Feeding and Handling Aspects of an Integrated System for Garment Manufacture.

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Leicester Polytechnic
June 1989.
The fact is, that civilisation requires slaves.
The Greeks were right there. Unless there are slaves
to do the ugly, horrible, uninteresting work,
culture and contemplation become almost impossible.
Human slavery is wrong, insecure and demoralising.
On mechanical slavery, on the slavery of the
machine, the future of the world depends.

Oscar Wilde
Summary

This thesis describes the research undertaken investigating the feeding and handling aspects of an integrated system for automated garment manufacture.

The original aims of the research project were to:

(i) Investigate and produce a prototype two dimensional feed mechanism for garment assembly, and
(ii) Investigate and develop flexible handling equipment for manipulating and positioning garments.

During the course of the project the areas of the investigation were broadened to include the development of a system for computer-based generation of garment patterns.

Each area of research has been undertaken with a view to incorporate it into an integrated system for automated garment manufacture. Such a system has been proposed in the study, however research has been restricted to the areas outlined above.

The results of experimental and development work have proved encouraging and certain aspects of the research have already attracted financial support for further development. In each area of work the potential in further research has been identified.
The research described herein was carried out jointly in the Schools of Textiles and Knitwear Technology and Mechanical and Production Engineering during the period September 1986 to June 1989.

The author would like to express his sincere gratitude and thanks to the supervisors of the research, Dr W J Blackwood (Director of Studies) and Dr W J Loweth (Second Supervisor), for their guidance, encouragement and assistance throughout each stage of the research programme.

I would especially like to thank the Worshipful Company of Drapers, London, for providing the necessary financial support to undertake this research.

I also wish to express my sincere gratitude to the academic and technical members of staff at Leicester Polytechnic, who have assisted in the development work. Thanks is due especially to the following; Dr R Parkin, for his assistance in the development of much of the micro-electronics; Professor D L Munden, for his guidance and help; Dr Comyn and Dr Brewin, for their help with the adhesive aspects of the project; Mr P Gildroy and Mrs I Hill for their help throughout the project; Mrs M J Ryan, for her assistance in putting the manuscript together; Mrs Levy, for helping during adhesive testing; The technicians responsible for manufacturing the various prototypes; and Mr R Capel for his help with the computer-based system for garment patterns.

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Finally I would sincerely like to thank my wife, Grace, for her considerable efforts in typing this manuscript, and for providing me with the support and encouragement which has enabled me to complete this undertaking.

M K Hall
June 1989.
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Chapter 1

Introduction
1.1 Preamble

The U.K. clothing industry is facing intense competition from low-cost high volume imports from the developing countries, and it is being hard pressed to improve productivity in order to compete and in some sectors, survive.

The nature and working conditions of the industry are major factors governing its performance and must be clearly understood before solutions to the problems facing the industry can be proposed. The economic overview which follows, examines its position in the 'league table' of industrial performers and highlights areas of weakness which are likely to have a significant influence on its future prosperity.

Most people associated with the clothing industry will accept that some form of change is necessary. The direction and feasibility of that change however, is something which must be carefully evaluated. Factors other than economics play their part in the complex structure of the industry, such as fashion, seasonal demands, and market trends. These factors offer challenges which must be taken into account before any proposed developments may be considered.

The main areas of study of this particular research programme were fabric feeding and handling aspects of an integrated system for garment manufacture. The scope of the project was later widened to include the area of computer-based pattern generation as it was felt that further research could be carried out in this area.

The research begins by presenting a review of major research
projects being carried out in the United Kingdom, Europe, the United States, and Japan. The review seeks to identify current research interests with regards to clothing manufacture. Following the review, a concept for an integrated system for garment manufacture is proposed. The concept is presented for reasons of completeness and is intended to guide the reader to view the research undertaken by the author as ultimately contributing to the attainment of such a proposed system.

Chapters 4, 5, and 6 detail the research undertaken in each of the following areas:

(1) Computer-based generation of garment block patterns,
(2) Automated fabric feeding to an industrial sewing machine, and
(3) Automated handling of fabrics and other flexible materials.

The final chapter presents the conclusion of the research project along with the discussions. It also identifies areas of further work, along with commercial applications.

A glossary of clothing terms and definitions is included in Appendix R for reference.
The clothing industry has a major role to play in the U.K. economy as a chief customer of the textile industry, main supplier of the retailing industry, major employer and exporter. Chart 1.1 shows the seven sectors over which the U.K. clothing industry is spread. It falls within the Standard Industrial Classification 1980 (SIC) group 453 - Clothing, Hats and Gloves. Hosiery, underwear, dresses, and other items made up by manufacturers of weft knitted fabrics, are classified separately under the SIC number 4363 - Hosiery and other weft knitted goods and fabrics. The classification numbers for the various sectors of the industry can be found in Appendix A.

It is as a major employer that the industry makes its greatest contribution to the U.K. economy. Chart 1.2 shows the position of the clothing industry as an employer, as compared with other major industries. The total clothing and footwear industries employ approximately 30% of the number of employees in the mechanical engineering industries and approximately 40% of the number in the electrical engineering industries. The number of employees involved specifically in clothing exceeds those employed in the telecommunications equipment, domestic electrical appliance, motor vehicle and engines, and instrument engineering industries.

The industry is located in many U.K. regions which suffer from high unemployment. Chart 1.3 shows the number and percentage of employees within the footwear and clothing industries according to geographical location.
1.2.1 Structure of the industry

The clothing industry is very labour intensive with approximately 13.14% of the labour involved in administrative, technical and clerical work. This means it is heavily dependent on manual labour, of which approximately 80% is female. Chart 1.4 shows how the industry is fragmented, with a large percentage of companies employing less than 20 persons. 76% of companies fall within a group specialising in only one process within the manufacturing chain, these companies tending to be small in size.

1.2.2 Problems facing the industry

The major threat to the industry comes from the rising levels of imports of high-volume low cost products. Graph 1.5 shows the value of U.K. imports and exports from 1975 to 1985. It shows that the value of imports of apparel, clothing accessories and footwear exceeds exports of those items by as much as 100%. Chart 1.6 identifies the source of imports and Chart 1.7 the source of exports, showing that a large percentage of imports come from developing countries with a low-wage pay structure.

The impact of rising quantities of low cost imports on employment levels has caused great concern within the industry. Jones attempted to determine the correlation between the level of employment in the U.K. clothing industry and total imports of clothing 1970 - 1983. He concluded that if the annual rate of growth of imports continues unabated the clothing industry is in danger of contracting into insignificance or even disappearing altogether.
The U.K. clothing manufacturing industry was hard hit by the 1980/81 world recession, which was due mainly to de-stocking, high inflation, high interest and low international exchange rates. Productivity in 1980 was 12% lower than in the previous year. Nearly 40,000 employees were forced to leave the industry in the 12 months to March 1981. However, despite the demise of many companies others were spurred on to improve production efficiency to levels which were virtually unknown in other industries. Chart 1.8 shows the index of production for clothing, hats and gloves. The effect of the recession can be seen together with the recovery trend that the industry is making.

Another of the problems facing the industry is the weak price structure. The retail price index for clothing has increased much more slowly than all the other retail price indices in recent years. This is in contrast to other countries (e.g. West Germany) where clothing retail prices have moved much more in line with all the other retail prices. The main reason for the weak price structure is the pressure from large volume low cost imports. This is also reflected in low profitability and low investment levels, especially in small and medium sized companies.

1.2.3 Protectionist measures

The Multi-Fibre Arrangement (MFA) is a scheme under which the most highly developed countries put quantitative limits on their imports of textiles and clothing from developing countries including the countries of Eastern Europe. The scheme was started in order to
relieve the pressure of imports from low wage developing countries on the textile and clothing industries in the developed countries\(^6\).

In return, the developed countries were expected to restructure their textile and clothing industries in such a way as to enable them to meet import competition from developing countries in due course. The MFA is negotiated under the auspices of the General Agreement on Tariffs and Trade (GATT) and is a permitted 'derogation' from GATT's free trade rules. The MFA has recently been renewed for a fourth term and is due to run until July 31, 1991. The arrangement has 43 signatories covering 54 countries; the European Community signs en bloc on behalf of its members\(^7,8\).

The effectiveness of the MFA is a topic widely disputed amongst its signatories. Some exporting countries such as India and China feel that the MFA is too restrictive and would like to see a return to GATT's 'free trade' rules. The European Community want greater access to the markets of the developing countries and are therefore prepared for a more liberal arrangement. The United States on the other hand believe that the arrangement is not restrictive enough and calls for a strengthened, less vague and less permissive MFA, which they consider is essential to the continuing survival of their industry and the livelihood of its 2 million employees\(^9\). Not all trade agreements are negotiated under MFA; the U.K. is free to make bilateral arrangements between itself and exporting countries. This is an important point as not all developing countries are signatories of the MFA.

Some experts believe that, rather than suffering from an import
problem, the U.K. textile and clothing industry suffers from an export problem\textsuperscript{10}. West Germany has high import penetration of its home market but at the same time manages to be an extremely successful exporter. Much of this success however, is due to "outward processing", which leads to high exports of fabric and high imports of clothing (much of which is subsequently re-exported to other countries).

Some of the problems manufacturers encounter when exporting are due in part to barriers put up by the low-cost exporting countries to protect their home market. Many of these barriers, put up by exporting countries classified as "developing", are perfectly legitimate under the terms of the General Agreement on Tariffs and Trade (GATT).

\subsection*{1.2.4 Investment levels}

One measure of the level of investment is to take expenditure on plant and machinery as a proportion of total sales over a period of time. Comparing clothing and footwear with other sectors of industry shows that the levels of expenditure have remained relatively low, see table 1.9. It must be added however, that the clothing and footwear industries are not as capital intensive as other industries. Table 1.10 shows that expenditure on plant and machinery expressed as a percentage of total net capital expenditure is however increasing.

Although useful in comparing levels of investment over a number of years, the figures can be misleading. They do not show how much of the capital expenditure is being invested in state-of-the-art and
advanced machinery as compared to simply replacing standard processing machinery.

1.2.5 Recent situation of the industry

Output recovered in 1984 and 1985 with clothing and footwear performance being only marginally lower than the figures for all manufacturing\textsuperscript{11}. Productivity in manufacturing also continues to rise sharply with textiles, leather and clothing achieving a greater rise than all the other areas of manufacturing\textsuperscript{12}. The retail sales of clothing and footwear have continued to rise since 1981 and their growth in terms of increased volume has been at a faster rate than the average. However, in terms of value the performance is less exceptional, which probably reflects the low rate of price increase of clothing and footwear.

Since 1960 the proportion of consumer income spent on clothing has fallen from 10.3\% to 7.3\%. This has occurred in a period of rising real incomes and a relatively low increase in clothing prices, yet people are still spending less of their income on clothing. Regional spending on clothing shows significant variation, much of which may be due to regional price variations.

Clothing exports for 1986 totalled 1.23 billion pounds which was an increase of 34\% on 1980 figures\textsuperscript{13}. Export performance in both volume and value terms has been very good since the mid 1970's. Some of this gain has been due to the fall in the value of the pound against the U.S dollar. Despite this, the negative balance of trade in clothing has continued to grow under the weight of ever increasing
imports which in 1985 stood at 766 million pounds an increase of 5.7% on 1980 figures.

Company liquidations and bankruptcies in clothing and textiles have risen steadily since 1979. 1985 was a bad year for company liquidations and bankruptcies although some improvement has been shown since. The number of redundancies in the clothing and footwear industries is showing a downward trend since its peak in 1980/1982.

1.2.6 Outlook on the future of the industry

Generally, the figures available for the current situation seem to contain a number of good signs on the productivity, sales, export and employment fronts. Two very worrying features remain however, the continued rise in imports and the long term fall in the proportion of consumer expenditure devoted to clothing.

More expenditure on research and development is vital if the industry is to remain competitive in the face of rising imports. Table 1.11 shows the extremely small proportion of expenditure devoted to research and development in the leather, footwear and clothing industries as compared to other major industries.

Current retail demand requires a quick response from clothing manufacturers, greater flexibility, greater product variety, and improved quality. These aspects are essential if the U.K. clothing industry is to retain, or better, its position in the 'league table' of industrial performers.
Chart 1.1 Shape of U.K. Clothing Industry

- 37.00% Women's and Girls Light Outerwear, Lingerie & infantswear
- 14.30% Mens and Boys Tailored Outerwear
- 14.20% Mens and Boys Tailored Outerwear
- 11.30% Foundationwear, Swimwear and Miscellaneous
- 9.10% Mens and Boys Shirts Underwear and Nightwear
- 8.30% Work Clothing and Mens and Boys Jeans
- 5.80% Weatherproof Outerwear

Output £3164 Million

Source: Dept. of Trade and Industry
Chart 1.3	Footwear and Clothing Industries

<table>
<thead>
<tr>
<th>Region</th>
<th>Employment (Thous.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Ireland</td>
<td>17.7</td>
</tr>
<tr>
<td>Scotland</td>
<td>23.4</td>
</tr>
<tr>
<td>Wales</td>
<td>10.7</td>
</tr>
<tr>
<td>North West</td>
<td>51.6</td>
</tr>
<tr>
<td>West Midlands</td>
<td>19.2</td>
</tr>
<tr>
<td>South West</td>
<td>17</td>
</tr>
<tr>
<td>South East</td>
<td>6.4</td>
</tr>
<tr>
<td>East Anglia</td>
<td>49.2</td>
</tr>
<tr>
<td>East Midlands</td>
<td>64.7</td>
</tr>
<tr>
<td>Yorks. &amp; Humber.</td>
<td>30.6</td>
</tr>
<tr>
<td>North</td>
<td>21</td>
</tr>
</tbody>
</table>
Chart 1.4 Size Distribution of Firms and Plants (1981)

Source: Census of Production
Chart 1.5 Value of U.K. Imports and Exports - Clothing and Footwear

Source: Dept. of Trade and Industry
Chart 1.6 Source of U.K. Imports 1986

Source: Overseas Trade Statistics
Chart 1.7 Source of U.K. Exports 1986

Source: Overseas Trade Statistics
Chart 1.8 Index of Output of Production

Clothing, Hats and Gloves (SIC 453)

Average 1980 = 100

Source: British Business
Table 1.9 Net capital expenditure on plant and machinery as a percentage of total sales

<table>
<thead>
<tr>
<th>Year</th>
<th>Clothing</th>
<th>Footwear</th>
<th>Aerospace</th>
<th>Domestic electric appliance</th>
<th>Pottery China</th>
<th>Office machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>1.0</td>
<td>0.8</td>
<td>2.7</td>
<td>2.3</td>
<td>4.7</td>
<td>2.1</td>
</tr>
<tr>
<td>1976</td>
<td>1.1</td>
<td>0.7</td>
<td>2.0</td>
<td>1.9</td>
<td>3.7</td>
<td>1.9</td>
</tr>
<tr>
<td>1977</td>
<td>1.1</td>
<td>0.7</td>
<td>1.7</td>
<td>2.5</td>
<td>4.4</td>
<td>2.4</td>
</tr>
<tr>
<td>1978</td>
<td>1.3</td>
<td>1.1</td>
<td>2.7</td>
<td>2.8</td>
<td>5.1</td>
<td>2.7</td>
</tr>
<tr>
<td>1979</td>
<td>1.3</td>
<td>0.8</td>
<td>3.7</td>
<td>2.5</td>
<td>5.2</td>
<td>2.6</td>
</tr>
<tr>
<td>1980</td>
<td>1.1</td>
<td>1.0</td>
<td>2.9</td>
<td>2.3</td>
<td>6.8</td>
<td>2.6</td>
</tr>
<tr>
<td>1981</td>
<td>1.2</td>
<td>0.7</td>
<td>2.3</td>
<td>1.9</td>
<td>3.9</td>
<td>2.4</td>
</tr>
<tr>
<td>1982</td>
<td>1.3</td>
<td>1.0</td>
<td>2.4</td>
<td>2.3</td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>1983</td>
<td>1.5</td>
<td>1.2</td>
<td>2.0</td>
<td>2.3</td>
<td>4.1</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Source: PA 1002 Business Monitor.
Table 1.10 Net investment on plant and machinery (acquisitions less disposals) as a percentage of total net capital expenditure.

<table>
<thead>
<tr>
<th></th>
<th>Capital Expenditure</th>
<th>Plant &amp; machinery</th>
<th>Plant &amp; machinery×100% Capital expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>66.9</td>
<td>38.0</td>
<td>56.8</td>
</tr>
<tr>
<td>1980</td>
<td>57.2</td>
<td>34.0</td>
<td>59.4</td>
</tr>
<tr>
<td>1981</td>
<td>52.9</td>
<td>34.0</td>
<td>64.2</td>
</tr>
<tr>
<td>1982</td>
<td>57.7</td>
<td>38.4</td>
<td>66.5</td>
</tr>
<tr>
<td>1983</td>
<td>80.6</td>
<td>48.0</td>
<td>59.6</td>
</tr>
<tr>
<td>1984</td>
<td>99.0</td>
<td>77.0</td>
<td>77.7</td>
</tr>
</tbody>
</table>

Source: PA 1002 Business Monitor.
Table 1.11  Expenditure on research and development in industry

Work performed within industry by sector and product group 1983.

<table>
<thead>
<tr>
<th>Product group</th>
<th>Total</th>
<th>Private</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod. of main industries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3869.9</td>
<td>3513.7</td>
<td>356.2</td>
</tr>
<tr>
<td>Chemical Industry: total</td>
<td>735.0</td>
<td>726.9</td>
<td>8.1</td>
</tr>
<tr>
<td>Mechanical Eng.: total</td>
<td>249.6</td>
<td>210.3</td>
<td>39.3</td>
</tr>
<tr>
<td>Metal working machine tools</td>
<td>13.2</td>
<td>11.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Office Machinery</td>
<td>10.7</td>
<td>10.7</td>
<td>-</td>
</tr>
<tr>
<td>Electronic data process equip.</td>
<td>247.3</td>
<td>246.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Electrical &amp; Electronic engineering: total</td>
<td>1333.6</td>
<td>1115.7</td>
<td>217.9</td>
</tr>
<tr>
<td>Motor vehicles &amp; parts</td>
<td>239.5</td>
<td>229.6</td>
<td>9.8</td>
</tr>
<tr>
<td>Instrument engineering</td>
<td>49.4</td>
<td>37.1</td>
<td>12.3</td>
</tr>
<tr>
<td>Textiles -other than man-made</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fibres</td>
<td>10.2</td>
<td>7.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Leather, footwear &amp; clothing</td>
<td>5.3</td>
<td>2.8</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Source: Dept. of Trade & Industry
1.3 Technological development in the clothing industry

Initial examination of the clothing industry would tend to indicate that since Weisenthal invented the needle with the eye in the centre in 1775; Thimmonier patented the first working sewing machine in 1830; Howe invented the lockstitch in 1856; there has been little fundamental difference between the way stitches are made now and the way in which they were made in the middle of the 19th century.

However, advances in technology involving electronic variable speed machine motors, efficient lubricating systems and new improved materials, have resulted in increased machine speeds as measured by the number of stitches produced per minute. At present the situation has been reached where the speeds obtainable for some classes of machine now exceed the ability of the operator to control the fabric as it is being machined.

The clothing industry has yet to overcome the technological disadvantage of the needle sewing process, which has traditionally required a one to one relationship between labour and sewing units. British Standard 3870 part 1 1982 classifies 6 different classes of stitch in which varying numbers of subclasses exist, making a total of 90 different stitch types. This situation is compounded by the manufacturers who add a variety of material transport and handling systems, not to mention the wide range of needle types that are used within the industry.

Having stated that the needle sewing process puts the industry
at a technological disadvantage, it is unlikely that needle sewn seams for the general apparel market are likely to be replaced in the near or mid-term future by any alternative method which can offer the same strength, quality, decorative or aesthetic characteristics.

Although it would appear that there has been little progress on a technological level in the clothing industry it would be more accurate to say that progress has been sporadic. There have been significant technological developments in the ancillary functions associated with needle sewing. These have changed the nature of production over the years and have replaced old out-of-date working methods.

At the 'front end' of the manufacturing process there have been considerable advances in computer aided design (CAD) systems, for the visual conception of garment styles and fabric design. Also advanced research is still being carried out on the problem of converting the three-dimensional image of the garment into two-dimensional information necessary to produce garment pattern pieces\textsuperscript{14}.\n
In dealing with two dimensional pattern pieces using CAD techniques, the situation is considerably improved. It is now possible to obtain CAD systems, which allow an experienced operator to take a standard pattern piece, digitise it or otherwise convert it into a numerical co-ordinate form for computer manipulation, modify the basic image on the visual display unit (VDU), generate other pattern pieces from it, grade up or down for other sizes, arrange pattern pieces on a lay and even direct a computer numerically controlled cutter.
Fabric cutting technology is also much improved, computer controlled cutting equipment has been with the industry for over a decade. The issue as to whether multi-layer or single ply cutting is more suited to automated production systems is at present being debated. Standard cutting technology involves the use of a reciprocating knife which is plunged into the fabric stack and driven around the pattern outline. Other methods have since become available these include laser and water jet cutters.

Modern sewing machines (despite operating in a mechanically similar way to those of the late 1800's) have advanced to the point where microprocessor control is now becoming an inherent feature. The microprocessor is used to control the stitching pattern, the feeding, ejecting and stacking of the sewn material, the number of stitches produced, and needle position, to name but a few features.

Advances have also been made in material handling systems with the introduction of computer controlled conveying systems. These are used to minimise the amount of work in progress and produce an orderly system of work avoiding the build up of work piles.
1.4 The changing needs of technology in clothing manufacture

At present most manufacturing industries in the U.K. and other developed countries throughout the world are emphasising the need for technological change in their production processes. The clothing industry is no exception and much activity is currently being undertaken to review its present situation. The main driving force behind this initiative is the threat posed by overseas competition in the form of low cost large volume imports. In some categories of apparel, imports to the U.K. are as high as 75%. In the past, an increase in imports did not seem so important, since the clothing industry was able to keep roughly abreast with exports. However in recent years the situation has changed dramatically and the current trade balance between imports and exports is large, see table 1.12.

Any hope of improvement for the clothing industry is at present pinned on technological change, or more specifically automation. Automation can be viewed in two ways, by its technical characteristics and by its effect on the industry. The characteristics of automation can generally be classified according to one of three technological types:

(i) Mechanisation

In clothing terms this refers to the building and use of devices that can be described as worker aids, such as simple mechanical devices similar to templates, guides and other positioning devices, designed to help the operator move
material reliably or perform simple operations on the work.

(ii) Hard Automation

In loose terms this can be described as dedicated machines that have been designed to do one specialist job extremely well. This term has a rather negative connotation, however, in that these machines lack flexibility. The time involved in retooling and performing mechanical adjustments can be very lengthy. Examples can be found in transfer systems designed for western-style jeans manufactured from denim material.

(iii) Flexible (Intelligent) Automation

This type of automation is most favoured because of its ability to respond to changing demands. It is exemplified in the form of an industrial robot. This is defined as:

"A re-programmable multi-functional manipulator designed to move materials, parts, tools, or other specialised devices, through variable programmed motions to accomplish a variety of tasks" [Official Robot Institute of America definition]. It is this type of automation that is currently receiving much attention in the research institutions associated with clothing.

Automation can also be classified by the effect it has on the industry itself. In this context, it can be distinguished as "evolutionary" or "revolutionary". Evolutionary effects are those in which a machine effectively replaces a human worker. The machine may or may not perform its tasks somewhat better than the worker did, but
the key concept is that the task is performed in the same manner as before. Revolutionary automation is characterised as the invention of a machine which revolutionises or drastically changes the way in which a task was previously performed.

Comparing the clothing industry to the textile industry shows that progress in the manufacturing area seems to be relatively slow. The textile industry, faced with similar problems to the clothing industry, has made major progress in process modernisation and automation over the last 5 to 10 years. Examples of these process improvements include automation of opening rooms; the installation of chute-feeds and high production cards; the automation (or part-automation) of drawing; the introduction of open end spinning; the increasing use of shuttle-less looms; the use of automatic systems for handling waste; and the almost universal use of microprocessor-controlled monitoring and reporting of production variables.

In contrast to this many present day clothing plants still rely almost totally on human labour, have confusing paths of material flow, and are operated on a piece-work basis. Some plants do have a high level of mechanisation or hard automation, this usually arises where great quantities of one product are manufactured e.g. denim jeans or shirts.

In the clothing industry emphasis is being placed on more efficient materials utilisation, and on speeding up the flow of material through the factory. This may in fact be more important in the long term than direct labour savings. However the cost of inventory is so high that any technology which allows a garment to
pass through the system in a few hours as opposed to days would be very cost effective. There is an increasing emphasis on automation in sewing and joining technologies as well as material transfer between work stations. It will be seen later that this is the thrust of the current research programmes in the automation of apparel manufacturing.

Idealised, futuristic concepts of fully automated garment manufacture have added to the already wide misunderstanding of automation. To use the word in its correct context would be to define it as the creation of orderly, intelligent, and efficient production system through the interaction of people, machines, computers and automatic feedback control systems to serve to direct functions, detect deviations, and self correct any errors in the functions.16.
Table 1.12 Trade balance by sector (SIC 1980 Group 453)

<table>
<thead>
<tr>
<th></th>
<th>4531</th>
<th>4532</th>
<th>4533</th>
<th>4534/5</th>
<th>4536</th>
<th>4537</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>-46.7</td>
<td>-93.9</td>
<td>+5.4</td>
<td>-128.0</td>
<td>-25.9</td>
<td>+4.3</td>
</tr>
<tr>
<td>1981</td>
<td>-69.0</td>
<td>-107.0</td>
<td>-29.9</td>
<td>-126.2</td>
<td>-52.5</td>
<td>+0.8</td>
</tr>
<tr>
<td>1982</td>
<td>-68.0</td>
<td>-116.0</td>
<td>-54.0</td>
<td>-125.0</td>
<td>-90.0</td>
<td>+1.0</td>
</tr>
<tr>
<td>1983</td>
<td>-56.0</td>
<td>-149.0</td>
<td>-61.0</td>
<td>-131.0</td>
<td>-101.0</td>
<td>-1.0</td>
</tr>
<tr>
<td>1984</td>
<td>-87.0</td>
<td>-184.0</td>
<td>-71.0</td>
<td>-193.0</td>
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<td>1985</td>
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<td>-62.0</td>
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<tr>
<td>1986*</td>
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<td>-162.0</td>
<td>-89.0</td>
<td>-151.0</td>
<td>-171.0</td>
<td>+2.0</td>
</tr>
</tbody>
</table>

* First three quarters only.

Source: Business Monitor (MQ10).

Note: Negative figures indicate that imports exceed Exports.

Key:

4531 - Weatherproof outerwear.

4532 - Women's and Girls tailored outerwear.

4534 - 4535 - Work clothing, men's and boy's wear, shirts, underwear and nightwear.

4536 - Women's and Girls light outerwear, lingerie and infantswear.

4537 - Hats, Caps and Millinery.
1.5 The need for automation in the clothing industry

Clearly it is the survival of the clothing industry that is the driving force behind the need for automation. However, the size advantage enjoyed by the low-wage countries is such that automation alone can in no way be regarded as the universal remedy to the problems facing the clothing industry\textsuperscript{17}. The case study set out in Appendix B serves to illustrate this point.

This case study may lead the reader on to ask the obvious question 'Why bother using automation to improve productivity when it is less costly to have the products made in countries with lower labour costs?' The question can be answered in a number of ways. Firstly, there is always the need for a nation to be able to clothe itself, particularly in the event of economic or political crisis. The rate of decline of the clothing industry has been such that in some countries (e.g. Sweden) it has already dropped below a viable size threshold. Secondly, the erosion of clothing manufacture leads to the erosion of upstream textile manufacturing as well, employing an additional 37 million people in the developed economies. Thirdly, there is a balance of payment requirement in some countries that the lack of a domestic clothing manufacturing competitiveness can only worsen. Fourthly, the retail industry will draw in even more imports if it cannot get what the consumer requires from the domestic market. Finally, there is the social imperative that this industry provides jobs on a large scale, the elimination of which would add to an already dire situation faced by many countries.
The only conclusion that can be drawn from the above argument is that the industry is faced with a 'do-or-die' situation with regard to automation. Parallels can readily be drawn with many industries faced with intense foreign competition. In these industries, which have managed to successfully compete with low wage cost competition, there has been a heavy investment in technology to make it more capital-intense, justified by the saving in high-cost labour and in the ability to supply a different or superior product. To the extent that, and for the time being the under-developed countries have not been able to justify, acquire or maintain that technology, it has given the high-cost economies the means of survival and growth in these industries. German steel, Italian cars, Japanese audio/tv, American textiles are all very good examples of this approach, where domestic high wage countries are competing successfully with low-wage sources.

It is often stated that the sole purpose of automation is to replace human labour. Many advocates of automation in the clothing industry do acknowledge that advanced automation will indeed lead to job losses but point out that the human dilemma will be far worse if industry is forced to practice labour-intensive manufacturing processes to the point of extinction.

More specifically automation can be used:-

(i) To improve the quality, the utility, the appearance, the desirability; in short the marketability of the product, thus selling more units and generating more income.
(ii) To improve the efficiency of the production process, producing more for less, thus reducing unit costs while supplying the increased demand.

(iii) To permit optimum management control of the entire process of manufacturing and marketing through computer based planning information gathering and performance monitoring, thus orchestrating the economic interplay of income and outflow to produce and to maximise profitability.
1.6 From automation to robotics in the clothing industry

In section 1.4, automation is defined according to one of three technological types: (i) Mechanisation; (ii) Hard automation; and (iii) Flexible (intelligent) automation. The question now arises, what constitutes a robot? This has led to much confusion in the clothing industry, and was highlighted by the author, in a review of automation at the IMB exhibition Cologne. Many of the automated machines on display were described as 'robotic'. The question as to what constitutes a robot is difficult to answer, since there exists differences in the terminology used to describe them. Appendix C includes a classification which may be used to describe robots.

"Second generation" robots are generally considered to be intelligent devices, with the capabilities to respond to changes in the working environment. By 1980's standards, many of the devices classified as fixed sequential or variable sequential robots, should not to be classified as robots.

Robots are generally considered for use because compared to a human worker, they tend to yield a product of more consistent quality, and produce a more predictable output. Their flexibility is very apparent when compared with the rigidity of hard automation systems. A robot can be re-configured quickly (through the use of specialist software and hardware accessories) to perform a large variety of functions. In contrast to this, hard automation has a fixed motion which generally has no redundant degrees of freedom to allow it to process products outside its narrow range. The
generality of a 'standard' industrial robot however, means that it has redundant links and features which can result in a slower processing time than a machine which has been designed for a specific task.

