1 mm

7.2.3 Feed Table Performance

The performance of the elevating feed table was found satisfactory. Operation of each of the table sensors was validated and the initialisation routines were found to operate correctly. No commissioning modifications were required. Initialisation time was determined at 22.4 s. The slow initialisation time would add to batch cycle time, but higher power drives could be used in a commercial version, providing faster elevation and retraction speeds. Table 7.2.3 shows the elevating feed table performance results.

Table 7.2.3. Elevating Feed Table Performance.

Retraction depth:	9.90 cm
Retraction time:	15.10 s
Derived retraction speed:	0.65 cm/s
Average batch height:	7.10 cm
Wait time after load (Preset):	3.00 s
Elevate to initialised position time:	4.31 s
Total initialise time:	22.41 s

7.3 PROCESS RESULTS

The processes described in section 7.1 were evaluated. A determination of experimental control performance was made in the first trial. Its objective was to establish the performance of the flexible de-stacking system operating in a mode emulating the pilot de-stacking system. Results from this experiment could be compared to results obtained from the pilot de-stacking scheme in chapter 4. Having formed a comparison between the two systems, results from further modified handling schemes could be related to the performance of the pilot de-stacking system.

7.3.1 Process A: The Experimental Control

The flexible de-stacking unit was programmed to operate in the same fashion as the mechanically coupled unit described in chapter 3. A group of 480 cut components in batches of four dozen, obtained from the collaborating industrial partner, were processed with the unit. Results are summarised in table 7.3.1a, and operating times given in table 7.3.1b.

Table 7.3.1a Experimental Control Process Results.

Batch size (plies):	48
Number of Batches:	10
Total plies tested:	480
Correctly delivered plies:	477
Incorrectly delivered plies:	3
Number of plies delivered:	480
Number of crumpled plies:	1
Number of double ply separations:	1
Process reliability:	0.995

Table 7.3.1b Experimental Control De-stacking Process Operation Times.

Cycle component.	Time.
Move gripper into position:	1.9 s
Feed a workpiece:	0.8 s
Actuate:	0.4 s
Transport:	1.5 s
Unroll:	1.4 s
Move gripper to standby position:	1.5 s
Total cycle time:	7.5 s
Batch initialisation time:	27.0 s
Associated parameters:	
Gripper power:	30 %
Clamp weight:	70 g
Primary Linear transporter power:	50 %

Cycle time was measured at 7.5 s. The unit was initialised at each cycle to ensure consistent operating conditions during the test. Reliability, α, was found equal to reliability obtained in section 4.6, at 0.995.

7.4 PROCESS REFINEMENTS

Based upon preliminary results obtained in the evaluation of the flexible de-stacking process, several modifications in the equipment and process were carried out. These are reported in sub-sections 7.4.1 to 7.4.4. Sub-section 7.4.1 describes a modified workpiece release process and 7.4.2 a modified ply separation process. The evaluation of a process using a modified fabric clamp technique is reported in sub-section 7.4.3. Successful features of the above were combined in a composite process, evaluated and reported in sub-section 7.4.4.

7.4.1 Process B: Modified Workpiece Release

A cause contributing to unreliable workpiece release was observed as failure of the fabric to commence unrolling when required at the release stage. Reasons are described below:

At commencement of unrolling, the edge must first detach from the roll and become clamped to the release area vacuum grille. Provision of vacuum to assist detachment did not prove wholly effective. This was found due to the indeterminate final position of the fabric edge on the gripper roller at the release point. If the edge position occurred before the top of the gripper at the release position, detachment occurred easily. However, if the position occurred beyond the top of the gripper roller, detachment did not occur immediately, being delayed until the gripper commenced its unrolling procedure and the fabric had rotated to a position where gravity aided detachment. In this event, release was indeterminate as it occurred during gripper movement and the variable detachment time resulted in variable edge positioning.

A modification to the release process was made to remove the deficiency described above. The modified process is illustrated in figure 7.4.1.

The de-stacking process was altered to leave a section of the ply unrolled. With the fabric partially rolled, the gripper transported the fabric, trailing the unrolled edge to the release position. Thus, the edge could be presented to the release area in an already detached condition and in a known state. Vacuum was then applied to clamp the trailing edge, allowing release of the remaining section of the workpiece. Due to the partially rolled condition of the fabric, the workpiece was unwound from the top of the gripper rather than unrolled

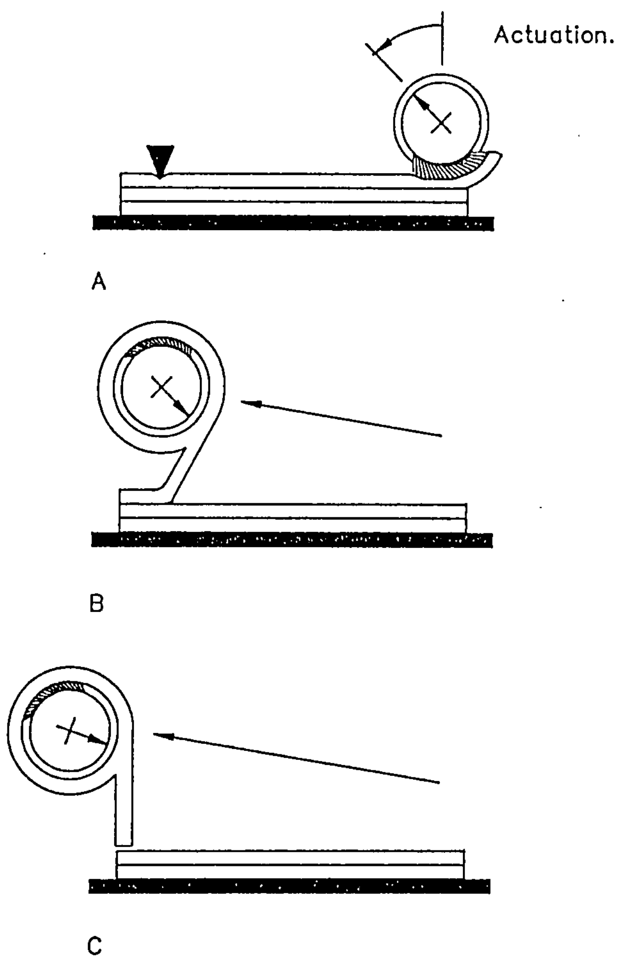


Figure 7.4.1 Modified Workpiece Transfer Process.

from its underside. In the mechanically uncoupled gripper arrangement, this could be achieved by rotating the roller in the opposite direction to the normal rolling process as the gripper laid the component at the release area. Following release, the gripper rotated to present its grip area upwards, reducing the possibility of inadvertent attachment to the laid component.

The above equipment and process refinements were evaluated in a further de-stacking trial. A run of 480 knife cut gusset components was obtained from the collaborating industrial partner and de-stacked in their original batches of 48 ply stacks by the de-stacking unit. The results obtained are presented in Table 7.4.1a summarising reliability results and operating parameters. Cycle time is summarised in table 7.4.1b. For reasons given in section 7.6.1, further increase in cycle time was not investigated, but transit time of the gripper unit was measured at 7.3 s to cross the linear transporter working area at a motor power of 60%. A further decrease of cycle time was thus feasible.

Table 7.4.1a Modified Workpiece Release.

Trailed workpiece edge length:	50 mm
Batch size (plies):	48
Number of Batches:	10
Total plies tested:	480
Correctly delivered plies:	478
Incorrectly delivered plies:	2
Number of plies delivered:	480
Number of crumpled plies:	0
Number of double ply separations:	1
process reliability, α:	0.996

Table 7.4.1b	Modified Workpiece Release Process Operation Times.
Cycle component.	Time.
Move gripper into position:	1.9 s
Feed a workpiece:	0.8 s
Actuate:	0.4 s
Transport:	1.4 s
Unroll:	1.2 s
Move gripper to standby position:	1.5 s
Total cycle time:	7.3 s
Batch initialisation time:	27.0 s
Associated parameters.	
Gripper power:	30 %
Clamp weight:	70 g
Primary Linear transporter power:	50 %

7.4.2 Process C: Modified Ply Separation

A process was evaluated offering simplification of the de-stacking operation and decrease in de-stacking time. In this process, power would be applied continually to the de-stacking gripper head during the actuation phase. The rear fabric clamp would be set to clamp under only moderate pressure, resulting in the topmost ply being first distorted then pulled from the under the clamp by the actuation force, followed by the component being rapidly and fully rolled onto the gripper unit, the gripper drive motor remaining energised. Thus the workpiece would be separated and prepared for transportation simultaneously. Tables 7.4.2a and 7.4.2b show measured reliability and cycle time components respectively for this mode.

Table 7.4.2a	Modified Ply De-stacking Reliability Results.
Batch size (plies):	48
Number of Batches:	10
Total plies tested:	480
Correctly delivered plies:	460
Incorrectly delivered plies:	17
Number of plies delivered:	477
Number of crumpled plies:	7
Number of double ply separations:	5
Process reliability, α:	0.958

Table 7.4.2b Modified Ply De-stacking Process Operation Times.

Cycle component.	Time.
Move gripper into position:	1.9 s
Feed a workpiece:	0.8 s
Actuate:	0.6 s
Transport:	1.2 s
Unroll:	1.4 s
Move gripper to standby position:	1.5 s
Total cycle time:	7.4 s
Batch initialisation time:	27.0 s
Associated parameters.	
Gripper power:	30 %
Clamp weight:	40 g
Primary Linear transporter power:	50 %

The ply separation time was measured at 0.6 s. This improvement arose from the single operation required to effect full ply separation. Transport time was reduced to 1.2 s, as higher primary transport power could be used, but α was reduced to 0.958, caused by disturbance of the fabric stack by the shearing action of the rolling process.

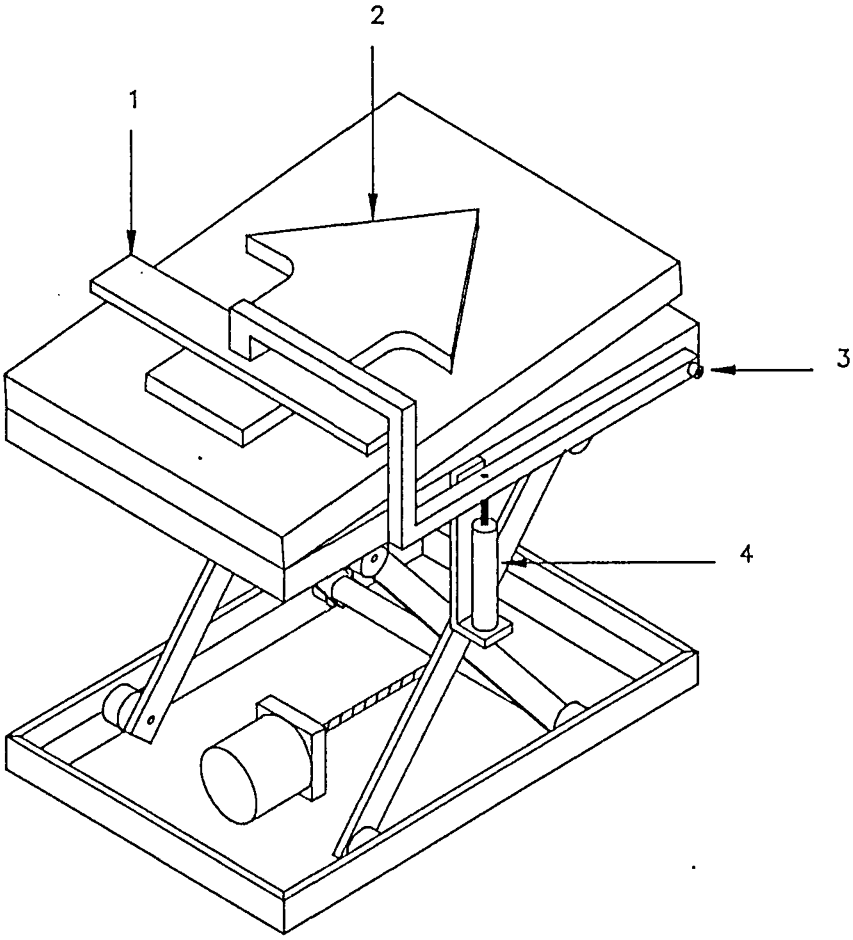
7.4.3 Process D: Modified Fabric Clamp

In the reported process, the fabric clamp operated by applying constant pressure to the stack. With this arrangement, a failure mechanism was was observed when the gripper attempted to withdraw its gripped workpiece from the clamped stack. In some cases, underlying plies were disturbed in this operation, effecting later de-stacking attempts.

Means to release and withdraw the clamp at this point was anticipated to improve the process reliability. To effect this, a mechanism was incorporated into the feed table to cause controlled clamp retraction, using a pneumatic ram. The modified feed table is shown in figure 7.4.3. The pneumatic cylinder rod was aligned to bear upon the clamp via a shaped cam. When energised, the ram actuated the arm, lifting the clamp. Height of lift was set to raise the clamp beyond the gripper height, so the gripper could pass underneath the clamp, peeling the workpiece from the top of the stack. Parameters of the new fabric clamp arrangement are summarised in table 7.4.1a. Measured reliability and cycle times are summarised in tables 7.4.1b and c respectively.

Table 7.4.3a Modified Fabric Clamp Arrangement Parameters.

Lift height:	50	mm
Pneumatic line pressure:	80	PSI
Lift time:	1.7	s
Clamp drop time:	2.0	s
Clamp dead weight:	50	g
Clamp dimensions:	17x2	cm



Key:

1. Clamp plate.
2. Fabric stack.
3. Pivot point.
4. Pneumatic ram.

Figure 7.4.3 Feed Table With Articulated Clamp.

Table 7.4.3b Performance of The Modified Fabric Clamp De-stacking Process.

Batch size (plies):	48
Number of Batches:	10
Total plies tested:	480
Correctly delivered plies:	478
Incorrectly delivered plies:	2
Number of plies delivered:	480
Number of crumpled plies:	0
Number of double ply separations:	1
Process reliability, α:	0.996

Table 7.4.3c Modified Fabric Clamp Process Operation Times

Cycle component.	Time.
Move gripper into position:	1.9 s
Clamp:	1.9 s
Feed a workpiece:	0.8 s
Actuate:	0.4 s
Roll to clamp:	1.4 s
Lift clamp:	1.4 s
Transport:	1.5 s
Unroll:	1.4 s
Move gripper to standby position:	1.5 s
Total cycle time:	12.2 s
Batch initialisation time:	27.0 s
Associated parameters.	
Gripper power:	30 %
Clamp weight:	70 g
Primary linear transporter power:	50 %

7.4.4 Process E: Composite

A composite process, termed process E, was designed based on results obtained from processes A, B, C, and D. This incorporated the modified release and fabric clamp procedure, as both elements improved reliability. The experimental rig was programmed to incorporate these features and a process evaluation was then carried out. At this stage the ply depth sensor on the gripper contact force routines were not incorporated. A group of 480 cut components in batches of four dozen were then processed by the equipment, and performance was recorded. Reliability results are summarised in table 7.3.2a and cycle time components in table 7.3.2b. Cycle time was maintained at 7.1 s. Process reliability improved to 0.997. Of the 0.3% failed attempts, none were observed due to incorrect workpiece release and all to ply removal from the fabric clamp.

Table 7.4.4a. Performance Of The Composite De-stacking Process.

Batch size (plies):	48
Number of Batches:	10
Total plies tested:	480
Correctly delivered plies:	479
Incorrectly delivered plies:	1
Number of plies delivered:	480
Number of crumpled plies:	1
Number of double ply separations:	0
Process reliability, α:	0.998

Table 7.4.4b Composite De-stacking Process Operation Times

Cycle component.	Time.
Move gripper into position:	1.9 s
Clamp:	1.9 s
Feed a workpiece:	0.8 s
Actuate:	0.4 s
Roll to clamp:	1.4 s
Lift clamp:	1.4 s
Transport:	1.5 s
Unroll:	1.4 s
Move gripper to standby position:	1.5 s
Total cycle time:	12.2 s
Batch initialisation time:	27.0 s
Associated parameters.	
Gripper power:	30 %
Clamp weight:	40 g
Primary Linear transporter power:	50 %

7.5 PROCESS FAILURE MECHANISMS

Observed mechanisms causing of failure of the de-stacking process were noted and are summarised below:

i. Incorrect ply separation.

ii. Partial adhesion of underlying workpiece following correct separation.

iii. Fabric slippage in clamp.

iv. Disturbance of underlying components following prior disturbance.

7.6 SUMMARY AND CONCLUSIONS

The flexible de-stacking system has been experimentally compared with the pilot de-stacking system. A 0.995 obtained for both systems indicated practical equivalence of reliability. Three modified handling processes were then evaluated. Initially, a handling procedure modification related to ply release and an inverted unrolling procedure was developed to improve the release stage. A modified de-stacking procedure was evaluated and found more rapid but less reliable than the basic procedure. The third employed a modified fabric clamp and ply removal from the clamp area was made more positive by this modification.

Conclusions drawn from results given in sections 7.1.1 to 7.1.3 are given in chapter 10.

7.6.1 Cycle Times

Particular ply separation and handling process times measured are given in the previous sections. Whilst de-stacking cycle time was of concern to the economic viability of the de-stacking process, the recorded times were not optimised, this being deferred until the reliability failure mechanisms could be properly identified and treated. Hence the recorded timings do not represent the potential minimum cycle times of the equipment. However, assignment of actuator power was made in the 20-60% range and therefore scope remains within the existing hardware for investigation of higher powered handling processes. Developed or alternative transport techniques would allow the reduction in process time. Furthermore, during software development, mechanical protection features not present in the prototype de-stacking unit were incorporated into the control routines. The unit was initialised to a datum position following each cycle, adding time into the cycle not required in a commercial prototype. Cycle times reported in this chapter were thus deliberately increased by approximately 30% over the prototype results. Table 7.6.1 summarises cycle time results.

Table 7.6.1 De-stacking Unit Cycle Time Summary

Process.	Time (s).	Actuation time (s).
Coupled gripper system:	3.8	0.4
De-coupled Process A:	7.5	0.4
De-coupled Process B:	7.3	0.4
De-coupled Process C:	7.4	0.6
De-coupled Process D:	12.2	0.4
De-coupled Process E:	12.2	0.4

Improvement in transportation speed would increase throughput as this was determined by cycle time. Aerodynamic effects on the workpiece were observed if the cycle time was decreased below 3.0 s, thus reduction in cycle time below this value incurred a reduction in performance whose solution may be regarded as a diminished return. Such effects could be avoided if multiple de-stacking units were operated in parallel at slower speeds, reducing overall de-stacking time in proportion. Investigation of the performance of multiple de-stacking arrangements is therefore suggested for further work.

7.6.2 Suggestions For Further Work

Employment of integrated multiple de-stacking units to decrease process time was suggested in sub-section 7.6.1 as a means to reduce overall de-stacking cycle time. Such an approach would not increase supervisory requirement or machine loading time, and would allow slower but more suitable drive units (step motors) to drive the linear transporters. A full investigation of the effects of sensory feedback from the gripper on process quality remains outstanding and thus presents an area for further research.

CHAPTER 8

INTEGRATION OF FABRIC DE-STACKING INTO AN ASSEMBLY CELL

8.1 INTRODUCTION

The attainment of computer supervised automation in assembly processes is a major objective of garment assembly research. Realisation of sufficient suitable basic handling techniques capable of combination in a modular fashion to implement the full range of assembly applications is required to meet the objective. To this end, several fundamental handling techniques were investigated in chapters 2 to 7 and were combined to form a widely used handling operation. However, other fundamental processes exist requiring attention. The Kurt-Salmon report [55], was commissioned by the EEC to report on technology for apparel manufacture aimed at categorising direction for future research into this technology in its BRITE and ESPRIT programmes. This report identified the following key areas for future research and development;

i. Full cycle automation.

ii. Full sequential automation.

iii. Alternative processes, such as moulding, full garment knitting, non woven and plastic technology

iv. Improved management through computer technology.

Additionally, the following key project areas were cited;

i. Versatile pick and place devices.

ii. Alignment devices.

iii. Acceptable fabric rigidification processes.

iv. Automatic sewing heads.

Based upon these conclusions, an investigation into more general assembly processes and their interaction with each other was proposed. This investigation was performed using the de-stacking unit as a sub-system of a robotic assembly cell automating an example assembly process. The cell assembly itself satisfied an auxiliary purpose of demonstrator unit for the assembly process, as such automation techniques must demonstrate their commercial viability to the industry before acceptance.

Experimental objectives, methodology, schedule and preparation are covered in sections 8.2 to 8.5 respectively. A description is then given of the experimental design, covering processes, electromechanical systems, controller and electronics. This is given in sections 8.6 to 8.9 respectively.

8.1.1 Application Process Selection

An example garment assembly process was selected as a subject for the investigation. A suitable example, the men's Y-Front type garment was identified in chapter 1 and was thus adopted for the following work. In the assembly of this garment, two preliminary sub-assembly operations involving fabric de-stacking were identified. These were;

i. The "Bind Front" operation.

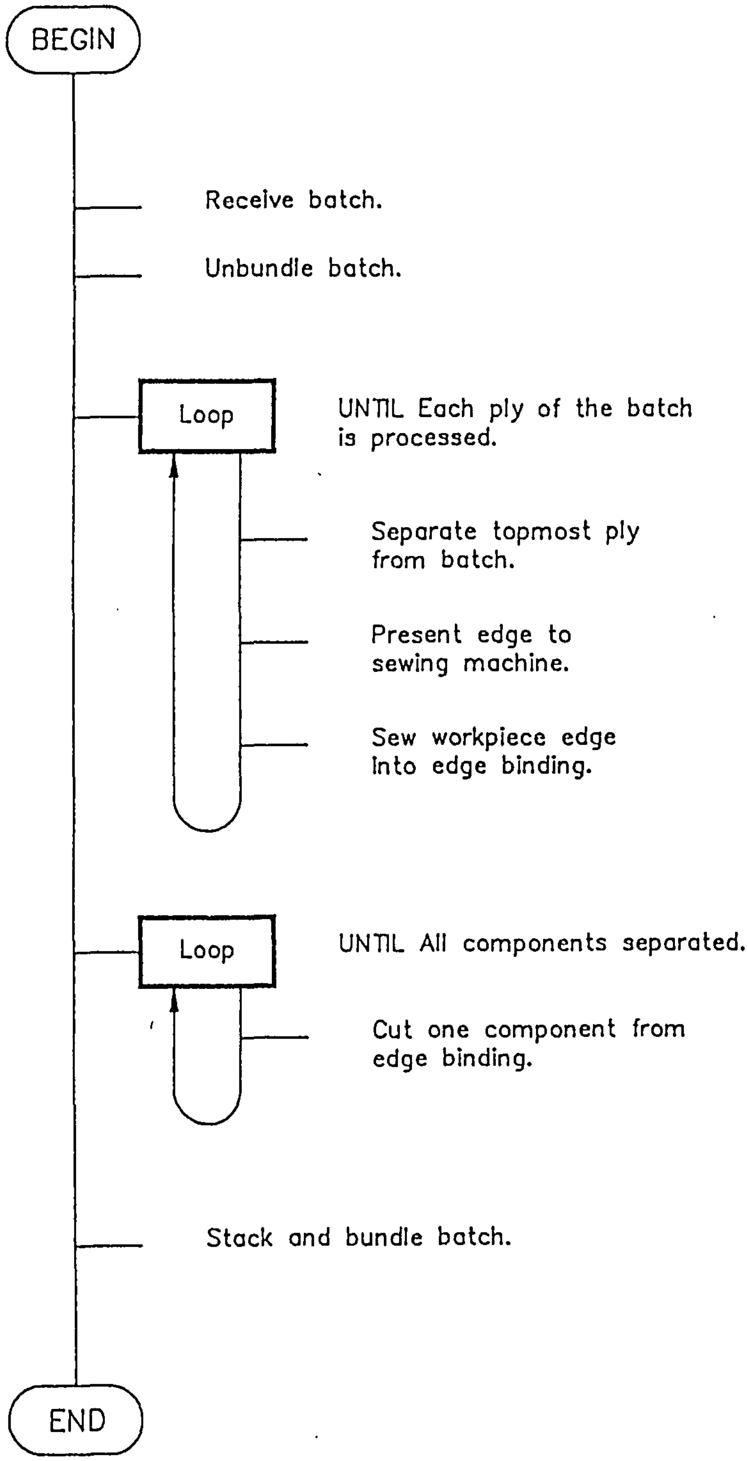
ii. The "Bind Gusset" operation.

Both operations were similar to each other and analogous to common operations in the assembly of related garments such as in T-Shirt neck binding. They were thus considered a common sub-assembly operation suited for investigation.

8.2 CONVENTIONAL IMPLEMENTATION OF THE EXAMPLE PROCESS

The conventional "Bind Front" process and the similar "Bind Gusset" process were organised as single workstation activities, each implemented by one operator at one sewing station. All sub-assembly operations were performed manually. The sewing station equipment employed comprised a high quality sewing machine such as the Rimoldi type 61 incorporating an edge binding feeder at the sewing machine jaws.

Flow diagram 8.2 shows the manual sub-assembly process operations. This process commenced with the reception by the operator of a batch of knife cut fabric material input from the upstream cutting process. For the "Bind Gusset" operation, the workpieces were formed in the shape of arrows. The operator manually de-stacked one workpiece at a time from the batch and fed it to the sewing machine with a combined hand operation separating each ply from the batch and guiding it through the sewing head.



Flow Diagram 8.2 Manual Process For The "Bind Front" Operation.

As each workpiece was fed to the machine, edge binding tape, supplied simultaneously by demand from a reel, was formed into a "U" shape by a former tube then drawn into the machine jaws with the workpiece. Following batch completion, the resulting strip of edge binding and gusset components was separated manually by scissors. The stacked batch was passed to the next stage downstream of the process.

8.3 EXPERIMENTAL OBJECTIVES

The investigation objectives were threefold. These are outlined below;

i. To establish the suitability of the de-stacking unit used as an element within the assembly cell automating the example process.

ii. To evaluate the performance of other experimental handling techniques integrated into the assembly process.

iii. To determine areas in the process requiring further investigation and suggesting potential areas for future investigation.

8.4 EXPERIMENTAL METHODOLOGY

The experimental methodology adopted for the following work was based upon the methodology employed within earlier investigations described in chapters 3 and 6. To simplify cell design, the assembly process was partitioned into five interacting sub-assembly processes to comprise the assembly cell activity. This allowed a modular design, organised upon separate sub-assembly stages whose design was of tractable proportion. Design of each module could thus be carried out individually. Either contemporary or experimental handling techniques were used in the design of the required processes. Construction followed and the automation sub-systems were subsequently evaluated and refined. Finally, performance evaluation of the integrated operation of the sub-assembly stages was carried out, allowing estimation of the overall cell performance.

8.5 EXPERIMENTAL SCHEDULE

Determinations of reliability, process quality and speed of operation were carried out for each sub-system of the cell. Having determined the performance for each element of the sub-system, the above parameters were experimentally evaluated for the integrated operation of the sub-system performing the intended cell activity.

8.6 EXPERIMENTAL PREPARATION

Experimental preparation for the described work included design and construction of the assembly cell. Furthermore, design, writing and testing of the control programming were required. As a large amount of electromechanical and electronic design was necessary, use was made of automated drafting facilities. The "AutoCad" version 2.0 drafting package was used to prepare the associated design drawings, hardware comprising a Duet 16 desktop computer, Calcomp 2000 digitising tablet and a Hewlett Packard 7475 A3 plotter.