Recent manufacturing trends have been to produce products with a relatively short life cycle. This normally requires manufacturing lines to be re-configured or replaced. A flexible system incorporating robots allows a higher percentage of components to be salvaged, or the system can be quickly adapted to meet the new requirements. Owen states that there are presently six recognisable configurations of robots:– polar, arm and elbow, cylindrical, cartesian, gantry and SCARA, these are shown in figure 1.13 (a) to (f).

The use of robots as part of the manufacturing process in some industries, notably the automotive industry, is becoming very evident. The question is whether such a level of automation can ever be established in the clothing industry. To some, the dream of a completely 'operatorless' factory, where garments are made by robots, is a dream within the reach of the available technology. As with all dreams however, one is faced with a certain degree of reality. One of the first problems in robotising the clothing industry is, unlike other industries the raw material being processed gives rise to technical problems which prevent "standard" industrial robots fitted with grippers being used.

It has been stated that in order for robots to become a reality in the garment-making industry, they would require to possess the following capabilities:–
1. The ability to recognise arbitrarily shaped two-dimensional pieces;
2. The ability to ply separate and pick up small and large two-dimensional pieces, in a controlled manner;
3. The ability to align fabric pieces, part-to-part and part-to-machine;
4. The ability to re-align these during the sewing operation, to allow compensation for changes in profile without loss of control; and
5. The ability to sense the need for, and take appropriate corrective action during the sewing operation.

It was further stated that a robot displaying capabilities 1-4 could be applied to 26% of pre-assembly sewing operations. Increasing by a further 11% if sensing (item 5) was included.

It is generally agreed that the introduction of robotics into the clothing industry will not happen overnight and is still some way away. The industry will however have to eventually embrace automation (which includes robotics) to cut its reliance on labour, in order to stay competitive in very competitive world markets.

The challenge facing the industry with the introduction of robotics, must be one of cost effectiveness. A machine designed to be ultra-flexible will almost certainly reflect its flexibility with increased costs. Clark states, there is a common misconception about robots in that they are best suited to repetitive tasks. This
misconception is in fact untrue, because if a task requires the same operation to be repeated time after time, then the operation is best served by a dedicated machine. Robots should only be used where there is a need for flexibility. It has also been stated that robots are not yet cost-effective in most large-volume production applications, because special large-volume production machinery can operate at higher speeds and perform more efficiently. Robotic systems only gain the edge when frequent changes in operation are required\(^26\).

At present the application of robots in the clothing industry has a number of limitations, it is likely their application will be "evolutionary" rather than "revolutionary", with the automation/robotisation of stand-alone modules. These eventually being coupled together to create larger sub-systems requiring reductions in manual labour content and interaction\(^27\). People will continue to play an important role in garment making as; (i) the industry is still a long way from automating effectively some of the three-dimensional sewing operations; (ii) The experience people acquire and their eye-hand coordination cannot easily be duplicated in a robot; and (iii) robots can do no more than they are told to do, and no robot has ever invented a creative idea.

The present use of robotics in the clothing industry is still very limited and as Disher\(^28\) reported in a review of robotics at ITMA 1987, "the few semi-robots for clothing were restricted to pick and place automats moving single plies of fabric". Automation and hence robotics will eventually be taken up in the clothing industry, according to Adeline\(^29\), who states:-

35
"Like automation, robotization should also improve quality while reducing the impact of absenteeism and staff turnover; three problems that have plagued the industry for as long as it has existed. For those reasons as well as for economy, the industry is likely to accept robotization as soon as it becomes available, even though it now expresses doubts about its needfulness".
Figure 1.13 Configuration of Robots

a) Polar

b) Arm and Elbow

c) Cylindrical
d) Cartesian

e) Gantry

f) SCARA
1.7 Social impact of the developing technologies

In order for the developed countries to be able to compete with the low-cost labour producers of the developing countries, it is generally accepted that the labour content needs to be reduced by as much as 50%. This reduction to be achieved by the introduction of automated equipment. The manpower requirements of the industry will therefore change dramatically over the next few decades, with great social implications, since the clothing and textile industries are major employers in the U.K.

Some unions are no longer vehemently opposed to the automation of the industry, as they appear to be faced with a double-edged sword. If automation is increased it is likely manpower requirements will be reduced; whilst without increased automation, the industry as a whole will not be able to compete with low-cost foreign imports and as a consequence will diminish, having an even greater effect on manpower requirements.

Accepting that some form of technological change is inevitable in the industry, and not wishing to hinder progress (or survival) unions are faced with the problem of how to best safe-guard the future of those employed in their industry. One way this is being achieved is by encouraging management to adopt a policy of re-training those employees displaced by new technology for equally satisfying positions within the company. Such a policy helps to convince the remaining employees that the introduction of new technology will not necessarily result in redundancies.
Another reason stated for introducing automation, is the dire shortage of skilled workers and an extremely high labour turnover in the clothing industry. This point was discussed with a research officer for a national union having a membership of over 47,000 in the hosiery and knitwear industries. In reply it was stated that evidence exists which shows the industry does indeed suffer from the lack of skilled workers and high labour turnover. However, high labour turnover was mainly due to the fact that over two thirds of the industry is made up of females, who leave their employment to get married, start families, and other personal reasons. It was also stated however that this is the traditional structure of the industry and the industry itself has done a lot to encourage this high labour turnover by not making the conditions more attractive, and thereby encouraging workers to remain.

The lack of skilled workers is again largely attributed to the industry which has not done enough over the years with regard to training. Only the larger companies tend to provide training for their employees, usually in-house. These trained personnel are very often attracted away from the company by smaller companies offering greater remuneration.

One product of automation is usually the de-skilling of a particular operation. This in effect counters the lack of skilled personnel, and increases the productivity of the operation. De-skilling an operation, especially for a skilled employee who continues to carry out the task, can greatly reduce the morale of the employee. This loss of morale can then spread through the company
leading to the general opinion that the introduction of new technology is not beneficial to them.

Rosenbrock\(^3\), in his paper on this subject poses the question - 'What kind of work will be provided in the future, in the areas which are affected by technological change?' Referring to past experience, and quoting from the theories of Ure and Taylor, he expressed the opinion that, where the situation has previously occurred, the outcome has not always been encouraging, with human operators relegated to performing trivial tasks such as attending to the automatic machines.

Rosenbrock expresses fears that human ability is being misused. An analogy is drawn with the mechanical engineering industry. It is suggested that an engineer would never consider using a general purpose robot for simple 'pick-and-place' functions. A human on the other hand, with their superior abilities are sometimes asked to perform such simple operations. He goes on to state that the intention behind automation is clear; it is to replace the skilled worker by a machine (or computer) leaving perhaps some unskilled work still to be done by people, who will eventually be replaced by a machine.

An alternative route for automation is proposed, whereby new technological developments are researched and developed with a view to the role that the worker will play in the final system. If the final system is to contain both machines and people [nothing can be produced without people] then the part played by both should be carefully considered. Although humans are not as consistent and
predictable as machines, they can be extremely flexible and can quickly react to unforeseen circumstances.

To obtain a truly flexible system without human intervention is extremely difficult and indeed expensive. Systems, therefore, need to be designed with human activities which reflect the expectations, skills and abilities of the worker. The aim should be to make the workers' skills more productive, by designing automated systems which accepts and collaborates with them. Existing skills need not be allowed to become fossilised and unrelated to new technology, but should be allowed time to evolve into new skills.

The final point he makes is that it is extremely difficult to convince engineers and scientists (East or West) that machines should be subordinate to human workers. A similar approach to the development of technology is held almost universally in all industrialised countries. A great many of those actively engaged in development do not believe:

(i) Human beings have properties not possessed by machines, or

(ii) The ability to construct machines is inherently limited and it is doubtful whether or not it will be possible, despite all the advances in science and technology, to construct a machine which can equal or surpass the abilities of a human being.
Chapter 2

Review of Major Research Projects in Automated Clothing Manufacture
2.1 Japanese research initiative - MITI

Research and development of an "Automated Sewing System" (ASS) was started in 1982 for the purpose of establishing the various technologies necessary for an automated sewing system. A system that would allow efficient small quantity production of a great variety of apparel products.

The total system seeks to establish an automated sewing system for small quantities of a variety of apparel in small and medium sized sewing enterprises, which will reduce the per-piece manufacturing time by more than half, compared with existing techniques. The research includes both a study of an automated production system according to the development procedures of flexible manufacturing systems (FMS) and Flexible Automation (FA), and a study of automation from the apparel side, by classifying research objectives into five apparel types; tops, bottoms, dresses, sportswear and nightwear.

2.1.1 Background to the automated sewing system project

In Japan the textile industry is very important in terms of economy and social factors. The number of employees concerned with textile (including their families) is approximately 10 million. Approximately 10% of the Japanese population derive their living from the textile industry. The Japanese textile industry, as in other advanced countries, is facing a number of problems. The first problem is the diversification of products and rapid change of consumer
demand. The industry cannot cope with this trend because it has a large volume production system based on speculative demand. The second problem is international competition. The surrounding countries are increasing their exports to Japan, but Japan's exports of textiles have decreased.

In order to overcome these problems the Japanese are attempting to change their textile industry. The changes are:

(i) Textiles are to be made based on actual and not speculative demand; and
(ii) The shift to manufacturing textile goods which have a high added value, and are different from those of other countries.

The Japanese felt that for a successful change in the textile industry, the clothing industry must first of all change, because it is closer to the consumer and adds high value to the goods. The clothing industry though has its own specific problems namely:

1. Highly labour intensive.
2. Large number of small enterprises.
3. Small capital equipment.
4. Low productivity.
5. Large financial losses due to speculative production.
2.1.2 Technological developments leading up to ASS

Efforts at automating clothing production were made before the "Automated Sewing System" project. "System J" was one of the forerunners of the current project, it was started in 1970 and discontinued in 1975. The project was modelled on the Singer Company's project (System 2000) which was started in 1967 and discontinued in 1969. The "System J" project was planned as one of MITI's large scale projects but was unable to get approval by the Ministry of Finance, because it was viewed at the time as being impractical. A three year sub-programme of "System J", the "Automatization of material handling of limp fabric" did however get approval and was carried out by the National Research Institute. Many of the researchers associated with "System J" are working on the present project. Table 2.1 shows technological developments leading up to the present project.44

["System J" was a name given to the project by MITI]
### Table 2.1 Technological Developments In The Japanese Apparel Industry

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 1969 - 1970</td>
<td>System J</td>
</tr>
<tr>
<td>1971 - 1973</td>
<td>Automation of material handling of limp fabric</td>
</tr>
<tr>
<td>2. 1974 - 1976</td>
<td>Automatic sewing machine of band loop</td>
</tr>
<tr>
<td>3. 1974 - 1976</td>
<td>Computerised management system of Apparel manufacturing process</td>
</tr>
<tr>
<td>4. 1975 - 1978</td>
<td>Systemation of material handling in parts sewing process</td>
</tr>
<tr>
<td>1976 - 1977</td>
<td>Making material handling technology effective in parts sewing process</td>
</tr>
</tbody>
</table>
2.1.3 Large Scale Projects

The Large Scale Project is formally called the National Research and Development Programme. It was founded in 1966 by the Agency of Industrial Science and Technology (AIST) MITI. At present this project supervises large scale developments in every field of industrial and mining technology, except energy. In 1984 eight such projects were underway, the budget for 1983 was US$70,000,000. Projects are selected if they are regarded as urgent research and development programmes, which require large budgets and long range programming, and also involve large risk. These are designated large scale projects in the interest of both public and industrial sectors. There are five basic criteria for selecting projects:

1. R & D of technology for advancing the industrial structure.
2. R & D of technology which is expected to make a great impact on the progress of manufacturing and mining.
3. R & D of technology which cannot be undertaken by private firms because of the large investment requirements, long term programming, absence of profit motives, high risk, etc.
4. R & D of technology with clearly specified targets and well-examined attainment prospects.
5. R & D of technology to be carried out in co-operation with universities and industry.

"Automated Sewing System" was chosen as a Large Scale Project because it satisfied all the above criteria.
2.1.4 Management of research and development

The Industrial Technology Council was established as an advisory body to the Ministry of International Trade and Industry (MITI). The council has the task of investigating and deliberating on important matters concerning manufacturing and mining, science and technology. The National Research & Development (NR&D) committee is responsible for selecting the projects, deciding on the basic programme of each project and implementing the plan for each year. The board of NR&D selects institutions with the ability to undertake research and development, and evaluates the results obtained. The automated sewing system project is directed by the NR&D committee.

The Technology Research Association of Automated Sewing System (TRAASS) was established in 1983, as an executive organisation of the Large Scale Project of AIST. The Association consists of one semi-public corporation and 27 private companies, see table 2.2. [A list of the member organisations is presented in Appendix D]

The Agency of Industrial Science and Technology (AIST) legally possesses all the results of research and development under the Large Scale Project, even those obtained by participating private companies entrusted with financial assistance from AIST including those obtained by affiliated laboratories and institutes under AIST\textsuperscript{35}. 
Table 2.2 Members of TRAASS

27 Private Companies:

<table>
<thead>
<tr>
<th>Industry</th>
<th>Count</th>
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<tbody>
<tr>
<td>Apparel</td>
<td>10</td>
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<tr>
<td>Textiles</td>
<td>3</td>
</tr>
<tr>
<td>Sewing machines</td>
<td>5</td>
</tr>
<tr>
<td>Dying &amp; Finishing</td>
<td>2</td>
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<tr>
<td>Interlining cloth</td>
<td>1</td>
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<tr>
<td>Electronics</td>
<td>4</td>
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<tr>
<td>Machinery</td>
<td>1</td>
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<tr>
<td>Chemicals</td>
<td>1</td>
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</table>

1 Corporation:

Textile Industry Rationalisation Agency

The TRAASS is supported solely by the member companies.
2.1.5 Basic programme of the Automated Sewing System

The period of the project is from 1982 to 1990 with a total estimated cost of 13 billion yen (50-60 million U.S. dollars). The concept of the Automated Sewing System is shown in figure 2.3. The research and development of the project is shown in figure 2.4, and the flow chart of research and development shown in figure 2.5.

The purpose of the project is to develop the necessary technologies for an efficient diversified, small quantity production system. The system will be able to respond to trends such as the diversified consumers' demand and short cycled fashion, it is not aimed at large-volume production.

The project has four fundamental targets each involving a number of key technologies\textsuperscript{36,37,38}. The outline of each target is briefly described below.

(I) Sewing Preparation

The objectives of this area relate to the introduction of fabric materials for the process proceeding sewing, these are classified into four sub-elemental techniques (key technologies):

1. Evaluation of physical characteristics

A data base will be established for setting up optimum working conditions for the cutting and sewing processes. The Kawabata Evaluation system (KES) [Discussed in Chapter 6], a high shape change and flexibility tester, a shape stability tester and others are being developed for measuring fabric properties and characteristics.
2. Stability of fabrics

In order to facilitate handling of fabrics in the sewing process, research into the techniques for temporarily or permanently stabilising fabrics and on remediying texture and curvature are being undertaken.

3. Advanced pattern making

The development of advanced (or high-performance) patterns for three dimensional sewing. The process involves the transformation, by software techniques, of widely used patterns into geometric elements. The purpose being to reduce the labour content in this area.

4. Inspection, spreading and cutting of fabrics

This area is divided into two parts, fabric inspection and fabric spreading, and cutting. Fabric inspection aims to establish a system that can automatically detect defects. The mesh knife cutting method is being evaluated. Also being studied is a method of converting cutting pattern data into mesh signals including a method for marking to avoid defects in the fabric. Laser cutting techniques for single ply cutting are also being investigated.
(II) Sewing and Assembly

The objectives of this area are the completion, by sewing, of fabrics that have been cut and prepared for sewing. This task is at present the most labour intensive. Systems are being developed for making parts in accordance with sewing information etc. which is integrated into the cut pieces of fabric, and performs assembly sewing by combining the pieces. There are three key technologies associated with this area:

1. Pre-sewing processing

In order to make the sewing process more efficient, techniques such as folding and temporary adhesion of pieces are being developed. Temporary joining by fluid is further being studied.

2. Highly sophisticated sewing

New sewing systems and mechanisms for automating sewing which go beyond traditional methods, are being developed. This involves three dimensional sewing techniques based on two principles:

(i) The sewing machine is moved along a pre-programmed path (or the fabric is moved relative to the sewing machine).

(ii) A technique called generative sewing is used, where a three dimensional support is not used, the three-dimensional form is generated (in real time) by the seam lines.

This area of work also involves the development of a lightweight compact sewing machine which can be carried on the end of a
robotic manipulator. Also being studied are developments in machine heads suitable for flexible manufacturing.

3. Highly sophisticated pressing

Research is being carried out into the automation of the finish pressing process by using a flexible dummy. The dummy is modelled on a human body, and is capable of changing its dimensions and profiles. Pressing of the garment on the dummy is achieved by internal and/or external means.

(III) Fabric Handling

This area of research involves the development of techniques for handling fabrics, from the completion of cutting stage through to the finish pressing stage. It requires the development of devices for conveying and positioning of the fabric between processes. The work is divided into three areas:

1. Pick-up of limp materials

This area involves the development of mechanisms for handling limp materials, simulating the actions of the human operator. Fabric holding devices are also being developed which can align and hold two plies of fabric during sewing.

2. Precise positioning of fabrics

This involves the positioning of fabrics accurately in an appointed place of the processing machine, and mating this with another piece of fabric. Various wrist modules for the robotic
manipulator are being studied, along with vision systems for the mating of parts.

3. Transfer of limp materials

An initial study was made of the way in which materials are carried during the making-up process. This analysis will be used to develop a conveying system arrangement for automatic transfer of the fabric between processes.

(IV) Production Control

This area concerns system management and control techniques which are aimed at reducing the lead time in automated sewing plants. The research involves four elements:

1. System control

This involves the research and development into finding the optimum process arrangement, load balancing and process control. This was thought necessary to prevent the reduction in output due to change-overs in product type.

2. Inspection and fault diagnosis

This area concerns the study of automatic in-process inspection of materials, using vision systems to detect faults. It also includes research into trouble shooting techniques to monitor the performance of automated processing equipment.
3. Control signals on pieces and parts

This area involves developing techniques for encoding control data onto the parts as they are cut. The data will be used to control the automated equipment used for processing the parts.

4. Recognition of information on cut pieces and parts

This final area of work concerns the development of recognition techniques which will identify the image information of parts, such as shape, working position, pattern matching, superimposition etc. It involves the use of vision systems and data capture techniques for the data encoded on the cut parts.
Figure 2.3 Concept of Automated Sewing System
### Figure 2.4 Research and Development Schedule

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<td>1. Research of total system</td>
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<td>2. Research of elemental technologies</td>
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<tr>
<td>(1) Sewing preparation technology</td>
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<td>(2) Sewing and assembly technology</td>
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<td>(3) Fabric handling technology</td>
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<td>(4) System control technology</td>
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- 1982: Conceptual design
- 1983: Basic design
- 1984: Study of automation of production system
- 1985: Details of test plant
- 1986: Construction, operation and general evaluation of test plant
- 1987: Supporting study
- 1988: Operation test
- 1989: Operation test
- 1990: Operation test
Figure 2.5 Flow Chart of Research and Development of Automated Sewing System

1. Development of Total System
- Tops
- Bottoms
- Dresses
- Sportswear
- Nightwear

5. System Management and Control Technology
- General Management
- Inspection and Troubleshooting
- Control Information Providing
- Information Recognizing

2. Sewing Preparation Technology
- Fabric Characteristic Evaluation
- Fabric Stabilization
- High Perf. Cutting Pattern
- Fabric Inspection
- Fabric Spreading & Cutting

3. Sewing Assembly Technology
- Sewing Pre-processing
- Parts Sewing
- Assembly Sewing
- High Perf. Pressing

4. Handling Technology
- Fabric Holding
- Positioning
- Conveying
2.1.6 Implications of the MITI research project

The "Automated Sewing System" was chosen as one of MITI's large scale projects because it was felt that its effects would be large and many. The Japanese expect the benefits of their R & D to be in two forms; direct and indirect.39. The direct benefits of the project being:

1) Improvement of productivity.
2) Rational utilisation of the labour force.
3) Reduction of total costs.
4) Improvement of product quality.
5) Promotion of a knowledge intensive apparel industry

On the fourth point the statement was made that the quality may not be as good as that achieved by a highly skilled worker, but better than that produced by unskilled workers. So, the quality of clothing produced will, on average, be improved or at least equalled.

From a technological point of view MITI feel that their research and development will increase the knowledge of handling soft and flexible materials. It is expected that this will have indirect benefits, not only in the clothing industry, but also in the medical world (handling of the human body). Other indirect benefits, relate specifically to the clothing industry and are expected to be of help to small manufacturers, who need not be disadvantaged by labour shortages.
On a more general note, some Japanese writers are of the opinion that Japanese management, workers and consumers are unanimously in favour of the robotisation of Japan's industries. It is claimed that:

(i) Management are in favour because:-
- robots can substitute diminishing labour.
- robots do not go on strike.
- robots can work 24 hours per day if necessary.
- robots can produce products of equal quality.

(ii) Workers are in favour because:-
- they are freed from boring monotonous tasks.
- they do not have to work in hazardous environments.
- they do not have to be worried about unemployment as lifetime employment with a company is a general policy.
- they will financially benefit if robotisation increases the companies production.

(iii) Consumers welcome robotisation because of the better quality and cheaper prices of the robot-produced products.
2.1.7 Progress of the "Automated Sewing System" project

The aim of the project was to develop a fully integrated "Automatic Sewing System", in order to fully automate the sewing and pressing operations of clothing production. To achieve this, all aspects of clothing production have been addressed such as: fabric variations; efficiency of cutting patterns; pre-sewing and assembly techniques; and the other areas outlined in the basic programme earlier.

At the time of writing, it can be seen from figure 2.4, the research and development schedule, that the project should be nearing the end of the study of automatisation of the production system, and nearing the period where details of the test plant should be emerging. As with many scheduled research programmes it is never easy to determine whether a project is running completely to schedule. This is more difficult with a large scale project, although various progress reports have emerged since the project began. These will be discussed further.

One of the first reports concerning the project was published in November 1983. In the article progress reports were presented in; pattern making; and pre-sewing. The following is a brief resume of the progress made.

i) Fabric inspection

At the Negano Textile Research Institute it was reported that considerable progress had been made in using mini computers to produce "handle" or "hand" profiles on the Kawabata system. At the
time it took about three hours for a fabric to be tested, mainly because the system relies on the manual placement of fabric pieces in the test equipment.

ii) Material stabilisation

Two avenues to achieve fabric stabilisation were being explored. The first method involves physical restraint of the fabric using plastic film, and the other involves applying chemicals to the fabric to stabilise it and subsequent removal of the chemicals after completion of the assembly process.

(iii) Pattern making

This area of research is being undertaken by Toray Industries, who have manufactured approximately 50% of the computer aided design (CAD) systems in Japan. This has involved close co-operation between industry and academia, and development work in this area is moving very rapidly.

iv) Pre-sewing

Although many sophisticated automatic spreading machines are being used, much of the spreading was still being performed manually. It would appear that the Japanese are not only developing their own technologies in this area, but are also adopting existing technologies. The Gerber cutting system, and the Spring Mills Automatic Cross Inspection System are being utilised and closely evaluated.

During this period there was no evidence that progress had been made in; the area of automatic pressing; in the area automated assembly; or in the automation of work flow. However, there was some
evidence put forward that the MITI Industrial Technology Research Institute felt that transferring goods between assembly processes, and establishing the rate of process flow would be more difficult to achieve than the automation of the sewing operations.\(^4\)

The above progress study was made during the early life of the project, it was included to show that a concerted effort was being made to achieve the goals of the project. However, the study was perhaps made too early to accurately evaluate whether real progress was being made. A more recent project progress report has been made by Aisaka, Director-General of the 4th department at MITI’s Research Institute for Polymers and Textiles. In his review of progress he covers in depth the studies being carried out in the four main areas of research.

A more objective review of current progress was recently presented by Hughes, assistant Director of Textile/Clothing Technology Corporation (TC).\(^2\) His report covers the unveiling of major technological developments in the "Automated Sewing System" project. Below is a brief resumé of those developments, which relate mainly to the pre-sewing activities:

(i) **Automated fabric inspection**

A fully automatic unit was demonstrated that was designed to identify the problem areas of width and length variations, contamination, location and type of defects, pattern or print areas, wrinkles and colour or shading variations. The system incorporates conventional mechanical and optical sensors, two and three
dimensional scanning systems using video cameras and image processors, these are all networked to the main computer. The future development plans include research into the setting of industry standards, the measurement of stripe widths, increasing the inspection speed and reducing the costs of the machinery.

(ii) Fabric stabilisation

A system has been developed which contains two distinct elements. The first involves the one-sided coating of fabric with a unique resin material which is applied either by a mesh roller or is sprayed on (depending on the fabric). The fabric is then passed through an infra-red oven where the coating is cured. The second part of the system reads the grain or stripe distortion. Based on the detector reading, the system can correct the distortion by the combined use of bow and skew rollers. The grain correction is checked before the fabric enters the fixation section, it must be within a deviation of +/- 2%. If it is passed then it will be steam pressed seven times, in order to stabilise the corrected fabric. The system is completely computerised.

(iii) High performance cutting patterns systems.

Research has led to the development of 63 rules relating primarily to the way patterns mate with each other. If the manner in which two pattern pieces are joined together or the curvature of the seam lines fall within one of the 63 rules, the computer then regenerates a new pattern by combining the two into one with related slits, notches and darts as required.
(iv) Automated cutting

A laser beam cutter has been developed for single ply cutting and a mesh knife cutter for multiple plies of small parts and difficult fabrics. The laser system combines automatic spreading with cutting. The parts have to be manually removed, although it was stated that they were working on automated parts removal. The system incorporates a stationary laser unit with the laser beam being driven through the X,Y co-ordinates by means of a mirror. As the focal point of the lens alters, the focusing lens is manipulated accordingly. The system is integrated with the inspection system, hence defects can be avoided. The entire cutting area is enclosed, and ozone is removed during operation.

The mesh knife system could be considered as a variable die cutting system. It consists of a matrix of 680 vertical cutting blades nested in a mesh pattern. The nested pattern can have two modes where either 4 or 8 blades are used. The blades can be extended by their own solenoids and locked into position. The blades are selected or de-selected by computer to approximate the line or curve to be cut, as it passes intermittently under the cutting assembly. As with the laser system, defect avoidance information is also used to avoid cutting a defective area.
2.2 United States research initiatives

As with the Japanese textile and clothing industry, the United States clothing industry is facing intense competition from low-cost imports. It has been stated that the clothing industries in the industrialised nations are unable, with current technologies, to retain their markets because the differences in labour costs are so great. At 1985 prices the hourly rates of clothing production workers in Korea, Taiwan and Hong Kong ranged from US$0.70 to $1.23. In contrast to this the rates in the U.S. and European countries ranged from US$5.70 to $10.40.

In August 1983 Kurt Salmon Associates (KSA), a world renown consultancy company, prepared a report for the American Apparel Manufacturers Association (AAMA) and the U.S. department of commerce entitled "The competitive needs of the U.S. Apparel Manufacturing Industry". The report stated that the average cost disadvantage between the U.S. apparel industry and the developing nations is approximately 14.7%. This means that a direct labour content reduction of 40 - 50% would need to be made in order for U.S. industry to regain a competitive position on a world-wide basis. They concluded that the only means of achieving this reduction in labour costs would be by increased automation.

In the United States there is no completely state-funded research programme for clothing automation as exists in Japan. Some institutions are, however, doing research and the U.S. Congress Office of Technology Assessment is funding research at North Carolina
State University that describes the current state and future directions of clothing and textile technology. Research is also being carried out in the private sector with firms such as Gerber, Cleutt-Peabody and Farah carrying out in-house research and development.

The most significant technological break-through in the area of clothing automation has been carried out by the Textile/Clothing Technology Corporation (TC). Another of the significant research efforts has been carried out by the Singer Company. The following is a review of the Singer MARS project and the (TC) project.

2.2.1 Singer's MARS project

MARS is an acronym for Manufacturer Applied Robotic Sewing System, developed by the Singer company. The system was first introduced at the 1984 Bobbin Show in Atlanta GA, USA. The robotic systems are designed with a view towards modularity and also designed around the same basic components, this allows costs to be minimised, maintaining the return on investment (ROI). Singer initially tackled four main areas; automotive products (seats etc.), shirts, jeans and shoes. The areas have since expanded and now include other items of clothing and also non-sewn products. All MARS units are designed to function without direct labour.

There is a great deal of secrecy surrounding Singer's MARS project, and information of a technical nature is very difficult to obtain, although MARS units have been commercially available for a number of years. The simplest of stations cost in the region of
$150,000. These systems have achieved some degree of success especially in the automotive car seat industry where a major contract to supply units has recently been won from General Motors\textsuperscript{49}. This success has not however been repeated in the clothing industry.

MARS Robotic units are based on a gantry configuration, (see figure 2.6) and are produced in a series of assemblies which are designed for the parts being made.

Series 100 units are 4-axis pneumatically driven sewing systems customised for processing small parts, incorporating a programmable 300u twin needle, two-thread chainstitch machine.

Series 200 units are 4-axis electrically driven gantry systems customised for joining two or more plies of material, sewing with or without simultaneous edge trimming, and binding or overedging single or multiple plies of material. In addition to the normal cartesian co-ordinate movement (X, Y & Z) the end effector has the ability to rotate around its axis.

The series 400 units are 2 to 5 axis pneumatic 'pick and place' systems customised for processing small parts used in the fabrication of garments and other articles. It can also be used for automatically loading existing garment transportation systems.

Also available is a range of computerised 'pick and place' robots which have articulated arms. End-effectors can be designed for particular applications, and can be quickly and easily mounted and interchanged\textsuperscript{50}.

MARS Robotic Systems incorporate technologies that can be combined into work stations for complete automatic performance of a
series of sewing assemblies. These work stations can be further
combined to form flexible in-line manufacturing systems to automate
product assemblies or sub-assemblies.

It is stated\textsuperscript{51} that "two dimensional robotic sewing can reduce
jeans direct labour content by as much as 46\% and that with the
eventual application of three dimensional robotic sewing systems, a
direct labour reduction of at least 75\% is feasible".

2.2.2 The Textile/Clothing Technology Corporation (TC)\textsuperscript{2}

The Textile/Clothing Technology Corporation (TC)\textsuperscript{2} was created
in response to a study carried out by two Harvard professors, Dr.
Frederick H Abernathy, an engineer, and Dr. John T Dunlop an
economist and former U.S. Secretary of Labor, to determine the needs
and directions for automation in the clothing industry.

During the study of the industry it was found that the areas of
cutting in many companies had been greatly influenced by modern
technology. But the joining operations (especially sewing) had not
changed over the last two decades. In the sewing operations it was
also found that the sewing machine was only run for approximately 25\%
of the time. The rest of the time was spent handling and manipulating
the material.

The sewing machine had been the subject of research and
development almost since it's invention. It was found unlikely that
dramatic improvements in clothing manufacture could be made by
concentrating on the machine itself, as speeds of operation are now
such that maximum speeds are rarely ever used. This left the area of
handling upon which to be concentrated.

The recommendations of the study led to representatives of the Amalgamated Clothing and Textile Workers Union (ACIWU), the textile industry, the clothing and fibre industries joining together to form what was originally called the "Tailored Clothing Technology Corporation". The U.S. government (Department of Commerce) provided half of the initial funding to match that provided by industry.

It was decided to target the initial research efforts on the complete automation of the sewing assembly operations for a single manufacturing task - a man's suit coat sleeve. This was to include the full range of problems that would be confronted in automating other items of clothing: inseam fullness, cuffs, vent tacking, and sewing of an outseam while maintaining careful alignment of the edges. Success in the development of a prototype indicated that the technology had much wider applicability than simply to mens' tailored clothing. This led to the change of the organisation's name, in 1984, to the Textile/Clothing Technology Corporation (TC)$^2$ 52. See Appendix E.

2.2.3 (TC)$^2$ research and development programme

The Charles Stark Draper Laboratory in Cambridge Mass. USA, noted for its invention of inertial guidance systems and participation in lunar landings, were selected by (TC)$^2$ to conduct the initial research and development programme. The decision was made early in the life of the project, that rather than carry out generic research, one particular item, the sleeve of man's suit jacket would
be chosen. The operations necessary to complete the sleeve are shown schematically in figure 2.7. The sequence beginning with the sewing of the pre-cut inner and outer sleeve segments at the seam (a). The cuff vents are then formed, first by opening the inner sleeve (b) followed by folding and tacking of the vents (c). The sleeve is then prepared for closing by returning the sleeve to its original position (d). Finally, it is completed by matching the inner and outer sleeve elbow edges and sewing the elbow seam (e). Research was carried out in four main areas; transporting the fabric; positioning the sewing machine; easing the fabric; and alignment of seam edges. Technical details of the control system for the robotic folders are presented in a paper by Bernardon and Kondoleon\textsuperscript{53}. The following gives a brief overview of the project.

1. Transporting the fabric

Two distinct approaches were taken in order to move the fabric. One involved moving the fabric by covering it with a foamed backed presser foot similar to that used in an automatic shirt cuff machine. The other involved supporting the fabric from above by a series of parallel foam backed belts. The first approach was rejected because of the limitation of having a different presser foot for each size of sleeve or part. The second approach of using the moving belt system was chosen for development.

2. Positioning the sewing machine

The moving belt system was designed to move the fabric through the sewing machine. By moving the sewing machine perpendicular to the
belt it is possible for the needle to follow the edge being stitched. The first version of the machine incorporated a standard lockstitch machine which was modified and mounted on a plate that allowed it to rotate about the needle position. A standard sewing head, feed system and presser foot were used in the original concept. This was later changed, with the standard feed being replaced by a continuous moving belt top feed system.

3. Easing the fabric

Rigidity of the fabric to be sewn was achieved by the moving belt system. These belts interlocked over the fabric but were capable of moving apart allowing access to the fabric by the sewing machine for stitching the seam. The belts can then close around the needle to support the fabric being stitched. A second series of belts below the fabric, just before the sewing machine allowed the fabric to be "eased" as it was being stitched. This was achieved by driving both belt systems at slightly different rates. The differential motion allows one ply to be advanced or retarded (eased) relative to the other, inserting fullness where required. The sewing system developed by (TC)² demonstrated that stitch quality can still be maintained when stitching a continuously moving fabric, as opposed to conventional sewing where the fabric is stationary when the needle enters.

The first three areas fabric transport, positioning the sewing machine and easing the fabric were regarded as the first milestone in the drive towards computer controlled sewing.
4. Alignment of seam edges

The next crucial step in the process of sewing the sleeve was to automatically align the edges of the seam to be sewn. This led to the development of a unique end effector which could be mounted on an industrial robot. The end effector consists of 14 cloth pickers, able to pick up individual plies of fabric from a multi-ply stack. The pickers are mounted on a flexible urethane spline which can be deformed to match most "c" or "s" -shaped cloth edges, see figure 2.8.

In order to determine the correct shape of the spline and position of the robot, a camera is located above a reflective folding table. Fabric edge location information gathered by the camera is fed to a microcomputer, which calculates the location of key work piece points and downloads to an IMB-PC. The PC takes the vision data and calculates the shape required for the spline and the robot coordinates needed for folding. The operating sequences are then downloaded from the PC to the robot controller and spline stepper motor controller.

All the elements necessary to complete the factory were built and assembled at the Draper Laboratory. It consisted of a number of modules:

1. An automatic loader to insert parts to be assembled into the transfer line.
2. A viewing table that allows the automatic vision system to recognise the parts.
3. A robot and end effector that can fold and align the edges.
4. A transfer door that slides the parts to the sewing
station and;
5. A sewing unit with feed belts and a sewing machine under computer control.

Figure 2.9 shows the (TC)$^2$ automated sewing system.

2.2.4 Commercialisation of the (TC)$^2$ prototype

The Singer Company was invited in late 1984 to review the technological developments that had been made by (TC)$^2$, with a view towards commercialising the prototype and its derivatives for the U.S. sewn products industry$^{54}$.

Singer had been working on their own project MARS (discussed earlier), and saw this as an exciting opportunity to combine their own research efforts with those of (TC)$^2$, to accelerate the application of new technology in the U.S. apparel industry.

Singer's first task was to carry out a feasibility study, of the (TC)$^2$ prototype, into the technical and economic aspects, which they did early in 1985. Their study found that the project was technically feasible since each module fell within current state-of-the-art technology. They found however, that in order for such a system to be economically viable they would need to address the manufacturing cost aspect with a view to significantly reducing the cost of the system.

The Singer Company then proposed a production readiness programme, which started in mid 1985 with the transfer of technology from the Draper Laboratories to Singer. This was achieved by building three prototypes, in a collaborative venture. They then followed this
in September 1985 by a product application; definition analysis; and a cost reduction analysis which started in January 1986.

The Singer Company also conducted an analysis to determine the near term application potential for the developed technology and the necessary combinations of modules to address the selected applications in the optimum manner. Their analysis showed that a significant market potential existed for the technology, as long as the product cost and throughput target levels could be reached.

The study considered the application of the technology to a wide range of apparel products, but concluded that in order to recognise the current state of the technology and the need to move quickly; the initial industry segment to address should be tailored clothing, with specific applications utilising (TC)$^2$ technology including:

1. Trousers side seam, waistband and inseam;
2. Coat sleeve outseam, vent tack and inseam;
3. Coat back seam;
4. Coat sleeve lining and outseam; and
5. Coat front to side seam with dart.

Singer have proposed a number of conceptualised multi-station modular transfer lines for each of the five application areas. Figure 2.10 shows the (TC)$^2$ transfer line for suit coat sleeves, this has been configured to achieve the same task as the original prototype but was designed to improve the throughput and payback times.
Singer estimate, from their preliminary analysis, that the payback periods will range from 1.6 to 3.4 years with an internal rate of return (IRR) of 38% and 18% respectively.

2.2.5 Progress and future of (TC)$^2$

The automated sewing system developed by (TC)$^2$ is currently being put under test at two leading U.S. apparel manufacturing plants, the Palm Beach Company and Hartmarx Inc. Each has accepted the prototype modular systems to carry out extensive tests in their respective manufacturing plants. Both companies were original participants in the (TC)$^2$ project and see great potential in applying the new technology in their production lines.

As the research and development of (TC)$^2$ progresses, the relationship between (TC)$^2$ and apparel manufacturers (who of course will be the customers) is growing. (TC)$^2$ and the American Apparel Manufacturers Association (AAMA) are taking steps to increase the cross fertilisation between the two organisations, with AAMA directors having influence over the research. The AAMA is also encouraging its members to join and support (TC)$^2$.

Although much research has yet to be done, (TC)$^2$ are beginning to tackle the broader needs of the industry. A research programme devoted to knitwear has also been started. This is viewed as a long term research effort and is directed at developing techniques for fully automating the production of knitwear items such as jogging suit bottoms. Also research is being carried out into the automation of sewing double-felled seams (the kind found in jeans).
(TC)$^2$ has established a technology centre in Raleigh NC, USA in order to encourage apparel manufacturers to take advantage of new technology. The centre is aimed at allowing fibre, textile and apparel manufacturers the opportunity to see at first hand the new developments. Also on offer will be the training and education of managers, engineers and technicians in the use of their technology.
Plate 2.6 MARS Series 200 Robotic Unit

(Source: The Singer Company)
Figure 2.7 Sequence of Operations in Sewing a Man’s Sleeve

(a) Unseam

(b) Inner sleeve

(c) Vent

(d) Vent tack

(e) Elbow seam
Figure 2.8 (TC)$^2$ Cloth Handling End-effector

- Stepper motors
- Flexible spline
- Cloth pickers
Figure 2.9  \((TC)^2\) Automated Sewing System
Figure 2.10 Concept of Transfer Line - Suit Coat Sleeves
2.3 European research initiatives

2.3.1 Chalmers University - FIGRAMA

Sweden was one of the first highly industrialised countries to be hit by the apparel crisis about 20 years ago. The causes were attributed to the following factors:

(i) High wage levels in the labour intensive Swedish apparel industry, meant that the industry was unable to compete with low-cost imports from the developing countries.

(ii) Sweden staunchly supported free-trade, the government did not, therefore, introduce any major protective trade barriers to shield its industry.

The decline of the industry had the following devastating effects:

(i) Personnel and technical developments, along with investment in new technology gradually declined.

(ii) Many apparel manufacturers went out of business and many retailers went "off shore" for cheaper manufacture.

(iii) The Swedish apparel work force declined to less than half its former size.

The few apparel manufacturers who managed to weather the storm did so by introducing high technology equipment and maintaining a high level production of the traditional strong points of Swedish
apparel that is high fashion/high quality apparel, manufactured in small quantities and delivered within an agreed time.

In order to ensure that the crisis did not completely devastate the apparel industry the government introduced a number of support programmes. This included financial support, amounting to some 40 million U.S. dollars annually. Approximately two thirds of which went into social programmes. Structural and technical development studies and projects were created, funded and administered by the National Swedish Board for Technical Development (STIB) and the National Industrial Board (SIND) in co-operation with the Swedish Textile and Apparel Manufacturers Association.

A special Apparel Research and Development group was also formed, it was chaired by Professor Bengt Edberg, Head of the Institute of Textile Technology at the Chalmers University of Technology in Gothenburg. The research part of the studies and programmes is carried out at Chalmers University and the Institute for Management of Innovation and Technology (IMIT) a Swedish non-profit research institute.

A number of research and development projects were initiated. Some were of a short term, direct industrial application nature, whilst others were of a longer term technology development nature. The former were allocated to apparel/equipment manufacturers, while the latter were handled by research teams at Chalmers University in co-operation with IMIT.
FIGARMA - Fully Integrated Garment Manufacture

FIGARMA is an attempt to outline a solution to the problem of automation in garment manufacture by applying the advanced technologies inherent in distributed, interactive data processing networks.

The following is a brief overview of the FIGARMA system taken from a paper presented by Nilsson\textsuperscript{56}, Associated Researcher at Chalmers University:

Basic areas of a sewing assembly operation

Automation of sewing assembly focused on the key operation of the sewn products industry, that is the sewing operation itself. The five major areas of a conventional sewing operation are classified as:

1. Garment elements

Fabric parts and accessories kept together throughout the entire assembly process by a Bundle Control System (BCS).

2. Machine functions

This comprises the sewing machine which is considered to consist of a single purpose stitching system. Ancillary equipment such as attachments are considered to form part of the machine functions.

3. Manual operator functions

This comprised the sewing operations. The functions consisting of pick-up, position/guide, sew/feed/speed, and extract/discard. The operator functions are either routine or skilled in nature.
4. Transport/handling functions

This is the transfer of material and parts by conveyors which move the bundles from one work station to another.

5. Supervisor functions

The production line supervisor controls the performance of the individual operator and machine functions. The main task of the supervisor is to achieve a smooth balanced processing of the garment elements through all assembly operations.

FIGARMA - Level One.

A Fully Integrated, Self-Adapting Production Cell

The FIGARMA concept concentrated on the five basic areas discussed above, and proposed changes that would occur in the future, in a fully integrated and computerised manufacturing environment:

1. Garment elements

These comprise the same elements as before, but the bundle control system is substituted for a Garment Identity System. The problem of automated re-threading in the Rotary Stitching System would need to be addressed.

2. Machine functions

This would comprise of a new concept in sewing machines - a multi purpose mechanical system with a rotary stitching system. The automated machine functions being controlled by a computer with the capability of adapting itself to variations generated by the data network environment.
3. Automated/manual operator functions

These would involve the use of automated operators (robots) for picking up, positioning etc. It would also need to include operators who would shuttle between operations or be permanently attached to a production cell where an operation cannot be automated.

4. Transport/handling functions

This would consist of a fully automated transfer conveyor. It would include a new concept in transfer conveyors - the shunting conveyor, which represented a standby transport/handling function interacting with the transport conveyor in linking all work stations, anywhere in the plant.

5. Automated supervision

This would comprise the now fully automated functions of the former line supervisor, performing automated self-aligning flow control.

All individual machines in the assembly line are controlled by a special machine control computer. It controls the performance of each machine and also re-sets the rotary stitching system of the flexible, multi purpose sewing machines. [The machine control computer referred to in the text would more accurately be described as a machine supervision computer.]

The special operator control computer monitors the on-line functions of all operators whether they are shuttling or stationary, and controls the performance of each operator.

The special product flow computer monitors the on-line functions of the production flow, and interacts with the machine and
operator control computers.

The shunting computer monitors, on-line, the functions of the shunting flow, interacting with the other three computers controlling machines, operators and product flow.

FIGARMA - Level Two

The Self-Aligning Production Flow

All three areas of production and handling activities are monitored and controlled by four line computers, which interact with each other. These line computers are connected to a central mainframe computer via a plant computer network.

During assembly the garment goes through a number of discrete operations. For each operation there is the process of; pick-up, operation, discard. This is performed in an in-line process, and is controlled by the machine control computer which interacts with each individual machine.

Relevant customer, style, material manufacturing and shipping information regarding the particular production order is stored at the onset in the plant computer network databases. Accessories, threads etc. flow onto the production line from stocks, and fabric parts from the preceding computer aided design (CAD) operations.

As a result of the intricate interaction between databases, software packages and other components of the plant computer network, the production flow of each individual line, and of all lines in the plant, is monitored and controlled on-line, in a way that cannot be achieved by present computerised management support systems.
In the event of a machine breakdown, the machine's on-board computer would inform the machine control computer, this in turn would inform the production flow computer and the operator control computer. The shuttle/cell operator should then be able to attend to the machine breakdown in accordance with instructions stored in random access memory (RAM) of the machine. The production flow computer in the mean time would have alerted the shunting conveyor, which begins to absorb the parts from the preceding operations of the machine which is down.

If the breakdown lasts longer than a pre-established deadline, the production flow computer would instruct the machine control computer to reset the rotary stitching systems of all machines, via their RAM, downstream of the machine which is down. Hence, if a production line were to consist of five machines numbered 1 to 5, in an in-line manufacturing system, and machine number 3 breaks down, then the machine control computer would instruct machine number 4 to change its functions to that of the "down" machine, number 3. Machine no. 5 machine would then change its functions to that of machine number 4. Each line would have two reserve machines, one of the reserve machines would replace the final machine required to complete the process (number 5). The shunting conveyor would then be instructed to re-direct the garments to machine number 4, thereby bypassing the broken down machine and preventing a bottle neck situation. When the "down" machine is repaired then the production flow computer would instruct the machines to return to their original set up.
The shunting line computer has the capability of balancing the production flow by changing the speed of both lines and/or spacing the parts as they are fed back to the production line. No operator is allowed to meddle with the computerised operations directly. Any interventions are made by a set of fail-safe emergency procedures stored in the databases of the plant computer network, controlled by the plant manager.

Machine speeds can be varied by the machine control computer under instruction from the production flow computer. This can contribute to balancing the flow of the production line.

The system proposed is self-aligning to other variations in the production flow, apart from pure emergencies. A similar, fully automated procedure is carried out when the production line has to be re-aligned for a new production order.

FIGARMA - Level Three
Local Data Processing Network

The FIGARMA data processing network comprises the familiar components inherent in traditional garment manufacture and some concepts that are completely new to the industry. The data network consists of software packages/programmes which cover the following:

Discrete Order Tracking System - "DOTS"
Resource Allocation Model - "REALM"
Design Optimisation Simulation Model - "DOSIM"
Production Optimisation Simulation Model - "POSIM"
Automated Monitoring System - "ATMOS"
The FIGARMA concept is extended further in the fully integrated macrosystem (FIRM) concept, where apart from the production aspects covered by FIGARMA, other areas of company operations that should form part of the fully integrated and computerised systems structure are included, namely:

Marketing,
Logistics, and
Administration.
2.3.2 BRITE

The Basic Research in Industries Technologies Programme (BRITE) is a programme of collaborative industrial research and technologies development programme supported and promoted by the European Community. It was started in 1985 and was designed to enhance the competitiveness of European manufacturing industries in world markets, and to encourage these industries to acquire a firm foundation in the industrial and materials technology base required for the essential strategic, innovative product and process development.

BRITE aims to achieve its objectives by supporting, on a shared cost basis, European industrial research and technologies development on promising new projects to be undertaken in a framework of international collaboration within the European Community and, under certain special conditions, European Free Trade Association (EFTA) countries. It promotes collaboration in strategic industrial research between industrial firms and complementary centres of expertise in industry, universities and research institutes. BRITE also seeks to encourage transfer of technology between industry sections and particularly to those sections with a high proportion of small and medium size enterprises (SME) which need to exploit new technologies to improve their performance.

Phase I of BRITE was for the period 1985 - 1988 and included clothing research and development projects to be fifty percent financed by Community Funds. These projects came under the heading of break-throughs in new production technologies suitable, for products
made from flexible materials. During 1986 13 contracts were awarded\(^{57}\). These are outlined in Table 2.11.

Phase II of BRITÉ provides a new list of projects for period 1989 - 1992. Under the first call for proposals it is expected that approximately 70 Mn ECU will be made available by the commission to support new projects\(^ {58}\). One of the priority themes for phase II in the third technical area, entitled 'Applications of manufacturing technologies', is manufacturing processes for flexible materials, in particular manufacturing processes for clothing and footwear. Under this priority theme calls are made for projects in the following areas:

3.2.1. Novel approaches to production, dyeing, printing and finishing of small batches of materials with consistent properties.

3.2.2. Design and simulation of manufacturing processes for applications in flexible materials, such as leather, textile and composite products.

3.2.3. Fault detection and analysis systems at all stages of the manufacturing process.

3.2.4. New spreading and cutting techniques including high speed, single ply systems for small batches and multi-layer systems for patterned materials.

3.2.5. Handling, transport and buffer stores for flexible materials between work stations.

3.2.6. New systems for removing pieces from the cutting table
and transfer directly to the next station.

3.2.7. Automated assembly cells able to work with minimum operator adjustments on a series of different items or on very small batches.

3.2.8. New sewing technologies (automatic thread changing or without the need for thread changing) to allow more flexible production.

3.2.9. New finished techniques to improve or replace ironing /pressing for assembled or semi-assembled products.

One of the projects that was approved for EEC funding under the BRITE scheme is a collaborative research project between Courtaulds Clothing Ltd., U.K., GEC Electrical Projects Ltd., U.K., and Pfaff Industriemaschinen GmbH, West Germany. The EC are providing 50% of projected research costs of 4.25m ECU (approx. £2.5m) for a three year project.

The objective of the project is to develop a system to take cut fabric parts, and using specially developed robotic handling devices, carry out some of the assembly and sewing operations totally under automatic control. It includes research to develop a series of interchangeable modules which can be integrated to form a sequential production line, which can be readily changed to suit alternative garment styles. The modules consisting of; stacked fabric separation and individual part feeding; sewing units; manipulation and assembly of parts in preparation for sewing and; transfer of parts between sewing and handling units. The sewing modules are to be associated
with highly sophisticated robots capable of the accurate speed and path control required for the sewing operation. Similar robots are being used with the manipulation and parts assembly modules.

Courtaulds Clothing Ltd. are responsible for co-ordinating the research project. In addition to their direct contribution, they will also fund work into solving the problems of handling non-dimensionally stable fabrics. GEC Electrical Projects Ltd. are responsible for the design and manufacture of robots and control systems to meet the requirements of this application. Pfaff Industriemashinen Gmbh are responsible for providing modified sewing machines which will ensure reliable operation without manual oversight or intervention.

Initial research by Courtaulds has involved the automated handling of the production of briefs, which are of a two dimensional construction from start to finish.

Progress reports on Phase I BRITE projects are extremely difficult to obtain as many of the projects are still under research. It is expected that when phase I projects are completed the resultant information will be made available for all EC participating countries.60
Table 2.11 EC BRITE Contracts for Clothing R & D Awarded in 1986

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Participating Countries</th>
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<tbody>
<tr>
<td>1.</td>
<td>A real-time integrated operator communication system affordable by SME</td>
<td>U.K.</td>
</tr>
<tr>
<td>2.</td>
<td>Computer-Aided Design of clothing</td>
<td>Netherlands</td>
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<td>Irish Republic</td>
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<td></td>
<td></td>
<td>France</td>
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<td>3.</td>
<td>Continuous cutting system with automatic inspection and dynamic pattern layout as applied to the garment industry</td>
<td>W. Germany</td>
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<tr>
<td>4.</td>
<td>Folding devices and sensors to automatic sewing machines for mixed production</td>
<td>Belgium</td>
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<td>5.</td>
<td>Highly flexible programmable modular sewing centre capable of performing the full range of operations</td>
<td>Netherlands</td>
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<tr>
<td>6.</td>
<td>Automatic sewing and ironing unit with heads coupled to simultaneously work the two opposite sides of an article of clothing</td>
<td>Italy</td>
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<tr>
<td>7.</td>
<td>Flexible manufacturing system for automated assembly of apparel</td>
<td>France</td>
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<tr>
<td>8.</td>
<td>Fit optimised pattern design on the interactive graphics screen (2D construction)</td>
<td>France</td>
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<tr>
<td>9.</td>
<td>2D and 3D garment modelling</td>
<td>France</td>
</tr>
<tr>
<td>10.</td>
<td>Automation of the processing and cutting of patterned materials</td>
<td>France</td>
</tr>
<tr>
<td>11.</td>
<td>Planning, development and demonstration of a pilot flexible cell for diversified manufacturing</td>
<td>W. Germany</td>
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<tr>
<td>12.</td>
<td>Planning and development of an information and communication system for computer integrated manufacturing</td>
<td>W. Germany</td>
</tr>
<tr>
<td>13.</td>
<td>Development of standardised material transport devices for the sequential automation of the processing of flexible materials</td>
<td>W. Germany</td>
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Source: European Commission
2.3.3 University Of Hull

The University of Hull have a number of on-going projects concerned with automated fabric handling. A brief overview of these projects follow:-

1 Prototype robot work station for the motif application process with the garment manufacturing industry.

This research project brings together two areas of development previously carried out at Hull; vision applied to the orientation of an embroidered motif in the textile industry and; a sensory gripper for handling textiles (described in chapter 6). The project is a collaborative project, funded by the U.K. Science and Engineering Research Council (SERC) robots initiative, between the University of Hull Robotics Research Group, Marks and Spencer PLC and Corah PLC.

The task undertaken was to use a programmable robot to pick up an individual ply of fabric from a stack, then place on this fabric a motif in the correct position (+/- 1mm) and orientation (+/- 1 degree), with a cycle time for the complete operation in the order of one minute. The motif application task was chosen, not for its importance within the industry, but because fabric handling and visual feedback technologies have to be incorporated. These are seen as essential ingredients of further automation of the industry.

A prototype laboratory system was developed, see figure 2.12. This consists of a Unimate PUMA 560 robot fitted with the Hull sensory gripper for handling single plies of material and for picking up motifs. In the area in front of the robot there is space for a
stack of material and for the robot to separate and lift a single ply of material and lay it down. A vision system, camera rotation table and motif bin form a module located to one side of the robot. The camera is mounted above the rotation table and monitors the orientation of the motif placed upon it. The vision system controls the rotation table, which can be stepped in increments of 0.375 degrees.

The work station consists of two discrete sub-systems; the robot sub-system comprising the robot, robot controller, air jet and vacuum control valves, gripper sensors and sensor interface. The vision equipment and task controller sub-system is controlled by a DEC LSI 11/2 microcomputer which performs image processing and task control operations.

The normal operation of the work station is as follows: The vision system is regarded as the system master and passes job numbers to the robot slave. The first task is to get a motif from the bin and place it on the rotation table. When the robot has completed its task, the vision system checks that the motif is correctly orientated and instructs the robot to separate a ply of fabric from the stack and lay it out. Whilst the robot is carrying out this task, the vision system sends commands to the rotation table to correct the orientation of the motif. When the robot has completed its task it sets an acknowledgement signal. When the motif has been correctly orientated the vision system acknowledges the robot and instructs it to pick up the motif from the rotation table and place it on the piece of fabric. The vision system then waits for the robot to
complete its task. The cycle is then complete.

The cycle time during normal operation is approximately 1 minute. The vision system software is capable of achieving orientation within 12.5 seconds. The robot system can achieve fabric separation, that is detecting a piece of fabric between the gripper jaws, in 4.5 seconds. The large cycle time is attributed to the slow speed of the robot movement when used with the gripper and by the vision system being slow at orienting the motifs. The cycle time would be increased further were errors to be encountered, such as; motif being placed out of the field of view of the camera; too many motifs placed on the table; motif placed the wrong side up on the table.

2. A garment assembly demonstrator

This was a SERC supported project during the period April 1985 to September 1988, in collaboration with Corah PLC. The overall aim of the Research was to demonstrate a robotic work cell for the automated assembly of fronts, backs and gussets of mens' and ladies' briefs.

Robotic manipulators (multiple UMI RTX robots) were used to perform the fabric handling in conjunction with conventional sewing machines. Sensory feedback was applied so that corrective action may be taken to ensure accurate and reliable assemblies.
Progress of the research as at March 1988 had achieved the following:

(i) The Hull sensory gripper had been improved to handle smaller pieces of fabric which can be placed accurately along one edge.

(ii) The UMI-RTX standard control system was by-passed to achieve satisfactory continuous path control for accurate sewing.

(iii) Pre-separated fabric pieces have been placed on top of each other prior to sewing using multiple gripper mounted solid state cameras to provide sensory feedback.

(iv) A prototype end-effector for the concealed seam construction sub-cell has been demonstrated and awaits further development.

3 Automation of shirt collar inspection and assembly

A SERC supported project for November 1984 to May 1988 in collaboration with IJ Dewhirst PLC and Marks and Spencer PLC. The objectives of the research is to produce a laboratory prototype system capable of de-stacking collar panels, inspecting them for fabric flaws, and accurately placing each of the three component panels one on top of the other for input to a fusing press. The whole cell, including the fusing press is to be monitored and integrated.

Initial experiments were carried out with various lighting arrangements and inspection algorithms, using an LSI 11/23 as the host computer. Optical and electronic alternatives to the digital
computer based FFT algorithm have been identified. These have the potential of giving much faster results with cheaper equipment costs.

The fabric handling part of the project involves separating and picking from stacks each of the three collar parts which are to be placed accurately (better than 1mm) on top of each other and then fed into a commercial fusing press. None of the existing pick-up and separation devices tested by Hull proved satisfactory on the collar pieces. A gripper was constructed that uses roller action and electro-statics to achieve ply separation, and is currently under evaluation.

4 Robotic assembly of a complete garment

This is a current SERC supported project starting in January 1989 up to December 1990, in collaboration with Corah PLC. The aim of the project is to demonstrate a flexible work cell which can assemble a wide range of mens and womens briefs.

The project builds on current work on garment sub-assembly. The same concept of multiple robotic handling devices combined with conventional sewing machines is to be used wherever possible. Robotic solutions to 2D and 3D fabric manipulation must be found. The sub-cells must be integrated and appropriate man-machine interfaces implemented.

At the time of writing, work on this project had only just commenced.
Figure 2.12 Motif Application Workstation Layout

- Robot
- Vision system camera
- Rotation table
- Motif bin
- Fabric stack
- Single ply
2.3.4 University of Durham

Research has been taking place at the University of Durham in the School of Engineering and Applied Science for a number of years, aimed at establishing principles for automation in garment assembly. A brief overview of completed and current research projects follow:

1 Integration of garment assembly automation 1982 - 1985

This was a collaborative research project between Durham and Lyle and Scott, U.K., supported by an SERC grant. The main objective of the research was the development of automation techniques for the handling and assembly of fabric components in large volume garment manufacturing.

The garment chosen to be used as a framework around which the work station was to be designed, was the men's Y-front brief manufactured commercially by Lyle and Scott. The assembly of Y-front briefs comprises a number of distinct operations, Durham's initial research concentrated on the first of these operations in which edge binding is attached to individual cut pieces prior to the pieces being sewn together.

The complete operation of the above research area comprises; the de-stacking of a single ply of fabric (the gusset) from a stack of pre-cut parts; the guidance through a sewing machine where edge binding fed from a continuous roll is attached along one edge; after sewing, the joined components are cut and re-stacked. It was found possible to reduce this problem to several tractable two-dimensional operations.
The strategy adopted for research was to develop and integrate four sub-systems, forming a work station capable of completely automating this operation. The operation of the work station being:

(i) A de-stacking section

A single ply gusset is removed from a stack, placed on an elevating feed table, by a gripper employing the oblique pin engagement technique, (covered in chapter 6), then transported to an orientating table by a linear transporter.

(ii) Orientation section

The component is aligned by optical means with three reflex photosensors and then transferred to a sewing sub-system by a vacuum plate attached to another linear transporter.

(iii) Conveying section

The component is deposited on a conveyor belt section in an aligned position and conveyed through the sewing machine in synchronisation with the stitching action of the machine. The component is then presented to the cut and stack stage.

(iv) Cutting and stacking section

The workpieces are separated from each other by cutting the continuous edge binding strip with a commercial cutting mechanism. The workpieces are then stacked in a manner suitable for onward processing.

The work station is shown schematically in Figure 2.13. The development of the work station was presented at the 1984 SERC
Grantees Conference\textsuperscript{64}. Modifications of two of the sub-systems have since been made and are described below:

The pick and place unit was modified to reduce the inertia of the transporter. Infra-red sensors were also incorporated into the gripper to detect the correct separation of plies, hoping to improve upon the recorded open loop reliability of 99.5%.