8.7 EQUIPMENT DESIGN: ASSEMBLY CELL SYSTEMS

8.7.1 System Design For Automation Of The Assembly Process

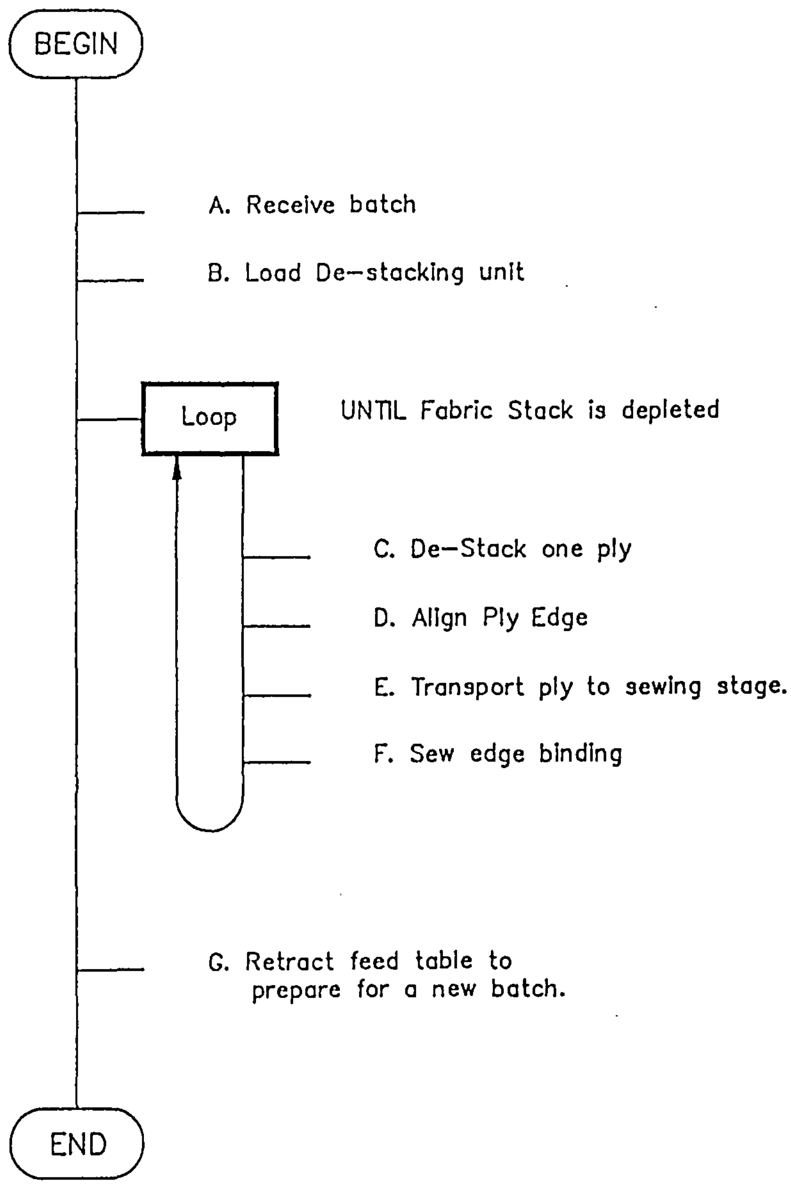
In common with other assembly stages in Y-Front and similar garment manufacture, the "Bind Gusset" process is carried out in batch. To provide compatability with existing production techniques, aimed to allow integration of the assembly cell into the industrial production line, the assembly cell process design also employed batch processing. Flow diagram 8.7.1 shows the proposed automation process. Here, a batch was received at the inlet stage (A) and then loaded by the supervisor into the de-stacking unit elevating feed table (B). A signal was then issued to the process controller to begin a batch processing cycle. Commencement of the cycle began and a loop was entered with one ply from the batch being singulated (C), transported to an edge alignment unit (D) where the ply edge was brought into accurate mechanical registration. Next, the aligned ply was transported to an automated sewing stage (E), where edge binding was attached (F). The loop was repeated until the entire batch was processed. Finally, the elevating feed table was retracted in preparation for a new batch load (G).

The required sub-process could thus be automated with;

i. A de-stacking unit to effect ply separation in batch.

ii. A fabric edge alignment stage to achieve mechanical registration of the ply edge.

iii. A transport stage to pass the aligned ply to the next sub-process.



Flow Diagram 8.7.1 Assembly Cell Process.

iv. An edge binding attachment stage.

Within the assembly cell, ply processing was conducted on a single ply processing basis.

8.7.2 The De-stacking Device Process

Results of the investigation into ply de-stacking were used to implement the ply de-stacking stage. The developed de-stacking sub-process was fundamentally identical to the process reported in section 6, but modification to the workpiece release area was required to aid workpiece passing to the next stage.

8.7.3 The Alignment Process

Mechanical registration of the workpiece edge was required to facilitate assembly in the processes downstream of the singulating unit. These processes were organised on an open loop basis and thus accurate mechanical registration was required prior to these stages. To achieve alignment in angular, X and Y DOF's, an alignment process was required. A powered articulated table surface was used to move the workpiece, alignment being effected with optical sensory feedback and suitable control programming.

Figure 8.7.3 shows the alignment process. The alignment process commenced with delivery of a workpiece from the de-stacking stage to the table surface. Prior to this, the table was placed in its reset position to accept the workpiece. Optical edge sensing was implemented with overhead mounted edge sensors. These were fabricated from reflex photosensors. The control programming performed simultaneous alignment

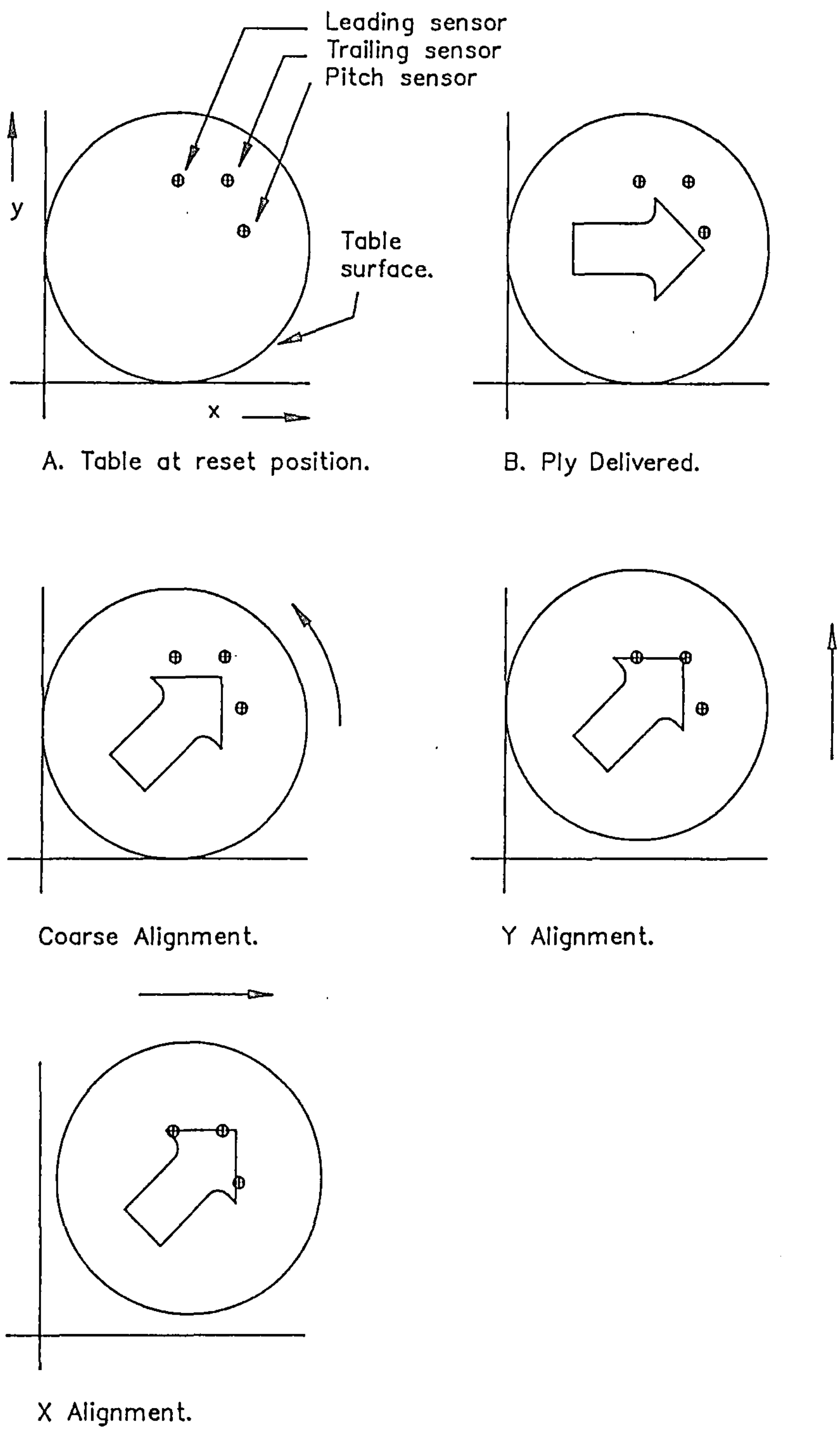


Figure 8.7.3 The Alignment Stage Process.

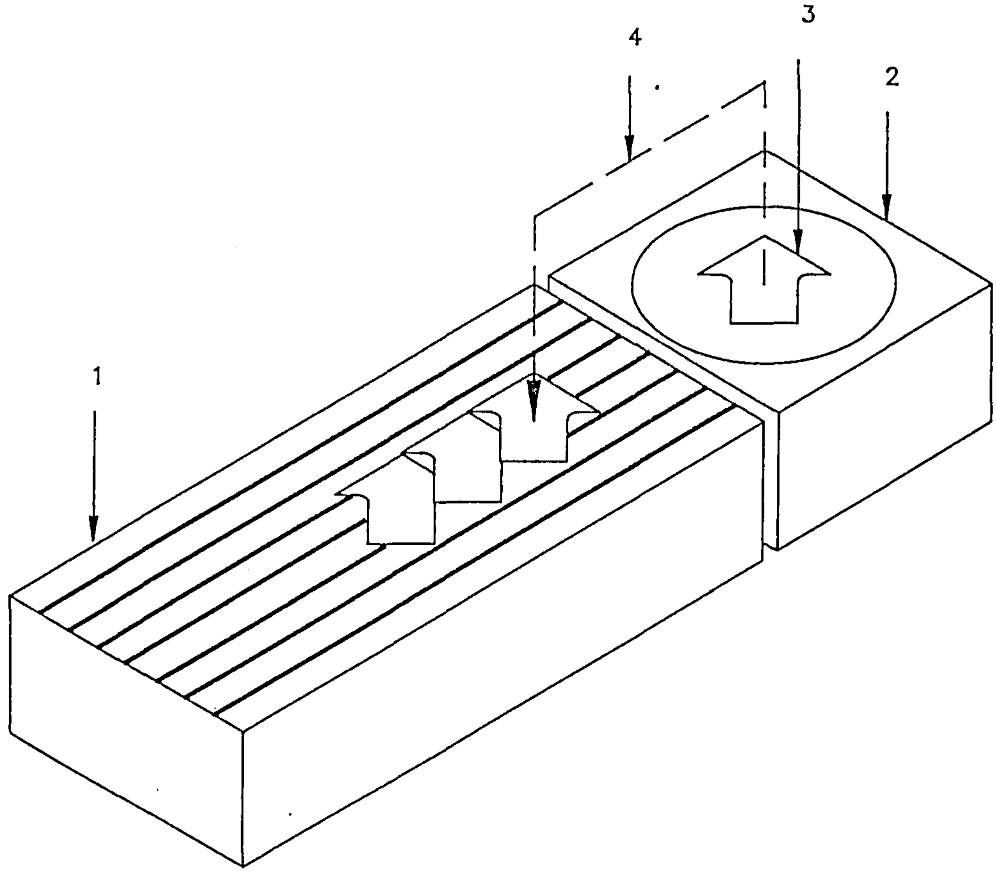
in X and Y axes to complete edge registration.

8.7.4 The Vacuum Based Transporter Process

Having achieved accurate edge alignment at the previous stage, further processes could then proceed in an open loop fashion. Workpiece transfer between the edge alignment stage and the edge binding attachment stage was implemented at the next stage. This was provided by an articulated vacuum based transporter. A clamp positively gripped the workpiece under vacuum in the process. The clamped component was moved to the transfer position by the clamp articulation under control of the cell controller. Figure 8.7.4 illustrates the transfer process. Transfer began at the completion of the edge alignment stage. Initially, the vacuum transporter commenced with the pad raised at the release position and vacuum turned off. When transfer was triggered, the pad moved in its raised state to the alignment stage, and then lowered the clamp onto the aligned fabric ply. Next, vacuum was turned off and the workpiece disengaged from the clamp. The transporter then raised the clamp to its initial standby position.

8.7.5 The Edge Binding Attachment Process

Attachment of edge binding was carried out by the "Edge Binding Attachment" sub-process. The sub-process accepted singulated fabric plies from the transport sub-process, located edge binding tape around the edge designated for attachment and joined the two components together by sewing. Some work on automated sewing has already been conducted within the industry and patents exist for automated guidance of curved components into sewing machines. Additionally, considerable



Key:

1. Conveyor.
2. Alignment table.
3. Workpiece.
4. Transfer path.

Figure 8.7.4 The Vacuum Transfer Process.

work has been carried out into sewing machine adjustments for automation [81, 86, 87, 148]. However, in this application, only straight edge guidance was required.

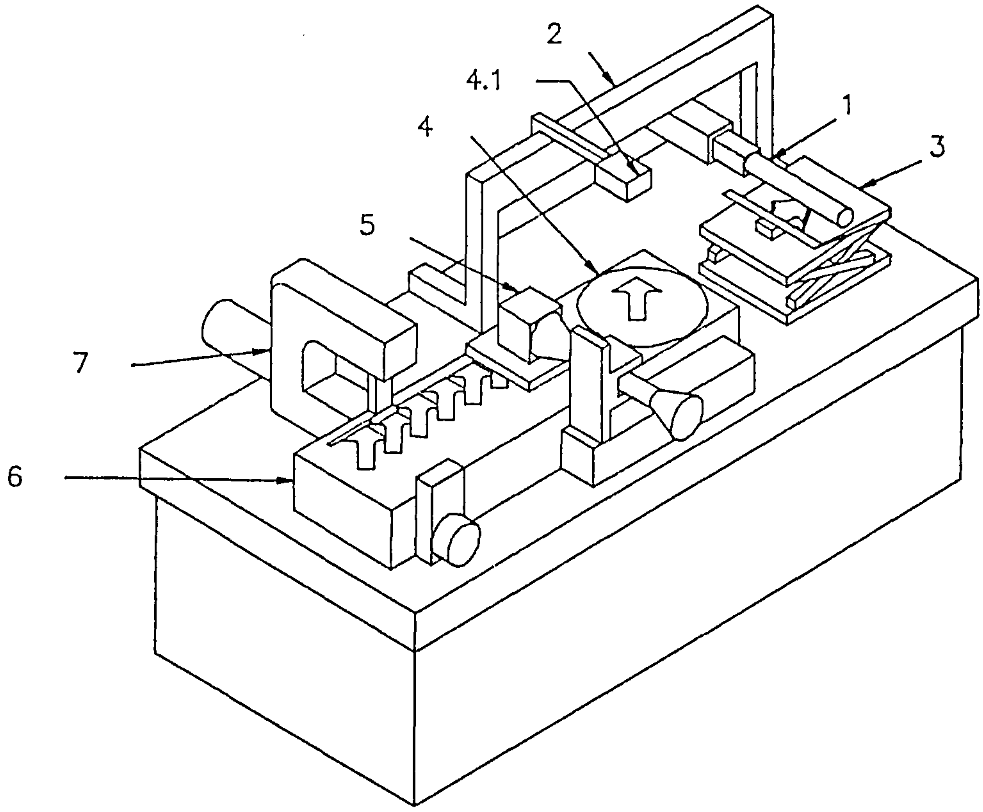
The process comprised an inlet stage where components were delivered from the transporter. A singulated component was released to a conveyor functioning as a component transporter and buffer. Workpieces were transported by this means to an industrial sewing machine adapted for computer control. Introduction of the workpiece edge into the sewing machine jaws was automatic and was assisted by binding tape, folded around the component edge in a "U" shape by a forming tube at the front of the jaws, stabilising entry of the workpiece to this process. The conveyor then moved the component in synchronism with the sewing machine stitch rate. Following attachment, the workpiece, joined to the edge binding tape left the machine. Separation of linked components was reserved to a further processing stage.

8.8 EQUIPMENT DESIGN: ELECTROMECHANICAL SYSTEMS

Separate electromechanical units were mounted upon a common bedplate supporting the cell wiring harness and its pneumatic supplies. Figure 8.8 shows the general arrangement for the bedplate and the electromechanical systems of the cell. Plate 8.8a shows the assembly cell and plate 8.8b a more detailed view of the de-stacking and alignment stages.

8.8.1 The De-stacking Sub-system

The de-stacking electromechanics used in the evaluation of the flexible de-stacking system of chapter 6 were used to provide the de-stacking



1. Gripper.
2. Linear Transporter.
3. Elevating Feed Table.
4. Alignment Photosensors.
   4.1 Alignment Photosensors.
5. Vacuum Based Transfer Mechanism.
6. Conveyor.
7. Automated Sewing Machine.

Figure 8.8 Assembly Cell General Arrangement.

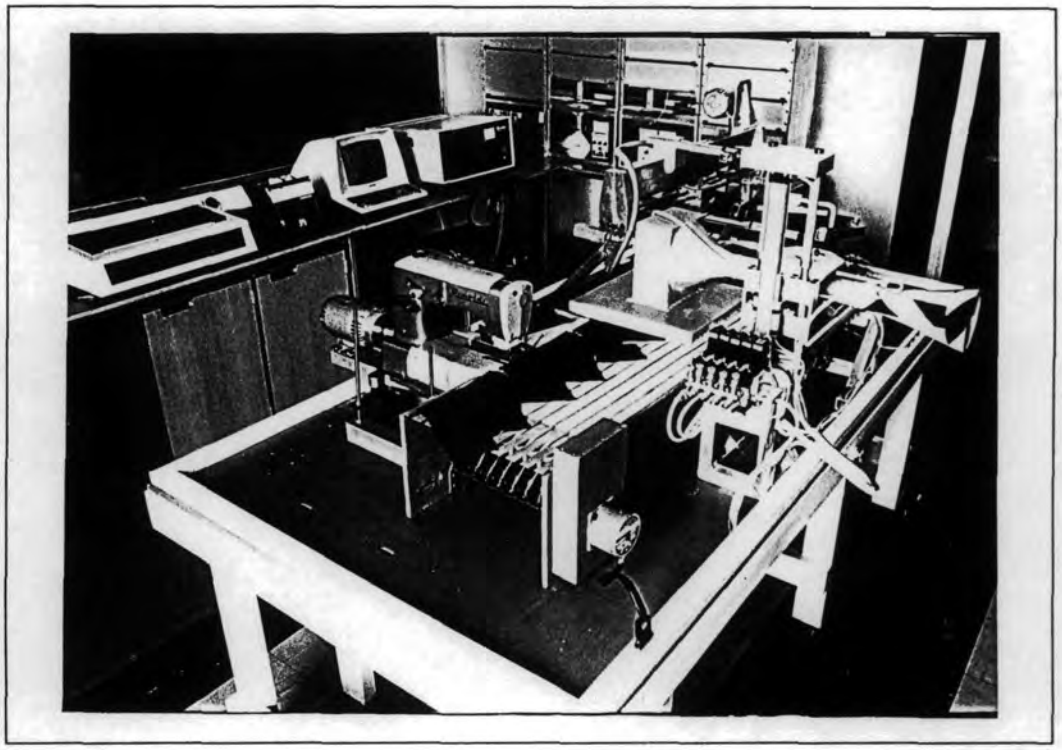


Plate 8.8a. The assembly cell.

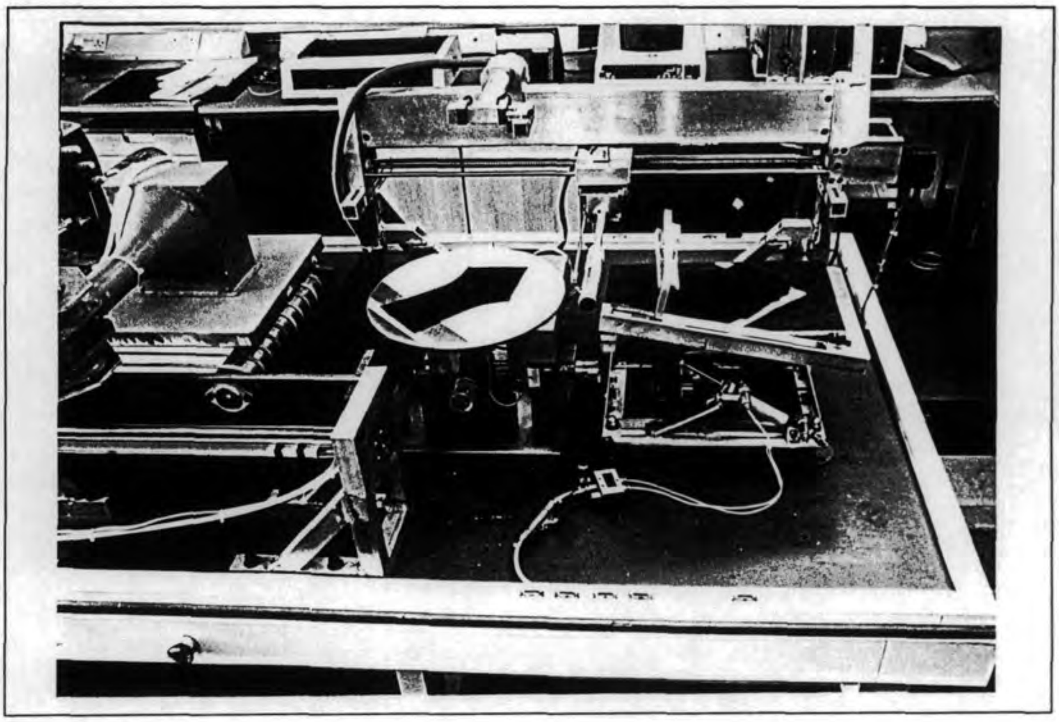


Plate 8.8b. The assembly cell de-stacking unit and alignment table.

system for the assembly cell. The unit was mounted onto the bedplate with welded aluminium legs. Electrical connection was made via the bedplate wiring harness. In this arrangement, the relative position of the workpiece feed table was maintained.

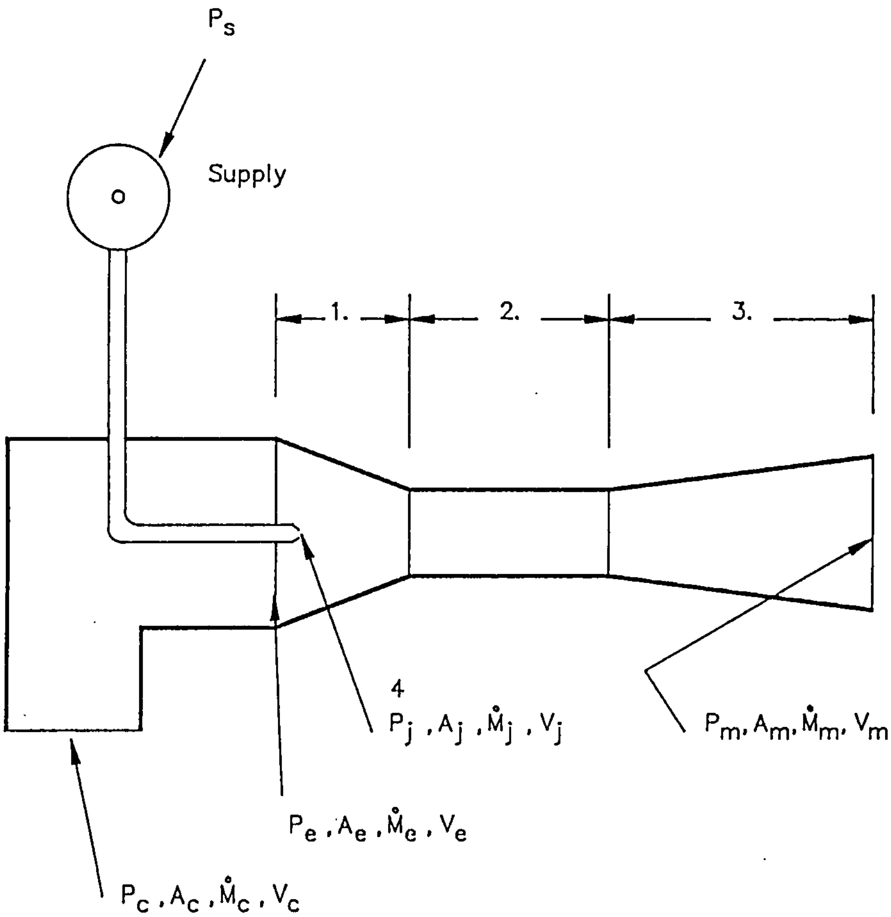
8.8.2 An Air Ejector Based Vacuum Clamp

This sub-section presents a novel means for generation and switching of vacuua suited to vacuum production in garment assembly.

Several of the described automation sub-systems employed vacuum clamp units. Means to generate vacuua for these were required. Here, high speed switching (< 0.5s) was desirable, as vacuum generation and destruction times added to the process time.

Initially, application of commercial exhauster units to develop the vacuua were considered. At the required flow rates and pressures, wide bore (> 1" diameter) ducting was necessary, hence solenoid or solenoid driven pilot valves of similar bore would be needed. Such valves were relatively expensive. Additionally, vacuum relief means were necessary to reduce clamp release times, requiring further large valves. Thus the above method would be bulky, heavy and expensive.

A novel approach was adopted. Vacuum generation by air ejector was investigated and found suitable for all applications described. The technique employed a single stage constant area mixer, with the mixing tube delivering output to atmosphere. Components of such an ejector are shown in figure 8.8.2, comprising an inlet cone (1), mixing tube (2), diffuser cone (3) and forcing nozzle (4).



Key:

1. Inlet Cone.
2. Mixer tube.
3. Diffuser cone.
4. Forcing nozzle.

Figure 8.8.2 Air Ejector Design.

Operation of the unit is described below: A pneumatic solenoid valve controlled compressed air supply to the forcing nozzle. When operated, compressed air was released into the mixing tube, transferring its momentum to the static air within the ejector body. The static air mixed and gained momentum thus developing an area of vacuum at the ejector inlet. When the solenoid valve switched off the compressed air supply, the mixing tube attained atmospheric pressure, causing destruction of the vacuum, effecting clamp release.

In air ejector design the following relationships may be applied:

From mass flow:

$$A_m V_m = A_j V_j + A_e V_e \quad \text{-- Eqn 8.8.2a}$$

From Newtons 2nd Law:

$$(P_e - P_m)(A_e + A_j) - \rho(A_m V_m^2 - A_j V_j^2 - A_e V_e^2) = 0 \quad \text{-- Eqn 8.8.2b}$$

From Bernoulli's equation [133], neglecting gravitational change in P.E:

$$P_s = P_j + \tfrac{1}{2}\rho V_j^2 \quad \text{-- Eqn 8.8.2c}$$

$$P_c + \tfrac{1}{2}\rho V_c^2 = P_e + \tfrac{1}{2}\rho V_e^2 \quad \text{-- Eqn 8.8.2d}$$

$$P_m + \tfrac{1}{2}\rho V_m^2 = P_e + \tfrac{1}{2}\rho V_e^2 + P_j + \tfrac{1}{2}\rho V_j^2 \quad \text{-- Eqn 8.8.2e}$$

Results from an extensive evaluation of air ejector performance by Kastner and Spooner [50] have shown ejector performance is determined by the ratio of the mixing tube diameter to forcing nozzle standoff from the mixing tube. Further analyses of air ejectors are given by Bonner [8]. For a given ratio, mass flow may be plotted against compression ratio. Such performance curves given by Kastner and Spooner were used in the design of the air ejector units. An experimental air ejector unit was constructed with a number of mixing tube diameters for evaluation. This allowed experimentation of trade-offs between terminal vacuum and flow rate.