The second modification was made to the orientation section. This was now activated by three DC geared motors to allow orientation of work pieces at high speed.
Figure 2.13 Durham University Workstation

- linear transporter
- alignment table
- single ply transporter
- automated sewing machine
- conveyor
- gripper
- elevating feed table
2 Automated garment manufacturing and product quality control 1985 - 1989

This research project follows on from phase one of the garment assembly research project and concentrates on three areas:

(i) Automated sewing station seam quality control

This sub-project aims at developing ways of improving and monitoring seam quality along with improving sewing machine performance. A yarn tension transducer has been developed which can monitor absolute yarn tension at full machine speed (6000 rpm). It is intended that the transducers are integrated into the sewing head, allowing yarn tension profiles to be monitored against sewing machine crankshaft angle whilst the machine is running.

Research is also being carried out to acquire information relating to machine speed, yarn tension and seam quality, allowing the point of optimum machine performance to be found.

It was recently reported\textsuperscript{65} that a £1.3m EC grant under the BRITE initiative has been made to Durham to fund a three year research programme into detecting stitch quality.

(ii) A flexible garment sub-assembly system

The objective of this sub-project is to produce a versatile fabric manipulator derived from the gripper developed in the previous SERC research grant. It is split into four stages:
a) The development of an end effector using the present oblique pin engagement technique. This will involve developing a light-weight version of the gripper and the instrumentation of, engagement torque, gripper rotation angle and contact pressure; allowing the gripper to operate in a more reproducible and reliable manner than presently achieved.

b) The acquisition of performance data relating to the reliability and efficiency of the gripper, in order to assess its overall effectiveness for knitted and woven fabrics and to determine optimum engagement torque and contact pressure for each.

c) The incorporation of a vision system to enable the use of the gripper to accurately place one work piece relative to a second for subsequent joining.

d) An evaluation of the integrated system.

(iii) A microprocessor based elastic feed control system

This research project is concerned with the insertion of elastic tape under tension into the waist band of a garment. A system is being proposed whereby sensory information will be taken from the machine output feed, the yarn tension control device, and an elastic tension transducer. This will make it possible to accurately de-tension or pre-tension the elastic tape for loading or for temporary workpiece removal. Tension may also be set in absolute units and be directly related to the final waistband size of the garment.
3 Other research projects

There are several projects currently underway which form part of a collaborative programme of research, involving the University of Durham, University of Hull, and British United Shoe Machinery (BUSM) Ltd. Work has also been carried out into the automated assembly of shoe uppers, this was wholly funded by BUSM and further research is envisaged for this project.
2.3.5 University of Leeds

The development of clothing automation research started around 1983 with a project funded by the Textile and Other Manufacturers Requirements Board (TOMBRB) of the Department of Trade and Industry. It had been realised that various fundamental problems would need to be solved before a commercially viable system could be developed. These were identified as:-

i) Separation and pick up of a single fabric from a stack.
ii) The alignment of the fabric after removal from the stack.
iii) The accurate positioning of two fabrics one on top of the other for two ply sewing or fusing operations.
iv) The development of robotic sewing, the guidance of the fabric by a robot during the sewing operation.

(i) Fabric pick up device

A new type of picker, designed to overcome some of the problems inherent in commercially available pickers, was developed at the Textiles Industries Dept., Leeds University. The department has not disclosed the method of operation of its picker but claim that it is capable of picking up larger pieces than other devices and is not generally restrictive in the shape of the pieces being picked up. The fabric pick up device is however described in a European patent application. The reliability of the picker is quoted to be in excess of 99.7%.
(ii) Vision for fabric alignment

A two camera approach was adopted, placing one camera over a salient feature of the fabric (e.g. a corner) and the other over a plain edge of the fabric. An optical camera was chosen and dedicated hardware developed. An IBM AT computer was used for hardware control and image computation. The system was designed to cope with the normal frayed edges of fabrics.

With a PUMA 560 robot using VAL I, and employing a sequential approach, to compute corrections needed, the average time taken to correct the position of a panel of fabric was approximately 6 seconds. It was found that the timing doubles with the use of two cameras. This however, can be reduced by approximately one-third with the use of the integrated approach, where both cameras are considered together.

(iii) Multiple ply positioning

As at July 1986 a prototype for multiple ply positioning based on a vision system was under development.

(iv) Robotic sewing

This research project is an investigation of the capabilities and limitations of robotic sewing. The development of the robotic sewing using multi-sensory feedback is covered in a paper by Gershon and Porat of the University of Leeds. The system consists of:-

- a PUMA 560 robot operating under VAL II
- a cell controller - an IBM AT computer
- two CCD cameras attached to the sewing machine.
- an instrumented finger for measuring cloth tension.

The sewing machine is interfaced to the IBM AT, this permits central control of all the sewing machine functions. A 280 microprocessor is used to supervise the cameras and performs frame grabbing and thresholding. The average time to take a picture and process it is 12 ms. The instrumented finger consists of two slender beams machined out of a monolithic block of Al. 2024. Strain gauges are attached to the beams, the signals produced are amplified and processed by a digital peak detector.

The cameras are used to view the position of the edge of the cloth in the vicinity of the needle. Whilst the sewing machine is operating the camera data is read by the IBM AT, along with the cloth tension and shaft encoder count. The IBM AT then calculates the robot position data and transmits it to VAL II. The control system consists of:

(i) a cloth edge tracking servo, to minimise the seam error, designed with the use of a simulation programme permitting optimisation of gain parameters and camera placement; and

(ii) a cloth tension servo, to minimise cloth tension, designed by measuring the frequency response of the open loop system to calculate the optimum gain parameters.

During the operation of the system the robot holds the end of the fabric against a smooth table, using two rubber-tipped fingers, spring mounted on the end effector. The cloth is fed into the sewing
machine by the conventional "drop feed" feeding mechanism of the machine. The robot path is generated in real time by two sensory servo systems:-

(i) seam tracking servo - controlling the sideways and rotational movements of the end-effector

(ii) cloth feed tracking servo - controlling the forward motion of the end effector, based on the sewing machine shaft encoder signal and the cloth tension measured by the instrumented finger.

In order to prevent the fabric buckling and to encourage correct pivoting of the fabric about the needle, it was found necessary to combine all sideways movements of the end-effector with a simultaneous pivoting of the end-effector about the instrumented finger. The auxiliary finger being rotated about the instrumented one so that both fingers were at all times equi-distant from the needle. Cloth feed tracking control was based on the cloth tension. Due to the effect of friction between the table surface and the finger, it was found necessary to limit the robot to forward displacements only and an allowance being made for the small off-set due to table friction.

The method of robotic sewing developed at Leeds was found to be only effective for finger to needle distances between 1000 mm and 250 mm. It was also found that seam quality varied considerably for different fabrics. However good seams have been achieved for sewing machine speeds up to 2000 stitches per minute, with radii of curvature down to 10 cm.
Other research projects

Leeds University have a collaborative project underway with Queens University, which is an extension of the Queens University research to produce algorithms for converting three-dimensional information from the design stage into the required pattern piece geometry needed for manufacture of a garment. The collaborative project aims to calculate from known parts, the shape of the garment given the response of the fabric dimensions to given known values.

The Textile Industries Department at Leeds University is already well advanced in developing software for production modelling and scheduling of a clothing factory. Models of production lines to facilitate production planning, scheduling and operation balancing have been created based on the SEE WHY (f) simulation software package.

[Simulation of clothing manufacture is also being carried out at Manchester Polytechnic, Department of Clothing Design and Technology, Hollings Faculty. This is a SERC sponsored project from September 1986 to March 1990, in collaboration with Courtaulds Clothing Ltd., Nottingham and MW(Scicon) Ltd., Wigan. The research investigates the process of clothing manufacture, where the human element is a major consideration. The simulation model is being developed to provide a means of improving production management practices, by rigorously describing and modelling aspects of the production system].
2.3.6 Loughborough University of Technology

The Department of Mechanical Engineering at Loughborough University has been involved in projects related to the automation of garment manufacture for over 15 years. Research is currently underway on a project in collaboration with Corah PLC (SERC sponsored to 1987). The project involves the development of a system to sense fabrics, process the resulting data, and manipulate the fabric at speeds commensurate with industrially acceptable production rates. The research is directed towards novel, low cost techniques and machinery for:

(i) rapid sensing of knitted loops,
(ii) processing the resulting data, and
(iii) high speed manipulation of the loops.

The research has centred on the automation of "linking" in the knitwear industry, whereby garment panels are joined by sewing through individual knitted loops in a particular row (slack course). The system under development includes an automatic magazine loading machine which accepts a bulk supply of collars, identifies the slack course of loops, inserts individual points through each of the loops, separates one collar from the next and then transfers it onto a row of points on the magazine bar. The magazine bar is then transferred to one of several linking machines, which is used to load collars for linking to the body panels.

The main functional elements of the automatic magazine
loading machine are:

(i) Fabric sensing

Due to the distortion in fabrics as they are manipulated, the fabric must be scanned progressively as the operations proceed, in order to take these changes into account. Previous work carried out at Loughborough University led to the construction of a research rig to identify knitted loops in fabric. The rig uses a 256 photosite linear array CCD sensor, and a Pentax 110 format camera lens. The host computer controlling the collection of vision data, being an Apple II microcomputer. A complete scan could be stored in approximately 260 ms75.

The research rig was modified to suit the specialised requirements of scanning ribbed trims. In order to incorporate the sensing system in the proposed machine the circuitry had to be re-designed to condense the parts around the sensing head and transfer much of the electronics into a main control cabinet. Also added was remote setting of the thresholding and improvements in mechanical mountings.

(ii) Carriage Traverse

The front and back of the machine are separated by a continuous length of knitted fabric. The sensor head and fabric positioning mechanism are carried on a carriage which traverses in front of the trims. Another carriage is used to carry the point inserting mechanism and light source output, this being behind the trims. One
stepping motor moves both carriages and maintains their alignment through a pair of re-circulating ball screws and timing belts. The sensor scans the fabric whilst the carriage traverses the length of the trim. The resulting data is processed to identify the slack course, select the loops to be loaded on the points and calculate the movements required to position the loops correctly.

(iii) Loop positioning

The fabric is held between a smooth face on the mounting of the light source, and a pair of rubber rollers which roll on the fabric as the head traverses. As each loop is detected the rollers act to position the fabric to align with a point. Axial movement of the rollers adjusts the fabric position vertically, advancing or retarding the rollers relative to the movement of the carriage is used to adjust the horizontal position of the fabric. The roller movements are controlled by separate, small stepping motors, each being controlled by a dedicated single board (8085 based) microcomputer, operating under the control of the host computer.

(iv) Point Insertion

It is envisaged that the production machine will include two pairs of carriages, which start to scan from the middle of the trim and work outwards to the edges, reducing the overall cycle time, and simplifying some of the problems of point insertion at the edges. At first the central loop is found by one scanning head which inserts a point and traverses to one edge inserting points as it moves. The
second head then moves into the central position and works toward the opposite edge. A cam, carried on the rear carriages, inserts the majority of the points through the loops as they traverse. Different methods are used at the beginning and end of each run.

(v) Fabric holding

At each side of the machine, two grippers tension the fabric by pulling at the extreme edges. This enables points to be inserted into the first and last loops of a trim. The gripper movements are powered pneumatically and controlled by the host computer. They involve finding the fabric, clamping the edges and tensioning the trim for different stages of the cycle.
2.3.7 Leicester Polytechnic - CIM Centre

A research proposal has been instigated by Leicester Polytechnic to create a centre where clothing research can be concentrated, in an attempt to form a flexible manufacturing production line and eventually a completely flexible production factory. The research programme is designed to attack the problem of increasing U.K. competitiveness, with the active co-operation and participation of forward looking industrial partners drawn from equipment manufacturers and users in both the U.K. and Europe.

At the time of writing, this research proposal had been prepared for submission for consideration by the AMT committee of the Department of Trade and Industry, to obtain funding to accelerate research work to produce hardware, software and new technologies, which could then be exploited by U.K. equipment supply companies to produce new products.

The initiative is seen as the beginning of a much needed co-ordinated research programme bringing together textile, production, electronic, mechanical, computing and management experts from academia throughout the U.K. together with similar experts from the industry with practical production expertise, to encourage the formation of a more competitive and profitable textile industry in the U.K. and Europe.

The project (CIMTEX) is concerned specifically with the computer integrated manufacture (CIM) of knitted garments, and comprises five work cells and three linking packages as shown in figure 2.14. The works cells are each discrete "islands of
automation" which together cover all the manufacturing operations necessary to produce a range of knitted garments, which would include; two-piece track suits, sweatshirts, casual shirts, t-shirts, muscle tops, mini/micro skirts and shorts - all of which could be made from three thread fleecy knitted fabric. The linking packages are those research areas which are of major influence in determining the successful integration of inter-cell operability.

The project has been designed to bring together previous and current research programmes being carried out at Leicester Polytechnic and other academic establishments including; The University of Hull, the University of Loughborough, and University of Manchester Institute of Science and Technology (UMIST). Two parallel production systems are to be included in the project, both of which are aimed at improving the output performance of the machinery. The first system is to be operator centred, and the second an automated production line requiring the minimum human supervision.

The operator centred line has been included because it represents 75% of the current type of production systems used by approximately 80% of manufacturers. The remaining 25% of the operator centred line would show these manufacturers how current production systems can be improved upon to increase throughput, reduce lead time and produce quality garments more efficiently. The technological developments included in this line would be used to point the way to a sensible migration from labour intensive production towards more automated manufacturing systems.

The automated line, which presently only represents between 10
to 20% of U.K. garment manufacture, but which probably accounts for
60 - 70% of finished goods, is designed to combine the most advanced
production machinery available into integrated production cells and
to further integrate these cells to produce a range of first class
quality products with an output, and at a cost that is competitive in
world markets.

The following is a brief overview of the work cells and the
linking packages which highlight the relationship between the cells
and their dependency on inter-cell operability. A detailed layout of
the proposed production system is shown in figure 2.15.

1. The work cells

(i) Generation of computer-based specifications from the creative
design process

The aim of this area of research is to take the design of a
garment sketched by a designer and turn it into an accurate 3
dimensional computer based specification of the shape, style, colour,
texture, and size of the garment; then to generate the manufacturing
instructions necessary for producing the finished product. This would
make use of previous work by Efrat76 for the design of patterns to
give accurate body fit.

The research will involve linking a creative design software
package to a pattern design system (PDS), which in turn receives
three-dimensional co-ordinates from a prototype body measuring
apparatus. The modified output from the PDS will then be fed directly
into a lay planning and cutting order optimisation package.
The resultant database created by inter-linking these software packages will be used as the principal source of core manufacturing data for the subsequent operator-centred and automated production operations.

(ii) Fabric spreading, cutting and stripping

This will involve two distinctive systems, operator-centred and automated.

A collection of state-of-the-art operator controlled spreading and cutting equipment will be assembled for the operator-centred system. A prototype modular construction system will then be researched and developed, allowing the equipment to be configured in such a way as to provide building blocks of automation for the end users.

The automated production system will include robot assisted carousel fabric loading, robotic spreading, computer directed cutting and robotic stripping at the end of the cutting stage. The robotic stripping stage is a totally new concept which will require considerable research effort involving developing special purpose end effectors; and downloading co-ordinate data from the lay planning/cut order scheduling process to the appropriate cell/robot controller. To complete the process, a third robot will undertake piece matching aided by a machine vision system, before loading a complete set of pieces onto an overhead conveyor system.

Extensive use will be made of the results of research undertaken at the University of Hull, Durham and Manchester in
preparing guidelines for the research effort to follow.

(iii) Semi-automated and automated sewing and scheduling

The semi-automated and automated sewing may or may not be physically integrated depending on the sequence in which the making up operations are to be performed. The semi-automated sewing stations will be operator-centred with the minimum of skill required to perform the particular task. The research aspect of this area will be directed towards improving the working environment, optimising work flow conditions and establishing an effective open communication system to the production scheduling system.

The automated sewing stations will be used for the automated attachment of the standard items associated with the garment i.e. collars and cuffs, together with trims. Adjustments to the automated machines, to cater for variations in the characteristics of the fabrics being used, will be identified by objective assessment testing and initiated automatically when the order is scheduled for production.

(iv) Automated finishing and packaging

This will involve research into transporting the finished garments to the presses in the correct orientation for the operators and/or the automatic pick-up devices attached to the former presses and the subsequent accurate location of the garments on the formers.

The accurate automatic assessment of pressing conditions, along with both human and machine vision inspection will form another area
of research. The unloading of garments from the presses and back onto the transporter system to carry them to areas for flat packaging or hanger packaging will also need to be investigated.

(v) Automatic methods for making-up knitted blanks

The aim of this programme is to conduct research into the control of the fabric on the knitting machine and during the subsequent handling and making-up processes, to prevent fabric distortion, curling and dimensional change. This will enable the making-up operations of linking and over-edging to be carried out automatically on fabrics which lie flat and are of known controlled dimensions.

The work in this area will include the research and development of a method of controlling the dimensions of knitted fabric blanks produced on V-bed or fully fashioned knitting machines. [HATRA have previously tackled the problem of control during the knitting and will collaborate in the programme as will the Department of Textile and Mechanical Engineering at Loughborough University of Technology]

Techniques for the automated handling of these controlled blanks through the making-up operations to the completed garment form, including automated linking and trimming processes, will be researched and developed - making use of previous research work carried out at Loughborough University into automated linking.
2. The linking packages

(i) Overall integration of manufacturing cells

This will involve research and implementation of a computer network which will link together the various production cells, along with a production control system. The proposed network is shown in figure 2.16. It consists essentially of a baseband system, taking the form of a communications backbone providing a highway to which the design, production control areas and production machinery are connected either directly or via suitable cell controllers.

The main research activity will be concentrated on defining a coherent networking strategy based on existing and emerging industry standards and tackling the problems of data exchange between the various manufacturing processes. Research will also focus on the development of new software for machinery which has not yet been linked together and interfacing this to commercial production control systems for operator controlled sewing.

The CIMTEK project is intended to work closely with companies and organisations, nationally and internationally who are following a similar route e.g. (TC)² Corporation and the Defense Logistics Agency project, Southern Tech. and Georgia Tech., Georgia, U.S.A.

(ii) Automatic vision inspection

In order to maintain quality and even possibly improve upon it, it is proposed that machine vision inspection will be used throughout the entire production system at various stages. This is expected to involve automated inspection of the fabric before and during
spreading; robotic guidance and control; inspection and location of seams during making-up; inspection of finished garments and packaging.

The aim is to produce a prototype inspection system for the detection and identification of flaws wherever it is appropriate in the garment manufacturing process. This will replace visual inspection carried out by operators, with the benefits being high throughput speed and the capability of 24 hour operation.

Research into the application of automated visual inspection of textile materials has been concentrated at Leicester Polytechnic for a number of years.

(iii) Objective assessment of textile materials

This will involve the testing of the raw materials such as the knitted fabric, yarn sewing threads etc., in order to determine the performance characteristics of the fabric prior to being made up.

Research will also be carried out to determine the effect of change on these objectively measured characteristics and the changes required in the settings of the processing equipment to ensure that the most effective and efficient automated production may be achieved.

Also to be developed are a number of prototype mechanisms to be fitted to sewing machines and ancillary apparatus to adjust the machinery automatically depending on the characteristic of the particular fabric being processed.
Objective Assessment of Textile Materials

Automatic Methods for Making-up Knitted Blanks

Automatic Finishing and Packaging

Operator-Centred and Automatic Sewing

Fabric Spreading, Cutting and Stripping

Automatic Vision Inspection

Generation of Computer based specifications from the Creative Design Process

Overall Integration of Manufacturing Cells
Figure 2.15 Knitwear and Garment Manufacturing and Assembly Plant
Figure 2.16
KNITWEAR AND GARMENT MANUFACTURING AND ASSEMBLY PLANT
COMMUNICATIONS SYSTEM
2.4 Discussion on the state of current research programmes

Described in sections 2.1 to 2.3 is a review of major research programmes being undertaken in Japan, America and Europe, both current and proposed. The review does not cover every type of research being carried out including that of equipment manufacturers, in the interests of brevity, and limitations of space.

From the above, it can be seen that the research effort by the industrialised nations, in a bid to make their apparel industries more competitive in world markets, is indeed considerable and moving at a rapid pace.

What is presented in the review is a general overview of the research programmes, with no attempt being made at comparisons or evaluations. The aim being to present an unbiased picture of each research programme. In this sub-section a critical evaluation will be made of the overall research efforts.

Clearly the largest and most extensive research programme, in terms of capital and manpower, being undertaken at present is that of the Japanese Ministry of International Trade and Industry (MITI), This eight year programme, due for completion in the year 1990, is expected to cost in excess of US$65 million. Once it had become evident that there were serious problems in the Japanese Apparel Industry, the Japanese felt that the next logical step was to mount a collective research effort to solve the problems. This action being entirely consistent with overall Japanese economic policy, Japanese firms are accustomed to collaborating under governmental "guidance".
therefore it did not take long from the recognition of the problem to the implementation of a collective action to solve it.\textsuperscript{77}

As well as research into completely new manufacturing processes such as three-dimensional robotic sewing, much of the Japanese effort could be seen as a drawing together of many existing technologies from within and outside of Japan. Many successful working practices developed in Japan have already been working for a number of years such as; The Melbo Apollo Project and Melbo Automatic Plotting System (MAPS) [supported by IBM specialists]\textsuperscript{78} and the Toyota Sewn System (TSS) developed by Aisin Seiki Co. Ltd.\textsuperscript{79,80} - both companies are involved in the MITI project.

Many of the developments to be included in the project are not new, and have been tried before. The process of stabilising fabric has been tried before, but problems associated with adding a fugitive to the fabric which caused yarn rupture and colour sublimation were experienced. Whether the Japanese can overcome the problems associated with fabric stabilisation remain to be seen. Laser-based fabric cutting was being investigated at Culham laboratory prior to 1974\textsuperscript{81}, and laser cutting in general has been developed into commercial applications.

There are fundamental problems associated with some of the concepts being proposed by the MITI project, one of which is three-dimensional robotic sewing. A concept involving the setting of a sleeve into a jacket has been demonstrated a number of times at international exhibitions. It relies on a great deal of pre-sewing of the sleeve opening and sleeve head in order that the two seams match,
as the robot stitcher has no facility for inserting fullness into the seam. There is also a great deal of manual manipulation of the garment on the formers to ensure correct positioning of the seam in relation to the robot. The stitching of the sleeve was a pre-programmed sequence with no real time control. Problems had been encountered in maintaining an accurate seam width of 10 mm and also consistent stitch lengths, particularly at the underarm. This was due in part to the robot movements.$^82$

The MITI project is not without its critics. A few apparel manufacturers [in Japan] have shown a negative attitude to this project. One reason being a belief that such a system may cause over-production since an expensive system of this kind would need to be operated 24 hours a day to provide an adequate return on investment (ROI). One notable critic of the programme outside of Japan is Nilsson$^83$ who states that the concept of a turn key fully integrated and automated production line is a technological "pipe-dream", and that such an approach represents a typical "cart-before-horse approach". He further states "that this vigorous, one-blow technical onslaught on the automation of apparel manufacture will take too long to give tangible results in the form of robust operative equipment".

Despite the criticism being levelled at the Japanese research programme, it is possible that the end result of this highly concentrated and co-ordinated effort may well be a radically different apparel industry of the future. It is certain that any large-scale effort at robotic development in Japan will result in a new Japanese industry for export, this would only be advantageous to
the Japanese. Already 80% of the world's sewing machines are produced in Japan, many appearing under well known European and U.S. brand names.

The success of the project will only become apparent at the end of the project, in 1990. It is interesting to note that in his review of the progress being made by the MITI project, Hughes Assistant Director of (TC)$^2$ states:

"In conclusion, it must be noted that the units demonstrated were not constructed in the typical prototype manner. They were well designed and constructed and appeared to be ready for commercial application. TRAASS and the small-to-medium-size enterprises, associates of MITI are to be congratulated for their accomplishments to date and it is very apparent that they will accomplish their future development targets."

This leads on to the research effort of the (TC)$^2$. In contrast to the Japanese approach (TC)$^2$ receives U.S. government funds based on membership dues from private industry, which in turn means that research efforts are co-ordinated on industrial needs along with the specific requirements of the member companies. It has been stated that essentially this research is being done to prove a principle.

Although for many years the American Apparel Industry has held the view that automation is the answer to the problem of increased import penetration from the developing countries. In further support of this viewpoint it has been stated that if there is no alternative, then more protectionist legislation would be sought. This would result in an increasingly divided society, more people out of work, and more
Apart from some of the technological developments incorporated in the \((\text{TC})^2\) project, such as robotic picking and folding, the research programme represents a change in attitude on the part of organised labour towards automation. In fact the Amalgamated Clothing and Textile Workers Union (ACTWU) have been closely involved with the project from its onset.

Singer's involvement in the \((\text{TC})^2\) project, has greatly advanced the assessment of the suitability of the prototype and its applicability to commercialisation. Singer have developed their own robotic systems - MARS, which is already successful in car seat production, although an automation plan for shirts met with limited success.

The original prototype of the \((\text{TC})^2\) robotic system has been described as "quite useful but far from a production model". The question of speed and cost is also an important factor in the ultimate success of the system. Some in the apparel industry [U.S.] criticise the project, partly on the basis that it represents a very expensive, very specialised machine, and partly on the basis that nothing has been done to change the sewing technology in any way. In operation the system is very slow. The computational power required to process information from the vision systems and feed it to the pickers to position the pieces is enormous. As much of \((\text{TC})^2\) work is still in the prototype stage, accurate costs of the finished system are not easily obtained, although prices in the region of $100,000 - $150,000 have been quoted.
The American research effort is summed up in a statement by Berkstresser:

"While the United States has more resources for the development of automated apparel technology than does Japan, the redundancies produced by the lack of co-ordination in the U.S. may well cause such a high degree of waste that the Japanese may produce an integrated automated sewing system before the U.S. However, the Japanese system may still rely heavily on U.S. technological breakthroughs for substantial segments of the total system."

A lack of a co-ordinated research effort in Europe is also a factor preventing significant advances in apparel automation to be made. The different languages, business laws and national goals, coupled with traditional suspicion among members of many sub-cultures does not make for a co-ordinated research environment.

One of the most comprehensive pieces of research in automated apparel manufacturing is that of Chalmers University with its FIGARMA concept. This programme is based on the belief that to start the arduous and expensive road to automation by constructing a full scale robotic production line (like the Japanese) cannot be considered to be a viable technical or economic endeavour; it is believed that it is far simpler and cheaper to build a mathematical computer model of various configurations of production lines.

The main problem with the FIGARMA approach is that it remains a concept, based on idealised conditions. Although many of the theories expounded are fine for the ideal situation, no mention is made of their practical implementation i.e data transfer between
machine/computers etc. Also no mention is made of the cost of such a comprehensive computer integrated system.

FIGARMA also relies on many undeveloped technologies such as the "rotary multi-purpose mechanical stitching system", which can perform different stitch types by rotation of the stitching head. So far such a concept has not proved practical. Rimoldi introduced a modular sewing machine in 1983 capable of covering a range of stitch types by simply changing the module of a standard section, called the "base and arm". Although response to the concept was favourable it never resulted in any firm commitment on Rimoldi's part to put the prototype into production. Rimoldi found that many of their customers preferred a conventional machine dedicated to performing particular tasks.

The FIGARMA approach does however point out critical areas for development of specific new technologies. It offers a total systems approach which is even broader than the Japanese project. It goes beyond the technological development required, into the area of management, such as building computer models for process and planning purposes.

Of the pre-BRITE activity being carried out in the U.K. and Europe, Sinclair writes "the final state of play with regards to the U.K. initiative is that a unified approach to EEC/U.K. findings is still awaiting development". This was written before the advent of BRITE, which aims at a unified co-ordinated research effort. Despite the aim of BRITE the main criticism is that it is fragmented, thus dissipating finances, efforts and energies. This was apparent during
the 21st conference of Clothing and Knitting Industry Technicians reported on by Disher. At the conference it was also noted that EEC officials had expressed dissatisfaction because project reports [BRITE] were not very clear, probably due in part to patent reservations. It was also concluded that some of the projects were not real research projects, as some groups were working on developments which were already established. There were also political aspects involved in the [BRITE] programme.

In his summing up of the BRITE project Harris\textsuperscript{97} comments that "on the surface it is a wonderful opportunity to make clothing in far more efficient, less labour intensive ways". He adds that there is not much in the programme to reflect the fickle nature of fashion trends. On a final note about BRITE however, he states that there is less danger in such a project of "re-inventing the wheel" and the attempt to co-ordinate effort is a step in the right direction.

The problem of research programmes being carried out under U.K. research initiatives is that they are mostly of a fragmentary nature, and tend to focus on a specific aspect of clothing automation. With many of the research centres being isolated from each other and the competitive nature of the research being carried out, the problem of compatibility of these individual developments would be bound to arise.

U.K. research projects and European research projects in general suffer very much from being under-financed, many of the projects require a 50% commitment from industry in order to proceed. However the availability of direct industrial support for project

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work is negligible. Although research projects are viewed as being of high value to the industry they receive little financial backing from individual clothing manufacturers. This is due in part to the fact that the manufacturers are very under-capitalised and are more concerned with 'putting out fires' in day to day running, than in investing in 'high risk' activities.

To sum up the global research effort, and put it in some perspective, Berkstresser states:

"Although some U.S. and European organisations may be in the lead in technological development on some machinery, it appears that the Japanese, with their highly respected ability to organise and manage projects that require cooperation between government, management, and labour, have taken a "giant step" forward in the total automated system development. Even if other industrialised nations recognise the full importance and implications of this development, it is still not known if they can or will allocate the necessary resources to respond to it."

There are those however, who are of the opinion that the new technologies developed will rapidly achieve global dissemination regardless of the country of origin. It is also felt that it would be extremely difficult to prevent any group from making use of the new technologies once they had been developed.
Chapter 3

Model for Proposed Integrated Garment Manufacturing System
3.1 The potential for an integrated garment manufacturing system

As discussed in Chapter 1, automation is viewed as being the solution to many of the problems facing the clothing industries of the industrialised nations. The review in Chapter 2 shows that the main thrust of research effort is being directed towards the attainment of partially automated or fully automated systems for garment manufacture. The problem is being tackled in a variety of ways, from a conceptualised systems approach (FIGARMA) through to a full blown hardware approach (MITI). Despite the differences in approach and philosophy, what is clear is that the potential for an integrated garment manufacturing system clearly exists.

Besides the developments likely to accrue from research programmes outlined in the review, it would appear that manufacturing companies in the U.K., are beginning to invest in computer technology. Although the U.K. clothing industry has been traditionally slow to invest in new technology, the past decade has witnessed the introduction of much new technology, especially in the areas of computer aided design (CAD) and computer controlled fabric cutting.

The result of this 'piece-meal' approach to technology has been the creation of 'islands of automation' within a typical company. These 'islands' being super-imposed on fairly traditional company structures. The links between these 'islands' are essentially paper orientated, with the consequence that much of the work is duplicated.
Another reason why 'islands' exist is that companies tend to invest in equipment best suited to a particular task, or within a pre-set budget. This invariably results in equipment being purchased from different suppliers.

Many manufacturers employ computers in the control of their equipment which have different hardware configurations, operating systems and software architectures. This results in incompatibility between equipment. The ultimate goal of computer integrated manufacture (CIM), is to bridge the communications gap existing between these "islands" and have equipment [computers] which is able to freely transfer data and other operational information. In addition to the technical problems associated with equipment exchanging information, the need exists in the clothing industry for the various production processes to be physically integrated.

There are now areas in the mechanical engineering industry [especially in automotive manufacture] where CIM has been successfully implemented. Unlike the mechanical engineering industry where the material being handled is essentially rigid, the clothing industry is hampered by its raw material - fabric. The ease with which a human operator can manipulate fabric and react to its properties has proved extremely difficult to emulate with any automated device or robot. There are those who believe that any attempt to design robotic systems to achieve human emulation are destined to fail.

Acknowledging that it is extremely difficult to eliminate the operator from the garment manufacturing process, it seems unlikely in
the near or mid-term future that a total flexible manufacturing system (FMS) for garment manufacture will be realised. What does appear achievable is the total flexible automation (FA) of 'sub-cells' within the garment manufacturing system. The whole system being integrated to create an orderly, intelligent, effective and efficient production system. This being achieved through the interaction of people, machines, computers and feedback devices which serve to direct functions, detect deviations, and self correct any errors in the functions.

In the following section such a system is proposed. It covers a conceptual design for an integrated garment manufacturing system. It includes references, where appropriate, to current research being carried out by the author and research being carried out elsewhere.
3.2 System overview

Figure 3.1 shows a concept for a computer integrated garment manufacturing system. It is designed to include all the functions inherent in garment manufacture, without being specific to any one particular garment. The concept embraces both traditional sectors of garments, woven and knitted (excluding fully fashioned garments).

At this stage of research no attempt is made at providing complete solutions to the problems of integrating various equipment/processes. The concept has been presented for reasons of completeness and to guide the reader to view the research undertaken by the author as being part of an overall system.

This concept presents no limitations on the type of equipment used, as any proposed type of working environment can be modelled and simulated. It is often the case that new automated equipment is introduced into a company without fully realising the effect it will have on the complete system.

The proposed production process is sub-divided into a number of stages. These representing the various processes involved in garment manufacture. The stages are grouped into three distinct areas:

1) Design and planning
2) Pre-assembly processes, and
3) Garment assembly.

All stages are integrated and information generated at each stage is available for utilisation by any other stage.
Figure 3.1 Concept for an Integrated Garment Manufacturing System

STAGE 1
3D Garment Modelling

STAGE 2
Identify Garment Pieces

STAGE 3
2D Pattern Engineering

STAGE 4
Measurement Generation

STAGE 5
Sample Make-up

STAGE 6
Production Planning/Order Scheduling

STAGE 7
Fabric Inspection/Flow Detection

STAGE 8
Layout Planning/Mark-making

STAGE 9
Cut Order Scheduling

STAGE 10
Spreading & Cutting

STAGE 11
Fabric Stripping

STAGE 12
Unit Production System

STAGE 13

2D (standard) Sewing Area

2D (complex) Sewing Area

Assembly

Small Make-up Unit (SMU)

Finishing

Robotics 'sub-cells'

20 (standard) Sewing Area

20 (complex) Sewing Area

Robotic 'sub-cells'

(C) M K HALL 1989
Figure 3.1A Design and Planning

STAGE 1
3D Garment Modelling

STAGE 2
Identify Garment Pieces

STAGE 3
2D Pattern Engineering

STAGE 4
Measurement Generation

STAGE 5
Sample Make-up

STAGE 6
Production Planning/Order Scheduling

basic block pattern database

style pattern database

fabric performance characteristics

fabric database

accessories database

personal measurements class 'A'

size charts class 'C'

personal measurements class 'B'

making-up sequence database

machine database

workplace layout database

casting information

STAGE 1
3D Garment Modelling

STAGE 2
Identify Garment Pieces

STAGE 3
2D Pattern Engineering

STAGE 4
Measurement Generation

STAGE 5
Sample Make-up

STAGE 6
Production Planning/Order Scheduling

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3.2.1 Design and planning

Stage 1 - 3D Garment modelling

This incorporates the following functions:

- Simulation of various design ideas
- Simulation of various fabrics on the computer generated model.
- Visualisation of colour combinations
- Animation of the computer generated model with simulated fabric properties (drape etc.)

With the above functions complete, the design could then be presented to prospective customers. This could be achieved by either a visual animated demonstration on the VDU or the generation of colour prints.

Designers would be encouraged to develop their ideas directly onto the VDU, and for security reasons designers would retain them on appropriate storage media.

Related research:

CDI/Microdynamics [3D modelling]
Queens University/Leeds University [3D pattern generation]
Leicester Polytechnic - CIM Centre [3D pattern generation]
Stage 2 Identification of pattern pieces

This involves:

- The setting up of a review area on the VDU in which two dimensional patterns can be viewed.
- The searching of the pattern databases for an existing pattern which could be modified in order to fit the new design.
- The identification on the 3D image of the specific location of points on the pattern to be modified, including the way in which they are to be modified.
- The search of the fabric database for suitable fabric or the automatic generation of an order for new fabric.
- The storage in the design working file of the selected existing patterns along with notes for their modification.

This stage would avoid the unnecessary process of generating pattern pieces for any new design. There would need to be two separate databases, a style pattern database and a block pattern database. The style pattern database would contain any pattern pieces which had been altered for previous designs. This database would be searched first. The block pattern database would contain basic pattern blocks, the base pattern from which the designer would work.
Each database would provide search routes in the following format:

```
MENS  LADIES
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SHIRTS</td>
<td></td>
</tr>
<tr>
<td>JACKET</td>
<td>TROUSERS</td>
</tr>
<tr>
<td>FORMAL</td>
<td>CASUAL</td>
</tr>
<tr>
<td>FRONT</td>
<td>BACK</td>
</tr>
</tbody>
</table>
```

Stage 3 Two Dimensional Pattern Engineering

This involves:
- The setting up of a 3D review area where the design generated in stage 1 can be viewed.
- The retrieval of each pattern piece from the design working file for the new design.
- The modification of the pattern in accordance with instructions generated at stage 2.
- The storage of the modified pattern pieces in the production working file.
- The identification of accessories, threads, trims etc. to be added to the production working file.

Each pattern is stored in the database in 'parametric' (macro) form. The 'parametric' would contain only the instructions required for generating the shape. Proportional sizes would be contained in the parametric file. When the designer/pattern cutter retrieves the pattern from the database the pattern is displayed on the VDU in the sample size selected. The designer would then have 'free reign' to modify the pattern, adding style features, darts etc., whilst viewing the 3D design sketch. Once the modifications are complete a new parametric would be generated, based on the modified pattern. This parametric would be added to the production working file as well as being added to the style pattern database. Before being added to the production working file, seam allowances, hems etc. would be added, these remaining in the file as instructions for garment make-up.

Related research:
M. Hall [parametric pattern generation]
Gerber/Lectra/etc. [pattern design systems].
Stage 4 Measurement generation

This would involve generating measurements by two methods:

(a) Personal measurements, and

(b) Size charts.

a) Personal measurements

These would be obtained either by:

(i) 3D co-ordinate measurement.

Generated at the retail outlet where the order originates. It would involve the use of high technology measuring techniques [lasers, ultrasonics, machine vision] currently being researched.

(ii) Direct measurement

Again generated at the retail outlet but involving the traditional manual method of obtaining direct measurement at specific locations on the body.

b) Size charts

The measurements being based on existing sizing data, known for particular groups. The size chart containing all the necessary measurements required for describing the figure of an individual in a particular group [e.g. tall men]. The measurements being computer coded for easy retrieval.

It is proposed that the integrated manufacturing system produces three classes of garment:
1) Class 'A' garments

Measurements obtained by method a)(i) - 3D co-ordinate measurement, could be used directly at stage 2 in the design process to generate patterns from the 3D computer generated model. These pattern pieces would then become 'customised' pattern pieces, made to fit the measured form perfectly.

2) Class 'B' garments

These garments would be constructed from measurements obtained via method a)(ii) - direct measurement. These would encompass the range of garments traditionally referred to as 'made-to-measure'. Unlike class 'A' garments, however measurements would be made by more traditional methods [tape measure]. These measurements would be directly related to parameters required to construct a pattern piece at stage 3 in the design process. Existing or modified pattern pieces would then become customised for the measured form.

3) Class 'C' garments

These garments would be constructed from standard size chart data. The data would be directly related to the pattern pieces generated in stage 3 of the production process. Size chart data would be constantly updated, as more accurate statistical information regarding particular groups of individuals becomes known. This range of garment would be equivalent to present 'off-the-shelf' ranges.

With such an approach to garment manufacture a manufacturer could cover a large range of garments required by the consumer - from
'designer' garments through to 'off-the-shelf' garments. The price structure of the garments would need to reflect the amount of work required in their production. Class 'A' garments would involve additional computer activity at stage 2 in the design process, it would also require highly sophisticated 3D co-ordinate measuring systems and skilled operators to fabricate these garments, resulting in a greater manufacturing cost.

Both class 'A' and class 'B' garments would need special production planning. They would have to be made as special 'one-offs' or be scheduled through with the larger volume production garments [class 'C'] with special instructions for their making-up. These garments might even necessitate a separate assembly unit, referred to as a small making-up unit (SMU). This unit would require a number of skilled operators who could respond quickly to the needs of the 'one-off' garment.

Related research:

M. Hall [proposed concept]
S. Efrat/CIM centre [3D co-ordinate measurement]
Leicester Polytechnic [3D co-ordinate measurement]
MITI (Japan) [3D co-ordinate measurement].
Stage 5 Sample make-up

This process involves:-

- Pattern pieces created in stage 3 - 2D pattern engineering being retrieved.

- The pattern pieces being plotted out full size to be cut from fabric, or single ply cut, in a sample size [e.g. size 100 cm chest].

- The transfer of the pattern pieces to the sample room where skilled operators make-up the garment.

- Any alterations required during making-up being noted for the designer/pattern cutter.

- The finalised garment would then be shown to the prospective customer(s), and if necessary a full range of garment sizes constructed for evaluation.

- Once the sample has been approved the pattern pieces in the production working file are finalised and become a production file.

This stage would require a small number of skilled operators, familiar with the latest equipment and making-up procedures. These operators would be required to work closely with the designer/pattern cutter, and using their combined skill and judgement be able to suggest any alterations which could make the garment easier to construct. The designer/pattern cutter/operator would have access to a making-up sequence database, in which making-up sequences for all garments manufactured would be stored.
Stage 6 Production planning/order scheduling

The sequence of operations required to make-up the garment is identified in the previous stage. These are included in the production file which is then passed to the production planning/order scheduling department.

Utilising the sequence of operations for the garment, each machine required to carry out the garment would be identified. This would be achieved by searching the machine database which includes any accessories which can be added to the machine. As well as the machines required to carry out the operations, the configuration the machines can accommodate would also be identified. If a particular assembly operation can be identified which may be performed automatically, then the necessary equipment would be identified at this stage. This process would require a database of current equipment and machine configurations to be accurately maintained.

Along with the above activity, the confirmed order is scheduled. The number, size and accessories required for the order, are identified and added to the production file.

Using a simulation package and the data contained in the production file, the sequence of production would be modelled. Any potential bottleneck operations being identified at this stage, and alternative configurations tested in order to minimise or eliminate them. The information generated at this stage would be used for accurate and realistic forecast dates. In addition to simulating the production for the new garment it would also be necessary to take into consideration existing orders currently in progress. The
finalised simulation configuration would be included in the production file. At this stage the decision would need to be made whether to fit the order in with an existing order, or to completely re-configure the assembly area for the new order. Both methods could be simulated to determine the best solution.

Related research:

Leeds University [work place simulation]
Manchester Polytechnic [work place simulation]
Figure 3.1B Pre-assembly Production

- **Stage 1**: Pre-assemble Product
- **Stage 2**: Product Layout Database
- **Stage 3**: Fabric Fabrication
- **Stage 4**: Cutting
- **Stage 5**: Production System

**Stages**

1. **Stage 1**: Pre-assemble Product
2. **Stage 2**: Product Layout Database
3. **Stage 3**: Fabric Fabrication
4. **Stage 4**: Cutting
5. **Stage 5**: Production System

**Flowchart**

- **Stage 8**: Layplanning/Marker Making
- **Stage 9**: Cut Order Scheduling
- **Stage 10**: Spreading & Cutting
- **Stage 11**: Fabric Stripping
- **Stage 12**: Unit Production System

**Connections**

- Marker database
- Costing Information
- Existing Order Database
- Fabric Inspection/Flaw Detection
- Fabric database

**Flow**

- Stage 1 to Stage 2
- Stage 2 to Stage 3
- Stage 3 to Stage 4
- Stage 4 to Stage 5

**Evaluation and Stores**

- Evaluation
- Stores

**Update**

- Update from Stage 3 to Stage 4
3.2.2 Pre-assembly production

Stage 7 Fabric Inspection/flaw detection

Fabric entering the company would be inspected on a machine either by an operator or by machine vision techniques. Any fabric faults being identified, and the fabric coded in some way [e.g. at the selvedge of woven fabric]. The fault code containing the type, size and location of the fault on the fabric.

Each fabric roll would also be identified by its width, length, fabric type, colour, and any other distinguishing features, in addition to any faults detected during inspection. A sample would then taken of the fabric and sent to the testing laboratory for evaluation. The fundamental fabric properties would be identified at this stage.

Once inspected and identified the fabric roll would be transferred to the storage area. Data concerning the fabric roll is then entered into the fabric database (this database is available to the designer for fabric selection). The fabric's location in the storage area is also included in the database, along with its fundamental properties, when they become known.

Ideally fabric inspection should be carried out at the source of manufacture [weavers/knitters]. It is realised that this is not always possible or practicable, and relies to some extent on a commitment on the part of the fabric supplier to provide this facility. Where companies have a vertical structure and produce their own fabric this would be practicable.
Sewing threads, buttons, trims, zips, and other accessories would be coded similarly on receipt. These would then be entered into the accessories database, and stored.

Related research:
KURIS [fabric inspection/CIM]
CIM Centre [fabric inspection/evaluation]
Kawabata [fabric evaluation].

**Stage 8 Lay planning/marker making**

The production pattern pieces generated at stage 5 would be retrieved from the production file. Using information concerning the order scheduling, the correct number and size of pattern pieces required would then selected.

An automatic lay plan would then be initiated. Once the efficiency had reached a pre-determined minimum value, lay planning would stop. The lay plan generated would be used as a first cost estimate of fabric consumption. The lay plan/marker database would be searched in the meantime for existing markers which may be used or modified. Existing markers would more likely be used for repeat orders.

If an existing marker is not found then the lay planner would work interactively with the computer system, using the automatically generated lay plan as a guide, to produce a new marker. The finalised marker is stored in the production file, and is also added to the marker database. The finalised marker is used for accurate garment costing.
Related research:

KURIS [markers/CIM]
CYBRID [automated lay planning]
Commercial systems [lay planning]

Stage 9 Cut-order Scheduling

The cut-order planning programme would retrieve all the information, from the production file, required to establish the spreading order. This would involve determining the type of fabric, quantity, and order in which it is to be spread out for cutting. The number of plies in a particular lay would also be determined, along with the cutting machine required. This information being included in the production file.

The order in which the pattern pieces are to be removed from the cutting table (stripping), along with the type of picker that would be required, and its orientation with respect to the edge upon which the first operation is to be performed would all need to be determined at this time. Each pattern piece is located by its relative position in the lay, so it is possible to specify the exact co-ordinates where the robotic picker can locate a particular piece. The stripping information would be included in the production file.

Related research:

Commercial CAD Systems [cut-order scheduling].
Stage 10 Spreading and Cutting

When the order is ready to go into production the production file would be retrieved. Fabric would be transferred from the stores in accordance the instructions for cut-order scheduling. The spreading machine would need to employ a carousel type system for the fabric rolls, so that a number of fabric rolls could be held for mixed or different orders.

The spreading machine would read the cut-order scheduling information contained in the production file and automatically select the correct fabric roll from the carousel and start spreading. The production file also contains information as to whether the fabric can be laid both ways (zig-zagging) or only one way (lay, cut, return).

When the spreading machine encountered a fault coded on the fabric spreading would stop. The fault would be compared to the production marker, and the decision whether to tolerate the flaw or remove it would be made. The spreading machine would record the fabric consumption and update the fabric database when spreading is complete.

The 'laid up' fabric would be automatically transferred on a conveyorized system, to the cutting table. The computer directed cutter interpreting the marker in the production file, would automatically cut the fabric. Cutting could be either single ply cutting for 'one-offs', or low/medium ply cutting for standard production. High ply cutting would be best suited to very large volume production.
Related research:
KURIS [fabric spreading/CIM]
CIM Centre [fabric spreading/CIM]
Gerber/commercial systems [NC fabric cutting]

Stage 11 Fabric stripping

Pattern piece stripping information would be retrieved from the production file and passed to the stripping robot controller. The controller would direct the robot through the sequence in which the pattern pieces are to be removed from the stripping table.

A number of fabric handling manipulators (pickers) would be available to the robot. These being selected from a magazine at the end of the stripping table (see figure 3.2). They would be easily inter-changeable and selected in accordance with instructions contained in the production file, depending on the size and type of piece to be handled.

Some degree of 'intelligence' would be built into the picker so that incorrect picking could be easily detected. On successful picking the pattern piece would be loaded onto the overhead conveyor (unit production system) for routing to the assembly areas. Pattern pieces would be loaded onto hangers in the correct orientation for subsequent work to be carried out on the piece.

Related research:
M. Hall [fabric handling]
CIM Centre [fabric stripping].
Figure 3.2 Pattern Piece Stripping

unit production system

robot

stripping table
Stage 12 Unit Production System (UPS)

As the cut pieces are picked from the stripping table and transferred to the garment piece hanger its intelligence unit would require updating with the description of the piece loaded onto it.

The unit production system controller would interface with the production file so that the routing of the pattern piece would be pre-determined. This being achieved by retrieving the previous order simulation contained in the production file. The UPS would comprise a hanging garment overhead rail system as supplied by a number of companies. In addition to the overhead rail there would be an accessories retrieval system which would allow accessories required for the order to be routed to the assembly areas from the stores.

The UPS would be used primarily to link the various production areas. It would also interface with the real-time control system, to provide supervisory control of the entire production process. In the event of machine breakdown, the UPS would be able to re-route garments and update the real-time control system.

The UPS would be responsible for accurate line balancing and would enable garments to be dispatched to operations with less work, possibly in a different sequence to the standard routing. Through the use of computer graphics, the plant supervisor would have a visual display of the production lines and also have real-time information concerning work in progress (WIP).

Related research:
Eton/Gerber/INA/Investronica/Juki/Veit/Jioe/OY T-Rolleytec/
Jet Age Systems/Durkopp [unit production systems]
Figure 3.1C Garment Assembly

STAGE 13

2D (standard) Sewing Area

- Robotic 'sub-cells'
  - Assembly

3D (complex) Sewing Area

- Assembly
  - Multi-machine working
  - Quick response sewing
  - Programmable units
  - Edge-guiding
  - Real-time control
  - Quality circles

Small Make-up Unit (SMU)

- Class 'A' garments
- Class 'B' garments

STAGE 14 Finishing

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3.2.3 Garment Assembly

Assembly areas (stage 13)

At the sample make-up stage (5) the order in which the garment is to be constructed has already been determined. The machines and configurations required to carry out the operations were identified at stage 6. These sequence of operations are broken down in those carried out automatically by robotic units, and more complex ones requiring human intervention.

In consequence the garment production area is divided into two sections:

(i) 2D (standard) sewing area, and
(ii) 3D (complex) sewing area

(i) 2D (standard) sewing area

This area would require only the minimum of human intervention, and would utilise the latest fully automated robotic equipment. It would comprise a number of 'sub-cells', each responsible for carrying out a particular operation [e.g. collar top stitching and button-holing]. The sub-cells would be linked to each other by the UPS, and also to the other areas of assembly.

Each robotic sub-cell would accept parts from the UPS in the correct number and orientation required to perform the operation. Any accessories, trims etc., being stored within the sub-cell in bulk form (stacks, rolls etc.), these being replaced when necessary from
the stores. Each sub-cells would be as flexible as possible and able to respond to changes in component specification, without the need for skilled setters.

If possible, the operation would be carried out on the garment piece whilst still attached to the hanger. Some operations however would not permit this, in this case provision would be made to re-position the garment on the hanger after the operation has been performed for routing to the next process.

(ii) 3D (Complex) sewing area

In this area maximum use would be made of the skills inherent in human operators for manipulating flexible materials and reacting to unforeseen circumstances. Although humans have tactile and sensory skills which are extremely difficult to emulate by robots, they suffer from a variable and inconsistent work output. Production equipment incorporated in this area would therefore need to take on various functions traditionally carried out by the operator. In effect many tasks would be de-skilled, but not to the extent where the operator merely becomes a 'machine minder'.

Due to the reduced skill requirements of the operations, operators would be able to operate a number of different type of machines. This would mean that operators would require new skills i.e. being able to handle a wide variety of equipment. This would also make operators more flexible and enable them to move quickly from one process to another.

For most efficient production, each piece of equipment would
need to incorporate the latest developments and include a programmable unit interfaced to the overall system controller. At the design stage the allowances and seam widths would be specified for each garment. This would require a device which could automatically adjust the position of the fabric being fed into the machine. The programmable unit would respond to the instructions for garment make-up contained in the production file and adjust the equipment [or direct the operator to adjust the equipment]. Also correct settings for the equipment to provide optimum make-up, based on the fabric's physical properties, would need to be taken into consideration.

A 'quick response' sewing system would be employed with operators working in teams. Equipment would also be configured in such a way as to allow efficient multi-machine working, and ease of re-configuration for different styles and lines.

Operators would interface with the real-time control system, their performance and output being monitored and used in conjunction with the payroll system for wage generation.

Inspection would be carried out by operators and where possible by machine vision systems. A 'quality circles' approach to garment production would be operated, with operators taking full responsibility for the quality of garments produced.

The small make-up unit (SMU) would be contained within the 3D (complex) sewing area, employing a small number of experienced operators responsible for producing class 'A' and some class 'B' garments.

The robotic sub-cells would be integrated with the 3D (complex)
sewing units as shown in figure 3.1C. Together they would combine to produce class 'C' garments.

Related research:
M. Hall [fabric guiding & feeding/fabric handling]
Durkopp & Adler [quick response sewing]
Rimoldi [quick response sewing]
Juki [quick response sewing]
Aisin Seiko [quick response sewing].

Stage 14 Finishing

Once the garment has been made up, it requires further treatment to ensure it is presented to the customer in an aesthetically pleasing and acceptable form. The process of finishing would involve:-
- Transport of the made-up garment to the press.
- Installation of the garment, in the correct orientation on the press.
- Transport of the garment from the press to the packaging equipment.
- Packaging of the garment.
- Transport of the garment to the warehouse/dispatch.

Related research:
CIM Centre [knitted garment finishing]
MITI [garment finishing].
3.3 Key research areas which need to be addressed before the concept of an integrated manufacturing system becomes a reality.

The foregoing section presents a concept for an integrated system for garment manufacture. Unlike many proposed research programmes, it proposes a somewhat intermediate approach to integrated garment manufacture, based on human activity in the assembly areas.

As highlighted in the previous sections (related research) a number of organisations are making on-going contributions to various areas within the proposed system. The main problem is that few organisations are tackling the complete integration task. This is due in part to the large number of equipment suppliers producing incompatible 'islands of automation'. In order for such a system to become a reality it would rely very much on a willingness on the part of equipment manufacturers to develop machinery which could 'plug-in' to a standard integrated system.

One particular company KURIS has done much in proposing a CIM concept for the linking of operations from fabric receipt and inspection through to programmable spreading machines and cutting systems (see figure 3.3). This concept however does not cover any design or making up operation, and necessitates equipment being compatible.

In order for such a concept to become a reality, there are a number of key areas which need to be addressed:
(i) Net-working of equipment - locally and globally.

CIM requires that various computers can talk to one another, exchanging information. This presents a number of technical difficulties which have impeded progress towards CIM. The International Standards Organisation (ISO) became involved with the problem of communications, and in 1981 they published the Open Systems Interconnection (OSI) model, consisting of seven layers of protocol to organise data transmission and two-way communication between computers. The first two layers relate to any local area network (LAN); layers 3 to 6 provide for data exchange between dissimilar machines in a wide area network (WAN); and layer 7 enables the user to access and use the services provided by the network.

The problem with any standard is that it must be accepted by all manufacturers in order for it to be effective. However, in addition to OSI there is the Manufacturing Automation Protocol (MAP) and the Technical and Office Protocol (TOP). Both systems are based on the OSI model but have been developed for different requirements in data transfer. They are only compatible above levels 1 & 2 of the OSI model.

Difficulties associated with interfacing different equipment are likely to be the major problem areas requiring to be resolved before CIM is possible.

(ii) System Control

For a CIM system for garment manufacture to run efficiently requires a tight control on the interaction between operators,
machines, and production. System control would need to include:
- Loading orders into the factory in a balanced way, to meet customer delivery requirements.
- Monitoring of orders against a pre-planned target.
- Maintaining manufacturing costs at a minimum level.
- Monitoring machine and operator performances and taking the necessary action in the event of machine breakdowns etc.

A computer integrated manufacturing system would require a far more complex 'real-time' system than those currently available.

(iii) Converting 3D designs to 2D patterns

This involves using three dimensional graphics packages to simulate a particular design, and from that design identify pattern pieces required to make-up the garment. Once the pieces have been identified then they would need to be modified in two dimensional form and then re-converted to three dimensional form to check the geometry of the pattern pieces.

(iv) Computer-based pattern generation

This would provide a radical new approach to conventional two-dimensional pattern engineering, which provides the designer with a flexible pattern piece which is automatically fit to the required constraints. This would move designers/pattern cutters away from working with traditional media [paper and pencil] and encourage visual display unit [VDU] working.
(v) Reliable fabric handling in stripping and in transfer between sewing areas

This is another critical area for realisation of a computer integrated garment manufacturing system. At present fabric handling at the cutting table (stripping) and at the various work stations is currently one of the most labour intensive operations in garment manufacture. Systems are required which can accurately and reliably handle a wide range of fabric types and garment shapes and sizes. This is an area which has presented a number of major problems to the industry over the years.

(vi) Encoding information on garment pieces

Information encoded on garment pieces would greatly aid system control. This information could be used to automatically adjust, or to direct the operator to make adjustments to the equipment. Fabric would need to be encoded at either the fabric cutting or fabric stripping stage. In this way each garment piece could be monitored throughout the various stages of the production process.

(vii) Control of fabric during the assembly process

With complex three dimensional assembly operations, the operator expends a large amount of effort in controlling the fabric as it is being fed into the sewing machine. This requires accurate hand and eye co-ordination. The development of systems which aid the operator in maintaining the quality of seams produced, would improve the overall quality of garments, and would not be subject to the
variations of performance experienced by human operators.

(viii) Fabric performance characteristics

A thorough investigation of general fabric performance characteristics in relation to their making-up ability needs to be undertaken. Fabric properties have a significant influence on the final garment fit and also influence their construction. At present insufficient knowledge exists concerning fundamental fabric properties and how they relate to machine settings, making-up conditions etc. Each new process requires an additional investigation into the relationship that fabric properties have on the process.
Figure 3.3 The KURIS CIM-Concept

(RECEIPT OF GOODS)

(COMPUTING CENTER
HOST)

(ORDER OPTIMIZATION
(PC))

(ORDER PRINT-OUT)

(MARKER MAKING)

(CLOTH CONTROL
WITH FLAW
CODING ON
KURIS TEXTILE
INSPECTION
MACHINE TIM)

(CODING OF
CLOTH ROLLS)

(DISK 3 1/2''
(alternative
online))

(DISK 3 1/2''
(alternative
online))

(DISK 3 1/2'');
5 1/4''' ; 8'''
(alternative
online)

(CLOTH ROLL STORAGE)

(CLOTH ROLL STORAGE)

(KURIS MULTIROLL-LIFT)

(KURIS HIGH-TECH-
CLOTH SPREADING
MACHINE PIONIER
SUPER II WITH KUPOS +
PRINTER, SPREADING
PRINT-OUT)

(KURIS SPREADING
PROCESSOR KUPOS III)

(SPREADING TABLE
PLIES BUFFER
AUTOMATIC CUTTER
TRANSFER TABLE)

(RS 232
INFRA-RED BARRIER)

(PIONIER SPREADING
TABLE SUPER II)

(PIONIER SPREADING
TABLE SUPER II)

(KUPOS III)

(KUPOS III)

(KURIS AUTOMATIC
CUTTER ORDER OPTIMIZATION
ORDER PROGRAM
AUTOMATIC SPREADING PROCEDURE
AUTOMATIC FLAW HANDLING
CAPTURE MATERIAL DATA
CAPTURE TIME DATA

(Source: KRAUSS u. REICHERT)
3.4 Selected areas to be pursued in this research programme

To create a computer integrated manufacturing (CIM) system for garment production is a major undertaking and could not be realistically achieved by any one individual or group. It involves the close co-operation of a number of persons/organisations, specialists in their respective areas. This means that the whole concept of CIM has to be broken down into achievable target areas.

At the start of this research programme it was thought that the areas of fabric feeding and handling should be the main areas of study. During the course of research however, the scope of the project was widened to include the area of computer-based pattern generation. This area was included since maximum use was not being made of computer systems for pattern design (PDS).

Making-up of the garment is one of the most important areas in garment manufacture. The making-up sector of the industry suffers from a high turnover of labour, hence a shortage of skilled workers. During the making-up process the garment parts have to be fed into the machine and controlled by the operator during stitching. This requires considerable skill on the part of the operator. Robotic sewing has been proposed, but as yet, has not even approached emulating the skills of experienced operators. The cost involved in developing such systems is likely to dissuade their uptake in the clothing industry. Therefore an intermediate approach has been proposed in this project, with the integration of robotic sub-cells and operators.
The area of fabric handling opens up many possibilities for development in integrated garment manufacture. Fabric has to be handled throughout the entire production process from the stripping stage through to the pressing and packaging stage. In handling fabrics, the properties of the fabric have to be carefully analysed in order to optimise the reliability of the operation.

The following chapters detail the research undertaken. It has been subdivided into three specific areas:-

3. Automating handling of fabrics and other flexible materials.
Chapter 4

Computer-Based Generation of Garment Pattern Blocks
4.1 Review of methods for creating garment patterns

Although the technology associated with computer aided design has been available in many industries since the 1970's, it is only during the 1980's that there has been a large scale introduction of computers into the sector of the clothing industry concerned with pattern making grading and apparel design\textsuperscript{102,103}. This has, in turn, led to a greater availability of these systems to the small and medium-sized companies allowing them to benefit from the greater flexibility and productivity offered by these systems\textsuperscript{104}.