8.8.3 The Alignment Table Electromechanics

Table 8.8.3 shows the alignment table electromechanical specification.

Table 8.8.3. Alignment Table Electromechanical Specification.

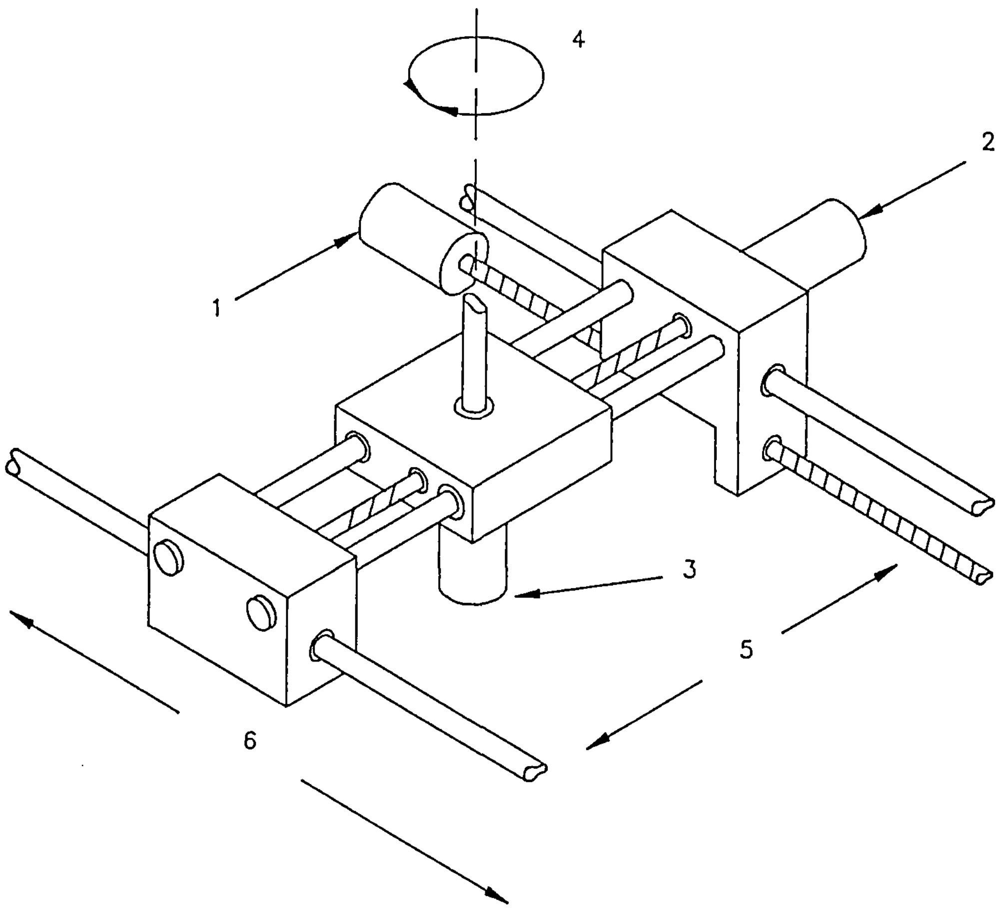
Axes of Articulation.	X, Y and θ
Initial laying tolerance;	
X axis:	±25 mm
Y axis:	±25 mm
Angular alignment :	±180°
Accuracy of alignment:	±1 mm

High alignment speed was desirable as the economics of the process were determined by throughput. To achieve both alignment speed and high positioning accuracy a novel linear actuation system was developed for use with the alignment table. A conventional linear drive employing a low pitch leadscrew and nut would require a high leadscrew speed to achieve high actuation speed. In the linear transporter design, improved performance for the speeds and accelerations required was offered by a low pitch leadscrew using an anti-backlash nut. A commercial 3 start high pitch leadscrew provided with a matching anti-backlash nut was identified, and this transmission was used to implement the table X and Y axis actuators. Leadscrew drive was provided by DC gearmotors coupled to the leadscrew by a flexible beam coupling. Maxon type 2332 DC motors were used (12V option) with 60:1 ratio gear-heads. Plate 8.8.3a shows the actuator arrangement in the alignment table.

Figure 8.8.3a illustrates the table articulation arrangement. A 3 mm thick aluminium disc was used to construct the articulated table providing low inertia to decrease actuation time. Support for the table was provided by a carriage sliding in a pair of guide rails located in two end support blocks. The carriage drive was formed by a leadscrew transmission whose drive motor was mounted in one of the end support blocks. Articulation in one DOF was thus achieved. A further DOF was provided by supporting the above assembly by its end blocks in a further pair of guide rails themselves located in two end blocks. Actuation in this axis similarly was effected by mounting an actuator unit on one support block and linking its leadscrew to the first assembly by a leadscrew nut. Thus articulation was achieved in two dimensions. Support bearings were formed from PTFE inserts.

Rotary articulation was implemented by supporting the table surface in a ballrace mounted spindle within the table support block. The spindle was linked via a flexible beam coupling to a further DC gearmotor. Four aluminium pillars supported the complete sliding assembly.

Sensory feedback was required for two purposes, the first being to detect the workpiece edge to allow alignment and the second to provide position feedback relating to the location of the table axes for out of limit detection and reset. Figure 8.8.3b shows the position detecting sensors used in the unit. Recovery of edge alignment data was achieved by retro reflective photosensors suspended approximately 250 mm above



Key:

1. X axis drive motor.
2. Y axis drive motor.
3. Rotary drive axis.
4. Rotary DOF.
5. Y axis DOF.
6. X axis DOF.

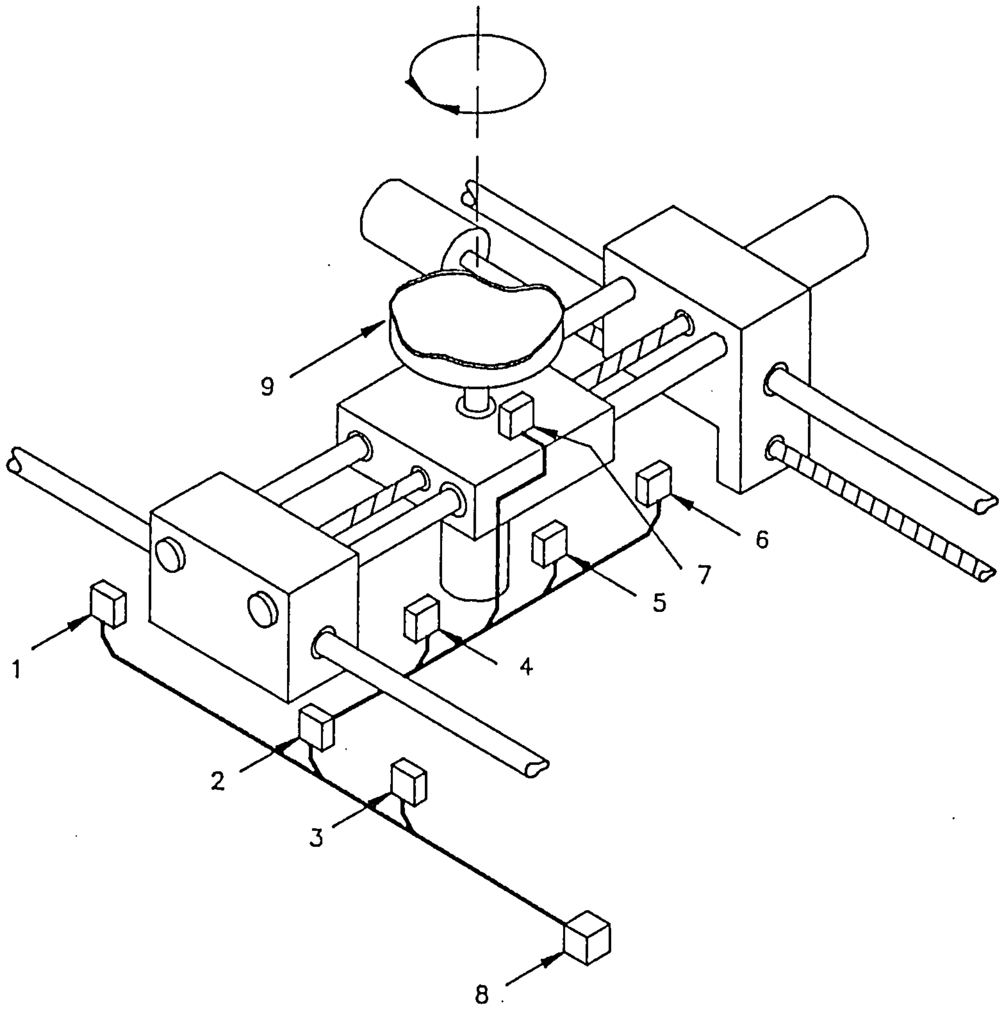
Figure 8.8.3a Alignment Table Articulation Arrangement.

the table surface. Figure 8.8.3c shows the edge detection sensor arrangement.

Reset position sensing was achieved by optical interruption operated transducers placed along the guide rod sections of the axes of articulation. A breaker plate attached to the moving component was used to operate the transducer. Dimensions of the breaker plate were designed to ensure the moving component would obscure or clear the transducer depending on its relative position to the reset position. The control algorithm therefore had absolute information available to drive the gearmotor in the restoring direction for reset. Reset sensors were mounted on all of the device axes.

The vacuum clamp element of the table employed an air ejector of the type described in sub-section 8.8.2. To reduce compressed air expansion noise, the air ejector was statically mounted under the table, and the vacuum was ducted through a 3" diameter flexible pipe. Airflow to the air ejector was controlled by a 12V DC solenoid spool valve. Plate 8.8.3b shows the alignment table with the air ejector attached.

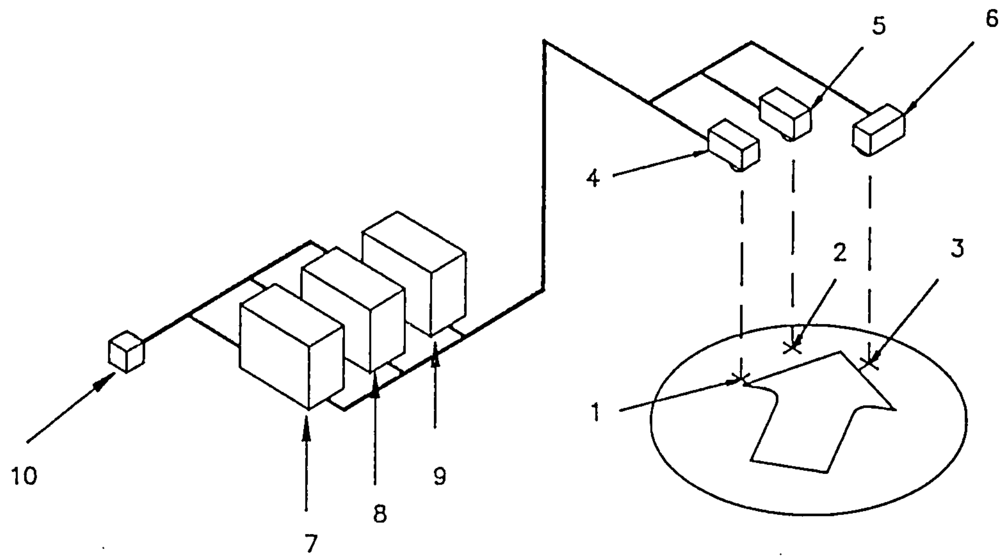
The table could thus align in X, Y and θ axes and clamp the workpiece during component release by the de-stacking device. Should alignment of a workpiece outside of the normal alignment range of the table be required, it was envisaged that alignment could be achieved by the coordinated operation of the alignment stage and the vacuum based transporter, using the transporter to clamp the workpiece whilst the table was moved to an offset position beneath it.



Key:

1. X axis left limit sensor.
2. X axis reset datum sensor.
3. X axis right limit sensor.
4. Y axis left limit sensor.
5. Y axis reset datum sensor.
7. Rotary axis reset datum sensor.
7. Y axis right datum sensor.
8. Multipole connector.
9. Section on table disc assembly.

Figure 8.8.3b Alignment Table Axis Position Detection Instrumentation.



Key:

1. Leading edge alignment point.
2. Trailing edge alignment point.
3. Pitch edge alignment point.
4. Leading edge alignment sensor.
5. Trailing edge alignment sensor.
6. Pitch edge alignment sensor.
7. Leading edge sensor control unit.
8. Trailing edge sensor control unit.
9. Pitch edge sesnor control unit.
10. Multipole output connector.

Figure 8.8.3c Alignment Table Workpiece Edge Sensing Arrangement.

8.8.4 The Vacuum Based Transporter Electromechanics

The purpose of the vacuum based transporter was to transfer a singulated ply of fabric aligned at the alignment stage and transport it to the conveyor section of the sewing sub-system. To achieve this, the transporter required a gripper assembly to clamp the workpiece and an articulation assembly to effect transportation of the workpiece. The gripper section is considered first.

Design requirements for the gripper included a capability to positively clamp single fabric plies at the alignment stage in flat form without losing initial mechanical registration throughout the handling process. This was possible with a clamping plate employing vacuum engagement and such plates were thus investigated. Use of a clamping plate was expected to condition the workpiece as vacuum engagement force, assisted by mechanical pressure applied by the articulation section of the transporter, would impart a flattening effect, removing some minor creases and partial folds in the fabric. An air ejector technique, described in the previous section was used to provide vacuum for the clamp. One transport cycle of the vacuum pad involved the moving of one aligned fabric component from the alignment table to the conveyor belt section of the sewing sub-system. To effect this, the transporter began at its reset position (air ejector off) above the conveyor in its lifted state and first moved in the lifted state to the alignment table. At this point the transporter moved to its lowered state and came into contact with the workpiece. The air ejector was then operated (clamping the workpiece) and remained operated until the transporter reached the release stage. To attain this state, the transporter lifted, moved back to its original position, then moved downwards and the air

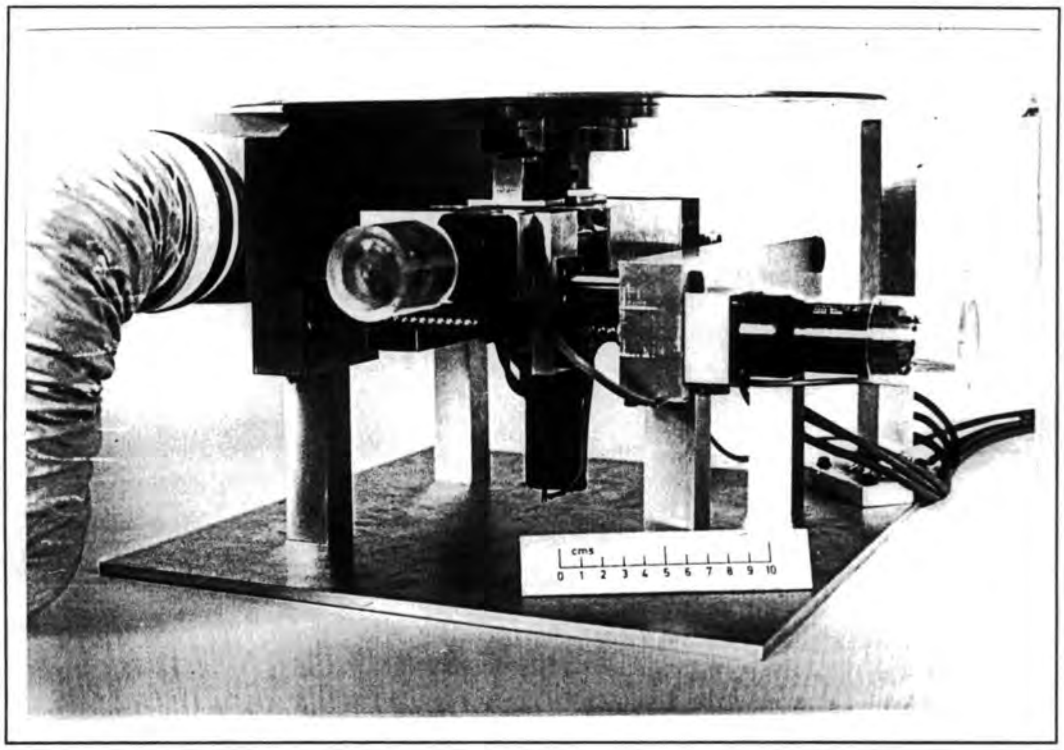


Plate 8.8.3a. The alignment table (actuators).

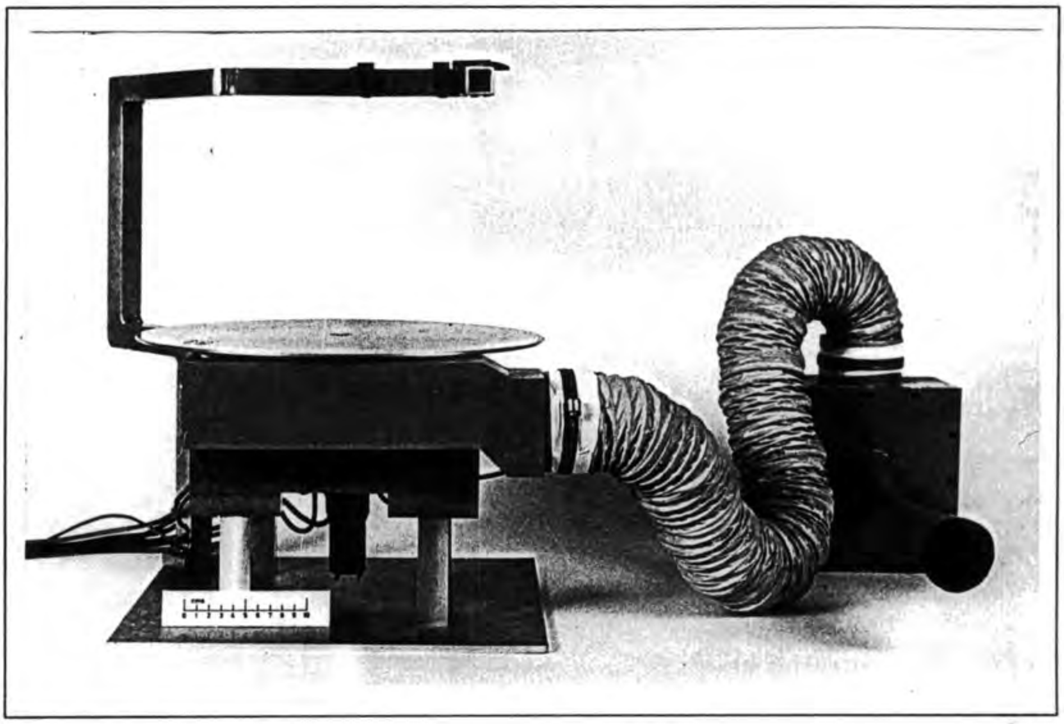


Plate 8.8.3b. The alignment table (Air Ejectors).

ejector was simultaneously turned off, releasing the workpiece from the vacuum pad. The workpiece fell from the vacuum pad to the sewing sub-system and the transporter returned to its reset position. A sewing sub-system cycle was then issued.

To allow the vacuum plate to follow this movement, it was mounted upon a two axis articulated transporter, constraining it to move up, down, left and right. The transporter state at endstops could therefore be: (A) at the conveyor belt, either down or lifted or (B) at the alignment table, either down or lifted.

This articulated transport mechanism was driven by pneumatic actuators. Self sealing rodless cylinders were used, allowing a compact structure for the transporter. The moving assembly for the transporter was constructed in aluminium as this provided strength and lightness. PTFE bushes were used as bearings for the transporter.

The rodless cylinder control system recommended by the manufacturer was adopted whereby actuator cylinder ports were normally charged with compressed air on both sides. To allow movement one side was depressurised to atmosphere in a controlled manner. Figure 8.8.4 shows the pneumatic circuit of the vacuum based transporter unit. Air restrictors were used to control the airflow from the actuators and thus the transporter speed. Pneumatic actuator ports were operated by electrical solenoid spool valves. Manufacturers data claimed an achievable accuracy of 0.1 mm in a mid travel stop position. The design of the pneumatic system required the actuator cylinders unpressurised at initialisation and to remain unpressurised until the axes were manually moved into their safe configuration.

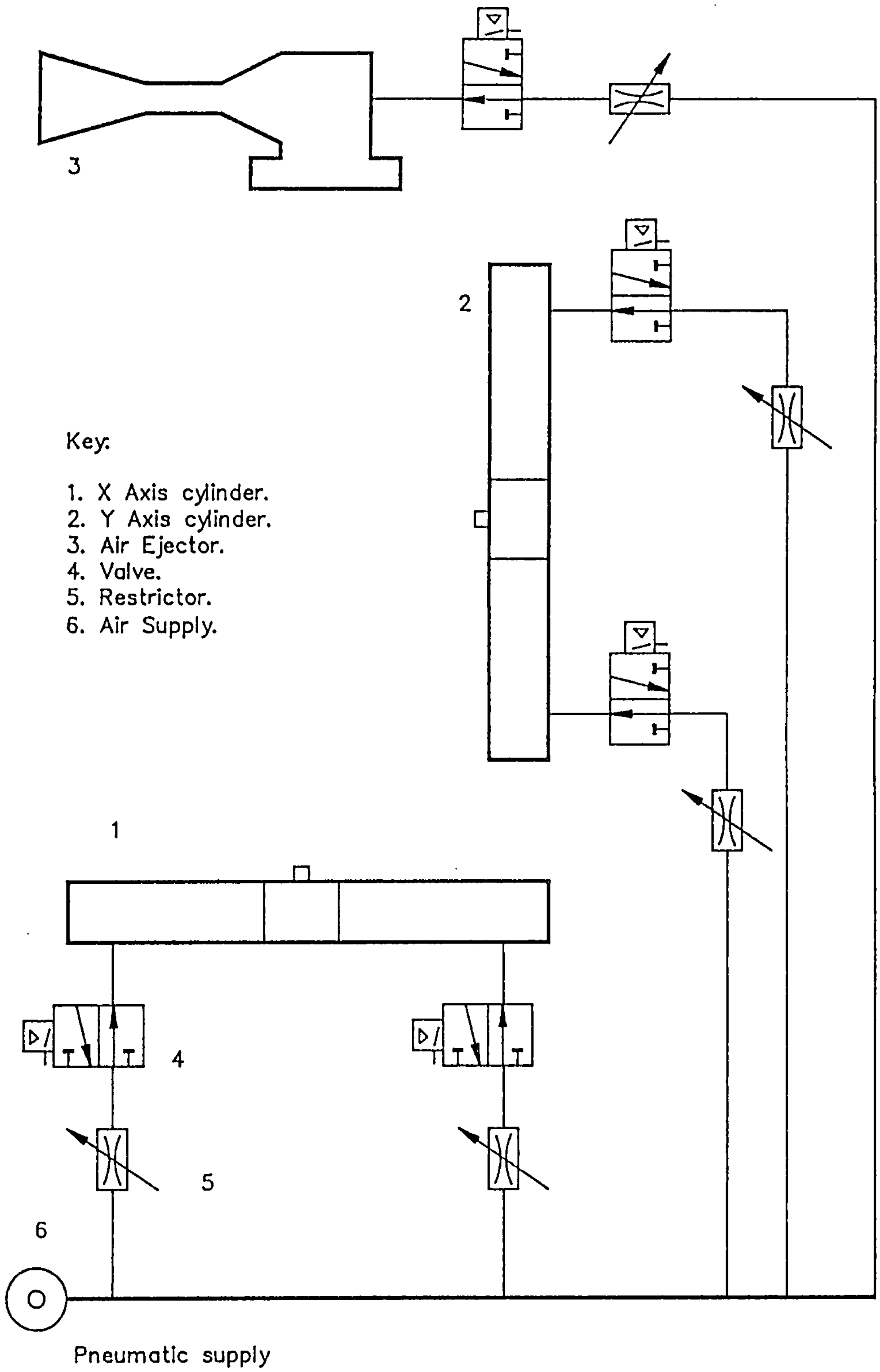


Figure 8.8.4 Assembly Cell Vacuum Based Transporter Pneumatic System Schematic.

Laboratory compressed air provided the air supply for the transport mechanism, air being dried and lubricated by an IMI-ENOTS air filter/drier and lubricator unit. Working pressure was 80 PSI.

8.8.5 Sewing Sub-system Electromechanics

The sewing sub-system was comprised of two elements; (A) an industrial sewing machine adapted for computer control and (B), an automated workpiece feed arrangement based upon a conveyor stage. A description of the former element is given first.

The sewing unit was designed for automatic intermittent computer speed controlled operation. This was done to facilitate the asynchronous delivery available from the upstream processing stages. In place of the conventional continuously running high inertia induction motor drive and associated clutch arrangement, a drive was designed to provide continuously variable power from a DC motor drive under electronic control. The DC motor was directly coupled via a flexible beam coupling to the sewing machine crankshaft and the motor was mounted upon an extension bracket attached to the machine body. To provide feedback of crankshaft angle and allow determination of crankshaft speed, an angular encoder with a TDC marker was coupled to the machine crankshaft.

Edge binding tape was provided in a similar manner to the manual process. A reel of binding tape was mounted free to rotate adjacent to the sewing machine and introduced into a tube shaped former causing tape folding around the workpiece as it entered the jaws of the sewing machine. With this arrangement, sewing of edge binding tape would take place when power was applied to the sewing machine and if a workpiece was presented to the machine it would be included in the seam. A conveyor was used to implement the workpiece feed element. A technique, found in the industry to prevent fabric disturbance during transport was incorporated into the conveyor design. This technique employed a conveyor belt comprising an array of individual conveyor strips, driven by a master roller, and moving against the flat surface of the conveyor. A tension system was included for each strip to take up slack. The conveyor drive was provided by a high power step motor and timing pulley transmission arrangement.

8.9 EQUIPMENT DESIGN: THE CONTROLLER SYSTEM

8.9.1 Controller Interface Requirements

To incorporate the additional I/O capacity required for the added automation sub-systems employed in the assembly cell, the existing controller I/O section was modified. The initial design of the controller I/O section was extensible to allow additional port mapping into the iAPX 8086 microprocessor I/O space. A limitation of 1024 ports was imposed by the iAPX 8086 architecture, but whilst port multiplexing techniques could be employed to extend this capacity, in practice the revised I/O schedule did not approach this limitation. Extended I/O capacity was thus provided by adding further peripheral interface devices into the I/O map. The selected peripheral devices, as in the initial controller design, were SY6522 VIA and MC6840 PTC devices. Use of these two devices were found sufficient to provide the complement of I/O control and sense lines, timer counters and autonomous pulse generators for the required DC motor control.

The new I/O lines adhered to the I/O isolation and buffering scheme employed in the initial I/O design. Thus opto isolation and logic buffering stages were also added with RC signal conditioning, maintaining isolation between the controller and the assembly cell. Figure 8.9.1 gives a block diagram of the new controller.

8.10 EQUIPMENT DESIGN: ELECTRONIC SYSTEMS

8.10.1 Alignment Table Electronics

The alignment table electronic sub-system was used to support sensory and actuating functions of the table. A description of the former group is given first.

The sensory sub-system for the table was employed to recover information enabling determination of workpiece edge position on the table surface. A secondary function was to determine the table surface alignment to allow the table to reset to a datum following unsuccessful workpiece alignment.

Edge position may be determined by tactile or optical means, the latter including:

i. Vision based devices.

ii. Interrupted beam reflex photosensors.

Both of the above methods offered advantages. Vision based systems were extremely flexible and suited to edge detection, but expensive if contemporary vision acquisition and processing were employed. For this application, relatively low resolution and digitisation precision would be acceptable, eg 256 x 256 x 6 bits. Numerous commercial products exist for direct use in commercial open architecture equipment computer

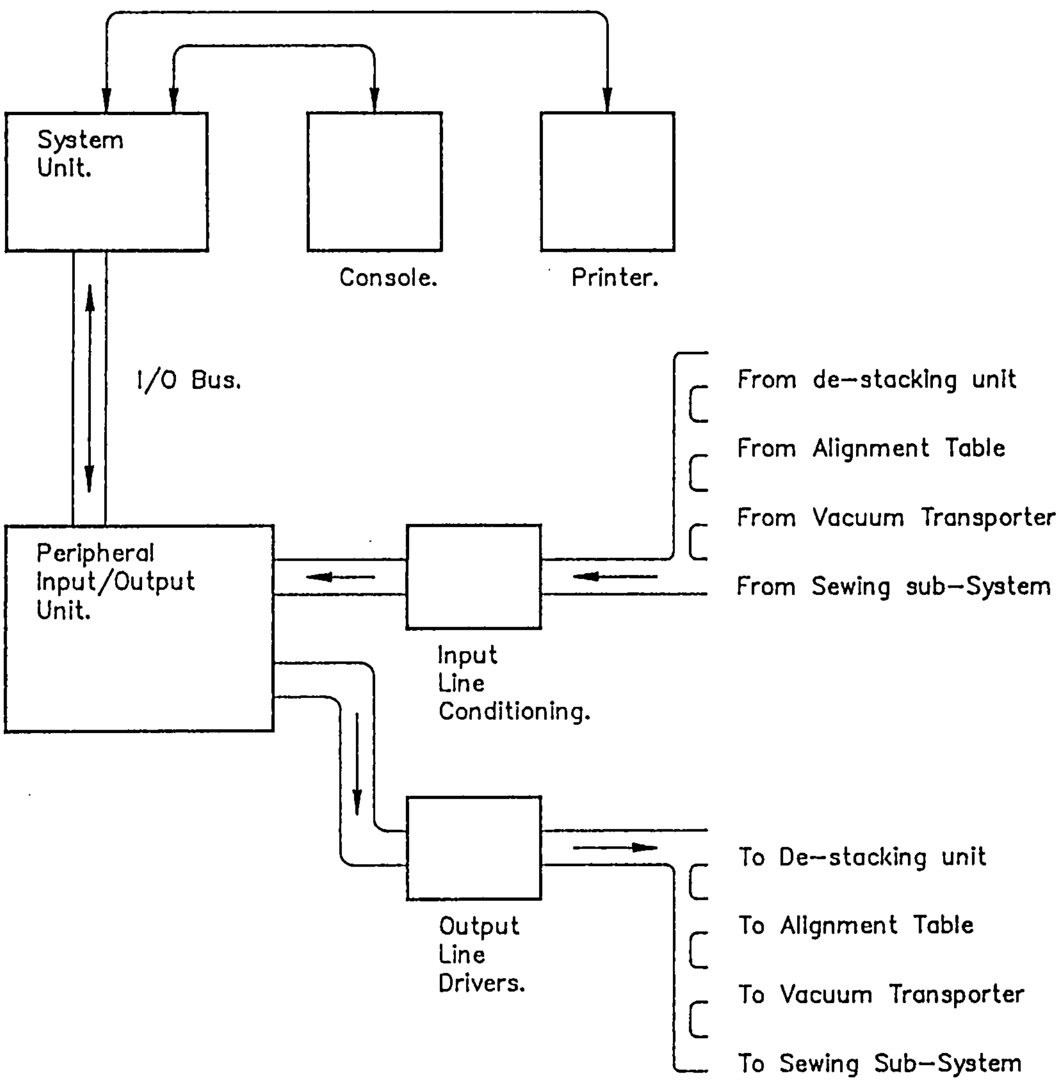


Figure 8.9.1 Assembly Cell Controller System Schematic.

systems, such as Multibus or VME bus at this resolution. Combined cost of this and other ancillary equipment would nevertheless be prohibitive. However, more recently developed low cost binary RAM imaging techniques were available offering a solution. Their imaging principle employed a dynamic RAM as the light sensitive element. Incoming light from the field of view discharged exposed memory cells of the RAM in a pattern determined by the intensity of the image. If the RAM sensor was mapped into a computer memory, a binary threshold image would be directly available for processing therein. Such equipment was available at lower cost than the above system and was commercially attractive. Work into binary imaging by Pugh [82] is relevant for such techniques.

The second means of optical processing used commercially available optical sensing equipment employing interrupted reflex sensors. This was potentially economic as such sensors were matured commercial products and thus inexpensive.

For this reason, initial work was conducted with reflex photosensing equipment. These sensors allow only binary edge detection and at least three units were required to locate a component in 2 dimensions. Three identical commercial reflex photosensors were thus used to achieve edge alignment. A parallel beam was employed by these units allowing operation at large distances from the target. Glass bead tape was attached to the alignment table to aid the reflex operation of the photosensors. The devices used were Leuze electronic V3/71 units with associated mains powered control circuits. Output from the V3/71 sensor was delivered by an open collector stage pulled up with a ballast resistor to the control unit 24V supply.

The three photosensor outputs, termed leading, trailing and pitch were connected via screened cables to the rig wiring harness and brought out to the interfacing rack input signal conditioning unit. Within the rack, the 24V inputs were subjected to RC signal conditioning and logic buffering before entering the opto isolation barrier. Following recovery of the signal at the output side of the optical barrier, the sense lines were connected to 3 bits of an input configured 6522 VIA port. Signal grounding and screening was observed throughout the wiring harness restricting electrical noise on the sense lines.

Table axis position encoding is now described. Sub-section 8.2.3 has described the mechanical arrangement for the 3 reset datum sensors and the four axis limit sensors comprising the position encoding equipment for the alignment table. Each reset and limit sensor comprised an interrupter plate and a commercial infra red interrupted beam optical module with internal logic buffering (Type no SPX2001). Electronics to support these sensors comprised a 5V logic and IR emitter supply, brought from the interfacing racks via the experimental rig wiring harness and decoupled at the sensor by 0.1 μF ceramic capacitors. The supply was provided from a screened cable, grounded at the interfacing racks. As the sensor was provided with an open collector type output, a pull up resistor was included at the sensor side. Sensor output was then directed into a screened bus terminating at the interfacing rack and included an in-line multipole connector at the alignment table side where the screened bus joined the main wiring harness. At the interfacing rack, the sensor outputs were terminated at an industrial screwed connector terminal rail and the led to the controller I/O boards via a RC network and logic buffering stage, passed through an optical barrier and further logic buffering then presented to a 6522 VIA port configured as an input.

The alignment axes limit switch signal processing was an exception to the above, and special treatment was given to this signal. Before entering the I/O board, the raw sensor output was used to control a computer override circuit. Control for the alignment table axis DC motors was provided by PWM control. Should a software or hardware computer error occur, immediate alteration of the peripheral registers in the autonomous PWM unit would be unlikely. This would result in the permanent application of power to the DC motor and the affected axes would drive. As the axis would meet its mechanical limit within 500 mS at full DC motor power, an operator would be unlikely to prevent collision with the end stop by applying a computer reset in time. To avoid mechanical damage to the drive mechanism under these conditions, the limit switches were used to provide early warning and override the computer control. The form of override was chosen to cause reversal of motor direction, should the sensor be activated. This was effected by use of combinational logic employing the computer direction control signal and the raw limit switch output. The resulting system would rather than impacting against a mechanical endstop thus oscillate around the limit switch actuation position until the computer control signal was removed, as described in section 8.2.3.

Direct sensing of the limit switch could then additionally take place if the software was operating correctly. Figure 8.10.1 shows the combinational logic circuit used the truth table and the logic conventions employed for 1 axis.

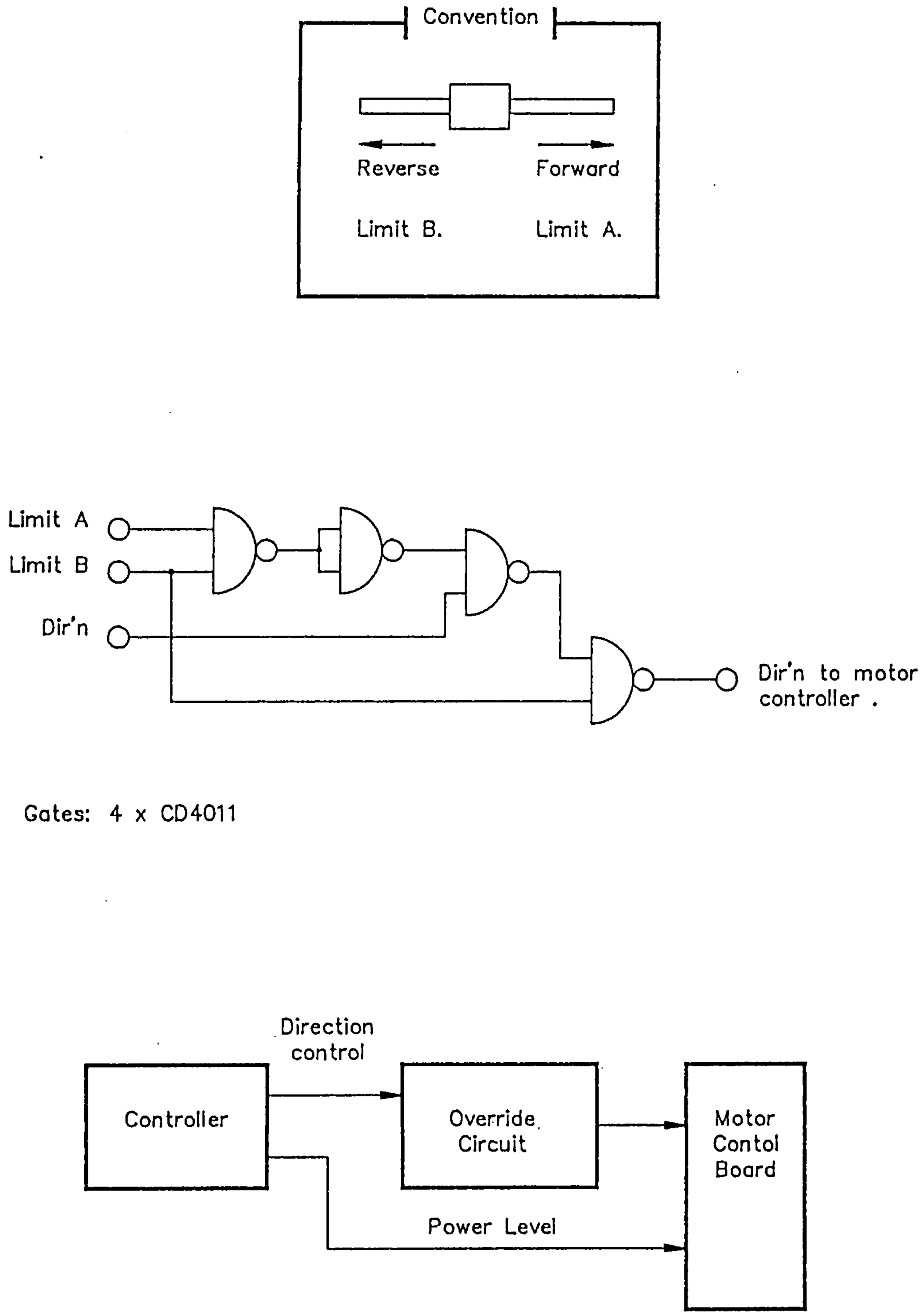


Figure 8.10.1 Alignment Table Axis Override Logic.

Actuator circuitry is described below. DC gearmotors were used in the 3 alignment table X, Y and θ axis drives. Power to these motors was provided by a PWM technique. The motors were placed within an H type transistor bridge identical to the unit described for the manipulator drive, sub-section 6.10.6.

PWM drive signals were provided from the controller I/O area. Air ejector control for the vacuum clamping plate was controlled by a solenoid valve operating from a single control line. The valve driver circuit was identical to that described in sub-section 3.9.3. Valve control was derived from a 6522 VIA port bit configured as an output and processed through the opto isolation and logic buffering stages described above before being fed into the driver stage.

8.10.2 Vacuum Based Transporter Electronics.

The transporter electronics comprised actuator control circuitry and sensor circuitry, actuator circuitry being described first.

The transporter employed five pneumatic valves to control its state. Two valves were required for horizontal axis control and two for vertical axis control. A fifth valve was used to operate the air ejector for the gripper element. All valves were electrically identical, employing 12v solenoid pilot valves. The solenoids were driven from circuitry identical to that described in sub-section 3.9.3. Here, attention was paid to the control logic polarity employed within the control lines for the pneumatic actuators as failure of any of the controller electronic stages must cause default to a safe (inactive and depressurised) state for the pneumatic system, the mechanical forces it develops being large. In-line multipole connectors were used to connect the solenoids to the rig wiring harness, facilitating removal of the electromechanical assembly for development. The wiring terminated at the power driver stage of the interfacing racks at a connector block.

The transporter sensory equipment is as follows: Four sensor channels were used by the transporter, two being used to indicate end stop limit at either end of the transporter horizontal axis and two to indicate end stop limit at either end of the transporter vertical axis. Their sensing elements employed reed switches, operated by magnets inserted into the piston of each rodless cylinder, providing binary limit indication. The sensors were commercial devices, obtained from the supplier of the rodless cylinders (Origa Ltd) and could be clipped on to the body of the cylinder.

The sensors were attached to the rig wiring harness by in-line multipole connectors. Wiring for the switches was continued through screened cable to the signal conditioning interface rack. Here the signals were RC filtered, logic buffered and opto isolated before connection to one of the computer controller peripheral 6522 VIA ports, configured as an input.

8.10.3 Sewing Sub System Electronics

Three electronic packages were required to support the sewing sub-system electronics. Each are listed below:

i. A Conveyor step motor drive package.

ii. A Sewing machine DC motor drive package.

iii. A Sewing machine drive encoder instrumentation package.

The conveyor step motor drive package is described first. The motor was a four phase type, each phase being driven by an LR output stage. With this drive mode, the current requirement was 5A and two phases were energised at any one time. A 10 A unregulated power supply was constructed to power the above drive package. Incorporation of a phase encoder described in section 6.10.6 within the package allowed reduction of the number of control lines required and to protect the package against overload, as the encoder ensured no more than 2 phases could be energised at one time.

As in the design of the linear transporter drive, a 200V DC motor was selected to power the sewing machine. For this application, the linear transporter drive package was duplicated, control being provided from the controller on the same basis and additional equivalent peripheral lines incorporated into the controller I/O section. An equivalent fail-to-safe convention was employed as in the linear transporter drive. The sewing machine drive motor was connected to the controller high power interfacing rack via the experimental rig wiring harness and an in-line multipole connector, allowing removal of the motor from the rig for development purposes.

To facilitate controller feedback for the sewing machine crankshaft control algorithm, the third package was provided, comprising sewing machine drive encoder instrumentation, and is described below:

Two sensory channels were employed to recover the sewing machine crankshaft angle. These comprised an integrated incremental shaft encoder and a shaft TDC sensor. Both sensors were based upon optical interruption and used a circular toothed interrupter plate mounted concentric with the sewing machine crankshaft. The sensors were SPX2001 types.

8.11 EQUIPMENT DESIGN: APPLICATION PROGRAMMING

8.11.1 General

The following sub-sections describe components of the assembly cell control programming. As the same controller used in work described in chapter 6 was employed, the original programming language and environment were retained. Likewise, the control programming is described in a similar fashion to the description made in chapter 6.

8.11.2 Program Operation And Structure

The control program was constructed using separate program modules. Its general structure was based upon the structure described for the de-stacking unit in chapter 6.11, but was extended with additional components to support the other automation elements of the assembly cell. Program compilation and execution was carried out in a similar manner to the method described in sub-section 6.11.3. Additionally, the earlier software development path was retained.

8.11.3 Program Components -- The Main Module

The program root flow segment was provided by the main module. Its function was similar to the main module described in sub-section 6.11.4, its flow diagram being identical to the flow diagram shown in 6.11.4. Extensions to control the assembly cell were made in the operator interface, further components being added to service the alignment, vacuum based transporter and sewing sub-system electromechanics.

8.11.4 Program Components -- The Operator Interface

Extensions were made to the operator interface described in sub-section 6.11.5 to support calls to the added program components required to control the assembly cell. The mechanism to select required procedures was unchanged and the additional procedures placed in new CASE entry blocks. Flow diagrams 8.11.4a, 8.11.4b and 8.11.4c give the flow implementing screens one to four respectively. In screen one the added procedures were:

i. Reset_OT_Axes. This procedure caused the alignment table to reset in all axes.

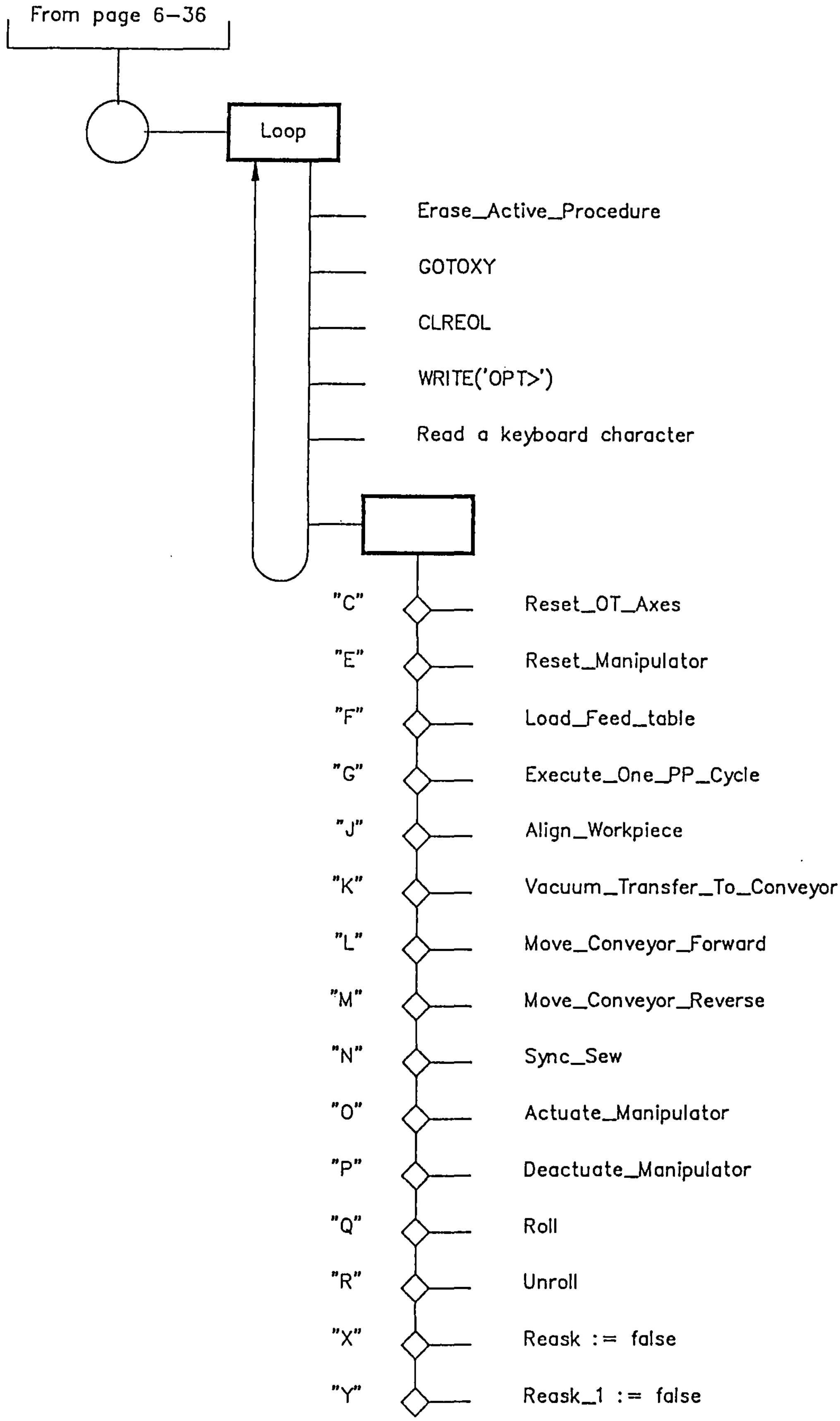
ii. Align_Workpiece. Alignment of the workpiece at the alignment table was effected by this procedure.

iii. Vacuum_Transfer_To_Conveyor. Cycling of the vacuum transport stage was controlled by this procedure.

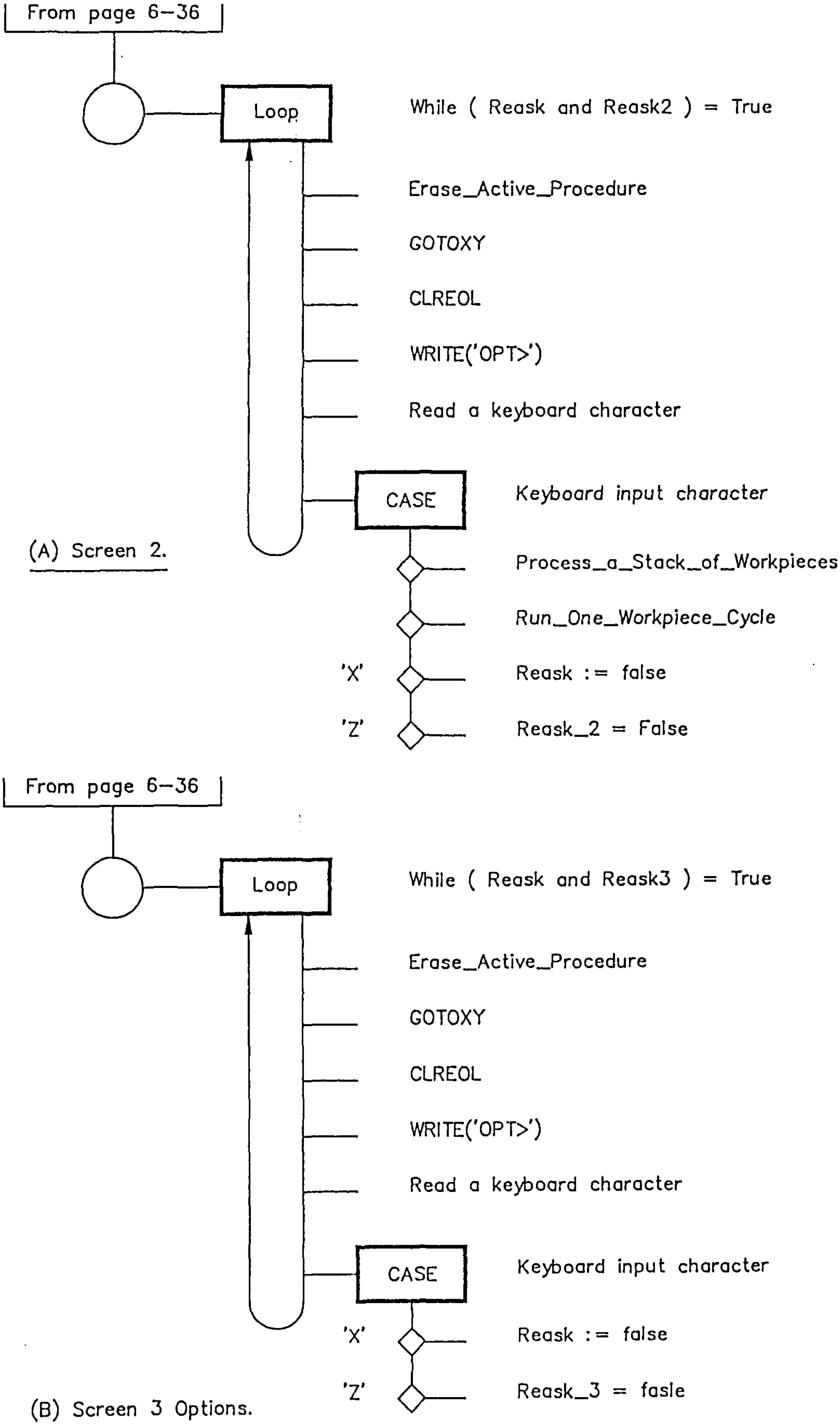
iv. Move_Conveyor_Forward. The conveyor element of the sewing station was cycled by one workpiece edge length by this procedure. A similar procedure Move_Conveyor_Reverse moves the conveyor backwards by the same length.

v. Sync_Sew. One cycle of the synchronised sewing system is performed by this procedure.

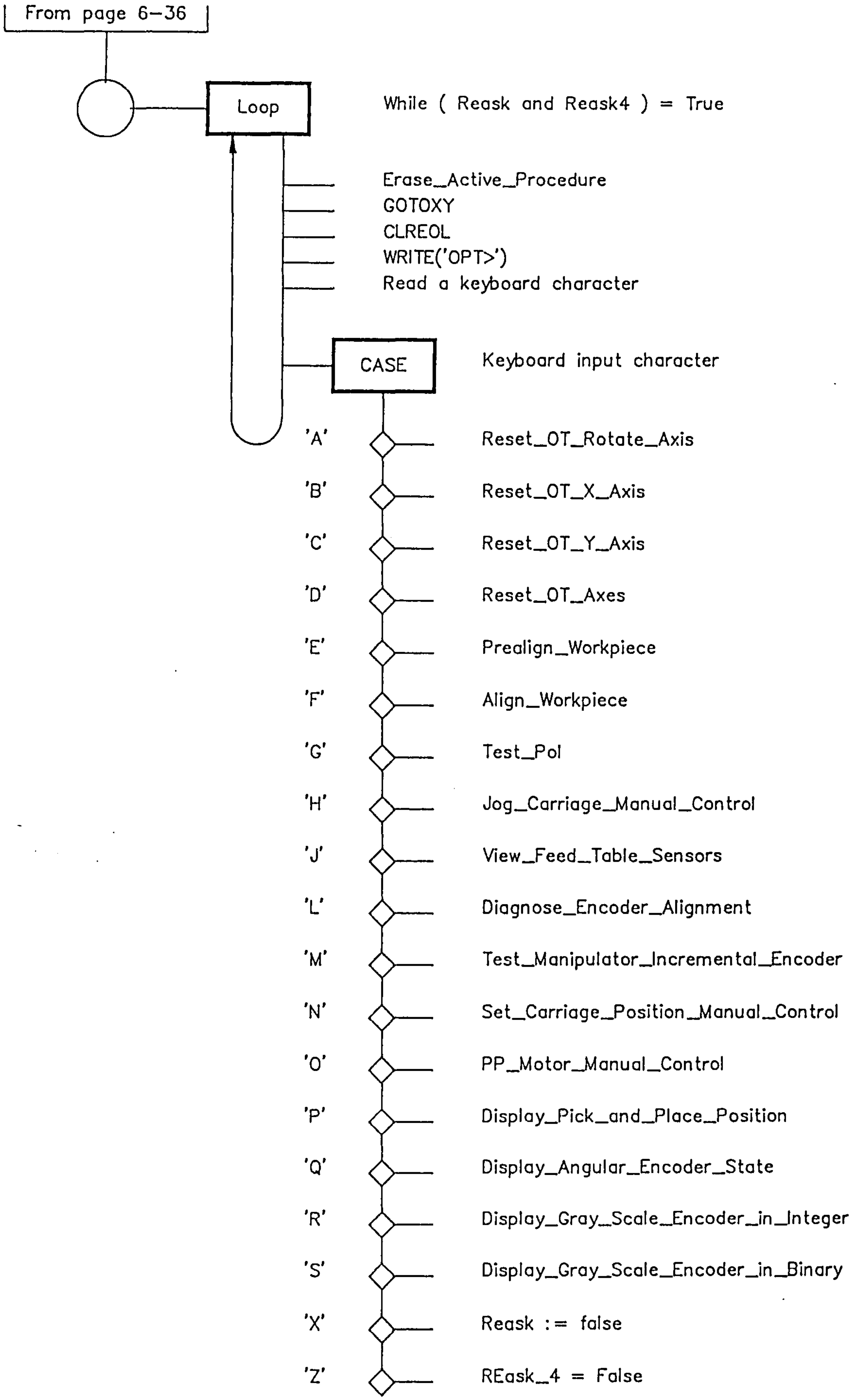
In screen two procedures Process_A_Stack_Of_Workpieces and Run_One_Workpiece_Cycle were added. The former caused a batch of workpieces to be processed and the latter a single workpiece to be processed. Screen three was not used, but its flow diagram is included



Flow Diagram 8.11.4a Assembly Cell Screen 1 Options.