Many of the traditional roles performed by the designer/pattern cutter, such as pattern grading and pattern modification can now be carried out interactively (sometimes automatically) on commercial computer-aided design (CAD) systems. One area has however remained unaffected by the use of such systems, that is the creation from first principles of basic pattern blocks. The evolution of computer-aided apparel design systems has developed around this activity and still today remains as the primary function in any commercial system.

In order to use any of the commercial computer-aided apparel design systems available, it is first necessary to record the geometrical description of the pattern piece in question in some computer-acceptable digital form, for use as and when required. At present this is carried out in one of two ways:-

(i) Digitising

This facilitates the use of a full-sized digitising board and a moveable cursor. Once the pattern piece has been
secured to the board, the operator uses the cursor to identify the specific locations (nodes) which are then stored in memory as a digital description of the pattern (see figure 4.1).

(ii) Scanning
This is a completely automated method of obtaining the digital description of the pattern piece. It involves the use of light sensitive (or similar) devices which are traversed across the pattern piece and change their state when edges of the pattern piece are encountered (see figure 4.2).

Scanning offers significant accuracy improvements over the digitising method in that it requires minimal human intervention to determine the digital description of the pattern. Both methods do however require the basic pattern (block) to be constructed manually [drafting] before it can be used. Any inaccuracies incurred during the drafting stage are therefore introduced directly into the system, where they will remain (possibly unnoticed) throughout the remaining operations.

In order to carry out an assessment of the working practices of designers and pattern cutters within the East Midland region a survey was carried out by the author, the detailed results of which are provided in Appendix F. The main findings of the survey are outlined over.
(i) The majority of designers and pattern cutters sampled still construct patterns using traditional techniques of modelling on work stands or point paper drafting.

(ii) Those who have access to a computer system, still prepare the pattern manually before it is converted to computerised graphical information.

(iii) Many designers and pattern cutters are unaware of the commercial availability of computer-aided design (CAD) systems.

(iv) Several respondents complained of the limited size of the screens of graphic display units (GDU) and the inability to work to full scale.

In general, the results of this survey were found to correlate closely with a similar experiment carried out by the Fashion Department at Trent Polytechnic, to investigate how knowledge of new technology can be made available to the clothing industry\textsuperscript{106}. Their investigation covered a wider geographical area of the East Midlands.

The findings were further reinforced by a study carried out by the Gloucestershire College of Arts and Technology to determine the use of CAD systems in the industry\textsuperscript{107}. Their work involved interviewing top designers in the U.K. and a sample of manufacturers and research organisations within the EEC. They found that most designers interviewed expressed anxiety about computer aided design for a variety of reasons including; a loss of ethos of fashion design and a loss of sensitivity in design caused by aids such as the digitiser or stylus and screen size.
Plate 4.1 Digitising Patterns

Plate 4.2 Pattern Scanning

This involves the drawing of a pattern on paper according to specifications which may be based on grid measurements or produced by the measurements of a pattern already in existence. The pattern may then be used for producing accurate and consistent repeats.
4.1.1 Creation of patterns

The pattern cutter, who is responsible for constructing the basic pattern and grading it to the specific requirements, is in the first instance, expected to translate the designer's ideas with accuracy and flair into a first sample. To achieve this requires a detailed analysis of the designer's working sketch and a decision of which particular pattern creation method is best suited for developing the pattern to the selected style.

There are three methods generally used by pattern cutters for generating patterns\textsuperscript{108}, commonly known as:

(i) Drafting,
(ii) Flat pattern design, and
(iii) Draping.

(i) Drafting

This involves the drawing of a pattern on paper according to specifications which may be body or garment measurements. Patterns produced by this method are referred to as blocks and have no design intricacies.
(ii) Flat pattern design

This involves the development of designs from a master pattern (or block) which has no design details. Through the use of darts and dart equivalents, a design pattern is developed. This method is used for producing moderate and low priced ready-to-wear garments.
(iii) Draping

Patterns are developed by observing grain lines of a fabric and smoothing the fabric over the body (or work room stand), and shaping near contours using darts. This is mostly used by couturiers (producers of high cost garments) and those who design lingerie.

Each method is effective, and depends upon the type of fabric and garment being made, and to a large extent on the personal preferences of the pattern cutter. It is essential that the pattern cutter understands not only the techniques for creating a pattern but also has a thorough knowledge of how the garment is to be constructed (made-up)\textsuperscript{109}.

The flat pattern design method is most commonly used for volume clothing production. Most new designs are developed from basic blocks, which frequently involves only minor adjustments or changes to an existing pattern from a previous fashion season.

Historically, systems of pattern construction developed in the early days of craft tailoring, long before the clothing industry was formed. They were devised to serve the needs of the busy tailor who needed a guide for drafting garments directly on the cloth. The acknowledged unreliability of the tape-measure for direct measurements helped to popularise proportionate measurement systems.

Kunick\textsuperscript{110} states that pattern construction can be divided into two parts; firstly, knowing the correct measurements; and secondly, a knowledge of the techniques of how they are applied to pattern construction.
The human form presents many geometrical problems in pattern construction, hence pattern cutters have always sought an ideal system, without realising that a system laid down by one person could not fully satisfy the needs of another. Many systems for pattern construction have therefore evolved. Hulme\textsuperscript{111} wrote in his book that:

"The clothing industry has been prolific in systematic methods of applying descriptive data, and it is fair to say that in many of these pattern systems the principles involved have not been too obvious, or even clearly stated. Many years of study of English, American and European pattern system suggest that the method may be unrelated to, or divorced from, principle. The widest variations exist in that large group of systems which not only do not state the principles applied, but which seem to proceed on the assumption that none exist, and that the whole operation is empirical."

Despite the limitations and inaccuracies of sizing data they are still used as the basis for pattern construction. Although block patterns are widely used in the industry, there are problems associated with garments constructed from them. In her paper 'patterns vs. people', Taylor\textsuperscript{112} states that considerable improvements in fitting the average person, can be obtained if more realistic block patterns are substituted for those currently being used.

Much of the problem of ill-fitting garments can be attributed to the fact that many patterns are developed on work room stands that are not true replicas of human form. This was investigated by Hutchinson\textsuperscript{113} who carried out research to discover the relationship between a two-dimensional paper pattern and the three dimensions of the human form; and later by Efrat\textsuperscript{114}.
4.1.2 Block patterns

A block is a foundation pattern which is constructed to a set of standard measurements for an individual of a particular size, in a particular size group. Block patterns are used in the industry to provide the pattern cutter with a basic shape from which many different garment designs can be developed.

In the clothing industry blocks are usually constructed using standard (average) measurements for specific groups e.g. regular sized men, regular sized women, tall men, etc. The size charts for these groups are based on the relationship of different measurements (e.g. chest to seat) of an average person in a particular group. Normally size charts are constructed bearing in mind two main factors:

(i) The type of garment, and
(ii) The market for which it is intended.

Blocks can also be constructed to fit an individual figure by using personal measurements. With this method it becomes vitally important that the personal measurements are taken accurately and in the correct place on the body if the resulting block is to be successful. A block will vary from company to company depending on such factors as:-

(i) The intended age group of the market [teenage, mature etc.]
(ii) Type of product [children's wear, men's wear, etc.]
(iii) Price range and fabric category.
(iv) Idiosyncrasies of the particular company.

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Block patterns are jealously guarded by each individual company since to a large extent their future sales depend on the fit and shape they provide.

A set of block patterns may consist of sections such as, a casual jacket, a one or two-piece sleeve and a collar. Each section will contain information such as:-

(i) Darts - which are used to shape the two dimensional fabric to the body contours.

(ii) Grain lines - which indicate the best fabric placement for each pattern section.

(iii) Important reference points such as centre back, centre front etc.

(iv) Basic seam allowances.

(v) The name, size and quantity to be cut of each section.

The most important characteristic of a block is that although the design shape may change dramatically the basic fit of the pattern will conform to the size of the basic block. This point is emphasised by Cain and Melliar who state that the fit of a garment is directly associated with the accuracy of the manufacturers basic block pattern and that design style has nothing to do with it.
4.2 The need for the establishment of a system for computer simulation

This area of research in no way attempts to address the subject of achieving good garment 'fit'. 'Fit' has been described as the presence of five standards or factors; Ease; Grain; Line; Balance; and Set\(^1\). The determination of 'fit' is highly subjective. The distinctions which skilled pattern cutters incorporate into patterns can represent the difference between mediocre and superlative garment fit. The subject of 'fit' has been discussed by others (discussed previously). This area of research is concerned with developing principles for generating garment patterns on a computer and not with pattern design in itself.

It has already been mentioned that many systems exist for pattern construction and that there is no hard and fast rule for selecting the best system. Much of the choice depends on the skill and experience of the pattern cutter, whose personal choice will often vary according to the particular style of garment to be constructed.

Choice of system will also depend on the type of garment to be made, as many systems are designed specifically for a particular category i.e. women's wear, children's wear, men's wear etc. Also the type of fabric may have some influence on the chosen system.

There is much literature which covers the subject of pattern cutting and block construction, also individual manufacturers may have their own specifications for block construction. Block patterns
for knitwear differ from those for woven fabric, however published literature on knitted garment blocks is notable for its scarcity.

The system chosen for development and computer simulation was that presented in the publication by Aldrich entitled 'Metric Pattern Cutting for Menswear'. This system was developed to help the designer to appreciate the benefits of designing round the figure rather than seeing it as a body that only possesses a front view. It was designed to avoid rigid systems of drafting specific garment shapes.

As a basis for development the particular blocks chosen were the basic casual jacket block - body section and the one-piece sleeve to match. The reason being that once a computer simulation system had been developed it would be possible to make-up a complete garment to test the geometry of pattern pieces.

It was not the purpose of this study to simply recreate a garment pattern on the visual display unit (VDU) of the computer in the same form as described in standard text. Rather it was to fully analyse the drafting system and apply the principles to a computer simulated model. The model of the block would contain only instructions for drafting the block, and would not be specific to any particular size. The user would then be able to retrieve the block which would then be drawn automatically to fit a standard size, or personal measurements.

A detailed analysis of the principles of manual block construction revealed that some form of mathematical model of the curves, especially at the neck and scye (armhole), was necessary, if
A successful computer simulation was to be achieved. Methods currently used to sketch the curves can lead to significant inaccuracies and inconsistencies.

The following section examines the theoretical considerations involved and describes the formulation of the principles employed in the development of computer programmes for the computer-based generation of block patterns.
4.3 Theoretical considerations

A pattern block can be thought of as a series of intersecting lines and curves which conform to the instructions contained in the block drafting instructions and which are based on the measurements obtained from the relevant size chart (or personal measurements).

The drafting instructions give co-ordinates of specific locations (or nodes) which then have to be joined by either a straight line or a curved line. It is the curved lines which present the greatest opportunity for error during the manual drafting process and which are subject to variation from designer to designer and company to company, figure 4.3 illustrates this point. Although the specific locations remain exactly the same for the particular block it is possible to construct a number of varying scye (armhole) or neck curves to fit the nodes.

The pattern cutter's skill is the factor which controls the curve and experience leads to the selection of the best curve to connect the nodes. Various drafting aids are available to the pattern cutter, such as the 'Patternmaster' and 'flexicurve' in order to obtain best fit curves through the nodes (see figure 4.4). The 'Patternmaster' is a clear plastic stencil one side of which has a shaped curve which can be used for drafting scye curves, the other side being straight. Lines are marked on the stencil parallel to the edges and at fixed distances apart. Once the nodes for a particular block have been located at the shoulder point and underarm point, the
'Patternmaster' can be placed on the pattern and traced around to produce a scye curve. The advantages of using this stencil are that:—

(i) It provides a standardised scye curve which can always be repeated, and
(ii) It produces a smooth precise curve through the nodes.

The disadvantages of using the stencil are:—

(i) The stencil has a limited range of curves which can be utilised.
(ii) It is not possible to vary the parameters of height and width.
(iii) The curve profile is fixed.

The 'flexicurve' on the other hand can be altered at will to fit any constraints. It suffers however in that it does not provide a standard curve which can be re-used once the shape has been altered.

The drafting of curves on pattern blocks therefore presents a number of problems which have until recently relied on the skill and experience of the pattern cutter to overcome. The following sections present a geometrical solution to the problem of generating curves to fit varying constraints of height and width at critical places in the block such as the neck and scye.
Figure 4.3 Possible Variation in Scye and Neck Curves

- possible neck curves
- shoulder point
- possible scye curves
- underarm point
Plate 4.4 'Patternmaster' Stencil and 'Flexicurve'
4.3.1 Geometric modelling of a neck curve

The development of a method for fitting a curve to the neck section of a block.

In many instances it is necessary to control the angle at which the neck curves intersect with the nodes, the depth at which curve is produced, and also the overall depth and width of the curve. These factors influence the fit and shape of the neck section of a garment.

(1) Curve to intercept both axes at $90^\circ$ and to touch a given radius from the origin.

where:

'a' is the overall width
'b' is the overall curve depth
and 'r' is the given radius.
Development of formulae relating curve radii to the overall width and depth and given radius

From the above diagram,

\[(R_1 + r)^2 = R_1^2 + b^2\]

\[\therefore R_1 = \frac{b^2 - r^2}{2r}\]  \hspace{1cm} (4.3.1)

and also,

\[(R_2 - R_1)^2 = c^2 + (R_2 - b)^2\]

\[\therefore R_2 = \frac{c^2 + b^2 - R_1^2}{2(b - R_1)}\]  \hspace{1cm} (4.3.2)

The point of intercept of \(R_1\) and \(R_2\) is given by:-

\[\gamma = \tan^{-1}\left(\frac{Y_2 - Y_1}{X_2 - X_1}\right)\]  \hspace{1cm} (4.3.3)

hence: \(X_3 = X_1 + R_1 \cos(\gamma)\) \hspace{1cm} (4.3.4)

\(Y_3 = Y_1 - R_1 \sin(\gamma)\) \hspace{1cm} (4.3.5)
2. Curve to intercept either axis at any given angle and to touch a given radius produced from the origin

a - overall width
b - overall depth.
α - angle of intercept with Y axis.
β - angle of intercept with X axis.
Development of formulae relating curve radii to the overall width and depth given radius and intercept angle.

Using the cosine rule,

\[(R_1 + r)^2 = R_1^2 + b^2 - 2R_1b \cos(90 + \alpha)\]

\[\therefore R_1 = \frac{b^2 - r^2}{2(r + b \cos(90 + \alpha))}\quad (4.3.6)\]

The origin of \(R_1\) relative to 0,0 is given by

\[X_1 = a - R_1 \cos(\alpha)\quad (4.3.7)\]

\[Y_1 = b + R_1 \sin(\alpha)\quad (4.3.8)\]
Now,
\[ c = X_1 + (b + R_1 \sin(\alpha)) \tan(\beta) \]  \hspace{1cm} (4.3.9)

and,
\[ d = \frac{(b + R_1 \sin(\alpha))}{\cos(\beta)} \]  \hspace{1cm} (4.3.10)

Again using the cosine rule,
\[ (R_2 - R_1)^2 = (R_2 - d)^2 + c^2 - (2c(R_2 - d) \cos(90 + \beta)) \]  \hspace{1cm} (4.3.11)

which gives,
\[ R_2 = \frac{d^2 + c^2 + 2dc \cos(90 + \beta) - R_1^2}{2(d - R_1 + c \cos(90 + \beta))} \]  \hspace{1cm} (4.3.12)

the origin of \( R_2 \) relative to \( 0,0 \) is given by
\[ X_2 = -R_2 \sin(\beta) \]  \hspace{1cm} (4.3.13)
\[ Y_2 = R_2 \cos(\beta) \]  \hspace{1cm} (4.3.14)

The intercept of the two radii \( R_1 \) and \( R_2 \) is given by:
\[ \gamma = \tan^{-1} \left[ \frac{(Y_2 - Y_1)}{(X_2 - X_1)} \right] \]  \hspace{1cm} (4.3.15)
\[ X_3 = X_1 + R_1 \cos(\gamma) \]  \hspace{1cm} (4.3.16)
\[ Y_3 = Y_1 - R_1 \sin(\gamma) \]  \hspace{1cm} (4.5.17)
4.3.2 The development of a curve to fit the scye section of a block

As previously mentioned the scye presents one of the major difficulties to accurate curve fitting. As a starting point to this investigation it was decided that a geometrical model of the drafting aid the 'Patternmaster' should be sought. The model however should have the capabilities to fit the standard scye curve to any reasonable parameters.

The 'Patternmaster' curve profile was constructed full-size and the overall height and width measured, see figure 4.5. The small radius at the top of the curve profile was ignored for the purpose of this investigation, as it is not normally used when drawing scye curves. For ease of modelling, the curve is divided into two parts; the bottom curve, and the top curve. The dividing point for the curves was determined as the point at which the curve intercepts the vertical axis. By construction this was determined as being 0.3 times the overall height, measured from the bottom.
Figure 4.5 'Patternmaster' Curve Profile
4.3.3 Geometric modelling of the bottom section of the scye curve

A curve based on two intersecting radii is best suited for parameters in which height is less than half the width, as with the neck section. An alternative method was developed for the bottom section of the scye curve, basing the curve on three intersecting radii. This approach allowing a smoother, more defined curve to be produced. In order for each radii to meet tangentially, it is necessary for each adjacent radii to have their origins on the same projected line.

where,
'c' represents the overall width of the bottom curve,
'f' the overall scye depth,
'r' a given distance that the curve must touch projected from the origin, and
'θ' the angle through which 'r' is inclined.
In order to equate the equations produced the angle is set at a 41° and the middle radius (2) is a function of the given distance 'r'. Radius 1 and 2 are assumed to intercept with the vertical axis and horizontal axis tangentially. This assumption is justified as the bottom curve must meet the top curve tangentially and the bottom curve must meet a mirrored version of itself also at a tangent.
Development of formulae relating curve radii to bottom curve width and height at a given distance from the origin

Assuming that,
\[ f = 0.3 \times \text{overall scye depth} \]  \hspace{2cm} (4.3.18)
\[ j = 1.8 r \]  \hspace{2cm} (4.3.19)
\[ \Theta = 41^\circ \]  \hspace{2cm} (4.3.20)

Note:
Although the values of 'f', 'j' and '\Theta' are assumed to be fixed they can be modified if necessary.
Making 'j' a function of 'r' allows it to alter as the distance r alters.
Now,
\[ h = (j + r) \sin(\theta) \]  \hspace{1cm} (4.3.21)
\[ p = (j + r) \cos(\theta) \]  \hspace{1cm} (4.3.22)
and
\[ e = c - p \]  \hspace{1cm} (4.3.23)

To find radius \( R_1 \) we have,
\[ (R_1 - j)^2 = (R_1 - h)^2 + e^2 \]

expanding and cancelling gives,
\[ R_1 = \frac{h^2 + e^2 - j^2}{2(h - j)} \]  \hspace{1cm} (4.3.24)

To find the point of intersection with radius \( j \) \((X_1, Y_1)\)
\[ \theta = \tan^{-1} \left[ \frac{e}{R_1 - h} \right] \]  \hspace{1cm} (4.3.25)
\[ X_1 = c - R_1 \sin(\theta) \]  \hspace{1cm} (4.3.26)
\[ Y_1 = R_1 - R_1 \cos(\theta) \]  \hspace{1cm} (4.3.27)

To refine the curve further between the intersection of the curve and the X axis the midpoint can be found by,
\[ \theta_2 = \left[ \frac{\theta}{2} \right] \]  \hspace{1cm} (4.3.28)
\[ X_4 = c - R_1 \sin(\theta_2) \]  \hspace{1cm} (4.3.29)
\[ Y_4 = R_1 - R_1 \cos(\theta_2) \]  \hspace{1cm} (4.3.30)
To find $R_2$, we have,

$$(R_2 - j)^2 = (R_2 - p)^2 + (f - h)^2$$

which gives,

$$R_2 = \frac{p^2 + (f - h)^2 - j^2}{2(p - j)} \quad (4.3.31)$$

The intersection with radius $j$ $(X_2, Y_2)$ is given by,

$$\alpha = \tan^{-1} \left[ \frac{f - h}{R_2 - p} \right] \quad (4.3.32)$$

$$X_2 = R_2 - R_2 \cos(\alpha) \quad (4.3.33)$$

$$Y_2 = f - R_2 \sin(\alpha) \quad (4.3.34)$$

Refining the curve as before,

$$\alpha_2 = \left[ \frac{\alpha}{2} \right] \quad (4.3.35)$$

$$X_5 = R_2 - R_2 \cos(\alpha_2) \quad (4.3.36)$$

$$Y_5 = f - R_2 \sin(\alpha_2) \quad (4.3.37)$$

The limiting factor for a curve produced with this method is that the distance 'p' must not exceed the width 'c', otherwise the radius $R_1$ will not meet the X-axis tangentially.
4.3.4 Geometric modelling of the top section of the scye curve

By visual inspection of the top curve it was felt that it could be modelled using the exponential function:

\[ f(x) = a(1 - e^{\alpha x}) \]

where,

'a' represents the amplitude of the function, and '\( \alpha \)' a modifying function.

By adjusting the value of 'a' and '\( \alpha \)' it is possible to alter the shape of the exponential function originating from (a) and passing through the point (b).

This method was thoroughly investigated and the resulting curves matched against the origin form. However none of the curves produced satisfactorily matched the original curve form, therefore another method was investigated.
Note:
There is no doubt that some mathematical function can be derived to model the curve through the two points. Use of the following method however has provided a very much simpler and effective method of modelling the curve.

Top curve section modelling by three points

where,

'm' represents top curve width, and

'n' top height.
Now,
\[ R_3^2 = (R_3 - m)^2 + n^2 \]
\[ \therefore R_3 = \frac{m^2 + n^2}{2m} \] \hspace{1cm} (4.3.38)

At a point mid-way on the curve, half the top curve height,
\[ \beta = \sin^{-1} \left( \frac{0.5n}{R_3} \right) \] \hspace{1cm} (4.3.39)

Now,
\[ R_3 - x = R_3 \cos(\beta) \]
\[ x = R_3 - (R_3 \cos(\beta)) \] \hspace{1cm} (4.3.40)

from this,
\[ x = 0.24 \text{ m} \] \hspace{1cm} (4.3.41)

In order to fully describe the curve it is only necessary to specify the locations \((0,0)\), \((x,0.5n)\) and \((m,n)\) - all of which are defined.

Note:
The above solution provides by far the best fit to the original curve.
4.4 Application of the modelling techniques to computer-based pattern generation

Computer-aided marker-making/pattern making/grading and cut order planning systems are perhaps one of the most beneficial developments which have taken place within the clothing industry in the past decade. Technology is moving very rapidly in this area as the cost of hardware has been reducing whilst at the same time technical capabilities have increased. Minicomputers have become available at much reduced prices. These have adequate and reliable storage capabilities which are able to operate a large number of programmes in parallel, and can utilise a number of terminals and printers.

The geometric models of the neck curve which intercept either axis at any given angle and at a given distance from the origin, and the scye curve, form the basis of the technique developed for computer-based generation of basic patterns. The models provide locations (nodes) along each curve which are ideally suited to the menu-based software package, Drawing Office Graphics System (DOGS), available for development of this technique.

The algorithms developed for the models can be run on any computer system which supports a graphics package. A minicomputer system (PRIME 2250) was used in this instance, however a micro-based system using a commercial 2D draughting package such as CADKEY or AUTOCAD could also have been used.

The principles outlined in this section have been developed
as a 'front end' addition to current computer-based pattern design systems (PDS), and are not intended as the basis for an alternative system approach. The programmes were developed using an available software package and on hardware readily to hand.
4.5 The development of a computer system to generate pattern blocks

To test the validity of the geometric models a parametric computer programme was developed which allowed a curve to be generated using the modelling techniques. The parameters which described the 'Patternmaster' stencil were measured and fed into the programme as top width, bottom width, overall height and the distance the curve should be away from the origin.

The computer programme (CRV.PR), detailed in Appendix G uses the formulae developed in sections 4.3. Using the PRIME system running DOGS, and down-loading the resulting drawing file to a plotter a full-sized computer generated curve was produced. This curve was matched against the profile of the 'Patternmaster' and it was found that a very good degree of similarity was obtained, see figure 4.6.

The computer programme developed allows any reasonable constraints to be placed on the computer generated curve. Figure 4.7 shows a typical scye curve form generated by the programme. Figure 4.8 shows how the parameters can be altered to produce a family of curves from the same origin with identical overall heights and bottom widths but with varying degrees of curvature and top width. The figure also shows how the curve can be fitted to smaller constraints.
Plate 4.6 'Patternmaster' Stencil and Computer-Generated Profile
Figure 4.7 Typical Computer Generated Scye Curve
Figure 4.8 Effect of Varying Parameters on the Computer Generated Curve Form
4.5.1 Hardware considerations

The PRIME 2250 Computer System

The digital computer used to develop the pattern block generation programme was a PRIME 2250 minicomputer. This is a high performance, low cost office system ideal for distributed processing network nodes or compact, multi-user system applications. The PRIME 2250 system includes a 32 bit central processor unit (CPU), 2kb cache memory, a communications controller with eight asynchronous and one synchronous communications lines, a 158 mb Winchester disk and a 15 mb cartridge tape unit and a diagnostic processor that also acts as a system console interface.

The PRIME 2250 supports up to 32 terminals in an interactive environment of up to 128 processes. It uses the PRIMOS operating system which supports interactive and batch processing and is compatible across the entire PRIME product range. It can be networked to other print systems using PRIMENET communications software, peripheral and controllers which are compatible. The PRIME system layout is shown diagrammatically in figure 4.9.
Figure 4.9 PRIME System Configuration
4.5.2 Software considerations

The Drawing Office Graphics System (DOGS) package, produced by PAFEC Ltd., is a computer programme which has been developed to help a draughtsperson or designer carry out all the tasks previously performed using a drawing board. DOGS also has facilities for performing operations that could not easily be carried out such as deletion, copying, dragging and hatching, together with the ability to have common shapes stored in memory for easy recall. DOGS is a menu driven programme which operates at three levels:

(i) The Master Menu

This is the first menu that appears on the Graphic Display Unit (GDU). It is an extensive control system which allows most of the design work to be carried out from within DOGS. As well as the actual draughting it is possible to do the necessary plotting work, compacting and archive investigations from here.

(ii) The Initialise Menu

On starting a new drawing, this is used to obtain important information that is needed to set up a new drawing.

(iii) The DOGS Menu

This allows the user to select from a very wide range of options without the need to learn computer commands or mnemonics. It consist of fourteen individual sub-menus, each of which has a simple descriptive name such as LINE, TEXT, COPY etc. within each sub-menu are a series of numbered options most of which have a simple descriptive name e.g. RESET USER ORIGIN, SINGLE LINE TEXT, etc.
In any form of drafting it is often found that standard items or symbols are frequently repeated. DOGS precludes the need for the repeated drawing of such symbols. Symbols need only be drawn once, the user can then instruct DOGS to store that symbol so that it can be easily retrieved.

A 'parametric' symbol is a list of instructions (programme) in DOGS which upon retrieval leads the programme through a series of menu options, as if the user has selected the options and supplied the data. Parametric programming within DOGS allows a considerable degree of flexibility. It also allows the user to run the programme without prior knowledge of the menu options.

The following sections detail the development of parametric programmes to run on the PRIME system, showing how the geometric models developed in section 4.3 are incorporated within the overall parametric programme to produce a man's basic casual jacket block and one-piece sleeve to match.
4.5.3 Development of parametric programmes for the basic casual jacket block and one-piece sleeve block

Although the Aldrich system of pattern cutting is used in this study it was felt that the block should be generated in a different way to that presented in her publication. The reason being that if the front and back sections were drafted separately it would be easier to add seam allowances to the final block, also it would allow for greater manipulation of the blocks in the future stages of lay planning and marker making.

Traditionally block patterns are drafted to one basic size and if other sizes are required then the pattern is 'graded'. Pattern grading involves adding or subtracting a known increment in either the X and/or the Y direction to provide a new location which either increases or decreases the pattern outline, see figure 4.10. Grading is used because it speeds up the process of re-drawing the pattern to various size requirements. However the known increments (known as grade rules) have to be accurate in order to ensure that the graded pattern pieces match the size requirements. Patterns can also be graded using the proportionate method whereby the largest and the smallest pattern pieces are drawn. The patterns are then placed on top of each other along a suitable datum. The salient points of each pattern are located and a line drawn through them. If, for example, four sizes are required, then the line is bisected into four equal parts. This process is repeated until all the necessary points required are identified. The intermediate patterns can then be drawn,
see figure 4.11.

From the above description it can be seen that pattern grading is a very lengthy process and requires a certain degree of skill to ensure that resulting patterns are correct. Commercially available computerised pattern making systems previously described, have greatly de-skilled and speeded-up the process of pattern grading, but they all however require the grade rules to be pre-programmed.

The process of pattern grading can best be summarised as a system whereby larger or smaller similarly featured patterns are produced without the need to obtain the standard measurements from a size chart and draft the pattern from first principles. The system was invaluable in the days when all drafting was performed using pencil and paper. However, now with the flexibility and ease of manipulation available using computer based drafting systems the task of drafting patterns to specific size requirements no longer presents major problems in terms of time or skill involved.

Using the command language (parametrics) available with the DOGS system it is possible to programme all the instructions necessary to draft a basic pattern from first principles in variable form, without specifying fixed dimensions. Then upon running the programme, sizes can be assigned to the variables allowing the block to be constructed based on the measurements.

In short, rather than attempt to develop a programme which merely drafts a particular sized pattern block, upon which subsequent operations have to be performed to obtain different sizes, the
developed programme contains all the instructions necessary to construct, from first principles, the block pattern. The sizes required can be assigned by the computer from the stored size chart or input by the user when prompted.

The developed programme allows the user to construct at the Graphics Display Unit (GDU) a man's basic casual jacket block and one-piece sleeve to match, having had no previous knowledge of pattern drafting or cutting. The block can be drawn to any one of a range of standard sizes classified in standard chest sizes ranging from 88 cm through to 120 cm, in increments of 4 cm. All other sizes associated with that standard chest size are retrieved automatically from the computer stored size chart and used by the parametric programme to construct the jacket and sleeve blocks.

Alternatively, if a standard chest size is not required and an intermediate size or a specific sized block is required then the user is prompted by the programme to input the measurements, which would normally be stored in the size chart, and uses these to construct the blocks. In both cases the user is prompted for the jacket length as this would vary according to the style and has no fixed length. Any proportionate measurements needed to construct the block are calculated within the programme, therefore the user has only to supply a standard chest size or input sizes which can be readily measured on the body to be able to construct the block.