Flow Diagram 8.11.4b Assembly Cell Screen 2 and 3 Options.



Flow Diagram 8.11.4c Assembly Cell Screen 4 Options.

in 8.11.4b.

Several additional diagnostic procedures were included in screen four to support the alignment, vacuum transportation and synchronised sewing stages.

8.11.5 Program Components -- De-stacking Unit Control

The developed de-stacking unit control procedures described in section 6.11 were retained for use. Those components relating to elevating feed table control, gripper control, linear transporter control and integrated unit control remained available to the operator interface. The integrated unit program component procedures were applied to facilitate control of the de-stacking unit from assembly cell level procedures.

8.11.6 Program Components -- Edge Alignment Unit Control

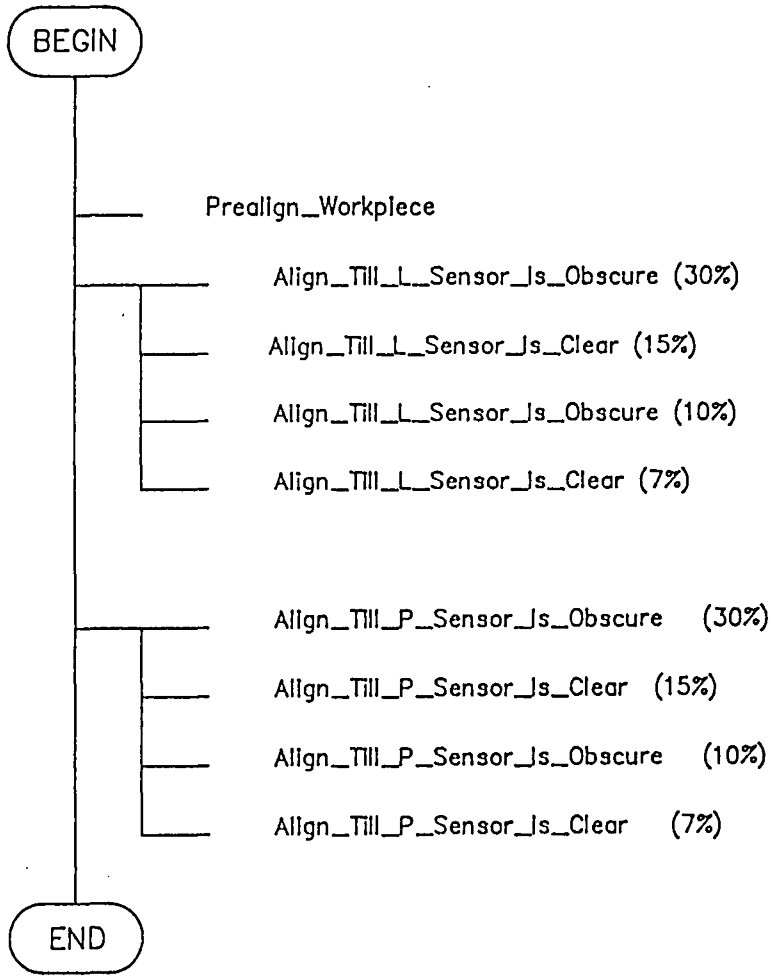
This program component contained procedures to perform the edge alignment process. Flow diagram 8.11.6 shows the the edge alignment procedure Align_Workpiece. Align_Workpiece began with the table aligned in all axes to their respective reset positions. A fabric workpiece was delivered to the table surface by the de-stacking unit, the surface now acting as a workpiece release area. Alignment was achieved by initially attaining a coarse open loop alignment in the θ axis. Coarse alignment was performed in the procedure Prealign_Workpiece by rotating the table under power until an optical interrupter datum sensor was operated. Closed loop alignment in the X and Y axes was then carried out.

To achieve two dimensional alignment in the X and Y axes, each axis was separately handled in sequence. Alignment was carried out firstly in the axis corresponding to the leading edge. Two procedures, Align_Till_L_Sensor_Is_Clear and Align_Till_L_Sensor_Is_Obscure were used. These drove the relevant axis with a power assignment passed to the procedure until the alignment condition (obscure or clear, indicated by the sensor) was met. Four calls to the above procedures were made with decreasing motor power, causing the leading edge to be finally positioned under the sensor trip point. The pitch axis was similarly aligned.

Provision of means to reset the table to a datum position in all three axes following alignment were required. All axes were reset in sequence by the control program to effect this function. In the case of the X axis, a determination of axis position relative to the reset datum was initially made. Power was then applied to the axis in such a direction as to restore the axis to the datum position. The datum position sensor was next observed until a change of state was detected. This procedure was repeated twice with reducing motor power, causing the axis to oscillate about the datum position in reducing increments of distance, arriving at a final position close to the datum. Similarly, the remaining axes were reset.

8.11.7 Program Components -- Vacuum Based Transporter Unit Control

The vacuum based transporter control was performed by procedures contained in this program component.

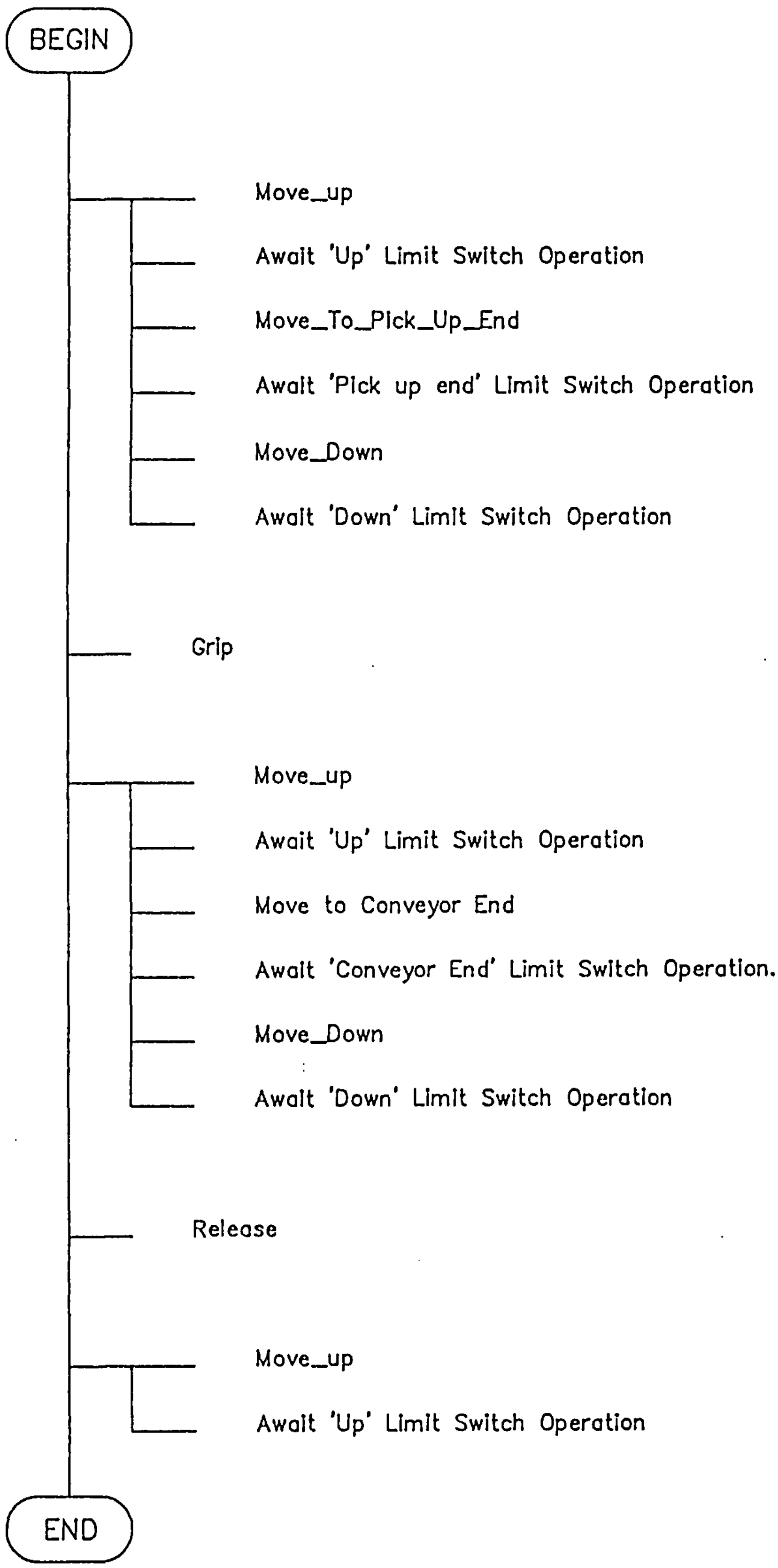


Flow Diagram 8.11.6 Workpiece Alignment Procedure.

Flow diagram 8.11.7 shows the operation of the procedure Perform_One_Pick_Up_Cycle causing the vacuum based transporter to pick and place one workpiece. Four procedures were used to cause transporter axis movement, these being Move_Up, Move_Down, Move_To_Pick_Up_End and Move_To_Conveyor_End. Each procedure set the required pneumatic ports to cause the relevant movement. Achievement of the required positioning was detected by operation of limit switches provided at the end of axis travel.

At the commencement of a pick and place cycle, the transporter was raised by a call to the Move_Up procedure. On detection of end of axis travel via operation of the associated limit switch, Move_To_Pick_Up_End was issued. The transporter was driven to the pick up end and then lowered. A procedure named grip was called, turning on the transporter vacuum, clamping the workpiece. Transportation to the conveyor end was then effected by calling in sequence Move_Up, Move_To_Conveyor_End and Move_Down. Next, a procedure named release was called to turn off the transporter grip vacuum, disengaging the workpiece. Finally, the transporter was raised to its standby position.

The above procedures were used to implement the transporter control logic. Before use, initialisation of the transporter was required as an incorrect startup port pressurisation sequence would initiate unprogrammed axis movement. To effect a proper start up pressurisation sequence, the unit was first required in a known configuration. The transporter configuration was thus tested before start up and the control program ended with an error message should the configuration be incorrect. In this case, the unit required manual positioning into the start up configuration. The procedure Start_Up_Transporter_Safely was



Flow Diagram 8.11.7 Vacuum Based Transporter Operation.

used to ensure the above condition. It was the responsibility of the main pick and place control procedure to leave the unit in start up configuration after exit. Each port was pressurised in a predefined order during initialisation with delays included to allow full pressurisation to occur.

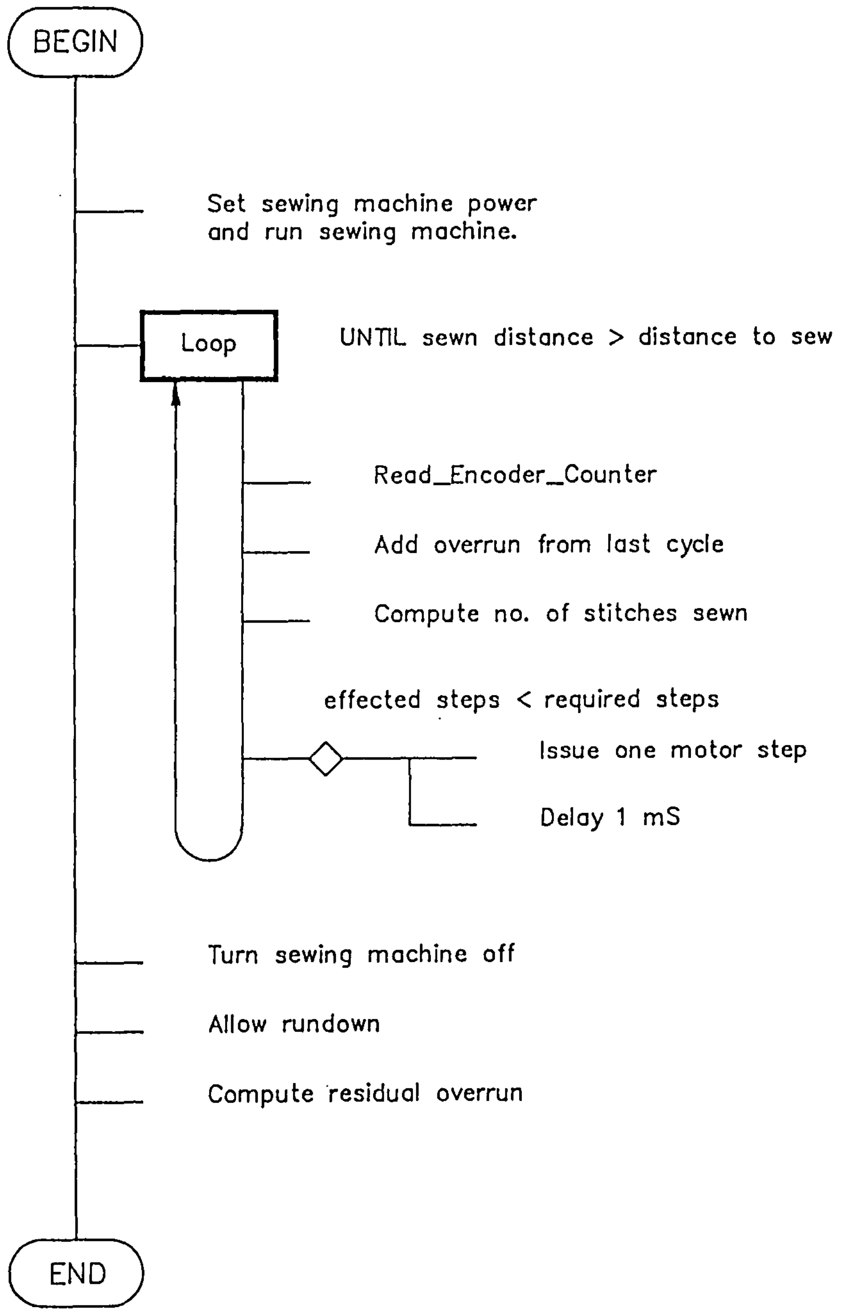
8.11.8 Program Components -- Sewing Unit Control

The control of the sewing unit was implemented with procedures contained in this program component.

Output procedures comprised a routine to assign conveyor step motor phase and a routine to set the sewing machine motor power assignment. Input procedures comprised routines to read the sewing machine shaft angle from the incremental and datum encoders.

A further conveyor related routine incremented the conveyor step motor phase and another procedure employed this to issue a preset group of steps to convey one workpiece length unit.

The synchronised sewing machine control logic was implemented by synchronising the conveyor feed to the sewing machine shaft angle in a procedure named Sync_Sew. Flow diagram 8.11.8 shows the operation of Sync_Sew. Power was initially applied to the sewing machine, causing the machine to run at its nominal speed. A loop was entered reading the accumulated crankshaft angle from the commencement of the procedure. A term, crankshaft overrun, described below, was added to this value and the number of stitches sewn computed. The required number of conveyor steps could then be determined and this was compared to the accumulated effected steps. Should insufficient steps have been issued, one



Flow Diagram 8.11.8 Synchronised Sewing Process.

conveyor drive step would be added with a 1 mS delay inserted in the procedure. The loop then cycled. A control process was thus established maintaining conveyor synchronisation. Exit from the loop occured when the required distance had been sewn. After loop exit, the sewing machine was turned off and the crankshaft rotation relating to the machine deceleration, crankshaft overrun, measured. As machine deceleration was short, no attempt was made to synchronise the conveyor during this period. Crankshaft overrun was maintained as a global variable and accounted for in the next cycle.

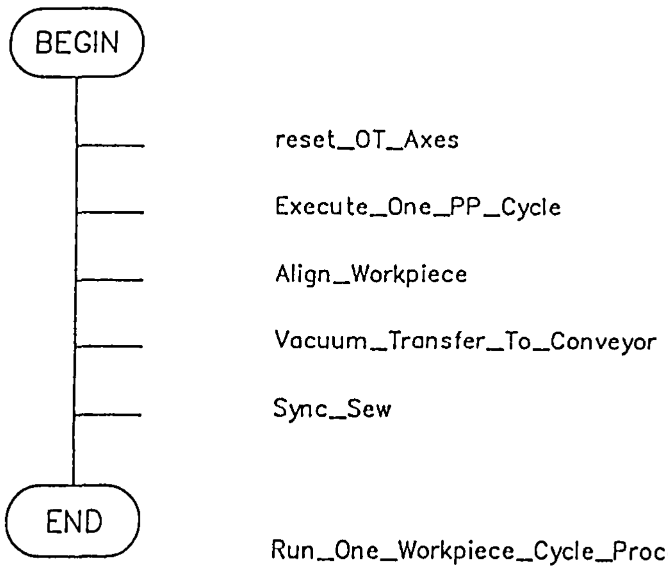
8.11.9 Program Components -- Integrated Process Control

Two procedures were required to effect integrated control of the assembly cell. These are described in flow diagrams 8.11.9a and b. The first procedure Run_One_Workpiece_Cycle sequenced the automation sub-systems for one cycle. This comprised a call to procedure Reset_OT_Axes, Execute_One_PP_Cycle, Align_Workpiece, Vacuum_Transfer_To_Conveyor and Sync_Sew in order.

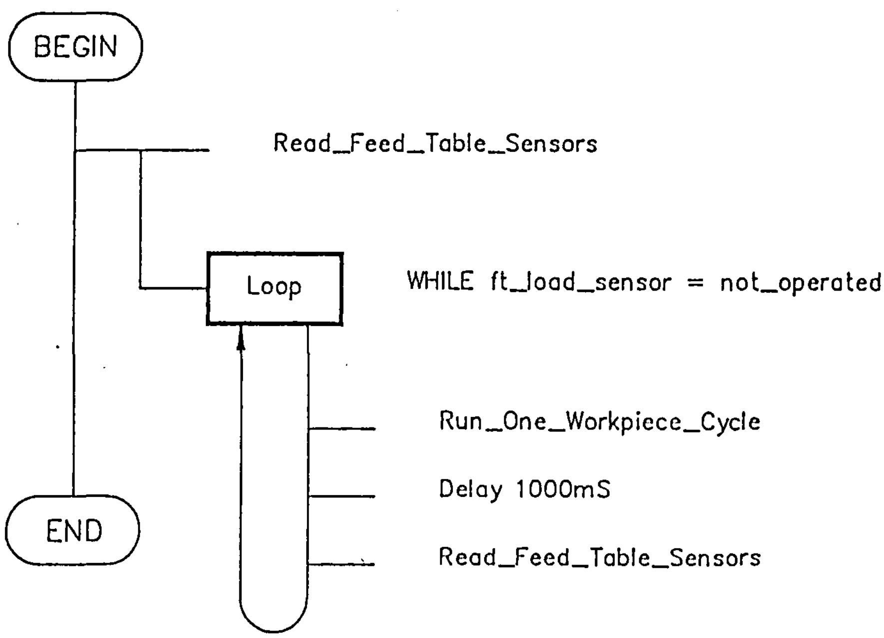
The second procedure, Process_A_Stack_Of_Workpieces, was used to process a complete batch of workpieces. In Process_A_Stack_Of_Workpieces, stack completion was indicated by the feed table load sensor becoming unoperated. The feed table sensors were firstly read and a loop was then entered running one workpiece cycle and reading the feed table sensors. When the feed table load sensor became unoperated the loop exited.

8.11.10 Program Components -- Initialisation Processor

The initialisation processor remained similar to the processor described



Run_One_Workpiece_Cycle_Procedure



Process_A_Stack_Of_Workpieces Procedure

Flow Diagram 8.11.9 Integrated Control Procedures in section 6.11.10, flow diagram 6.11.10. Changes in the procedure Init_Input_Output were made to accommodate initialisation of the added peripheral devices.

8.11.11 Control Of Dc Motor Power

DC motors were used at six locations within the assembly cell. The design required continuously variable input power to the motors. Means to assign a given percentage of maximum power for each motor was incorporated into the software

The hardware means to control power was provided by a PWM technique, the PWM waveform originating for a given motor from an MC6840 PTC configured as a one shot pulse generator, triggered by a clock supplied from a SY6522 VIA port bit set up as a square wave generator. The time period of the MC6840 PTC pulse generator was adjustable in software, providing a mechanism to adjust the PWM signal mark-to-space ratio. For a required percentage power, computation of the required values was carried out and these were assigned to the PTC. Within the control program the required power was represented by a global variable Dc_Motor_Power. Computation of register values was carried out by procedure Preset_200v_Motor_Latchvalue. For a given motor, register values were loaded by the separate procedures. These procedures also assigned DC motor direction bits.

8.11.12 Recovery Of Sensory Data

Incoming sensory data from the assembly cell was presented in digital form to 6522 VIA input ports. To retain full flexibility of the controller for future developments, interrupts were used to indicate sensor state change. Two types of data input were used, single channel sensory inputs, eg limit switch state, and multiple channel inputs, eg absolute angular encoder values. The former type is considered first.

An input channel may be interrogated by a iAPX8086 I/O read. This was performed in TURBO PASCAL via the PORT procedure, reference to a port array on the RHS of an assignment statement automatically performing this function. Thus a particular bit could be examined by first executing a PORT read and operating upon the resultant BYTE type variable with TURBO PASCAL binary operator extensions. A boolean variable representing the sensor was next assigned a state depending upon the electrical value of the associated bit. Multiple channel data may be input in a similar fashion, but require processing procedures to assign related integer variables.

Initialisation of the sensor channels required configuration of the associated peripheral devices once only during initialisation. This was performed within the initialisation procedure Init_Input_Output.

8.12 SUMMARY

Sections 8.1, 8.2 and 8.3 have described the experimental design and construction of the electromechanical, electronic and software elements of the assembly cell. The equipment was optimised for research purposes and flexibility was provided within the sub-systems to allow investigation of the assembly cell. Features were provided to allow rapid verification of assembly cell hardware. Several novel gripper techniques were embodied within the assembly cell and investigation results of the electromechanics and control combination are reported in chapter 9.

CHAPTER 9

EXPERIMENTAL PERFORMANCE OF THE GARMENT ASSEMBLY CELL

9.1 INTRODUCTION

In this chapter, experimental results obtained in the evaluation of the assembly cell are described. The evaluation initially determined the performance of the individual assembly cell automation elements. Results obtained from the de-stacking unit, fabric alignment unit, vacuum based transporter unit, and the sewing unit are given in sections 9.2, 9.3, 9.4 and 9.5 respectively. An evaluation of the integrated operation of the system followed, results being reported in section 9.6. Sub-sections 9.6.2 and 9.6.3 report non-concurrent and predicted concurrent results for the integrated process. Finally, a summary of this chapter is presented in section 9.7.

The performance of the de-stacking process was evaluated in chapter 7 and as the unit is operated in a non concurrent mode, conditions for evaluation were similar to the conditions of chapter 7. Reference is therefore made to the previous de-stacking unit results.

9.2 PERFORMANCE OF THE ALIGNMENT PROCESS

Performance of the alignment process was quantified by achieved alignment accuracy and speed. This was dependent upon the performance obtained from the workpiece edge position detecting sensors, control algorithm and assigned motor power. Commissioning results are first reported.

Table axes were found to drive correctly at the anticipated speed. To display the axis position indicator states, the edge detector sensor states, and verify their correct operation the diagnostic routine TEST_POL was used. The axis limit override hardware was verified to operate correctly. Performance evaluation was then carried out.

An accuracy test was made upon the V3/71 reflex photosensor units used to detect the workpiece edge. Accuracy was determined at ±1 mm, falling within the specified range of ±3 mm. Thus alignment accuracy requirements for both workpiece edges were met. Results are presented in table 9.2a.

Table 9.2a. Alignment Table Workpiece Edge Sensor Accuracy.

Sensor.	Accuracy (mm).
Leading edge:	±1.0
Trailing edge:	±1.0
Pitch:	±1.0

The cycle time of the process was considered next. Performance of the alignment algorithm, documented in chapter 8.10.7, was evaluated.

Alignment axis motor power was set at 20% of maximum in the algorithm, and alignment time was recorded. Results are given in table 9.2b, and algorithm parameters in table 9.2c:

Table 9.2b. Alignment Process Performance.

X axis alignment accuracy:	±1.5 mm
Y axis alignment accuracy:	±1.5 mm
Angular alignment time:	2.1 s
X axis alignment time:	1.4 s
Y axis alignment time:	1.3 s
Total alignment time:	3.5 s
X axis reset time (min):	0.0 s
X axis reset time (max):	0.7 s
Y axis reset time (min):	0.0 s
Y axis reset time (max):	0.7 s
θ axis reset time (min):	0.6 s
θ axis reset time (max):	2.4 s
Total reset time (max):	3.8 s

Table 9.2c. Alignment Process Parameters.

Axis drive.	Assigned power (%).
X:	30
Y:	30
θ:	30

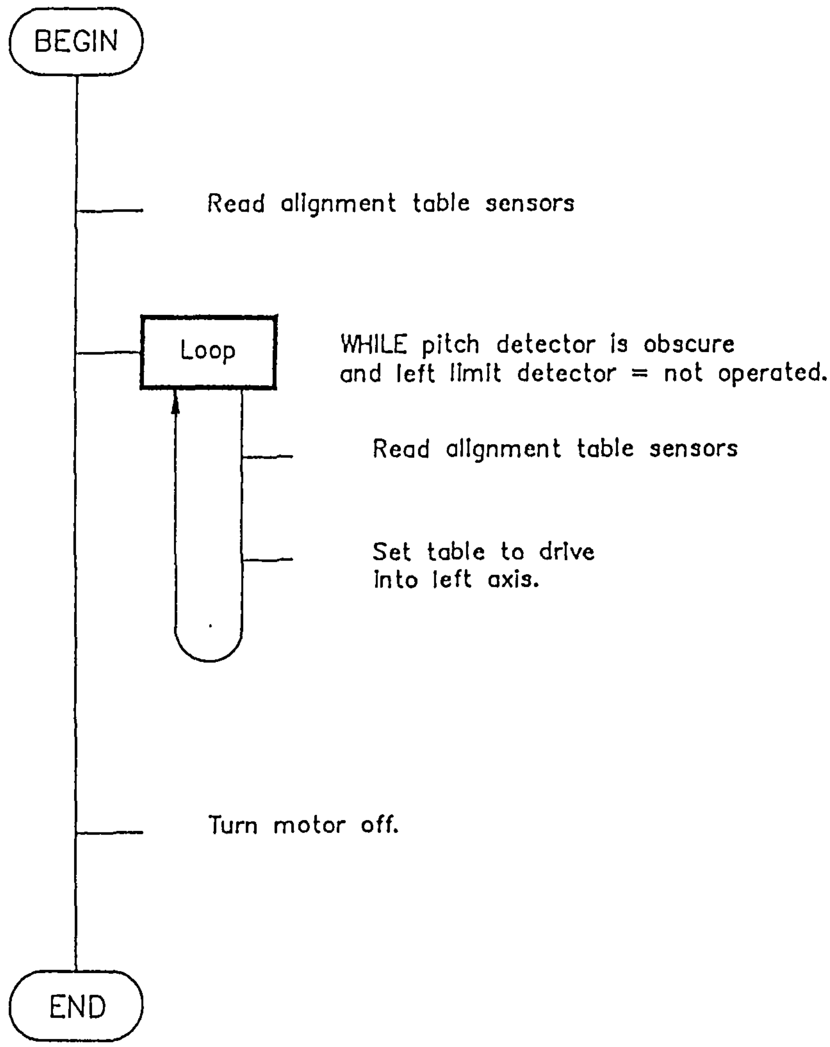
The alignment speed affected the throughput of the system if the process lay on the critical path of the complete assembly cell process. Further development to increase alignment speed was reserved until a timing analysis was performed on each component of the system. This analysis is reported in sub-section 9.6.3.