The flow chart of the main parametric programme is shown in figure 4.12. On running the programme, and supplying a standard size or personal size required, the block is automatically displayed on
the GDU. The programme selects all the relevant DOGS menu options to enable the outline of the block to be drafted. The programme then calls a separate parametric programme to draw in the scye curves, the overall height and widths at the top and bottom of which are supplied to the sub-programme from the main programme. Having drawn in the scye curves, control is then passed back to the main programme.

The main programme then calls the parametric programme which draws in the neck curves. Again the overall height and widths are calculated within the main programme and passed to the sub-programme. During the running of the sub-programmes the respective curve lengths for the scye, front neck, and back neck sections, are calculated and passed back to the main programme to be stored as variables. Text information is then added to the block, this includes the calculated curve lengths.

If a sleeve is to be drafted, then the view is automatically changed. The parametric which generates the one-piece sleeve block is then called, and the variables relating to the scye curve length are passed to it. All calculations required to draft the block are performed within this sub-programme, except the sleeve length which would have been retrieved from the size chart, or supplied by the user. The programme selects the menu options necessary to generate the sleeve block. Control is then passed to the main programme.

The parametric programme then stops and control of the DOGS menu is now passed to the user. If the sleeve was not required then the programme would stop without drawing a sleeve block. The programme structure is shown diagrammatically in figure 4.13.
The user now has control of the DOGS menu and can use any of the menu options to alternate between the jacket and sleeve block, modify the basic block in any way, zoom in on any part of the drawing, add seam allowances, etc. An immediate hard copy of the drawing of the blocks can be obtained using the on-line printer. Alternatively, using the plotting facility, a high quality full size (or any scaled size) plot can be obtained which can be used as a pattern for the subsequent cutting of material. The main programme (BCJ2.PAR) along with the sub-programmes are listed in Appendix G.

A description of each sub-programme follows, showing how the geometrical models have been used.
Figure 4.10 Grading Using Grade Rules

GRADE RULE
0 -1000

GRADE RULE
400 -800

GRADE POINTS
8 MM
4 MM

Figure 4.11 Proportionate Grading

5 EQUAL DIVISIONS
Figure 4.12 Basic Casual Jacket Block Parametric Programme Flow Chart

START

IS BLOCK A STANDARD CHEST SIZE

YES

INPUT SIZE

RETRIEVE ALL OTHER SIZES FROM SIZE CHART

CALCULATE ALL PROPORTIONATE SIZES

DRAW BASIC BLOCK OUTLINES

DRAW ARM SCYES ON BLOCK

CALL ARM SCYE PARAMETRIC

CALL FRONT NECK PARAMETRIC

DRAW FRONT NECK ON BLOCK

CALL BACK NECK PARAMETRIC

DRAW BACK NECK ON BLOCK

PRINT OUT ALL CALCULATED CURVE LENGTHS

IS ONE-PIECE SLEEVE REQUIRED

NO

END

YES

CHANGE DRAWING VIEW

DRAW ONE-PIECE SLEEVE

CALL ONE-PIECE SLEEVE PARAMETRIC

END

PROMPT USER FOR ALL THE REQUIRED SIZES
Figure 4.13 Jacket and One-piece Sleeve Parametric Programme Structure
4.5.4 Arm scye parametric programme

This programme uses the models developed in sections 4.3.2, 4.3.3, and 4.3.4 to enable points along the scye curve to be calculated, and is a further development of the programme (CRV.PR). The programme selects the continuous line option of the DOGS programme to draw a continuous curve through the calculated co-ordinate points to produce the arm scye curve. The values for the overall height, top width and bottom width are calculated in the main programme and used as the constraints for the curve.

In the industry points along the curves of the arm scye and sleeve head, known as pitch points, are used to facilitate matching of the two parts during making-up. This is catered for within the programme and appear on the resulting blocks as FP and BP, front pitch point and back pitch point respectively.

Manual drafting of the pattern requires that the scye curve length be measured with a tape measure. This is notoriously inaccurate and can lead to many errors. This is eliminated in the programme by automatically calculating the curve length, achieved by totalling the lengths of curve sections which were used to define it. Curve lengths from the pitch points to shoulder point or underarm point are also calculated along the curve or in a straight line as required. The values are stored as variables to be passed back to the main programme.
4.5.5 Back neck curve parametric programme

The programme uses the continuous line facility of the DOGS programme to draw the profile of the back neck. It uses the theoretical model developed in section 4.3.1, to calculate the radii of the two intersecting curves which make up the curve. The model can be adapted to allow the curve to intercept with either axis at any stated angle and at any stated distance from the origin. In practice these values would be fixed (as they have been in the programme).

The overall width and height of the curve is calculated in the main programme and the values passed to the the front neck curve programme in order to calculate the radii of the intersecting curves. Once the radii have been calculated positions along the curves are calculated relative to the origin and used for the continuous curve option to draw in the curve.

As the curve is of known geometric form it is now possible to calculate its length, which is done within the programme and stored.

4.5.6 Front neck curve parametric programme

This programme also uses the continuous line facility of the DOGS programme to draw in the front neck curve profile. Owing to the limitations of the back neck curve programme which is best suited for curve profiles which are relatively long in proportion to their height it was decided to adapt the arm scye programme. The programme was easily adapted by simply using the model created for the lower part of the curve and applying it to the front neck section.
The overall height and width of the front neck is calculated within the main programme and the values passed to the front neck programme when it is called. Although it is possible to alter the depth of the curve it was felt that the added advantage of having this facility would not be required in the initial phases of development.

As with the back neck curve it is possible to calculate the total length of the curve by adding together all the lengths of curves from which it is derived. The value is stored and passed on to the main programme.

4.5.7 Sleeve block parametric programme

The programme drafts a basic one-piece sleeve block to match the jacket block being drafted by the main programme. The sleeve length and scye curve lengths are supplied by the main programme. The programme selects the relevant menu options to enable the block to be drawn and adds the text information. Locations of the front and back pitch points are also shown on the block to be used later for matching with the jacket.
4.6 Experimental details

The primary objective in this area of the study was to create a system of computer-based pattern generation that could be used to create a basic pattern block. This could then be used as a pattern for a garment to be made-up. The programme was developed in a modular fashion to allow the sub-programmes to be called by the main programme as and when required. This allows the various sub-programmes to be used with other programmes which may require similar curve forms.

Figure 4.14 shows the computer generated basic casual block - body section to fit a standard chest size of 100 cm and figure 4.15 the one-piece sleeve block to match. Indicated on figure 4.14 are the areas where the sub-programmes were called to fit the curves to the jacket block. The block contains all the textual information necessary to cut pattern pieces. The variables listed on the left hand side of the block provide information on the following:-

TT - The total scye curve lengths (front + back) used for matching the sleeve head.

SP - The distance (measured in a straight line) from the front pitch point FP to the shoulder point.

FPO - The distance along the curve from the front pitch point FP to the underarm point.

FPS - The distance along the curve from the front pitch point FP to the shoulder point.
BPO - The distance along the curve from the back pitch point BP to the underarm point.

BPS - The distance along the curve from the back pitch point BP to the shoulder point.

YC - The distance from the front pitch point FP and the axis passing through the underarm point.

SLO - The sleeve length for the block (taken from the size chart).

BCL - Back Neck curve length - calculated within the sub-programme.

FCL - Front Neck curve length - calculated within the sub-programme.

Figures 4.16 to 4.19 show several standard basic blocks. DOGS has the facility of allowing the user to add lines or curves parallel to existing line or curves. This facility can be used to add seam and hem allowances to the block. Figures 4.20 and 4.21 show the basic casual jacket block and sleeve, for a 100 cm standard chest size, with seam and hem allowances included. Once the parametric programme has generated the blocks, the user is free to add or delete lines as necessary.

The next stage of the investigation was to construct a garment based on the computer generated block. The block size chosen was a standard 104 cm. The block pattern was created simply by retrieving and running the programme BCJ2.PAR and inputting the chest size of 104 cm along with the jacket length of 80 cm. Seam and hem allowances were added to the blocks, and a plot file was created to allow an off-line full size plot to be produced on the CALCOMP drum plotter.
The full size plot was used as the actual pattern for cutting out the garment pieces from medium weight calico. The garment was then made up and tested for fit. Plates 4.22 and 4.23 show the blocks produced for the jacket and one-piece sleeve to match.

As the garment was made-up from basic block patterns which contained no styling features, it was felt that 'fit' of the garment could not be fully investigated. Of main interest were the ease and accuracy with which the garment pieces could be assembled, and the degree of fit obtained at the arm scye sections. Plate 4.24 shows the garment made up using the computer generated blocks, plates 4.25 and 4.26 show the degree of fit obtained at the arm scye.

The first point noticed during making-up was that the sleeve could be attached to the body with ease and that the pitch points matched up correctly. A basic collar was cut using the measurements calculated from the programme, this again was made-up with no difficulties encountered. Styling of the pattern was omitted intentionally as it was really only the basic fit of the garment that was in question.

In general not much can be said about the assessment of the fit, except that the garment made-up accurately and no modifications were necessary. Making-up was carried out by an experienced machinist at the Polytechnic and the resulting garment inspected by the technical staff who found it to be correctly drafted.

The system has been described in article published in Knitting International\textsuperscript{119} (see Appendix Q).
Figure 4.15  Basic One-piece Sleeve Block

ONE-PIECE SLEEVE
(TO FIT CHEST - 100.00)
CUT 2

ELBOW LINE
Figure 4.16  BASIC CASUAL JACKET BLOCK - BODY SECTION
CHEST SIZE (CM) - 88.00

TT = 47.87
SP = 15.96
FP0 = 3.95
FPS = 18.57
BPO = 11.18
BPS = 13.42
YC = 1.19
SLO = 63.60
BCL = 8.34
FCL = 12.58

DRAWN - MPH
DATE - 04/11/87
Figure 4.17  BASIC CASUAL JACKET BLOCK - BODY SECTION
CHEST SIZE (CM) - 96.00

TT= 51.53
SP=  17.18
FPO =4.96
FPS =19.61
BPO =12.28
BPS =14.00
YC =1.66
SLO =64.80
BCL =8.84
FCL =13.28

DRAWN - MH
DATE - 04/11/87
Figure 4.18 CHEST SIZE (CM) = 112.00

TT = 58.25
SP = 19.42
FP0 = 7.07
FPS = 21.19
BPO = 14.40
BPS = 14.98
YC = 2.75
SLO = 66.00
BCL = 9.83
FCL = 14.68

DRAWN - HNH
DATE - 01/11/87
Figure 4.19

CHEST SIZE (CM) - 120.00

TT = 60.68
SP = 20.23
FPO = 8.18
FPS = 21.38
BPO = 15.32
BPS = 15.17
YC = 3.36
SLO = 66.00
BCL = 10.33
FCL = 15.38

DRAWN - MPH
DATE - 01/11/87
Figure 4.20

**BASIC CASUAL JACKET BLOCK - BODY SECTION**

**CHEST SIZE (CM) - 100.00**

- **TT** = 53.37
- **SP** = 17.79
- **FP0** = 5.47
- **FPS** = 20.11
- **BPO** = 12.83
- **BPS** = 14.30
- **YC** = 1.92
- **SLO** = 65.40
- **BCL** = 9.09
- **FCL** = 13.63

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**DRAWN - MH**

**DATE - 28/04/88**
Figure 4.21 Basic Sleeve Block With Seam and Hem Allowances

ONE-PIECE SLEEVE
(TO FIT CHEST - 100.00)
CUT 2

ELBOW LINE

BP
FP
Plate 4.24 Completed Garment
4.7 Conclusions and further work

4.7.1 Conclusions

The study has shown that using appropriate modelling techniques it is possible to create a reliable and consistent computer based system for the generation of basic pattern blocks. This offers significant advantages to the user in the following areas:

(i) There is no need for digitising/scanning of pattern pieces, eliminating many inherent errors and also expensive hardware.

(ii) Parametric programming allows an extremely flexible user-friendly system to be developed.

(iii) Manual drafting is time consuming and requires a great deal of skill on the part of the pattern cutter.

(iv) Digitising of lines and curves requires the additional stages of straightening up the lines and modifying the curve profiles.

(v) Digitising of pattern pieces requires an operator who has undergone specialist training with the particular computer system used.

(vi) There is no need for any grading with parametric programming as all instructions are in variable form.

(vii) The computer stored size chart can be easily modified as all sizes relate to standard body measurements.

(viii) The system is quicker and easier to use than manipulating a basic rectangle on the graphics display unit (GDU).

(ix) Parametric programming ensures 100% repeatability when
constructing the same block on different drawings.

(x) Consistency of drawn curves at the neck and arm scye is obtained.

(xi) Geometric modelling of the curves allows their lengths to be accurately calculated.

(xii) Collar lengths and sleeve curve lengths can be accurately matched to the block.

4.7.2 The need for further work

In developing this system for computer-based pattern blocks it was found that an alternative approach could be made to the present practice of digitising and grading pattern pieces. It seems unlikely present practices will disappear altogether with the introduction of CAD, as many designers and pattern makers are still very reluctant to carry out their work at the computer terminal.

The system developed presents an intermediate step in applying computer technology to the art of pattern making, in that a range of basic block patterns will be available to the designer or pattern cutter. These blocks can then be manipulated at will to add style features and any other features that are required. The designer would be certain that the block is correctly constructed and based on standard sizes.

The system as it stands is not by any means complete as at present only a basic casual jacket block and one-piece sleeve are available. What this particular system does however show is that by
using appropriate modelling techniques it is possible to create any block required. The particular blocks were chosen because they have elements which were considered difficult to model such as the scye curve sections.

The principles outlined at present favour the woven garment industry more so than the knitted garment industry because of the wealth of excellent literature concerning block and pattern construction. Although the blocks for knitted garments tend to be much simpler than for woven blocks, many are developed 'in-house' and published literature is scarce.

In order to fully develop the computer based system, tried and tested block construction instructions are required. These instructions need to be carefully analysed, and were necessary modifications implemented, to emulate the principles involved in construction and formulate models of areas where inaccurate sketching techniques have previously been used. The system should find commercial application because of its flexible nature and modularity.
Chapter 5

Automated Fabric Feeding
to an Industrial Sewing Machine
5.1 Historical development of feeding systems

Prior to Walter Hunt's sewing machine of the 1830's no provision had been made for the cloth to be fed through the machine at a regular and reliable rate. Prior to this time the cloth had to be fed through the machine by hand, an extremely difficult task requiring considerable skill on the part of the operator to ensure the formation of regular stitches. Hunt's machine went part of the way to solving this problem by attaching the fabric to a rack on the machine. The rack moved a predetermined amount as stitches were being formed. At the end of the travel of the rack, the machine had to be reset and the cloth repositioned if the seam was longer than the rack.

By 1842 Benjamin W Bean had developed a continuous feeding system. This involved feeding the cloth through a set of gears. It was used for run stitching, where an infinite length of seam could be produced. In May 1849 John Bachelder invented a system for continuous cloth feeding. The cloth holder was in the form of an endless belt supported on cylindrical rollers. The belt carried a series of wire protrusions near the edge adjacent to the needle. Whilst the machine was in motion the cloth was carried forward under the needle, and after being stitched was separated from the belt (see plate 5.1).

A year later A B Wilson incorporated a feed on his machine which consisted of a sliding bar against which the cloth was held by a stationary presser. Whilst the needle was still in the cloth the sliding bar returned for a fresh grip on the fabric and so carry it
forward after the stitch. Wilson also made what is perhaps the most important contribution to cloth feeding - the 'four motion feed', patented in 1854. It is interesting to note that over a hundred years on it still remains as one of the most important features of a sewing machine.

The years 1850 - 1900 also saw many other important feeding system introduced. In 1857 a United States patent was issued to Chase for a needle-feed machine. As the needle descended into the cloth the needle lever was caused to move, carrying the cloth with it. The success of this system has not been well documented but without any additional feeding devices to assist in cloth feeding it is likely that constant bending or breaking of the needle would have occurred.

Singer was also granted a patent in 1857 for a differential feeding system incorporating two rollers. The 'universal feed' was also developed around this time by Lyman Reed Blake. This allowed the feeding mechanism to be revolved in order to change the direction in which the component is fed as it was being stitched. A reverse-feed mechanism was also developed allowing the operator to effect reverse feeding of the cloth to back-tack and secure the stitches.

In 1860 two machines were developed that had different feeding systems. The first developed by G B Arnold consisted of a mechanism that ruffled the cloth as it was being stitched. It used two 'four-motion feed' dogs placed one in front of the other, each having independent travel lengths. The second, developed by Allen and Molyneux, used two serrated or toothed rollers, placed one above the other, only the top roller was driven, the other being an idler or
support roller.

George Barker and Charles Davies received a British patent in 1866 for a device which consisted of a top feeding foot to move the cloth. An article of the time concerning this patent makes mention of a needle feed mechanism working in conjunction with the feeding top foot, but it is not completely certain that this ever actually appeared in the original full patent specification. The article went on to state: "had this system operated in conjunction with a four-motion feed underneath the cloth plate, instead of against a smooth cloth plate, the patent would have covered the system used today in alternating pressers compound feeds."
5.2 Review of feed mechanisms used with industrial sewing machines

Any sewing machine requires some means by which the fabric being sewn can be moved under the needle, without this every stitch would be formed in the same place on the fabric. In the earliest forms of sewing machine no feed mechanism was provided, the operator had to move the fabric during stitching, this was not an easy task and consistency in stitch length could not be maintained.

Further developments in the sewing machine incorporated a feed (or feeding) mechanism which ensured that the fabric was moved forward a predetermined distance during stitching. The mechanism became an integral part of the machine. Cams were used to provide the necessary timing and to ensure feeding occurred at the correct time.

This section reviews the most common and widely used feed mechanisms in use with most types of lockstitch and overedge machines. Published literature on this subject is extremely scarce hence references are mostly made to commercial mechanisms.\textsuperscript{120,121}
1) Drop Feed Mechanism (Four Motion Feed)

This is the most widely used feed mechanism for standard lockstitch and overedging machines, although many modifications have been made to the basic mechanism. The mechanism consists of:

(i) the presser foot,
(ii) the throat plate, and
(iii) the feed dog (see figure 5.2).

The function of these elements are as follows:-

(i) The Presser Foot

This holds the fabric down firmly against the throat plate as it is being stitched and prevents it from moving up and down (flagging) as the needle enters and leaves the fabric. This action aids the proper formation of the needle thread loop, and also provides pressure against the feed dog to ensure that the material will be moved forward, one stitch, with the feed dog as it advances. The presser foot pressure is achieved by spring force which can be adjusted to ensure correct feeding conditions for the particular fabric being stitched.

(ii) The Throat Plate

This provides a smooth surface over which the fabric passes as successive stitches are made. Openings in the throat plate allow access for the teeth of the feed dog to protrude. As the
feed dog rises to commence its forward motion the teeth engage in the fabric and press it against the under surface of the presser foot. On completion of the forward motion the feed dog drops down beneath the surface of the throat plate to return to its start position, ensuring the fabric is not moved back with the feed dog. There is also an opening in the throat plate to allow the needle to pass completely through the material and interact with the stitch forming components underneath the throat plate.

(iii) The Feed Dog
This moves the fabric forward by a predetermined distance between successive stitches. The amount of movement of the feed dog is adjusted by means of a stitch regulator. This in effect alters linkages within the sewing machine to alter the stroke length of the feed dog. The correct timing of the motion of the feed dog, the part which is responsible for moving the fabric, is extremely important. The movement of the fabric must take place when the needle is not penetrating it, otherwise fabric distortion and/or needle breakage will occur.

Although the drop feed mechanism is widely used it is not without its difficulties. Feeding of the fabric is produced purely by friction on the under surface, whereas there is pressure on the top surface which leads to friction between the presser foot and the fabric, tending to hold it stationary. This can lead to problems when
feeding very slippery materials, heavy materials or more than one layer of material. In multi-layer feeding there is a tendency for the top layer to be retarded as it is being fed. Also problems can occur if the top and bottom layers have different stretch properties.

Increasing the presser foot pressure can eliminate many of the above mentioned problems, but can cause other problems such as seam pucker. Bertoldi and Munden\textsuperscript{122} made an investigation of the effect presser foot pressure has on the degree of pucker produced, they concluded pressure foot pressure did not have a significant effect on the degree of pucker but seam pucker increased at extreme settings of feed dog height. Galuszynski\textsuperscript{123} on the other hand showed the pressure exerted against the throat plate causes the fabric to spread, thus the seam is made on a fabric of which dimension has been momentarily altered. When the fabric returns to its original dimension, the type of seam pucker known as 'waviness' can occur, see figure 5.3.

Despite the many problems associated with its use, the drop feed mechanism is in general one of the simplest and least expensive mechanisms. [It is used predominantly in the standard domestic sewing machine]

2) Differential Feed Mechanism

This is a type of drop feed mechanism which consists of two feed dogs arranged in tandem, and which can be moved independently. The two feed dogs work in unison but their strokes can be varied to allow for 'positive' or 'negative' differential feed to be obtained. When it is set for positive differential feeding the feed dog
forward of the needle makes a longer stroke than the feed dog behind
the needle. This has the effect of accumulating material under the
presser foot thus cancelling out the spreading effect caused by the
pressure of the presser foot. It can also be used in a decorative
effect where one ply is to be stitched in an almost pleated
condition. When 'negative' differential feeding is employed the feed
dog forward of the needle is given a shorter movement. This tends to
'stretch' the bottom ply and is used were fullness in the seam is
required to be eliminated.

3) Compound Feed Mechanisms

This type of mechanism comprises a drop feed mechanism with
a reciprocating needle bar mechanism. The two mechanisms are
synchronised to work in unison. The needle descends into the fabric
and into the needle hole of the feed dog. As the feed dog moves
forward the needle moves forward as well (still engaged in the
fabric). This assists in feeding and minimises slippage between the
top and bottom plies during feeding. The relative movement during
feeding always remains constant even when stitch length is changed.

4) Needle Feed Mechanism

The needle and material move forward in unison whilst the
needle is through the fabric. This is achieved by the use of a
reciprocating needle bar. Using the needle to feed the material tends
to prevent movement between plies. Needle feed is commonly used in
conjunction with a drop feed mechanism, in which case it is known as
5) Alternating Feed, Alternating Pressers

This consists of a mechanism which includes a feeding foot and a lifting foot, operating in conjunction with the lower feed mechanism. The alternating pressers are arranged such that they press down alternately on the fabric. The feeding foot (sometimes referred to as a walking foot or follower foot) travels along a line of feed in contact with the fabric. After the feeding stroke, it lifts clear of the fabric and returns to its starting position. This can be achieved by either (i) a spring-return feeding foot or (ii) a positively driven feeding foot.

After the fabric has been fed and the feeding foot lifts, the lifting foot descends with the needle, holding the fabric firmly until the stitch has been formed and the needle exits the fabric.

In most machines with alternating pressers, the stroke of the feeding foot and feed dog travel are synchronised. Machines which allow the stroke of the feeding foot to be increased or decreased relative to the feed dog stroke are termed 'Alternating Pressers, with independently adjustable upper and under feed'.

6) Alternating Pressers with compound feed

This mechanism comprises a compound feed used in conjunction with alternating pressers. Feeding takes place whilst the needle is in the fabric and the needle moves together with the feeding foot. The lifting foot holds the fabric before the next feeding stroke.
7) Feeding Foot Mechanism (Top Feed)

When the term is used alone it implies feeding is accomplished entirely by means of an upper (top) feed mechanism which is positively driven. In general terms however, 'top feed' is used to describe a mechanism in which the presser foot is driven from a separate cam to the underfeed mechanism. This allows it to engage and disengage the upper surface of the fabric as the under-feed mechanism engages and disengages the under surface of the fabric, the two feeds working simultaneously. This type of feed is used on commercial overedge and lockstitch machines where unstable fabrics are being stitched and it is important that seams must finish even. The relative strokes of the top and bottom feeds can be adjusted so that gathering or stretching can be applied to either the top or bottom layer (where fullness is required or where it needs to be eliminated), in this case it would be described as an 'independent upper (top) and under (bottom) feed'.

8) Universal Upper Feed

This is a mechanism which allows the direction of movement of the upper feed to be altered, so that it can be fed in any direction. This type of mechanism is commonly found in the footwear and embroidery industries.

9) Walking Foot Mechanism

This is a driven two-part presser foot, each part of which has its own independently operated presser bar. Each part feeds the
material in turn, the parts lift alternately but always ensuring that at least one part is in contact with the material being fed. This gives the impression of walking. The parts of the foot are not independently adjustable as their movements are synchronised.

10) Reciprocating Feed Mechanism

The feed dog moves forward and backward in the horizontal plane without rising and falling. In some machines, with this type of feed, the throat plate lifts the material above the grip of the feed dog teeth during the return movement and drops again to permit the material to feed during the forward movement of the feed dog. Other types of machines rely upon the shape of the feed dog teeth to provide the correct direction of feeding.

11) Parallelogram Feed

This type of feed was developed by Rockwell-Rimoldi and is used on their commercial overedge machines for the apparel industry. One of the problems associated with the 'drop feed' mechanism is that the line of the teeth of the feed dog do not remain parallel to the fabric being stitched as feeding takes place. The parallelogram feed was designed to overcome this problem by ensuring that the feeders are always parallel to the needle plate during feeding, see figure 5.5.

12) Continuous Feed Mechanisms

These mechanisms use rollers, wheels or belts in constant contact with the material being fed such that the material moves
continuously during the stitching operation. The type of mechanism described above are classified as 'intermittent feed' because the material moves only part of the time during the stitching operation.

13) Puller Feed

This consists of one or two rollers at least one of which is driven. The rollers rotate about the horizontal axis and are placed either behind the standard drop feed mechanism to assist in feeding the material from the machine or are fitted in place of the drop feed mechanism. Although classified under continuous feed they may be operated intermittently.

14) Wheel Feed

This type of feed consists of a driven wheel held in constant engagement with the material. It can be positioned under or on top of the material and may be driven continuously or intermittently. Wheels which are not driven are sometimes used to replace the conventional presser foot. Wheel feeds are used frequently in the leather trade where it is an advantage to have minimum contact between feed and presser roller to facilitate ease of handling and provide good visibility.

15) Cup Feed

Cup feed is used on machines in which the needle operates in the horizontal plane. Feeding is achieved by two wheels or discs rotating about their vertical axes, one or both of which may be
driven, the material passes between the edges of the discs. Alternatively feeding can be achieved by a single disc operating against a suitable presser surface. This type of feed is used where it is necessary to see both sides of the plies being stitched. It is used extensively in the assembly of fully fashioned knitwear, in the glove trade and also in the fur trade.

16) Independently Driven Feeding Mechanisms

Machines which are not fitted with an integral feeding mechanism rely on feeding to be controlled by some external means. An example of such is a 'jig' or 'auto jig' machine. This consists of a jig or pattern of the seam to be stitched into which the fabric is clamped. The jig is fitted to a moveable carriage which can be driven in the 'X' or 'Y' directions independently. On the earliest forms of jig machines the operator had the task of moving the jig under the stitching needle. On later and modern machines however the task is carried out automatically. On microprocessor-based machines the motors which move the jig in the two principal directions are controlled by the microprocessor. This movement is synchronised with the needle motion to ensure that feeding only occurs whilst the needle is out of the fabric. Jig machines have only a limited area over which they can be used and are not suitable for long seams.

The above principle is also used in embroidery machines and other decorative effect machines. The pattern to be embroidered can be preprogrammed onto Erpoms, stored on tape or disc, in computer memory or even digitised directly into computer memory. The
microprocessor then controls the movement of the motors to reproduce the stored image either to an enlarged or reduced size. Again embroidery machines only have a limited area in which the stitching can be applied.

Various types of motors can be used to achieve the 'X' and 'Y' motions, the commonest of which are DC servo motors and stepping motors. DC servo motors are generally fitted with feedback loops so that their relative positions are constantly monitored. Stepping motors are easier to control using a microprocessor, and tend to be used in open loop systems.

Each type of feeding mechanism described has its advantages and disadvantages, and there appear to be no clear consensus of opinion as to the ideal feeding system for particular applications. A survey carried out by Bobbin Magazine, sought to identify which type of feed mechanism should be used in different situations. The survey found significant disagreement existed between their respondents, and that there was a need for clarification on the subject.

Many clothing manufacturers appear to be unaware of the variety of feeding mechanisms that are available to them. They tend to opt for machines incorporating the standard 'drop feed' feeding mechanism, and rely on the experience and skill of the operator to overcome many of the problems associated with its use in fabric feeding.
Figure 5.2 Four Motion Feed

Figure 5.3 'Waviness' Caused by Excessive Presser Foot Pressure
Figure 5.4 Rimoldi Parallelogram Feed
5.3 The need for research in sewing machine development

It is almost certain that the clothing industry will, at least in the foreseeable future, continue to demand conventional dedicated sewing machines. This will in turn continue to cause machine manufacturers to vie with each other to produce faster and faster machines.

High speed in a sewing machine is not always desirable. Studies have shown that the time the sewing machine is actually sewing (needle time) amounts to approximately 15% of the total time spent sewing a garment\textsuperscript{125}. The major part of the total time is spent handling the garment (handling time). Simply increasing the speed with which stitches are formed therefore has a small impact on the total time required to complete a garment.

Problems can also be encountered with fabric feeding in high speed sewing machines incorporating traditional 'drop feed' feeding mechanisms. At very high speeds the feed dog is literally flung upwards onto the presser foot. This causes the presser foot to act against its retaining spring and can, depending on its weight and inertia effects, lose contact with the fabric momentarily. This effect is shown clearly in a study into the variations of pressure foot pressure as sewing machine speed is increased, carried out by Sunbrand, a division of Willcox & Gibbs, USA\textsuperscript{126}. In the study the pressure exerted on the fabric by the pressure foot was measured using an oscilloscope. It was found at low speeds the trace given by the oscilloscope followed that shown in figure 5.5.
where:
Stage 1 - Shows the pressure gradually increasing as the feed dog begins to rise.
Stage 2 - While the fabric is being fed there is a fairly constant pressure exerted between the presser foot and the feed dog.
Stage 3 - The pressure gradually decreases as the feed dog lowers.
Stage 4 - Presser foot pressure reduces to the minimum as the feed dog loses contact with the under-side of the fabric.

As the speed of the machine is increased the shape of the trace alters and clearly shows that the pressure peaks become exaggerated, giving an instance where pressure decreases, see figure 5.5. This momentary loss of control of the fabric can cause irregular feeding. Increasing the presser foot pressure does not always solve this problem and can lead to others such as seam pucker discussed earlier in this work.