An undesirable artifact of limited alignment axis travel was observed during evaluation. Should the end stop limit switch of either the X or Y axis be reached in the alignment process, the hardware direction override would operate and the alignment table would oscillate about the associated limit switch position. The control program would however continue to attempt to achieve alignment. In the above condition, alignment could not be reached, the process would not progress beyond this stage and production would cease. It was therefore necessary to detect and respond to this state. A new alignment program was designed to respond to this condition, its flow diagram being shown in flowchart 9.2. In the amended process detection was based upon X and Y limit states.

9.3 PERFORMANCE OF THE VACUUM BASED TRANSPORTER

Before evaluation proceeded, the vacuum based transporter unit was commissioned. Each axis was verified to operate, firstly by manual override of the computer control system, then from the controller via a diagnostic routine. Operation of the air ejector based vacuum clamp was similarly verified. Axis limit switch sensors were tested by a diagnostic routine and found to operate correctly.

As high actuating forces and a fast operating cycle were developed by the unit, safety controls for the vacuum based transporter pneumatic actuation system were verified. Initial pressurisation interlocking by the control system until the correct start up configuration was met was confirmed. The fail to safe scheme used in the control of the pneumatic actuators was observed to function correctly when the control computer



Flow Diagram 9.2 Modified Alignment Procedure.

reset button was operated. In this event all ports became depressurised as the design required. Additionally, all permutations of power supply failure within the controller circuitry were simulated and found not to initiate unprogrammed movement of the transporter axes as required by the system design. Performance evaluation could then proceed.

The designed performance of the air ejector was experimentally proven. With the vacuum pad unmasked, flow rate and vacuum were found sufficient to cause clamping of the workpiece. No disturbance of the fabric was observed during transport nor induced disturbance of already lain plies was observed. Accuracy of placement was measured at less than ±1 mm.

Transporter cycle time was measured. Results are summarised in table 9.4.

Table 9.4 Vacuum Based Transporter Performance.

Placement accuracy:	±1 mm
Time to develop full clamp vacuum:	0.2 s
Time to remove clamp vacuum:	0.2 s
Raise Vacuum pad:	1.0 s
Move to the alignment table:	3.0 s
Lower Vacuum Pad:	1.1 s
Move to workpiece release position:	1.0 s
Reset horizontal axis (max):	3.0 s
Reset Vertical axis (max):	1.0 s

The articulation times shown in table 9.4 were relatively large due to the inertia associated with the articulation mechanics. This high inertia arose from the additional components in the transporter inbuilt for flexibility during research, but a commercial prototype could be constructed with less weight and could achieve a faster operating cycle.

As with the alignment table, consideration to increase alignment speed was reserved until a timing analysis was performed on each component of the system (sub-section 9.6.3).

9.4 PERFORMANCE OF THE SEWING SUB-SYSTEM

The two elements comprising the sewing sub-system, (1) conveyor and (2) sewing unit were individually tested before their combined operation was evaluated. Results from the former are given first.

A diagnostic procedure was prepared to test the conveyor and integrated into the assembly cell control program. This provided means to exercise the conveyor mechanics by issuing steps at a predetermined rate and number.

During initial trials, the belt section of the conveyor was found to develop considerable resistance to motion. Gear ratios used in the conveyor drive were adjusted to increase drive torque, ensuring the drive would not stall and the conveyor would drive at the required rate. The procedure could be called from the diagnostic option page of the control program menu. Transportation of the workpieces was found to occur without introducing anticipated mechanical disturbance due to vibration from the drive.

Automated sewing sub-system results are reported next. A diagnostic procedure allowing assignment a given power to the machine drive motor was prepared for testing purposes and integrated into the assembly cell control program. The procedure was used to determine the open loop speed to percentage power assigned, results being shown in graph 9.5.

conveyor belt and the sewing machine threaded with yarn and edge binding tape. The initial position of the workpiece was marked against a datum and a point upon the binding tape emerging from the machine output similarly marked. SYNC_SEW was ran for one cycle and both workpiece and edge binding feed lengths were noted. Results are given below:

Table 9.5b Synchronised Sewing Results.

Edge binding feed:	10.51 cm
Workpiece Feed length:	10.21 cm
synchronisation maintenance:	0.07 cm

Synchronisation of the stepper motor to the sewing machine was reported by the SYNC_SEW algorithm at less than 6 steps, equivalent to 0.07 cm of the linear conveyor feed.

Having verified the correct operation of the SYNC_SEW algorithm, the system was evaluated in full with the sewing machine threaded and provided with edge binding tape. Workpieces were repeatedly fed from the alignment table onto the conveyor. The conveyor buffer eventually filled, the workpieces progressed in the buffer queue to the sewing machine and were then introduced into the machine jaws. A guiding bar was added to direct the workpiece edge into the binding tape as both components entered the jaws. No disturbance of the workpieces were observed in its introduction to the sewing machine and no further workpiece clamping arrangement was required for the process to proceed reliably. Attachment of the edge binding tape to the workpiece was found satisfactory.

Output from the sewing sub system was allowed to collect as no cut and stack element was was installed at the time of the evaluation.

9.5 INTEGRATED ASSEMBLY CELL PERFORMANCE

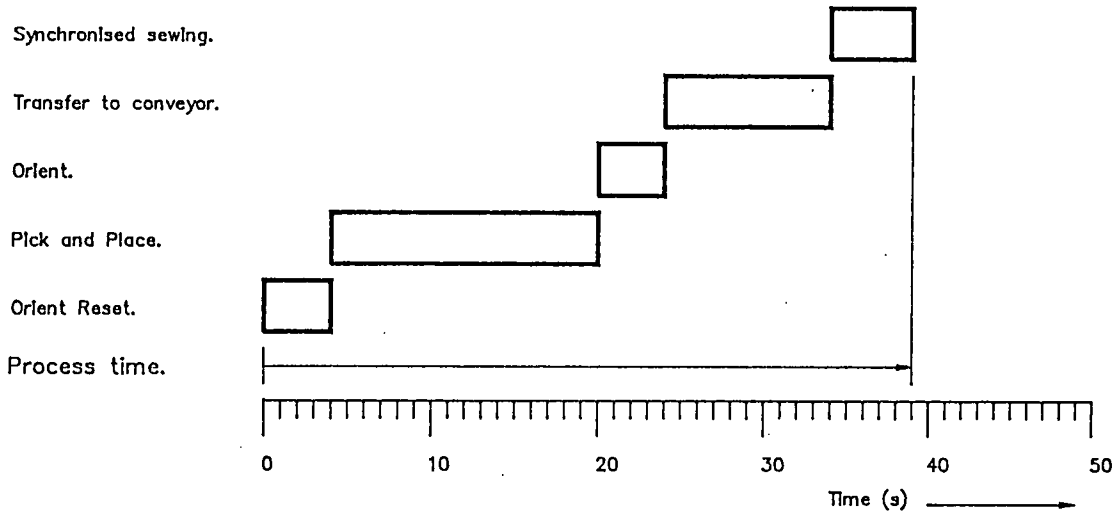
9.5.1 Integrated Control

The integrated control of the assembly cell was evaluated using the procedure Process_A_stack_Of_Workpieces, described in section 8.10.10. This procedure provided high level commands to operate each of the automation elements in sequence and provide control for batch initialisation and completion. It would therefore enable full processing of a fabric batch. Therefore this section concerns the interaction between automation elements and the reliability of passing workpieces between the elements.

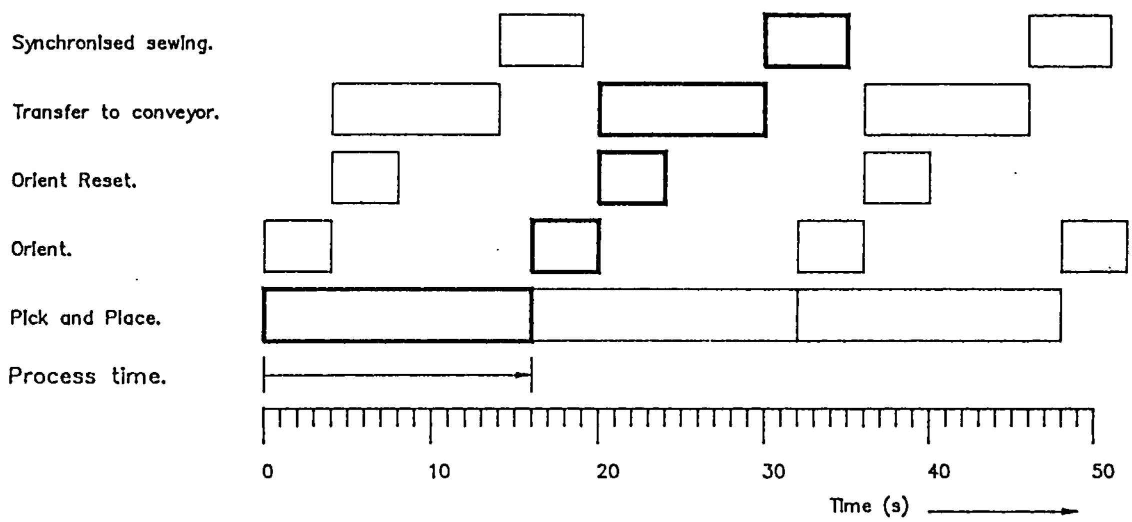
Experimental evaluation of the procedure Process_A_stack_Of_Workpieces was carried out by running the procedure, called from the control program menu. After processing ten stacks of workpieces, no mishandling during workpiece passing was observed in the transfer mechanisms and the integrated process therefore performed as designed.

9.5.2 Cycle Times With Non-concurrent Control

This section reports measured cycle times for the individual sub-processes and for the complete integrated process. Figure 9.5.2 presents the results in graphical form. Numeric results are tabulated in table 9.5.2a. Comparative assembly times, obtained from time and motion studies from the industrial partner, are shown in table 9.5.2b.



A. Present Process Order.



B. Proposed Process Order (With Concurrency).

Figure 9.5.2 Assembly Cell Process Times.

Table 9.5.2a	Assembly Cell Process Times.
Process	Time (s)
De-stacking:	16.0
Alignment:	3.5
Alignment reset:	3.8
Transport:	10.0
Sewing:	5.0
Integrated:	38.3

Table 9.5.2b	Manual Assembly Process Times.
Process	Time (minutes)
Bind front:	2.208
Bind gusset:	2.160
Cut fronts apart:	1.712
Cut gussets apart:	1.472
Fasten bundle and put aside:	0.360
Fetch bundle and unfasten:	0.280
Sub-Total:	8.192
Relaxation allowance and contingencies at 18%:	1.475
Total:	9.677
Average handling time per piece:	6.04 s

9.5.3 Predicted Cycle Times With Concurrent Control

The process elements could operate concurrently with multitasking software rather than in purely sequential order. Figure 9.5.2b shows a feasible concurrent ordering of the processes, using times obtained in sub-section 9.6.2.

As the total alignment time is less than the recorded de-stacking time, the process does not lie on the integrated and interleaved process critical path time and speed increase would not be required until de-stacking time is reduced. The resulting overall cycle time, excluding batch initialisation time, reduces to 13.0 s in this case. The alignment stage and sewing unit will not effect cycle time until the process times of the above elements is reduced.

9.6 SUMMARY

The assembly cell hardware was constructed and experimentally evaluated. Experimental performance of the assembly cell sub-systems and their integrated function were given. Non optimised overall cycle time was measured and reported. The above results have been reported by Sterling, Sarhardi and Nicholson [102, 105]. Assessment of these results is made in chapter 10 and suggestions for further work are given therein.

CHAPTER 10

DISCUSSION AND CONCLUSIONS

10.1 INTRODUCTION

A number of advances in fabric handling technology have been described in chapters 1 to 9. These are summarised within this chapter and conclusions are drawn. In this chapter, section 10.2 describes the suitability of the assembly cell for computer supervised operation and section 10.3 discusses the commercial viability of the system. Comments on the methodology used in this investigation are given in section 10.4 and areas of research for further work are then identified and presented in section 10.5. Finally, the work comprising this thesis is reviewed in section 10.6, where concluding remarks are made.

10.2 SUPERVISION REQUIREMENT OF THE ASSEMBLY CELL

An objective of work with the assembly cell was attainment of computer supervised operation for the example assembly process. Some departure from the anticipated performance was observed. Handling errors developed in practice were associated mainly in the upstream de-stacking process. This was exhibited by its infrequent production of multiple de-stacked fabric plies, no plies or release of crumpled or excessively displaced plies at the de-stacking release area. Downstream open loop operations were normally unable able to recover the workpiece condition in these cases, resulting in below standard production. Improvement in the de-stacking process is therefore desirable and means to attain this are suggested in section 7.6.2.

Observations were made on the effects of handling failures in the cell. Workpiece mishandling normally resulted in reduction of the assembled quality of the workpiece, but the remaining batch was generally unaffected. As an outcome, the process did not halt following a failure and incorrectly processed components could be removed in a downstream quality control stage. Practical operation of the system could be carried out on this basis.

10.3 COMMERCIAL VIABILITY

The de-stacking process has been shown to operate with cycle times potentially compatible with conventional commercial production times. This process has been recorded by the industrial partners and a confidential large scale commercial research and development project to automate Y-front assembly processes has been undertaken. Interest in the assembly cell and the de-stacking process has simultaneously been shown by competing industrial bodies.

10.4 METHODOLOGY CONSIDERATIONS

A single controller unit was used for this work. The operating system was not multitasking and thus the assembly cell processes were driven from a single task. This was sufficient to demonstrate the function of each sub-system but provided no mechanism to allow time interleaving of all assembly cell processes. Thus the apparent cycle time of the assembly cell was greatly extended to allow wholly sequential operation of each of the assembly cell sub-systems. Predicted reduction in cycle time, should multi tasking be employed was calculated and is given in sub-section 9.6.3.

For research and development purposes, either a multitasking controller or separate controllers for each sub-system are recommended to model the process more closely to the commercial requirement. Techniques to schedule interaction of the automation sub-systems are presented by Coffman [21].

10.5 SUGGESTIONS FOR FURTHER WORK

10.5.1 Controller Modifications

Further modification to the controller is suggested. Equipment supporting concurrency (multitasking or multiprogramming) is necessary to effectively coordinate and demonstrate automation schemes of the size of the assembly cell, thus replacement of the controller with a more suitable processor and operating environment would provide a route to achieve concurrent control. Examples of low cost multitasking controllers were given in section 3.8.3, a specific example being the DEC PDP 11 range. As computing power requirement is not large for most processes, several small computers, such as personal computer systems would provide an alternative development route. Likewise, use of PLC units to control and acquire data from the electromechanics would allow offloading of low level control and enable high level control from a co-ordinating computer.

Results from a performance evaluation in a shop floor prototype await revision of the assembly cell to remove deficiencies noted in this evaluation.

10.5.2 Error Correction Routines

Design and evaluation of de-stacking error correcting routines are required. Design and evaluation of routines detecting multiple ply separation using the ply depth sensor and gripper force sensors remain to and may comprise future work.

10.5.3 Alignment Table Control

Control of the alignment table is presently carried out using feedback derived from reflex photosensors. Sensory information is returned from three points only. Considerably more information could be made available if binary imaging RAM cameras were used. These would provide the following advantages over photosensors;

i. Whilst fully developed commercial RAM camera products are presently unavailable, prototype component costs are low and work with experimental prototypes is therefore justified.

ii. A RAM camera system may be arranged to scan the whole area of the alignment table and recover a complete image of the workpiece. Assurance the correct edge is aligned is therefore possible as all edges may be identified.

iii. Accuracy of alignment may be increased if magnification is used in the view recovered of the edge alignment area.

iv. Auxiliary quality control may be carried out from views of the workpiece. Material defects such as incorrect shape or holes in the fabric may be detected and the workpiece rejected by a blast of compressed air at the alignment table.

Some improvement in the performance of the table axis position control algorithms are required. These arise from the lack of full position encoding on axes and result in overshoot at the demanded position. Therefore, provision of further high resolution sensors combined with revision of the reset control algorithm would provide improvement in the alignment process. Alternatively, if imaging devices are used, reset may be carried out by feedback from the position of a recognised marker on the alignment table surface. The following work has been covered in this thesis: In chapter 1, a general introduction to garment assembly was given and the state automation in this field was described. Relevance of automation to garment assembly was discussed and contemporary work investigating garment assembly automation outlined. Areas of automated garment assembly able to benefit from research were identified and were made research objectives. The initial research area was determined as the de-stacking of fabric from batch cut components for assembly.

Chapter 2 covered theoretical aspects of fabric de-stacking automation and proposed a new robotic de-stacking gripper, subsequently designed for experimental evaluation and documented in chapter 3. A novel de-stacking technique was produced. Results from the evaluation were reported in chapter 4 and improvements were made to the system based on these results. The criterion of high speed was met by the device and means to ensure high reliability were outlined. Extensions to the gripper system were then proposed in chapter 5 to enhance reliability of the de-stacking process and these were detailed. Enhancements were next evaluated experimentally, chapter 6 describing the flexible gripper system and its controller, results being reported in chapter 7.

At this point, detailed investigation of the de-stacking process was concluded. Other fabric handling and assembly techniques were of interest in addition to the de-stacking process and several of these were investigated. In this investigation, a key sub-assembly operation was identified within the manufacture of a typical garment. Automation of the sub-assembly operation was investigated, and automata based upon the new de-stacking device and other novel handling equipment were proposed and experimentally described in chapter 8. An automated assembly cell was then constructed and evaluated in the laboratory, this being described in chapter 9.

Handling techniques for single plies have also been investigated. Edge alignment techniques have been developed and experimentally tested. A novel air ejector based handling process was invented and experimentally proven to successfully operate. The overall project has been recently described in Apparel International [142] and the gripper system described in the UK Research in Advanced Manufacture conference [93].

CHAPTER 11

REFERENCES AND BIBLIOGRAPHY

[1] Allen Bradley Ltd, "Programmable Controllers Training Manual".

[2] Atkinson R.E. (Rockwell Rimoldi), "Delphi Survey Of The Swedish Ready Made Clothing Industry", March, 1978.

[3] Ben-Ari M, 'Principles Of Concurrent Programming', Prentice-Hall International; ISBN 0-13-701078-8, 1982.

[4] Bijttebier, "A Process and Apparatus For Separating Supple Sheets From A Stack", U.K. Patent Number 1,443,498, July 21 1978.

[5] Billingsely, "Online Correction And Adaptation Of Automated Manufacturing Processes Using Inspection And Quality Control Data", Proc of the ACME conference on advanced production machines, including Robotics, Trevelyan College, Durham, 30 Sept- 20 Oct 1985.

[6] Bolton T, "Industrial LANs - Foundation For Company Wide Networking", Proc 9th International Fibre Optic Communications and Local Area Networks Exposition, Brooks Hall, San Fransisco, CA, September 18-20 1985, P121.

[7] Bonney M.C, Edwards P.J, Gleave J. A, Green J.L, Marshall R.J, Young Y.F, "The Grasp Computer Aided Design System", Proc. of the SERC Robotics Initiative 3rd Grantees Conference, University of Surrey, Sept 1984, P 13.

[8] Bonnington S.T, "The Design Of Ejectors Driven By And Entraining Compressible fluids", The British Hydromechanics Research Association, February 1962.

[9] Brotherton A. A, Tyer J.T, "Clupicker Performance And Flexible Apparel Automation", Hollings Apparel Industrial Review, Manchester Polytechnic, Summer 1986.

[10] Bruess L, "Turning The Garment Industry Inside Out", Computer Decisions, Jan 1979, pp 42-43

[11] Burdess I.R, "Microprocessor Control of Circular Knitting Machines", Proc. of 4th Annual Conference on Microsystems, Wembley, London 11-13 March 81, P80-89.

[12] Burdess I.R, "Feed Control Procedure", Patent application description, no. 8215999, 1 June 1982.

[13] CAMAC Instrumentation and Interface Standards, IEEE Publication, 1976.

[14] CP/M-86 Operating System Programmers Guide, Digital Research, June 1981.

[15] CP/M-86 System Guide, Digital Research, June 1981.

[16] CP/M-86 Users Guide, Digital Research, June 1981.

[17] Carnaby G A, "The Compression Of Fibrous Assemblies, With Applications To Yarn Mechanics", NATO Advanced Study Institute Series, no 38, 1980.

[18] Chelpanov I.B, S. N. Kolpashnikov, "Problems With The Mechanics Of Industrial Robot Grippers", Mechanism and Machine Theory, Vol 18, No 4, pp. 295-299, 1983.

[19] Chen F.Y, "Gripping Mechanisms for Industrial Robots: An Overview.", Mechanism and Machine Theory, Vol 17, No 5, pp. 299-311, 1982.

[20] Clayton G. B, "Operational Amplifiers", 2nd ed, Butterworths, 1981.

[21] Coffman E.G, "Computer And Job-Shop Scheduling Theory", Wiley 1976, ISBN 0-471-16319-8.

[22] Coles G, "A Microcomputer Toolkit For Fully Fashioned Knitwear Designers", Knitting International, Sept 1981 pp 45-48.

[23] DEC RSX11 Handbook.

[24] Dandliker R, Hess, K, and Sidler, T, "Hybrid Coherent Optical And Electronic Object Recognition", Applied Optics, Vol 22, no 14, 2081, 15 July 1983.

[25] Davey P.G. "Research And Development In The United Kingdom", Robotic Technology, Peter Peringus Ltd, pp. 10-14, 1983.

[26] Davies B, "The Design Of Industrial Robot Manipulators", Robotic Technology, Peter Peringus Ltd, pp. 142-150, 1983.

[27] Di-Stefano J.J., Stubberud, A.R., Williams, I.J., Feedback And Control Systems, Schaum outline series, Mc Graw-Hill, 1967.

[28] Digital Research Inc, "Concurrent CP/M Operating System Guide" January 1984.

[29] Dooner M, "Computer Simulation To Aid Robot Selection" Robotic Technology, Peter Peringus Ltd, pp. 103-111, 1983.

[30] Douglas H.R., "IEEE 802.4 Theory And Application.", Proc 9th International Fibre Optic Communications and Local Area Networks Exposition, Brooks Hall, San Fransisco, CA, September 18-20 1985, P126-128.

[31] Elder H.M, Fisher S, Armstrong K, Huchinson G, "Fabric Stiffness, Handle and Flexion", Journal of the Textile Institute, Vol 75 no 2, 1984.

[32] Gaetean M, "Sewn Products Engineering And Reference Manual", Bobbin Publications, 1977.

[33] Gara A. D, "Real Time Tracking Of Moving Objects By Optical Correlation", Applied Optics, Vol 18, no2, 15 January 1979.

[34] Grills R, Brown S, "Productivity In Sewing Operations", Shirley Institute Publication S20, 1975.

[35] Grosberg P, "The Bending of Yarns and Plain Woven Fabrics", NATO Advanced Study Institute Series, no 38, 1980.

[36] Grosberg P, "An Introduction To Textile Mechanisms", E. Benn, 1968.

[37] Hanna L, "Shop Floor Communications - MAP", Proc 9th International Fibre Optic Communications and Local Area Networks Exposition, Brooks Hall, San Fransisco, CA, September 18-20 1985, P122-125.

[38] Hansen Perbrinch, "The Architecture Of Concurrent Programs', Prentice Hall, International; ISBN 0-13-044628-9, 1977.

[39] Happey F, "Contemporary Textile Engineering", Academic Press, 1982.

[40] Hardill I, "A Report On The Clothing Industry", Washington Development Corporation, March 1985.

[41] Hashim A. A et al, "Applications of Automated Visual Inspection In The Textile And Machine Tool Manufacturing Industries", Proc. of the ACME Grantees Conference on Advanced Production Machines, Trevelyan College, Durham, Oct 1985, P14.

[42] Hashim A. A, Lefley M, Spencer D, "Automated Visual Inspection And Classification Of Textile Materials And Garments", Proc.of the Textile institute Annual World Conference, "Computers In The World Of Textiles", Sept 26-29, 1984.

[43] Hearle S.W.S, "Mechanics Of Dense Fibre Assemblies", NATO Advanced Study Institute Series, no 38, 1980.

[44] Hollingum J, "The MAP Report", IFS Publications Ltd, Springer Verlag, ISBN 0-948507-26-8, 1986.

[45] Hunt V.D, "Industrial Robotics Handbook", Industrial Press Inc, 1983.

[46] Intel Corporation, "MCS-86 Assembly Language Reference Manual", Manual order no 9800640A, 1978.

[47] Intel Multibus Standard, Manual order no. 9800683, Intel Corporation, 1978.

[48] Intersil Ltd, "Data Book", 1981.

[49] Jensen and Wirth, "Pascal Users Manual And Report"

[50] Kastner L.J, J. R. Spooner, "An Investigation Of The Performance And Design Of The Air Ejector Employing Low-pressure Air As The Driving Fluid", 2 May 1949.

[51] Kawachi Y, "Mecha-Electronics Of Garment Sewing System", Annual World Conference of the Textile Institute, Sept 26-29, 1984.

[52] Kemp D.R, G.E. Taylor, P.M. Taylor, A. Pugh, "A Sensory Gripper For Handling Textiles", Proc. 13th. International Symposium on Industrial Robots, Chicago, 1983.

[53] Kemp D.R, P.M. Taylor, "A Prototype Robot Workstation For The Motif Application Process Within The Garment Manufacturing Industry", Proc. 2nd IASTED International Symposium on Robotics and Automation, Luguano 1983, 4pp.

[54] Krieg L., "LAN Management For The Automated Factory", Proc 9th International Fibre Optic Communications and Local Area Networks Exposition, Brooks Hall, San Fransisco, CA, September 18-20 1985, P129-131.

[55] Kurt Salmon Associates (Management Consultants), "A Report On Technology For Apparel Manufacture To The EEC Commission", Dec 1979.

[56] Leaf G. A. V, "Woven Fabric Tensile Mechanics", NATO Advanced Study Institute Series, no 38, 1980.

[57] Leaf G. A. V, Sheta A.M.F, "The Initial Shear Modulus Of Plain Woven Fabrics", Journal of the Textile Institute, Vol 75, no 3, 1984.

[58] Lhote et al, "Robot Components And Systems", Hermes Publishing, 1983, ISBN 0-85038-649-7.

[59] Linger R.C, "Structured Programming", The Systems Programming Series, Addison Wesley, 1979.

[60] Littlewood K.J, "Method and Apparatus For Handling Fabric Workpieces" U.K. Patent Number 1,533,536, November 29 1978.

[61] Littlewood K.J, "Mechanical Handling Of Limp Material", Clothing Institute Journal Vol XXIII, p 369-376.

[62] Liu H.K, and Duthie, J. G, "Real Time Screen Aided Multiple-Image Optical Holographic Matched-filter Correlator", Applied Optics, Vol 21, No 18, 15 Sept 1982.

[63] Lord P.R. "Automation, Quality And Costing", Journal of the Textile institute, Vol 75 no 6, 1984.

[64] Lumley J W, "A Parallel Approach To Machine Control Using A Single Sequential Microprocessor", Proc. Microsystems 81, 4th Annual Conference, Wembley, London, 11-13 March 1981.

[65] Marsh P, "Underwear By Robots", Financial Times, 3 May 1985.

[66] McLellan E. "Robot Languages - The Current Position" Robotic Technology, Peter Peringus Ltd, pp. 111-112, 1983.

[67] Mills R.W, "Fully Fashioned Garment Manufacture", Cassel, 1965.

[68] Mitchell I, D. G. Whitehead, A. Pugh, "A Multi Processor System For Sensory Robotic Assembly", Sensor Review, pp. 94-96, April, 1983.

[69] Morton K.O, "Nipping And Lifting Means For Fabric Sections And The Like" U.K. Patent Number 1,511,184, May 6 1975.

[70] "Mechanics Meets Electronics", Johnston, B, New Scientist, May 10 1986.

[71] Nissan A. H, "Textile Engineering Processes", Butterworths, 1959.

[72] Nordby "The Load-Elongation Properties Of Fabrics With Special Reference To Hysterysis", Ph. D. Thesis, Dept of Textile Industries, Leeds University, May 1968.

[73] Ogawa S, "A National Research And Design Project", Bobbin, 1984, 5(6), pp 82-102.

[74] Olroyd D, "Devices For Picking Up Pieces of Sheet Material From A Stack Of Pieces" U.K. Patent Number 1,218,433, Jan 6 1971.

[75] Pascal/MT+86 Language Reference Manual, Digital Research, March 1982.

[76] Peatman John B, "Digital Hardware Design.", pp 26-27, Mc Graw-Hill 1980. ISBN 0-07-0664 70-6.

[77] Perry and Lissner, "The Strain Gauge Primer", McGraw Hill Inc, 2nd ed, 1962.

[78] Potma T, "Strain Gauges Theory And Application", Ilfe Books Ltd.

[79] Preece C., Balding, N., personal discussion relating to the bleasdale operating system, Jan. 86.

[80] Prentis J. M, "Dynamics Of Mechanical Systems", 2nd ed, Ellis Horwood series in Engineering Science, ISBN 0-85312-158-3, pp 386.

[81] Price C.D, A. Rae, "Variability In Sewing", British Clothing Industry Productivity and Technology Centre, 21 October 1982.

[82] Pugh A, "Processing Of Binary Images", Robotic Technology, Peter Peringus Ltd, pp. 63-87, 1983.

[83] Pugh A, "Second Generation Robotics And Robot Vision", Robotic Technology, Peter Peringus Ltd, pp. 1-9, 1983.

[84] Pugh A, P.M. Taylor et al, "A Research Program In Sensor Guided Assembly", Proc AUTOMAN, Birmingham 1983, pp223-234.

[85] RSX11 Handbook, Digital Equipment Corporation, 1984-85

[86] Rae A, "Draft Interim Report: Sewing Tension Variations. 'Static' Tests On Needle Thread Tension System." WIRA Report, 9 December 1981.

[87] Rae A, "Report On Kirby-lester Tension Analyser (phase 1)", WIRA internal report ref 1/302, February 1976.

[88] Rennel R. W, Haltof b, "Robotics In Garment Manufacture", Shirley Institute and Salford University Industrial Centre Ltd, November 1983.

[89] Richards, "The Dissipation Of Static Electricity In Textile Fibres", Ph. D. Thesis, Dept of Textile Industries, Leeds University, 1954.

[90] Ros D.T, J. B. Goodenough, C. A. Irvine, "Software Engineering: Process, Principles and Goals", Computer (May 1975):65.

[91] Rothon N. M, "Design Structure Diagrams - A New Standard In Flow Diagrams", Computer Bulletin, March 1979.

[92] SY6522 Versatile Interface Adapter data sheet, Synertek 1981-1982 Data Catalogue, section 3-95 to 3-114.

[93] Sarhadi M., Nicholson, P.R and Simmons, J.E., "Advances in Gripper Technology for Apparel Manufacturing", UK Research in Advanced Manufacture, Proceedings of the Institution of Mechanical Engineers, 10th December 1986.

[94] Sarhardi M, P.R. Nicholson, J.C. Brown, "AUTOMATED GARMENT MANUFACTURING", Birmingham Polytechnic, May 1984.

[95] Shinners S.M., MODERN CONTROL SYSTEM THEORY AND APPLICATION, (2nd ED), Addison-Wesley Publishing Company, Inc, 1978. ISBN 0-201-07059-6.

[96] Shinohara A, Shinohara F, Sakaebara K, "Theoretical Study on Anisotropy of Bending Rigidity of Woven Fabrics", J. Textile Machinery Society of Japan, Vol 26 No 3, July 1980.

[97] Simons G.L, "Computers In Engineering And Manufacture", The National Computer Centre, 1982

[98] Sinclair D, (Manchester Polytechnic Hollings Faculty to the BCIA.), "Toyota Sewing Management System".

[99] Stephens R. C, "Strength Of materials", Edward Arnold Ltd, 1974.

[100] Sterling M.J.H, "Real Time Languages", Undergraduate course notes.

[101] Sterling M.J.H, M. Sarhardi, P. R. Nicholson, "Automated Garment Assembly", Proceedings of the Robotics initiative, 2nd SERC Grantees conference, September 1983.

[102] Sterling M.J.H, Nicholson, P.R. "Automated Garment Assembly", Proc of the ACME conference on advanced production machines, including Robotics, Trevelyan College, Durham, 30 Sept- 20 Oct 1985, P30.

[103] Sterling M.J.H, Nicholson, P.R. "Automated Garment Assembly", Progress report to SERC, April 1984.

[104] Sterling M.J.H, Nicholson, P.R. "Garment Manufacture By Hard Automation", Proc of SERC 3rd Grantees Conference, University of Surrey, Guilford, Oct 1984.

[105] Sterling M.J.H, Nicholson, P.R. "Automated Garment Manufacturing And Product Quality Control." Proc of the ACME conference on advanced production machines, including Robotics, Trevelyan College, Durham, 30 Sept- 20 Oct 1985, P31.

[106] Stuck B.W. "802 Local Area Network Access Method Handling Characteristics: Token Bus VS Token Ring VS CSMA/CD Bus VS slotted Ring", Proc 9th International Fibre Optic Communications and Local Area Networks Exposition, Sept 18-20 1985.

[107] Tanenbaum A.S., "Computer Networks" Prentice/Hall, ISBN 0-13-164699-0, 1981.

[108] Taylor G.E, "An Adaptive Sensory Gripper For Fabric Handling", 4th IASTED Symposium on Robotics and Automation, Amsterdam 1984.

[109] Taylor G.E, D.R. Kemp, P.M. Taylor, A. Pugh, "Vision Applied To The Orientation Of Embroidered Motifs In The Textile Industry", Proc. 2nd International Conference on Robot Vision and Sensory Controls, Stuttgart 1982.

[110] Taylor G.E, P.M. Taylor, D.R. Kemp, "An Adaptive Sensory Gripper For Fabric Handling", Proc. 4th IASTED International Symposium on Robotics and Automation, Amsterdam 1984, pp48-51.

[111] Taylor P.M, "A Garment Assembly Demonstrator", Proc. of the ACME Grantees Conference on Advanced Production Machines, Trevelyan College, Durham, Oct 1985, P37.

[112] Taylor P.M, "Application Of Robots In The Garment Manufacturing Industry", Proc. of the 3rd SERC Robotics Initiative Grantees Conference, University of Surrey, Sept 1984, P45.

[113] Taylor P.M, "Automation Of Shirt Collar Inspection And Assembly", Proc. of the 3rd SERC Robotics Initiative Grantees Conference, University of Surrey, Sept 1984, P44.

[114] Taylor P.M, "The Hull Fabric Handling Project", Knitting International, September 1985, p88-89.

[115] Taylor P.M, "The Application Of Robots To Garment Manufacture", Encyclopedia of Systems and Control, 1985, 7pp.

[116] Taylor P.M, Bowden P, "Accurate Picking And Placing Of Fabric Panels For Subsequent Joining".

[117] Taylor P.M, C. A. Stubbings, "Control Of A Sensory Assembly Workstation", IEE Conf. Control 85, Cambridge, July 1985.

[118] Taylor P.M, C. A. Stubbings, "LASCAR: A Language For Assembly Station Control At Runtime", Proc. 4th IASTED International Symposium on Robotics and Automation, Amsterdam 1984, pp48-51.

[119] Taylor P.M, C. A. Stubbings, "Software And Hardware Aspects Of A Flexible Workstation For Assembly Tasks Using Sensory Robots", Proc. 2nd IASTED International Symposium on Robotics and Automation, Luguano 1983, pp48-51.

[120] Taylor P.M, G.E. Taylor, A. Pugh, D.R. Kemp, "The Application Of Robots In The Garment Manufacturing Industry", IEE seminar on U.K. Robotics Research, Dec 1983, digest no 1983/104.

[121] Taylor P.M, K.K.W. Selke, Taylor G.E, "Closed Loop Control Of An Industrial Robot Using Visual Feedback From A Sensory Gripper", Proc. 12th ISIR, Paris, 1982.

[122] Taylor P.M, Taylor G.E, "A Collaborative Research Proposal For Automation Of Shirt Collar Inspection And Assembly", Proc. of the ACME Grantees Conference on Advanced Production Machines, Trevelyan College, Durham, Oct 1985, P36.

[123] Taylor P.M. et al, "The Application Of Robotics In Garment Manufacturing Industry", Proc. ACME Robotics Initiative, 3rd Grantees Conf, University of Surrey, 1984, Sec 45.

[124] Teauge E, "Robots by 1989", Textile Horizons, Dec 1984.

[125] "Textile Machinery", Textile Horizons, Feb 1984.

[126] Thompson B, J, "Hybrid Processing Systems -- An Assessment", Proc. IEEE, Vol. 65, No 1, pp 62, January 1977.

[127] Trabka E. A, and Roetling, P. G, "Image Transformations For Patten Recognition Using Incoherent Illumination And Bipolar Aperture Masks", J. Opt. Soc. Am 54, 1242, 1964.

[128] "Turbo Pascal Users Manual", Borland Incorporated, 1985.

[129] Van Luijk C.J, Carr A.Z, Carnaby G. A, "Finite Element Analysis Of Yarns", Journal of the Textile Institute, Vol 75, no 5, 1984.

[130] Vitols R, Baker J.E, Wray G.R, Murphy B.J.M, "Parameters Governing The Detection, Alignment And Joining Of Flexible Assemblages", Proc. of SERC Robotics Initiative Grantees Conf, Univ. of Birmingham, 1982, P19.

[131] Vitols R, Wray G.R, Baker J.E, "High Speed Sensing And Manipulation Of Knitted Fabrics", Proc. of the ACME Grantees Conference on Advanced Production Machines, Trevelyan College, Durham, Oct 1985, P40.

[132] Vitols R, Wray G.R, Murphey B.J.M, Baker J.E, King T.G, "Computer Controlled Machinery For Garment Manufacture", Proc.of the Textile institute Annual World Conference, "Computers in the World of Textiles", Sept 26-29, 1984.

[133] Wallace F.J, Linning, W. A, "Basic Engineering Thermodynamics", Pitman Press, 1970.

[134] Walter C, "The Application of Robotics In Context Of Garment Making Up Automation", Knitting International, Feb 1985, pp 20-22.

[135] Whitehead D.G, Mitchell I, Mellor P.V, "A Low Resolution Vision System", J. Phys. E. Sci. Instrum, March 1984, Vol 17, pp 653-656.

[136] William R. Conner Sr, "Automatic Feeder For Workpieces Of Fabric And The Like", U.S. Patent No 3,670,674, June 20 1972.

[137] XASM68-68, 6800/6801 Users manual, Avocet Systems Inc, Assembler version 1.99, Manual revision 1.5, 804 South State St., Dover, Delaware, 17/3/81.

[138] Yamaguchi T, Yanawa T, Kimuna H, "Elastic Recovery Of A Viscoelastic Model Under Power Law" J. Textile Machinery Society of Japan.

[139] "FactoryLink Programmers Reference Manual", USdata Incorporated, 1984.

[140] "Guide To Design Structure Diagrams For Use In Program Design And Other Logic Applications", BS 6224: 1982, British Standards Institution.

[141] "Inspect By Robot", Textile Horizons, Oct 1984.

[142] "International Innovations", Apparel International, Vol 10, July 1986, pp 19-21.

[143] "Japanese New Robot System", Style, Page 5, 25th August 1982.

[144] "Programmable Controller Product Survey", Control and Instrumentation, P54, January 1987.

[145] "Real Time Interface Co-processor Technical Reference Manual", IBM Corporation, First Edition, 1986.

[146] "TopView V1.10 Reference Manual", IBM Corporation, 1986.

[147] "Toyota Sewing Management System", Style Magazine, August 25 1982.

[148] "Velocities And Accelerations Of Moving Parts Of Sewing Machines".

[149] "What potential For Robots In The Industry?", Knitting International, July 1983.

APPENDIX A

STRAIN GAUGE SPECIFICATION

The specification for strain gauge units used in work relating to force sensing (chapter 6) is given below:

Type:	TML linear strain gauge. FLA-3-11. CU-NI foil on epoxy carrier. Gauge factor 2.11 3 mm length.
Nominal resistance:	120R ± 0.3%

APPENDIX B

CONTROL PROGRAM SEGMENT REFERENCE TREE

The following flow segment reference tree is given for the control program described in chapters 6 and 8. A calling hierarchy of procedures from the root segment mainrig is given by the tree. Procedures called from a given procedure are indented inwards one level from the calling procedure. Each level of indentation represents a branch in the tree. Lines comprising the tree are numbered sequentially. To reduce the size of the tree, a given procedure is described fully on its first occurence in the tree. Subsequent occurences are described by the procedure name prefixed with a minus (-) sign and post-fixed with the line number in brackets representing the initial description for reference. The second number on a given line, under the DEFN column represents a full description of the procedure flow produced by the PDL processor generating the tree but is not given due to space limitation.

```
 LN   DEFN  SEGMENT
 ----  ----  -------

   1   325   Mainrig
   2    18   CLRSCR
   3    41   INIT_INPUT_OUTPUT
   4    25       INIT_VIA_1_PIO
   5    18           PORT
```

```
 6    27        INIT_VIA_2_PI0
 7    18            PORT
 8    29        INIT_VIA_1_PI1
 9    18            PORT
10    31        INIT_VIA_1_PI2
11    18            PORT
12    33        INIT_VIA_2_PI2
13    18            PORT
14    35        INIT_PTC_1_PI0
15    18            PORT
16    37        INIT_PTC_1_PI1
17    18            PORT
18    39        INIT_PTC_2_PI1
19    18            PORT
20    51    INITIALISE_VARIABLES
21    43    INIT_SCREEN1
22    18        CrtInit
23    18        GOTOXY
24    18        WRITELN
25    18        GOTOXY
26   321    Erase_Active_Procedure
27    18        GOTOXY
28    18        CLREOL
29    18    GOTOXY
30    18    CLREOL
31    18    WRITE
32    18    READ
33   323    Bleep
34    18        WRITE
35   319        Procedure_Active
36    18            GOTOXY
37    18            WRITE
38    18            GOTOXY
39   151    RESET_OT_AXES
40   147        RESET_OT_X_AXIS
41   135            SET_OTX_DC_MOTOR_STATE
42    59                ASSIGN_12V_DC_MOTOR_PTC_LATCHVALUE
43   129                SET_OTX_MOTOR_PWM
44    18                    PORT
45   123                SET_OTX_MOTOR_DIRECTION
46    18                    PORT
47   117            READ_OT_POS_DETECTORS
48    18                WRITELN
49   141            REVERSE_DC_MOTOR_DIRECTION
50   135           -SET_OTX_DC_MOTOR_STATE   (41)
51   117           -READ_OT_POS_DETECTORS   (47)
52   141            REVERSE_DC_MOTOR_DIRECTION
53   135           -SET_OTX_DC_MOTOR_STATE   (41)
54   117           -READ_OT_POS_DETECTORS   (47)
55   135           -SET_OTX_DC_MOTOR_STATE   (41)
56   149        RESET_OT_Y_AXIS
57   137            SET_OTY_DC_MOTOR_STATE
58    59                ASSIGN_12V_DC_MOTOR_PTC_LATCHVALUE
59   131                SET_OTY_MOTOR_PWM
60    18                    PORT
61   125                SET_OTY_MOTOR_DIRECTION
```

```
 62    18                   PORT
 63   117          -READ_OT_POS_DETECTORS   (47)
 64   141           REVERSE_DC_MOTOR_DIRECTION
 65   137          -SET_OTY_DC_MOTOR_STATE   (57)
 66   117          -READ_OT_POS_DETECTORS   (47)
 67   141           REVERSE_DC_MOTOR_DIRECTION
 68   137          -SET_OTY_DC_MOTOR_STATE   (57)
 69   117          -READ_OT_POS_DETECTORS   (47)
 70   137          -SET_OTY_DC_MOTOR_STATE   (57)
 71   145       RESET_OT_ROTATE_AXIS
 72   143           ACQUIRE_OT_ROTATE_AXIS_INTERRUPTER_EDGE
 73   139               SET_OTDISC_DC_MOTOR_STATE
 74    59                   ASSIGN_12V_DC_MOTOR_PTC_LATCHVALUE
 75   133                   SET_OTDISC_MOTOR_PWM
 76    18                       PORT
 77   127                   SET_OTDISC_MOTOR_DIRECTION
 78    18                       PORT
 79   117              -READ_OT_POS_DETECTORS   (47)
 80   141               REVERSE_DC_MOTOR_DIRECTION
 81   139              -SET_OTDISC_DC_MOTOR_STATE   (73)
 82   117              -READ_OT_POS_DETECTORS   (47)
 83   141               REVERSE_DC_MOTOR_DIRECTION
 84   139              -SET_OTDISC_DC_MOTOR_STATE   (73)
 85   117              -READ_OT_POS_DETECTORS   (47)
 86   141               REVERSE_DC_MOTOR_DIRECTION
 87   139              -SET_OTDISC_DC_MOTOR_STATE   (73)
 88   117              -READ_OT_POS_DETECTORS   (47)
 89   141               REVERSE_DC_MOTOR_DIRECTION
 90   139              -SET_OTDISC_DC_MOTOR_STATE   (73)
 91   117              -READ_OT_POS_DETECTORS   (47)
 92   141               REVERSE_DC_MOTOR_DIRECTION
 93   139              -SET_OTDISC_DC_MOTOR_STATE   (73)
 94   117              -READ_OT_POS_DETECTORS   (47)
 95   139              -SET_OTDISC_DC_MOTOR_STATE   (73)
 96   323  -Bleep   (33)
 97    63   RESET_MANIPULATOR
 98    61       SET_MANIPULATOR_DC_MOTOR_STATE
 99    59           ASSIGN_12V_DC_MOTOR_PTC_LATCHVALUE
100    57           SET_MANIPULATOR_12V_MOTOR_PWM
101    18               PORT
102    55           SET_MANIPULATOR_DIRECTION
103    18               PORT
104    53       READ_MANIPULATOR_RESET_CHANNEL
105    61      -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
106    53       READ_MANIPULATOR_RESET_CHANNEL
107    61      -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
108    18       GOTOXY
109   323  -Bleep   (33)
110   105   LOAD_FEED_TABLE
111    95       INCH_FEED_TABLE_DOWN
112    93           SET_FT_STEP_MOTOR_PHASE
113    18               PORT
114    18               DELAY
115   101       READ_FEED_TABLE_SENSORS
116    18       WRITELN
117   323  -Bleep   (33)
```

```
118   313   EXECUTE_ONE_PP_CYCLE
119    18       WRITELN
120    63      -RESET_MANIPULATOR   (97)
121    83       ROTATE_MANIPULATOR_1
122    65           CLEAR_MANIPULATOR_ENCODER_REGISTERS
123    18               PORT
124    75           SET_MANIPULATOR_ANGLE
125    67               READ_MANIPULATOR_ENCODER
126    71               DETERMINE_MANIP_POWER_FOR_SYNCHRONISATION
127    18                   ABS
128    61              -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
129   267       JOG_CARRIAGE
130   247           DETERMINE_CARRIAGE_POSITION
131   243               READ_LT_POSN_ENCODERS
132   237               FORM_GRAY_SCALE_DATA_AS_INTEGER
133   233                   UNPACK_GRAY_BYTE
134   231                   GRAY_CODE_TO_BINARY_ALGORITHM
135   235                   PACK_BINARY_BYTE
136    18               WRITELN
137   255           SET_PP_MOTOR_STATE
138   253               PRESET_200V_MOTOR_VARIABLES_FOR_REGISTERS
139    18               PORT
140   247          -DETERMINE_CARRIAGE_POSITION   (130)
141   255          -SET_PP_MOTOR_STATE   (137)
142    89       CLAMP_FABRIC
143    18           PORT
144    18       DELAY
145    63      -RESET_MANIPULATOR   (97)
146   109       RAISE_FEED_TABLE_TO_PRESSURE_LIMIT
147   101           READ_FEED_TABLE_SENSORS
148    97           INCH_FEED_TABLE_UP
149    93              -SET_FT_STEP_MOTOR_PHASE   (112)
150   101           READ_FEED_TABLE_SENSORS
151   111       DROP_FEED_TABLE_UNTIL_PRESSURE_RELAXED
152   101           READ_FEED_TABLE_SENSORS
153    95          -INCH_FEED_TABLE_DOWN   (111)
154   101           READ_FEED_TABLE_SENSORS
155    79       ACTUATE_MANIPULATOR_2
156    18           WRITELN
157    65          -CLEAR_MANIPULATOR_ENCODER_REGISTERS   (122)
158    61          -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
159    18           DELAY
160    67           READ_MANIPULATOR_ENCODER
161    18           ROUND
162    18           WRITELN
163   305       ROLL
164   305          *ROLL   (163)
165   247          -DETERMINE_CARRIAGE_POSITION   (130)
166    65          -CLEAR_MANIPULATOR_ENCODER_REGISTERS   (122)
167   255          -SET_PP_MOTOR_STATE   (137)
168   247          -DETERMINE_CARRIAGE_POSITION   (130)
169    67           READ_MANIPULATOR_ENCODER
170    71          -DETERMINE_MANIP_POWER_FOR_SYNCHRONISATION   (126)
171    73           UPDATE_MANIP_POWER
172    61              -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
173    18               DELAY
```

```
174    61                -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
175    61            -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
176   255            -SET_PP_MOTOR_STATE   (137)
177    87         RELAX_WORKPIECE_TENSION
178    18             WRITE
179    85             ROTATE_MANIPULATOR_2
180    65                -CLEAR_MANIPULATOR_ENCODER_REGISTERS   (122)
181    75                -SET_MANIPULATOR_ANGLE   (124)
182    18             WRITELN
183    91         UNCLAMP_FABRIC
184    18             PORT
185    18         DELAY
186   267        -JOG_CARRIAGE   (129)
187   113         TURN_OT_VAC_ON
188    18             PORT
189    18         DELAY
190   309         UNWIND
191   247            -DETERMINE_CARRIAGE_POSITION   (130)
192    65            -CLEAR_MANIPULATOR_ENCODER_REGISTERS   (122)
193   255            -SET_PP_MOTOR_STATE   (137)
194   247            -DETERMINE_CARRIAGE_POSITION   (130)
195    67             READ_MANIPULATOR_ENCODER
196    71            -DETERMINE_MANIP_POWER_FOR_SYNCHRONISATION   (126)
197    73            -UPDATE_MANIP_POWER   (171)
198    61            -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
199   255            -SET_PP_MOTOR_STATE   (137)
200    81         DEACTUATE_MANIPULATOR
201    61            -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
202    18             DELAY
203    61            -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
204   115         TURN_OT_VAC_OFF
205    18             PORT
206    63        -RESET_MANIPULATOR   (97)
207    83        -ROTATE_MANIPULATOR_1   (121)
208   267        -JOG_CARRIAGE   (129)
209   323    -Bleep   (33)
210   167     ALIGN_WORKPIECE
211   153         PREALIGN_WORKPIECE
212   143            -ACQUIRE_OT_ROTATE_AXIS_INTERRUPTER_EDGE   (72)
213   165         ALIGN_TILL_L_SENSOR_IS_OBSCURE
214   121             READ_ORIENTING_TABLE_SENSORS
215   119                 READ_WORKPIECE_ALIGNMENT_SENSORS
216   117                -READ_OT_POS_DETECTORS   (47)
217   157             CONTROL_OTY_DC_MOTOR
218   137                -SET_OTY_DC_MOTOR_STATE   (57)
219   163         ALIGN_TILL_L_SENSOR_IS_CLEAR
220   121            -READ_ORIENTING_TABLE_SENSORS   (214)
221   157            -CONTROL_OTY_DC_MOTOR   (217)
222   165        -ALIGN_TILL_L_SENSOR_IS_OBSCURE   (213)
223   163        -ALIGN_TILL_L_SENSOR_IS_CLEAR   (219)
224   159         ALIGN_TILL_P_SENSOR_IS_OBSCURE
225   121            -READ_ORIENTING_TABLE_SENSORS   (214)
226   155             CONTROL_OTX_DC_MOTOR
227   135                -SET_OTX_DC_MOTOR_STATE   (41)
228   161         ALIGN_TILL_P_SENSOR_IS_CLEAR
229   121            -READ_ORIENTING_TABLE_SENSORS   (214)
```

```
230   155          -CONTROL_OTX_DC_MOTOR   (226)
231   159      -ALIGN_TILL_P_SENSOR_IS_OBSCURE   (224)
232   161      -ALIGN_TILL_P_SENSOR_IS_CLEAR   (228)
233   323  -Bleep   (33)
234   219   Vacuum_Transfer_To_Conveyor
235   177       Clear_Screen_Of_Garbage
236    18           GOTOXY
237    18           CLREOL
238   175       Read_Vacuum_Transport_Sensors
239   215       Start_Up_Transporter_Safely
240   211           Transporter_Must_Be_At_Conveyor_End
241   175               Read_Vacuum_Transport_Sensors
242   169               Beep
243    18                   WRITE
244    18               GOTOXY
245    18               WRITE
246   175               Read_Vacuum_Transport_Sensors
247    18               GOTOXY
248    18               WRITE
249   193               Right_On
250   179                   Set_Valve
251    18                       PORT
252   213           Transporter_Vacuum_Pad_Must_Be_Down
253   181               Up_On
254   179                  -Set_Valve   (250)
255   177      -Clear_Screen_Of_Garbage   (235)
256   201       Make_Transporter_Fully_Operational
257   193          -Right_On   (249)
258   185           Down_On
259   179              -Set_Valve   (250)
260    18           DELAY
261   197           Left_On
262   179              -Set_Valve   (250)
263   181          -Up_On   (253)
264   217       Perform_One_Pick_Up_Cycle
265   203           Move_Up
266   183               Up_Off
267   179                  -Set_Valve   (250)
268   185              -Down_On   (258)
269   175           Read_Vacuum_Transport_Sensors
270    18           DELAY
271   209           Move_To_Pick_Up_End
272   195               Right_off
273   179                  -Set_Valve   (250)
274   197              -Left_On   (261)
275   175           Read_Vacuum_Transport_Sensors
276    18           DELAY
277   205           Move_Down
278   187               Down_Off
279   179                  -Set_Valve   (250)
280   181              -Up_On   (253)
281   175           Read_Vacuum_Transport_Sensors
282    18           DELAY
283   189           Grip
284   179              -Set_Valve   (250)
285   203          -Move_Up   (265)
```

```
286   175             Read_Vacuum_Transport_Sensors
287    18             DELAY
288   207             Move_To_Conveyor_End
289   199                 Left_Off
290   179                    -Set_Valve   (250)
291   193                -Right_On   (249)
292   175             Read_Vacuum_Transport_Sensors
293    18             DELAY
294   205            -Move_Down   (277)
295   175             Read_Vacuum_Transport_Sensors
296   191             Release
297   179                -Set_Valve   (250)
298   175             Read_Vacuum_Transport_Sensors
299    18             DELAY
300   191            -Release   (296)
301    18             DELAY
302   203            -Move_Up   (265)
303   175             Read_Vacuum_Transport_Sensors
304   177        -Clear_Screen_Of_Garbage   (235)
305    18         GOTOXY
306   323    -Bleep   (33)
307   227     MOVE_CONVEYOR_FORWARD
308   223         EXECUTE_ONE_CONVEYOR_STEP_FORWARD
309   221             SET_CONVEYOR_STEP_MOTOR_PHASE
310    18                 PORT
311    18         DELAY
312    18         GOTOXY
313   323    -Bleep   (33)
314   229     MOVE_CONVEYOR_REVERSE
315    18         GOTOXY
316    18         WRITE
317   225         EXECUTE_ONE_CONVEYOR_STEP_REVERSE
318   221            -SET_CONVEYOR_STEP_MOTOR_PHASE   (309)
319    18         DELAY
320    18         GOTOXY
321    18         CLREOL
322    18         GOTOXY
323   323    -Bleep   (33)
324    77     ACTUATE_MANIPULATOR
325    61        -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
326    18         DELAY
327    61        -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
328    18         DELAY
329    61        -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
330   323    -Bleep   (33)
331    81    -DEACTUATE_MANIPULATOR   (200)
332   323    -Bleep   (33)
333   305    -ROLL   (163)
334   323    -Bleep   (33)
335   307     UNROLL
336   247        -DETERMINE_CARRIAGE_POSITION   (130)
337    65        -CLEAR_MANIPULATOR_ENCODER_REGISTERS   (122)
338   255        -SET_PP_MOTOR_STATE   (137)
339   247        -DETERMINE_CARRIAGE_POSITION   (130)
340    67         READ_MANIPULATOR_ENCODER
341    71        -DETERMINE_MANIP_POWER_FOR_SYNCHRONISATION   (126)
```

```
342   73        -UPDATE_MANIP_POWER   (171)
343   61        -SET_MANIPULATOR_DC_MOTOR_STATE   (98)
344  255        -SET_PP_MOTOR_STATE   (137)
345  323    -Bleep   (33)
346   45     INIT_SCREEN2
347   18         CrtInit
348   18         GOTOXY
349   18         WRITELN
350   18         GOTOXY
351  321    -Erase_Active_Procedure   (26)
352   18     GOTOXY
353   18     CLREOL
354   18     WRITE
355   18     READ
356  323    -Bleep   (33)
357  317     PROCESS_A_STACK_OF_WORKPIECES
358  101         READ_FEED_TABLE_SENSORS
359  315         RUN_ONE_WORKPIECE_CYCLE
360  151            -RESET_OT_AXES   (39)
361  313            -EXECUTE_ONE_PP_CYCLE   (118)
362  167            -ALIGN_WORKPIECE   (210)
363  219            -Vacuum_Transfer_To_Conveyor   (234)
364  279             SYNC_SEW
365  275                 SET_SM_MOTOR_STATE
366  253                     PRESET_200V_MOTOR_VARIABLES_FOR_REGISTERS
367   18                     PORT
368  273                 READ_SM_ENCODER_COUNTER
369  223                -EXECUTE_ONE_CONVEYOR_STEP_FORWARD   (308)
370   18                 DELAY
371  275                -SET_SM_MOTOR_STATE   (365)
372  271                 CLEAR_SM_COUNTER
373   18                     PORT
374   18                 DELAY
375  273                 READ_SM_ENCODER_COUNTER
376   18                 WRITELN
377   18         DELAY
378  101         READ_FEED_TABLE_SENSORS
379   18         WRITELN
380  105        -LOAD_FEED_TABLE   (110)
381  323    -Bleep   (33)
382  315    -RUN_ONE_WORKPIECE_CYCLE   (359)
383  323    -Bleep   (33)
384  281     Multiple_Elevate_In
385  281        *Multiple_Elevate_In   (384)
386  323    -Bleep   (33)
387  283     Multiple_Pick_And_Place_In
388  281        -Multiple_Elevate_In   (384)
389  323    -Bleep   (33)
390  285     Multiple_Orient_Workpiece_In
391  283        -Multiple_Pick_And_Place_In   (387)
392  323    -Bleep   (33)
393  287     Multiple_Transfer_To_Conveyor_In
394  285        -Multiple_Orient_Workpiece_In   (390)
395  219        -Vacuum_Transfer_To_Conveyor   (234)
396  323    -Bleep   (33)
397  289     Multiple_Conveyor_Index_Forward_In
```

```
398   287       -Multiple_Transfer_To_Conveyor_In   (393)
399   227       -MOVE_CONVEYOR_FORWARD   (307)
400   323   -Bleep   (33)
401   303    Run
402   323   -Bleep   (33)
403    47    INIT_SCREEN3
404    18        CrtInit
405    18        GOTOXY
406    18        WRITELN
407    18        GOTOXY
408   321   -Erase_Active_Procedure   (26)
409    18    GOTOXY
410    18    CLREOL
411    18    WRITE
412    18    READ
413   323   -Bleep   (33)
414   303    Run
415   323   -Bleep   (33)
416   299    Multiple_Elevate_Out
417   297        Multiple_Pick_And_Place_Out
418   295            Multiple_Orient_Workpiece_Out
419   293                Multiple_Transfer_To_Conveyor_Out
420   219                   -Vacuum_Transfer_To_Conveyor   (234)
421   291                    Multiple_Conveyor_Index_Forward_Out
422   227                       -MOVE_CONVEYOR_FORWARD   (307)
423   323   -Bleep   (33)
424   297   -Multiple_Pick_And_Place_Out   (417)
425   323   -Bleep   (33)
426   295   -Multiple_Orient_Workpiece_Out   (418)
427   323   -Bleep   (33)
428   293   -Multiple_Transfer_To_Conveyor_Out   (419)
429   323   -Bleep   (33)
430   291   -Multiple_Conveyor_Index_Forward_Out   (421)
431   323   -Bleep   (33)
432    49    INIT_SCREEN4
433    18        CrtInit
434    18        GOTOXY
435    18        WRITELN
436         18           GOTOXY
437   321   -Erase_Active_Procedure   (26)
438    18    GOTOXY
439    18    CLREOL
440    18    WRITE
441    18    READ
442   323   -Bleep   (33)
443   145   -RESET_OT_ROTATE_AXIS   (71)
444   323   -Bleep   (33)
445   147   -RESET_OT_X_AXIS   (40)
446   323   -Bleep   (33)
447   149   -RESET_OT_Y_AXIS   (56)
448   323   -Bleep   (33)
449   151   -RESET_OT_AXES   (39)
450   323   -Bleep   (33)
451   153   -PREALIGN_WORKPIECE   (211)
452   323   -Bleep   (33)
453   167   -ALIGN_WORKPIECE   (210)
```

```
454   323  -Bleep   (33)
455   171   TEST_POL
456    18       CLRSCR
457   121      -READ_ORIENTING_TABLE_SENSORS   (214)
458    18       WRITELN
459   323  -Bleep   (33)
460   269   JOG_CARRIAGE_MANUAL_CONTROL
461    18       WRITELN
462    18       WRITE
463    18       READ
464    18       WRITE
465    18       READ
466    18       WRITELN
467   267      -JOG_CARRIAGE   (129)
468    18       WRITELN
469    18       DELAY
470   247      -DETERMINE_CARRIAGE_POSITION   (130)
471    18       WRITELN
472   323  -Bleep   (33)
473   103   VIEW_FEED_TABLE_SENSORS
474    18       CLRSCR
475    18       GOTOXY
476   101       READ_FEED_TABLE_SENSORS
477    18       WRITELN
478   323  -Bleep   (33)
479   277   SM_MOTOR_MANUAL_CONTROL
480    18       GOTOXY
481    18       CLREOL
482    18       WRITE
483    18       GOTOXY
484    18       READ
485    18       GOTOXY
486    18       WRITE
487    18       GOTOXY
488    18       READ
489   275      -SET_SM_MOTOR_STATE   (365)
490   323  -Bleep   (33)
491   251   DIAGNOSE_ENCODER_ALIGNMENT
492    18       CLRSCR
493    18       WRITE
494    18       GOTOXY
495    18       WRITE
496    18       GOTOXY
497    18       WRITE
498    18       GOTOXY
499    18       WRITE
500   243       READ_LT_POSN_ENCODERS
501   237      -FORM_GRAY_SCALE_DATA_AS_INTEGER   (132)
502    18       GOTOXY
503    18       WRITE
504    18       GOTOXY
505    18       WRITE
506    18       GOTOXY
507    18       WRITE
508   323  -Bleep   (33)
509    69   TEST_MANIPULATOR_INCREMENTAL_ENCODER
```

```
510    65        -CLEAR_MANIPULATOR_ENCODER_REGISTERS   (122)
511    67         READ_MANIPULATOR_ENCODER
512    18         WRITELN
513   323   -Bleep   (33)
514   265    SET_CARRIAGE_POSITION_MANUAL_CONTROL
515    18         GOTOXY
516    18         CLREOL
517    18         WRITE
518    18         READ
519   263         SET_CARRIAGE_POSITION
520   259             CHECK_DEMANDED_POSITION
521   255                -SET_PP_MOTOR_STATE   (137)
522    18                 GOTOXY
523    18                 CLREOL
524    18                 WRITELN
525   247            -DETERMINE_CARRIAGE_POSITION   (130)
526   261             DETERMINE_PP_MOTOR_POWER_FOR_POSITIONING
527   259                -CHECK_DEMANDED_POSITION   (520)
528    18                 ABS
529    18             WRITELN
530   255            -SET_PP_MOTOR_STATE   (137)
531    18         GOTOXY
532    18         CLREOL
533   247        -DETERMINE_CARRIAGE_POSITION   (130)
534    18         WRITE
535    18         DELAY
536   323   -Bleep   (33)
537   257    PP_MOTOR_MANUAL_CONTROL
538    18         GOTOXY
539    18         CLREOL
540    18         WRITE
541    18         GOTOXY
542    18         READ
543    18         GOTOXY
544    18         WRITE
545    18         GOTOXY
546    18         READ
547   255        -SET_PP_MOTOR_STATE   (137)
548   323   -Bleep   (33)
549   249    DISPLAY_PICK_AND_PLACE_POSITION
550    18         GOTOXY
551    18         CLREOL
552    18         WRITE
553   247        -DETERMINE_CARRIAGE_POSITION   (130)
554    18         GOTOXY
555    18         WRITELN
556   323   -Bleep   (33)
557   245    DISPLAY_ANGULAR_ENCODER_STATE
558    18         GOTOXY
559    18         CLREOL
560    18         WRITE
561   243         READ_LT_POSN_ENCODERS
562    18         GOTOXY
563    18         WRITE
564   323   -Bleep   (33)
565   239    DISPLAY_GRAY_SCALE_ENCODER_IN_INTEGER
```

```
566    18        GOTOXY
567    18        CLREOL
568    18        WRITE
569   237       -FORM_GRAY_SCALE_DATA_AS_INTEGER   (132)
570    18        GOTOXY
571    18        WRITE
572   323   -Bleep   (33)
573   241    DISPLAY_GRAY_SCALE_ENCODER_IN_BINARY
574    18        GOTOXY
575    18        CLREOL
576    18        WRITE
577    18        GOTOXY
578    18        WRITE
579   323   -Bleep   (33)
580    18    CLRSCR
```

APPENDIX C

CONTROL PROGRAM PROCEDURE DESCRIPTIONS

The following procedures are used in the Turbo Pascal coded control program described in chapters 6 and 8. Each procedure is briefly described and listed alphabetically.

1. ABS. A Turbo Pascal procedure to return the modulus of a variable.

2. ACQUIRE_OT_ROTATE_AXIS_INTERRUPTER_EDGE. An alignment table procedure to cause the table to rotate such that the rotary optical interrupter edge is moved beneath the edge sensor.

3. ACTUATE_MANIPULATOR. A Gripper control procedure to cause workpiece actuation by gripper rotation.

4. ACTUATE_MANIPULATOR_2. A Gripper control procedure to cause workpiece actuation, using a different actuation angle to ACTUATE_MANIPULATOR.

5. ALIGN_TILL_L_SENSOR_IS_CLEAR. An alignment table procedure to cause table motion clearing the leading edge sensor.

6. ALIGN_TILL_L_SENSOR_IS_OBSCURE. An alignment table procedure to cause table motion setting the leading edge sensor.

7. ALIGN_TILL_P_SENSOR_IS_CLEAR. An alignment table procedure to cause table motion clearing the pitch edge sensor.

8. ALIGN_TILL_P_SENSOR_IS_OBSCURE. An alignment table procedure to cause table motion setting the pitch edge sensor.

9. ALIGN_WORKPIECE. An alignment table procedure to cause table motion to fully align the workpiece.

10. ASSIGN_12V_DC_MOTOR_PTC_LATCHVALUE. A 12V DC motor procedure to set PTC latch values generating a PWM waveform from a given power assignment.

11. Beep. An operator interface procedure to ring the console bell.

12. Bleep. An operator interface procedure to ring the console bell.

13. CHECK_DEMANDED_POSITION. A Linear Transporter control procedure to determine whether a demanded position has been crossed.

14. CLAMP_FABRIC. A De-stacking unit procedure to clamp fabric in the elevating feed table.

15. CLEAR_MANIPULATOR_ENCODER_REGISTERS. A Gripper control procedure to clear PTC registers used by the roller incremental encoder.

16. CLEAR_SM_COUNTER. A sewing sub-system procedure to clear PTC registers used by the crankshaft incremental encoder.

17. CLREOL. A Turbo Pascal procedure to clear to the end of the current terminal line.

18. CLRSCR. A Turbo Pascal procedure to clear the terminal screen.

19. CONTROL_OTX_DC_MOTOR. An Alignment table procedure to assign a given X axis motor power and direction.

20. CONTROL_OTY_DC_MOTOR. An Alignment table procedure to assign a given Y axis motor power and direction.

21. Clear_Screen_Of_Garbage. An operator interface procedure to clear the option entry line.

22. CrtInit. A Turbo Pascal procedure to initialise the console terminal.

23. DEACTUATE_MANIPULATOR. A Gripper control procedure to de-actuate the manipulator.

24. DELAY. A Turbo Pascal procedure to cause a delay for a given number of milliseconds.

25. DETERMINE_CARRIAGE_POSITION. A Linear Transporter control procedure to determine the carriage position by reading the transporter position sensors.

26. DETERMINE_MANIP_POWER_FOR_SYNCHRONISATION. A Gripper control procedure used in effecting synchronisation of the gripper rotary motion to the linear transporter motion.

27. DETERMINE_PP_MOTOR_POWER_FOR_POSITIONING. A Linear Transporter control procedure used in the proportional position control scheme to determine motor power from the transfer function.

28. DIAGNOSE_ENCODER_ALIGNMENT. A diagnostic procedure to display coarse position encoder states.

29. DISPLAY_ANGULAR_ENCODER_STATE. A diagnostic procedure to display the absolute angular encoder value.

30. DISPLAY_GRAY_SCALE_ENCODER_IN_BINARY. A diagnostic procedure to display the read coarse position gray scale value.

31. DISPLAY_GRAY_SCALE_ENCODER_IN_INTEGER. A diagnostic procedure to display the read coarse position gray scale value in integer.

32. DISPLAY_PICK_AND_PLACE_POSITION. A diagnostic procedure to display the determined pick and place carriage position.

33. DROP_FEED_TABLE_UNTIL_PRESSURE_RELAXED. A De-stacking unit procedure to remove the achieved workpiece-to-griper contact pressure. This would leave the gripper in contact with the workpiece but with in low pressure contact with the fabric stack.

34. Down_Off. A Vacuum Based Transporter procedure to set the down position pneumatic valve off.

35. Down_On. A Vacuum Based Transporter procedure to set the down position pneumatic valve on.

36. EXECUTE_ONE_CONVEYOR_STEP_FORWARD. A Sewing sub-system procedure to advance the conveyor by one step motor step.

37. EXECUTE_ONE_CONVEYOR_STEP_REVERSE. A Sewing sub-system procedure to retract the conveyor by one step motor step.

38. EXECUTE_ONE_PP_CYCLE. An operator interface option to initiate one fabric de-stacking pick and place cycle.

39. Erase_Active_Procedure. An operator interface procedure to clear a procedure marked active at the console.

40. FORM_GRAY_SCALE_DATA_AS_INTEGER. A Linear Transporter control procedure to convert gray scale data to integer format.

41. GOTOXY. A Turbo Pascal procedure to set the console cursor to a given position.

42. GRAY_CODE_TO_BINARY_ALGORITHM. A procedure implementing the gray code to binary algorithm.

43. Grip. A Vacuum Based Transporter procedure to energise the grip pad.

44. INCH_FEED_TABLE_DOWN. A De-stacking unit procedure to lower the feed table by one step motor step.

45. INCH_FEED_TABLE_UP. A De-stacking unit procedure to raise the feed table by one step motor step.

46. INITIALISE_VARIABLES. An initialisation procedure to assign global variable values.

47. INIT_INPUT_OUTPUT. A root procedure to initialise I/O devices.

48. INIT_PTC_1_PI0. An initialisation procedure to configure I/O board 0 PTC device 1.

49. INIT_PTC_1_PI1. An initialisation procedure to configure I/O board 1 PTC device 1.

50. INIT_PTC_2_PI1. An initialisation procedure to configure I/O board 2 PTC device 1.

51. INIT_SCREEN1. An initialisation procedure to print operator interface screen 1.

52. INIT_SCREEN2. An initialisation procedure to print operator interface screen 2.

53. INIT_SCREEN3. An initialisation procedure to print operator interface screen 3.

54. INIT_SCREEN4. An initialisation procedure to print operator interface screen 4.

55. INIT_VIA_1_PI0. An initialisation procedure to configure I/O board 0 VIA device 1.

56. INIT_VIA_1_PI1. An initialisation procedure to configure I/O board 1 VIA device 1.

57. INIT_VIA_1_PI2. An initialisation procedure to configure I/O board 2 VIA device 1.

58. INIT_VIA_2_PI0. An initialisation procedure to configure I/O board 0 VIA device 2.

59. INIT_VIA_2_PI2. An initialisation procedure to configure I/O board 2 VIA device 2.

60. JOG_CARRIAGE. A Linear Transporter control procedure to position the carriage to a demanded position using the jog carriage process.

61. JOG_CARRIAGE_MANUAL_CONTROL. A diagnostic procedure to position the carriage manually to a demanded position using the jog carriage process.

62. LOAD_FEED_TABLE. A De-stacking unit procedure to allow the feed table to be loaded with fabric.

63. Left_Off. A Vacuum Based Transporter procedure to set the left position pneumatic valve off.

64. Left_On. A Vacuum Based Transporter procedure to set the left position pneumatic valve on.

65. MOVE_CONVEYOR_FORWARD. A sewing sub-system procedure to advance the conveyor by one workpiece edge.

66. MOVE_CONVEYOR_REVERSE. A sewing sub-system procedure to move the conveyor back by one workpiece edge.

67. Mainrig. The root segment for the task

68. Make_Transporter_Fully_Operational. An initialisation procedure to start the vacuum based transporter.

69. Move_Down. A Vacuum Based Transporter procedure to cause the grip pad axis to move down.

70. Move_To_Conveyor_End. A Vacuum Based Transporter procedure to cause the transport axis to move to the conveyor end.

71. Move_To_Pick_Up_End. A Vacuum Based Transporter procedure to cause the transport axis to move to the pick up end.

72. Move_Up. A Vacuum Based Transporter procedure to cause the grip pad axis to up down.

73. PACK_BINARY_BYTE. A procedure used in the conversion of gray to binary data to integer.

74. PORT. A Turbo Pascal procedure to write or read to an I/0 address

75. PP_MOTOR_MANUAL_CONTROL. A diagnostic procedure to manually set the linear transporter carriage.

76. PREALIGN_WORKPIECE. An alignment table procedure to cause coarse rotary workpiece alignment.

77. PRESET_200V_MOTOR_VARIABLES_FOR_REGISTERS. A procedure to calculate PTC latch values for 200V DC motors from a given power.

78. PROCESS_A_STACK_OF_WORKPIECES. An operator interface option to de-stack and edge bind a batch of fabric

79. Perform_One_Pick_Up_Cycle. An operator interface option to execute one pick and place cycle.

80. Procedure_Active. An operator interface procedure to display a given procedure as active

81. RAISE_FEED_TABLE_TO_PRESSURE_LIMIT. A De-stacking unit procedure to raise the feed table to attain workpiece-to-gripper pressure.

82. READ. A Turbo Pascal procedure to read data from the console keyboard.

83. READ_FEED_TABLE_SENSORS. A de-stacking unit procedure to recover feed table sensor states.

84. READ_LT_POSN_ENCODERS. A Linear Transporter control procedure to read the position encoder values.

85. READ_MANIPULATOR_ENCODER. A Gripper control procedure to read the roller position encoder value.

86. READ_MANIPULATOR_RESET_CHANNEL. A Gripper control procedure to read the roller TDC datum encoder.

87. READ_ORIENTING_TABLE_SENSORS. An Alignment table procedure to read the alignment and axis sensors.

88. READ_OT_POS_DETECTORS. An Alignment table procedure to read the axis position detectors.

89. READ_SM_ENCODER_COUNTER. A Sewing sub-system procedure to read the crankshaft encoder values

90. READ_WORKPIECE_ALIGNMENT_SENSORS. An Alignment table procedure to read the workpiece alignment sensors.

91. RELAX_WORKPIECE_TENSION. A De-stacking unit procedure to remove stretch in the fabric by an incremental revers motion.

92. RESET_MANIPULATOR. A Gripper control procedure to cause the roller to move to its TDC position.

93. RESET_OT_AXES. An Alignment table procedure to set all axes to their datum position.

94. RESET_OT_ROTATE_AXIS. An Alignment table procedure to set the rotational axis to its datum position.

95. RESET_OT_X_AXIS. An Alignment table procedure to set the X axis to its datum position.

96. RESET_OT_Y_AXIS. An Alignment table procedure to set the Y axis to its datum position.

97. REVERSE_DC_MOTOR_DIRECTION. A procedure to invert the DC motor direction control variable

98. ROLL. A procedure to effect synchronised rolling with the gripper and linear transporter.

99. ROTATE_MANIPULATOR_1. A Gripper control procedure to rotate the gripper by a preset angle.

100. ROTATE_MANIPULATOR_2. A Gripper control procedure to rotate the gripper by a preset angle.

101. ROUND. A Turbo Pascal procedure to truncate a floating point variable.

102. RUN_ONE_WORKPIECE_CYCLE. An operator interface procedure to de-stack and edge bind one workpiece.

103. Read_Vacuum_Transport_Sensors. A De-stacking unit procedure to read the limit switches associated with end of axis travel.

104. Release. A Vacuum Based Transporter procedure to turn off the vacuum grip.

105. Right_On. A Vacuum Based Transporter procedure to set the right position pneumatic valve on.

106. Right_off. A Vacuum Based Transporter procedure to set the right position pneumatic valve off.

107. Run. A procedure to run the edge binding process.

108. SET_CARRIAGE_POSITION. A Carriage position control procedure using proportional control.

109. SET_CARRIAGE_POSITION_MANUAL_CONTROL. A diagnostic procedure to set carriage position from the keyboard.

110. SET_CONVEYOR_STEP_MOTOR_PHASE. A Sewing sub-system procedure to assign the step motor phase states.

111. SET_FT_STEP_MOTOR_PHASE. A De-stacking unit procedure to assign the step motor phase states.

112. SET_MANIPULATOR_12V_MOTOR_PWM. A Gripper control procedure to assign a given percentage power to the gripper motor.

113. SET_MANIPULATOR_ANGLE. A Gripper control procedure to cause the gripper roller to move to a demanded angle.

114. SET_MANIPULATOR_DC_MOTOR_STATE. A Gripper control procedure to to assign the alignment gripper motor direction and power.

115. SET_MANIPULATOR_DIRECTION. A Gripper control procedure to assign a given direction to the gripper motor.

116. SET_OTDISC_DC_MOTOR_STATE. An Alignment table procedure to assign the alignment table rotary motor direction and power.

117. SET_OTDISC_MOTOR_DIRECTION. An Alignment table procedure to assign a given direction to the rotary axis motor.

118. SET_OTDISC_MOTOR_PWM. An Alignment table procedure to assign a given percentage power to the alignment table motor.

119. SET_OTX_DC_MOTOR_STATE. An Alignment table procedure to assign the table X axis motor direction and power.

120. SET_OTX_MOTOR_DIRECTION. An Alignment table procedure to assign a given direction to the X axis motor.

121. SET_OTX_MOTOR_PWM. An Alignment table procedure to assign a given percentage power to the table X axis motor.

122. SET_OTY_DC_MOTOR_STATE. An Alignment table procedure to to assign the alignment table Y axis motor direction and power.

123. SET_OTY_MOTOR_DIRECTION. An Alignment table procedure to assign a given direction to the Y axis motor.

124. SET_OTY_MOTOR_PWM. An Alignment table procedure to assign a given percentage power to the Y axis motor.

125. SET_PP_MOTOR_STATE. A Linear Transporter control procedure to to assign the motor direction and power.

126. SET_SM_MOTOR_STATE. A Sewing sub-system procedure to to assign its motor direction and power.

127. SM_MOTOR_MANUAL_CONTROL. A diagnostic procedure to allow manual assignment of the sewing machine power.

128. SYNC_SEW. A Sewing sub-system procedure to cause one synchronised sewing cycle.

129. Set_Valve. A pneumatic valve control procedure to set a given valve state.

130. Start_Up_Transporter_Safely. An initialisation procedure to ensure the vacuum based transporter starts from a known state.

131. TEST_MANIPULATOR_INCREMENTAL_ENCODER. A diagnostic procedure to display the gripper incremental encoder state.

132. TEST_POL. A diagnostic procedure to

133. TURN_OT_VAC_OFF. An Alignment table procedure to turn the fabric vacuum clamp off.

134. TURN_OT_VAC_ON. An Alignment table procedure to turn the fabric vacuum clamp on.

135. Transporter_Must_Be_At_Conveyor_End. A Vacuum Based Transporter procedure to ensure the transport axis is at the conveyor position.

136. Transporter_Vacuum_Pad_Must_Be_Down. A Vacuum Based Transporter procedure to ensure the grip pad axis is in the down state.

137. UNCLAMP_FABRIC. A De-stacking unit procedure to remove the feed table fabric clamp.

138. UNPACK_GRAY_BYTE. A Linear Transporter control procedure to decode the gray scale encoder data into array form.

139. UNROLL. A De-stacking unit procedure to cause workpiece release by unrolling.

140. UNWIND. A De-stacking unit procedure to cause workpiece release by unwinding from the top of the roller.

141. UPDATE_MANIP_POWER. A Gripper control procedure to assign a new power to the motor.

142. Up_Off. A Vacuum Based Transporter procedure to set the up position pneumatic valve off.

143. Up_On. A Vacuum Based Transporter procedure to set the up position pneumatic valve on.

144. VIEW_FEED_TABLE_SENSORS. A diagnostic procedure to display the feed table sensor states.

145. Vacuum_Transfer_To_Conveyor. A Vacuum Based Transporter procedure to cause one transfer cycle.

146. WRITE. A Turbo Pascal procedure to write to the console without a carriage return.

147. WRITELN. A Turbo Pascal procedure to write to the console with a carriage return.