With fabric or garment handling, at present the operator has the task of guiding the fabric through the machine during stitching in order to produce an acceptable seam. An operator has to be capable of noting small deviations during sewing and be able to respond to them quickly. The response time depends on the ability to move small groups of muscles in order to take corrective action. A sewing machine operating at 6,000 stitches per minute, with a stitch length of 2.5 mm, feeds fabric through the machine at 15 metres per minute. The operator usually controls the fabric edges between 15 cm to 20 cm ahead of the needle, see plate 5.7. Any deviation from the required seam line requires the operator to take corrective action using the
guiding hand. This corrective action however only becomes effective after a short delay 'reaction time'. The reaction time includes the time taken for a person's brain, nerves, and muscles to respond to a certain signal. It has been found that the small group of muscles, as found in the fingers take approximately 0.2 seconds to react to an optical signal. It normally takes longer [0.3 seconds] to react with the feet.\(^{127}\)

When the operator observes a seam deviation (such as when sewing contours), a corrective motion has to be made. With a reaction time of 0.2 seconds, the machine operating at 6000 spm and a with a stitch length of 2.5 mm, then 50 mm of seam will have been sewn outside the specified seam line. As the operator's hand controls the fabric at some distance from needle, the same distance may be sewn once again outside the specified seam line. This can result in a total deviation from the desired seam line covering 10 cm. Indeed, a measure of a sewing machine operator's skill is the accuracy with which consistent seams can be produced at high speed. With trainee operators, the machine speed has to be limited to avoid the machine 'racing away'.

From the above discussion it can be seen that the task of aligning and guiding the fabric through a high speed machine presents problems, becoming greater as speed increases. The operator therefore requires some assistance in order to maintain accurate and consistent seams during stitching. Various aids are available to the operator which mainly fall into the category of fixed guides. Plate 5.7 shows an example of such a guide which can be attached to standard
conventional sewing machines. It is designed to make assembly seaming more accurate and productive, by keeping seams perfectly aligned, freeing the operator from the task of having to stop and realign seam edges. Fixed edge guides can also be found on the new generation of contour and long seamers. The main drawbacks in using fixed guides are that:

(i) they require adjustment for various types of fabric;
(ii) they require physical repositioning to change the seam width; and
(iii) they tend to be fairly expensive.

Arising from the problems identified with fabric feeding during high speed sewing, the following sections investigates the development of a new method for automatically guiding and aligning the edge of the fabric during seaming. It was also felt necessary to investigate the feeding mechanism commonly found on conventional machines with the aim of developing an efficient and effective mechanism for multi-ply feeding.
Figure 5.5 Presser Foot Pressure at Low Sewing Machine Speeds

Figure 5.6 Presser Foot Pressure as Sewing Machine Speed Increases
Plate 5.7 Fabric Being Controlled by Operator

Plate 5.8 'Zippy' Automatic Seaming System

(source: PROFEEL s.r.l.)
5.4 Research, design and manufacture of a 'top-feed' feeding mechanism for an industrial sewing machine

As outlined in section 5.2 the 'drop feed' feeding mechanism is by far the most commonly and widely used feeding mechanism found in both industrial and domestic sewing machines. Despite the technical problems associated with this system, it has been found to be sufficient for most seaming applications. The system is relatively simple in operation and is one of the least expensive feeding systems in use.

Amongst the technical problems associated with the 'drop-feed' feeding mechanism, previously discussed, are:-

(i) Ply Slippage
Feeding of the fabric is achieved purely by friction on the under-surface of the fabric. There is a static pressure applied to the top surface of the fabric by the presser foot. This can cause ply slippage in the multi-ply feeding of some fabrics. Although the rate of shifting may be small, the accumulated shift may result in significant ply slippage in longer seams.

(ii) Seam pucker and fabric stretch
In an attempt to overcome the above problem, the pressure exerted by the presser foot is very often increased. This can lead to other problems such as seam pucker and stretching of the fabric under the presser foot.
In order to overcome these technical problems other types of feeding mechanisms have been developed, the details of which have been presented earlier. These devices, in general tend to significantly increase the price of the standard unit and are favoured mostly for specialist applications.

This section concerns the development of a 'top feed' mechanism, which has been developed to operate in conjunction with a standard 'drop feed' feeding mechanism. The mechanism has been designed to be 'retro-fitted' to an industrial machine, without the need for any additional prime movers for the 'top feed'.

5.4.1 Research and design criteria

Although advances in materials technology, lubrication and motor systems have led to ever increasing capabilities of machine speed, the basic principle governing the way in which the fabric is fed by the four-motion feed has not changed significantly, since its invention, by Wilson in the mid 1800's.

Figure 5.9 shows a diagram of a conventional lock stitch sewing machine, 'four motion' feed dog. The movement of the feed dog is divided into four motions:

1) The feed dog rises to a position just above the surface of the throat plate, where the teeth of the dog enters the fabric.
2) The feed dog moves in a lateral direction, maintaining its height and feeding the fabric.
3) The feed dog lowers, losing contact with the fabric, hence
feeding stops.

4) The feed dog returns to its starting position.

The complete feeding cycle described above takes place as each stitch is formed. The movement of the feed dog however, has to be synchronised with the movement of the needle. Fabric can only be fed whilst the needle is out of the fabric, otherwise needle damage/breakage can occur. For a sewing machine operating at 6000 stitches per minute the feeding cycle will take place in 0.01 seconds.

In order to maintain accurate synchronisation between feed dog and needle, the motion drive for the feed dog is usually taken from the main shaft of the sewing machine driving the needle bar. The rotary motion of the main shaft is converted to the linear/rotary motions necessary for the feed dog, through the use of cams, cam followers, and linkages. The arrangement of these differ from manufacturer to manufacturer, although the principles of obtaining feed dog motion remain constant.

The following describes the development of a novel 'top feed' mechanism applied to an industrial Singer model 95K sewing machine. Although the machine no longer appears in its present form, the principles used for obtaining feed dog motion are still widely used.
Figure 5.9 Four Motion Feed Dog Motion

presser foot

fabric

throat plate

feed dog

feed dog cycle
5.4.2 Analysis of the feed mechanism

A schematic diagram of the Singer model 95K sewing machine is shown in figure 5.10. The figure shows the arm and head of the sewing machine, containing the main shaft and linkages for driving the needle bar. It also shows the two shafts beneath the base of the machine used for providing motion to the feed dog [referred to as 'feed shafts'].

The forward and back feed shafts, driven from the top shaft by means of a cam follower and linkages, provide motion to the feed dog as shown in figure 5.11. By adjusting the linkages, the oscillation of the back feed shaft is altered, thus altering the feeding stroke (stitch length).

Graph 5.12 shows the dynamic analysis of the feed dog motions in relation to the needle motion. Fabric feeding occurs between $0^\circ$ (needle at TDC) and $135^\circ$ (needle at point of entering fabric). During this period the feed dog has reached and maintains its maximum height, whilst being displaced the length of its forward stroke. When the needle enters the fabric, the feed dog has reached its maximum stroke and begins to descend. The fabric being securely held to the throat plate by the presser foot, allowing stitch formation to occur.

Plate 5.13 shows the latest Singer lockstitch machine [model 591], and plate 5.14 the under-side of the machine. It can be seen that although many additional components have been included, the principle of obtaining feed dog motion using two feed shafts has not changed.
Figure 5.10 Schematic Diagram of Singer 95K

- main (top) shaft
- needle bar
- back feed shaft
- feed dog
- forward feed shaft
Figure 5.11 Singer 95K Feed Dog Motion

Forward and reverse motion of feed dog

Feed dog

Rise and fall motion of feed dog

Axis of back feed shaft

Axis of forward feed shaft
Graph 5.12 Dynamic Analysis of Feed Dog Motion

- Needle at top dead centre (TDC)
- Needle point enters fabric
- Needle point exits fabric
- TDC needle displacement
- Feed dog height (scale 5:1)
- Feed dog stroke (scale 5:1)

Displacement (mm)

Main Shaft Rotation °
Plate 5.13 Singer 591 Industrial Lockstitch Machine

Plate 5.14 Underside of Singer 591 Machine

- front feed shaft
- back feed shaft
5.4.3 Design, manufacture and implementation of the top-feed mechanism

Design of the top feed mechanism

Analysis of the feeding mechanism shows that the motion of the feed dog is governed by the oscillation of the two feed shafts, see figure 5.11. Any mechanism designed to effect top feeding must be synchronised with the action of the under-feed dog, otherwise differential ply feeding will occur.

Various methods of top feed mechanism were investigated which included:

(i) a top puller device positioned to one side of the needle,
(ii) a top feed foot operated by a separate cam attached to the main shaft, and
(iii) a top feed foot driven from the existing feed shafts.

It was decided that alternative (iii) a top feed foot driven from the existing feed shaft would be pursued. This providing a low-cost solution to the problem of top feeding.

The two main feed shafts situated under the base of the sewing machine provide motion to the feed dog by way of oscillatory motion. The design of the top feed is based on obtaining the feed and lift of the top feed foot motion, by translating the oscillations of the feed shafts into the necessary motions.

Figure 5.15 shows how the lateral motion for the top feed foot
is obtained by connecting a linkage to the back feed shaft and translating the motions through an auxiliary shaft mounted on the back of the arm of sewing machine, down to an angled linkage driving the top feed foot.

In the proposed arrangement, the top feed foot replaces the standard presser foot and is attached to the presser bar. Figure 5.16 shows how the lift for the feeding foot is obtained. The driving linkage is secured to the forward feed shaft and is connected to an angled linkage, free to rotate about the back feed shaft. A hollow shaft rotates about the auxiliary axis and drives the lifting linkage.

By accurately designing the linkages and determining their relative positions on each shaft, it is possible to accurately reproduce the motion of the under feed dog, in a mirrored version acting above the fabric. The most important motion is the lateral movement which must accurately follow and be of the same stroke as the under feed dog, otherwise differential ply feeding will occur. The lift of the top feed foot determines the thickness of fabric that can be fed through the sewing head.

Figure 5.17 shows how the proposed linkages are combined to provide lateral and lifting motion of the top feed foot.
Manufacture and implementation of the top feed mechanism

In order to incorporate the proposed top feed mechanism into the sewing machine it was necessary to carry out the following modifications to the existing machine:

(i) Faces on the back of the arm to mount the auxiliary shaft were machined.
(ii) Portions of the feed shafts to carry the driving linkages were machined.
(iii) A face on the back of the machine head was machined for supporting the angled linkage for driving the top feed foot.
(iv) A hole in the base of the machine was machined to allow access for the linkage connecting rods.

The above works were carried out without any major dismantling of the sewing machine being necessary. Plate 5.18 shows the underside of the modified sewing machine, showing how the linkages are attached to the feed shafts. It also shows the access hole machined into the base for the connecting rods. Plate 5.19 shows the auxiliary shaft mounted on the arm of the machine.

Stitch formation will not take place unless the fabric is prevented from moving up with the needle as it rises from its lowest point. The removal of the standard presser foot necessitated the provision of some other form of fabric retention device. This was achieved by attaching a spring loaded lever to the stationary section of the top feed foot, see plate 5.20.
Figure 5.15 Linkages for Providing Lateral Motion of the Top Feed Foot
Figure 5.16 Linkages for Providing Lift of the Top Feed Foot

- Hollow shaft mounted on auxiliary shaft
- Lifting linkage
- Top feed foot
- Front feed shaft
- Back feed shaft
- Pivoting linkage
Figure 5.17 Combined Linkages for Driving Top Feed Foot
Plate 5.18 Underside of Modified Machine
Plate 5.20 Close-up of Top Feed Foot
5.5 Research, design and manufacture of an edge positioning device for an industrial sewing machine

The use of conventional sewing machines involves a skilled operator whose task it is to guide the fabric through the machine whilst stitches are being formed. By constantly manipulating the fabric and adjusting it accordingly, a seam is produced parallel to the edge of the fabric [in many operations], and at a constant distance from the edge.

Guiding the fabric through the machine to maintain constant seam widths, requires considerable skill on the part of the operator. It has already been shown that the ability of the operator to control the fabric diminishes as the sewing machine speed increases. This can lead to considerable portions of the seam being stitched outside the desired line of stitching.

This problem has been recognised by the industry for many years. Manufacturers have responded to this by making guiding aids available in the form of contour guides, folders, and another attachments to the basic sewing machine unit. The following presents an outline of the type of attachment available¹²８

(i) Guide attachments: visual focus, tactile focus

These are guiding elements attached to either the machine head face, the machine bed, or the presser foot bar. These attachments present an edge or spot to the operator, who use it as a focusing point. The operator carries out the positioning when a guide is used.
The attachment guiding point (or edge) may be physically moved closer to, or farther away from the point of stitching. The operator guides the fabric using visual sensing, tactile sensing or both. The simplest form of guide is a 'T' guide or vertical extension from the presser foot surface to the throat plate, which the operator uses as a focal point. In order to align the fabric properly, it must touch the 'T' guide along its edge.

The present generation of long seaming, or contour seaming machines use a fixed guide arrangement. Instead of the operator guiding the fabric edge along the guide, the fabric is 'floated' on a cushion of air and directed towards the guide to achieve edge contact.

(ii) Positioning attachments

These attachments cause the fabric (or trimming) to bend, fold or shift during the sewing operation. Fell seam and felling attachments have curved links which fold the fabric, referred to as 'fellers'. The feller folds the fabric either to the left or right as the fabric feeds into the machine. They are usually manufactured with respect to fabric thickness.

Hemming attachments for blind-stitch hems, have guide blocks which prohibit the under fold (stitched fold) from reaching the machine knife which trims the edge of the hem before the edge is overedged and stitched to the fold beneath. These tend to have micrometer controls (thumb screw locked by a stud screw) which permit the variation of block position relative to the machine knife.
Other types of positioning attachment include; gathering and shirring attachments; tucking attachments; and automatic positioners used with stop-motion sewing machines. Automatic positioners are attachments which have a tripper mechanism to stop the sewing and positioning action after a given length of sewing.

(iii) Preparation and finishing attachments

Some preparation attachments process the fabric after it has been seamed. In this situation the succeeding operation is harnessed to the end of the seaming operation. An example of this is a strap or belt operation which has a pressing device attached to the machine head. The attachments have feed devices which feed the belting or stripping in and out of the press.

Fabric cutting devices can also be attached to the machine which can cut the seamed belting, strap, or stripping into desired lengths. Thread cutting attachments are also available which can be either automatic, or hand or foot operated.

(iv) Gauges and templates

These are sewing machine accessories used by the operator as sewing guides to improve the quality or quantity of production. The function of a gauge or template is the same as a machine (guide) attachment. The gauge or template is never attached to the machine, it is either moved by an independent mechanism as with automatic jig machines, or moved by the operator.

The main disadvantages of using guiding and positioning
attachments are:-

(i) Physical adjustment or replacement of the attachment is necessary for different types of fabric.

(ii) Physical adjustment of the attachment is necessary to obtain different seam widths, and

(iii) Accurate guiding relies on the intimate contact between the fabric edge and guide being maintained throughout the seaming operation.

The following sections detail the development of a low-cost computer controlled edge detection system for use with an industrial sewing machine.
5.5.1 Design criteria for proposed system

The design criteria for the development of the computer controlled edge positioning device for an industrial sewing machine are detailed as follows:

(i) A low-cost system using available technology.

(ii) A system capable of automatically responding to changes in fabric edge contour, and adjusting the fabric accordingly such that a consistent seam width is maintained.

(iii) To be easily fitted to an industrial sewing machine with the minimum modifications to the machine necessary.

(iv) To use existing power sources, electricity or compressed air.

(v) Cater for a wide range of fabric types including woven and knitted fabric.

(vi) To be safe in operation.

(vii) Not contaminate or damage the fabric in any way during operation.
5.5.2 Overview of proposed system

A schematic diagram showing the proposed system is shown in figure 5.21. Fabric is fed under the roller of the positioning device (by the operator). An infra-red emitter and detector array is positioned just in advance of the needle. As the fabric edge passes over the detector array a number of detectors will be covered, depending on the position of the edge.

The computer, being interfaced to the detectors, calculates the position of the fabric edge, relative to the fixed needle position. It then checks whether the fabric edge coincides with the pre-programmed position. If the edge does not coincide, then a signal is sent to the positioning motor to rotate either clockwise or anti-clockwise. The motor controls the positioning device, which consists of a roller in constant contact with the fabric attached to an arm.

The computer continues checking the fabric edge position and sending signals to the positioning motor, until the correct position has been attained. Further feeding of the fabric allows it to enter into the feeding mechanism, whereupon it is automatically fed through the machine. As the fabric is being fed, the computer continues checking the position of the edge relative to the needle and issues any corrective signals necessary to the positioning motor.

A block diagram showing the circuit for the proposed system is shown in figure 5.22. A description of the main components follows:
1 Computer

The computer used for development of the prototype system was the RCS Eleven Q single board computer/controller. This is a low cost system intended for applications such as controllers, distribution systems, energy management, data logging etc.

The Eleven Q has a 20 character alphanumeric display, up to 44 I/O lines (including a 6522 VIA and both positive and negative edged interrupts), an RS232 port with hand shakes, 4K bytes battery back up RAM and up to 8K bytes of user/monitor firmware (2 x 2532 Eproms).

The Resident Monitor program provides utilities to support the system I/O, display, RS232 port and optional keyboard. It also has debug facilities. The RCS Eleven Q system block diagram is shown in Appendix H.

The computer is interfaced to the phototransistor array by a tri-state buffer.

2 Infra-red emitters and phototransistor arrays

The LD261 series, GaAs infra-red emitting diodes utilised, emit radiation at a wavelength in the near infra-red range. They are designed for use with the BPX 81 series phototransistors with a spacing between each of approximately 10 mm. Both emitters and phototransistors are low-cost devices available in miniature size as an array. A six unit array was chosen for development into a system for enabling four seam widths to be provided. Details of the LD261 series infra-red emitters and BPX81 series phototransistors can be found in Appendix H.
The arrangement of emitters and phototransistor arrays are shown below:

The narrow acceptance angle of the phototransistors prevents optical 'cross-modulation' from the adjacent system. The pitch between emitter/phototransistors are according to the standard lead spacing of 2.54 mm.

The emitters and phototransistors are connected in circuit as shown over.
If $R = 120\Omega$ then $I_D$ is limited to 31 mA.

**Buffer**

Farnell CD4503 Hex Non inverting 3 state buffer will

drive 1 x standard TTL

$V_{DD} = 3v$ to 18 V
3 Stepping motor

An Evershed 24 Volt stepping motor was chosen for this application which had the following specifications:

Model - FDS 4/A 51  
Coil voltage = 5.3 V

Coil resistance = 4.5Ω  
Iph = 5.3 = 1.18 A

4.5

The motor drive circuit developed is shown in figure 5.23. The following formulae is used for calculating the resistances $R_1$ and $R_2$ required for the drive circuit.

$$R_2 = R$$

$$R_1 = \frac{R}{2}$$

$$R = \frac{24 - Vm}{2 \times Iph}$$

where, $Vm$ = motor coil voltage = 5.3 V

and, $Iph$ = current/phase with 2 coils energised

= 1.18A

$$R = \frac{24 - 5.3}{2 \times 1.18} = 7.9 \Omega$$

$$R_2 = 7.9 \Omega$$

$$R_1 = \frac{7.9}{2} = 3.97 \Omega$$

wattage = $(24 - 5.3) \times 1.18A = 22W$

nearest standard sizes

$R_2$ - 10Ω / 50 W

$R_1$ - 4.7Ω / 50 W.

The power hexfet [IRF510] is chosen to suit $Iph$. 

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4 Positioning device

The positioning device consists essentially of an arm driven through a rack and pinion by the stepping motor. At the end of the arm is attached a roller by means of a spring actuated lever. The detailed arrangement is shown in figure 5.24.

The axis of the roller lies parallel to the sewing machine axis. The roller contacts the fabric along its cylindrical side and allows the fabric to be fed normal to its axis without hindrance. However, due to the friction between the fabric and roller surface being greater than that of the fabric and work surface, lateral movement of the roller causes the fabric to be shifted along with the roller.

This principle is used to control the fabric as it is being fed into the machine. The device is connected in an open loop circuit. Providing there is no excessive slippage between the fabric and roller, the device will act to control the position of the fabric edge in accordance with the signals issued to the positioning motor from the single board computer.
Figure 5.21 Schematic Diagram of Developed System

infra-red emitters

phototransitors

fabric

positioning motor

positioning device
Figure 5.22 Block Diagram of Proposed System Circuit

INFRA-RED EMITTER
ARRAY

PHOTOTRANSISTOR
ARRAY

SENSOR BUFFER

RCS ELEVEN Q
SINGLE BOARD
COMPUTER

MOTOR DRIVE
CIRCUIT

POSITIONING
DEVICE
Figure 5.23 Stepping Motor Drive Circuit
Figure 5.24 Detailed Arrangement of Positioning Device

PART LIST

<table>
<thead>
<tr>
<th>REF.</th>
<th>DESCRIPTION</th>
<th>MATER. REF.</th>
<th>MATERIAL, FINISH</th>
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<tr>
<td>1</td>
<td>FRONT PLATE</td>
<td>EP002</td>
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<td>2</td>
<td>BACK PLATE</td>
<td>EP005</td>
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<td>END PLATE</td>
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<td>MILD STEEL</td>
</tr>
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<td>4</td>
<td>BASE PLATE</td>
<td>EP000</td>
<td>MILD STEEL</td>
</tr>
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<td>5</td>
<td>POSITIONING ARM</td>
<td>EP002</td>
<td>MILD STEEL</td>
</tr>
<tr>
<td>6</td>
<td>PIVOT BRACKET</td>
<td>EP003</td>
<td>MILD STEEL</td>
</tr>
<tr>
<td>7</td>
<td>PIVOT ARM</td>
<td>EP003</td>
<td>MILD STEEL</td>
</tr>
<tr>
<td>8</td>
<td>ROLLER SHAFT</td>
<td>EP006</td>
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<td>CABLE SCREW</td>
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<td>PINION</td>
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<td>BS SUPPLIED</td>
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<td>15</td>
<td>RACK</td>
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<td>MILD STEEL</td>
</tr>
<tr>
<td>16</td>
<td>C-BASE SCREW</td>
<td></td>
<td>2BA x 6 LONG</td>
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<td>ALLEN SCREW</td>
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<td>2BA x 6 LONG</td>
</tr>
<tr>
<td>18</td>
<td>ALLEN SCREW</td>
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<td>M8 x 6 LONG</td>
</tr>
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<td>19</td>
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</tr>
<tr>
<td>20</td>
<td>SCREW</td>
<td></td>
<td>M8 x 6 LONG</td>
</tr>
</tbody>
</table>

SEWING MACHINE NEEDLE POSITION

TOLERANCES

MATERIAL

TITLE

FABRIC EDGE POSITIONER

FINISH

ASSEMBLED

DRAWN

CHECKED

DATE

EP001

AUG 97

5.5.3 Software considerations

Based on the hardware configurations described in the previous section a computer programme was developed, which according to the reading obtained from the sensor array, transmits signals to the stepping motor to move the positioning arm and roller in contact with the fabric. The location of the sensors and positioning rollers relative to the needle position are shown below:

Infra-red radiation from the emitters phototransistors (sensors) causes the output signal to be close to zero (low). When the phototransistor is covered the output signal changes and is pulled up to +5 volts (high).

This change in state is recognised by the computer programme, and is used to direct the stepping motor. If two adjacent sensors are used for controlling motor direction then the motor tends to 'hunt', constantly changing direction. Due to this it was decided that one sensor would be used to determine the desired edge location. The sensors on either side would signal the motor to move either clockwise or anti-clockwise.
In the above example sensor number 2 is used to indicate the desired fabric edge position. If sensor 1 is covered then the computer sends a signal to rotate the motor anti-clockwise moving the fabric in direction B until sensor 2 becomes covered. If the fabric edge covers any sensor from 3 to 6, then a signal is sent to the motor to rotate clockwise, moving the fabric in direction A. Hence as the fabric is being fed through the machine the phototransistors will change their state as the edge position of the fabric changes relative to the needle position.

Software control of the system allows the position of the desired fabric edge to be altered by simply changing the codes which direct the motor either clockwise or anti-clockwise.

With such an arrangement of sensors it is possible to specify four seam widths. The physical size of the sensors limits these
widths to an approximate spacing of 2.5 mm, the width of the first seam being 5.0 mm. Six memory locations ($10B0 - $10B5) are used for storing the codes for motor direction, $11 is used to rotate motor anti-clockwise, $00 is ignored, and $FF is used to rotate the motor clockwise. The following shows how the motor direction codes are stored depending on the seam width required.

<table>
<thead>
<tr>
<th>KEY PRESSED</th>
<th>MEMORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4</td>
<td>LOCATION</td>
</tr>
<tr>
<td>11 11 11 11</td>
<td>$10B0</td>
</tr>
<tr>
<td>00 11 11 11</td>
<td>$10B1</td>
</tr>
<tr>
<td>FF 00 11 11</td>
<td>$10B2</td>
</tr>
<tr>
<td>FF FF 00 11</td>
<td>$10B3</td>
</tr>
<tr>
<td>FF FF FF 00</td>
<td>$10B4</td>
</tr>
<tr>
<td>FF FF FF FF</td>
<td>$10B5</td>
</tr>
</tbody>
</table>

The sensors, motor control lines, and tri-state buffer enable are connected to the Input/Output ports of the single board computer as shown over:
The flow chart of the positioning device control programme is shown in figure 5.25. [A complete programme listing can be found in Appendix I]

The programme looks for covered sensors in the following configuration:
Any other configuration is ignored by the programme. This eliminates the possibility of any spurious readings being obtained as may be experienced if one sensor is covered by a stray object such as lint.

The programme only issues one pulse at a time to the motor in the required direction. The sensors are then rechecked to see if other pulses are required. The delay in issuing pulses is necessary as the motor will not operate if the maximum pulse rate is exceeded.
Figure 5.25 Flow Chart For Positioning Device Control Programme

START

DISPLAY MESSAGE
"ENTER SEAM WIDTH (1-4)"

ENTER KEY NUMBER (1-4)

SET UP MEMORY LOCATIONS $1080-1085

INITIALISE I/O PORTS A & B

CHECK FOR ANY KEY PRESSED

YES

NO

ENABLE TRI-STATE BUFFER

LOAD DATA FROM PORT A

MASK OUT MOTOR LINES

COMPARE DATA TO ZERO

EQUAL

NOT EQUAL

CHECK HOW MANY SENSORS ARE COVERED

DISPLAY NUMBER OF SENSORS COVERED

READ CODE FOR MOTOR DIRECTION

=000

COMPARE VALUE

=8FF

SET MOTOR DIRECTION CLOCKWISE

=11

SET MOTOR DIRECTION ANTI-CLOCKWISE

PULSE MOTOR

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5.5.4 Manufacture and implementation of the edge positioning device

The principle of controlling the fabric edge by the method previously outlined was designed to be applied to any industrial lockstitch sewing machine. The machine chosen for development was the Singer model 95K industrial lockstitch machine, subject of the earlier research interest.

In order for the proposed system to operate, the infra-red emitter array and phototransistor array must be placed either side of the fabric, as close to the needle as possible. It was preferable that the phototransistor array does not protrude above the level of the base of the machine, otherwise the fabric would contact the lens of phototransistor. This necessitated the throat plate being recessed, to allow access to the phototransistor array. A small face was machined on the head of the machine to allow the emitter array to be positioned directly above the phototransistor array, see plate 5.26.

The positioning motor, arm and roller were designed as a self contained unit, which could be positioned as desired. This unit was fixed to the sewing machine base as shown in plate 5.27. A frame was constructed and attached to the sewing machine to allow the single board computer to be easily accessed by the operator, see plate 5.28. The circuit board and power supply units were positioned under the machine table.
Plate 5.27 Positioning Device Mounted on Machine
Plate 5.28 Computer-Controlled Edge Positioning System Layout
5.5.5 Analysis of edge positioning device

The response time of the system can be found by totalling the number of computer processor (machine) cycles required to carry out each operation in order to transmit a signal to the stepping motor to rotate either clockwise or anti-clockwise. Reference to the programme listing for the sensor and motor control routine in Appendix I, shows that:

**Stepping motor one step clockwise**

- Number of machine cycles = 110
- Clock frequency = 1 MHz
- Response time = $0.11 \times 10^{-3}$ seconds (0.11 ms)

**Stepping motor one step anti-clockwise**

- Number of machine cycles = 115
- Clock frequency = 1 MHz
- Response time = $0.115 \times 10^{-3}$ seconds (0.115 ms)

Analysis of the feeding cycle in section 5.4.2 shows that the fabric is only fed forward when the teeth of the feed dog protrude above the surface of the throat plate. This occurs over approximately one quarter of the complete cycle, finishing just prior to the point at which the needle enters the fabric. The developed top feed foot mirrors the action of the under feed dog, hence as the under feed dog teeth lose contact with the under-side of the fabric, the top feed foot teeth lose contact with the upper surface of the fabric.

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At this point, the fabric is controlled by the spring actuated 'hold down' lever attached to the stationary section of the feeding foot.

As fabric is fed into the machine any change in edge contour is accompanied by a system response, as the positioning roller seeks to correct the position of the fabric edge. If the roller attempts to correct the fabric when the under feed dog and top feed foot are in contact with the fabric then either (i) the fabric will buckle momentarily, or (ii) the friction between the roller surface and the fabric will be overcome and the roller will slip on the fabric.

The type of fabric being controlled will determine whether condition (i) or (ii) will occur. Lighter, more flexible fabric with a high coefficient of surface friction will tend to buckle with lateral roller movement. Whilst heavier, more rigid fabric with a low coefficient of friction will cause roller slippage to occur.
When the fabric is released by the under feed dog and top feed foot, the fabric is controlled by the hold down lever. The lever contacts the top surface of the fabric over a small area. If the fabric edge position is corrected during this instance, then the fabric will tend to pivot about the contact point of the hold down lever.

(i) fabric buckle  
(ii) roller slippage  
(iii) fabric pivots about point of contact of hold down lever
There also exists an instance in the stitch cycle when the needle enters and remains in the fabric. In this case, lateral movement of the roller will cause the fabric to pivot about the needle.

Situation (i) or (ii) will occur approximately 25% of the stitch cycle if continual fabric positioning is occurring. However as soon as the under feed dog and top feed foot lose contact with the fabric this condition will be eliminated. Situations (i) and (ii) can be eliminated by only correcting fabric position whilst the feed dog and foot are not in contact with the fabric. This requires monitoring the rotation of the sewing machine shaft and only transmitting motor control during certain rotation angles. For the purpose of this study this approach was not implemented, as satisfactory positioning conditions (iii) or (iv) should occur for 75% of the stitch cycle.
5.6 Experimental details

The aims of the experimentation in this section were to:

(i) Fully analyse the seam produced by the prototype machine,
(ii) Analyse seams produced by 'experienced' and 'inexperienced' operators, and
(iii) Make a comparison of seams produced by the prototype machine, experienced operators and inexperienced operators.

'Experienced' operators were classified as those who have had a number of years experience in the clothing industry as skilled machinists, and were familiar with industrial lockstitch sewing machines. 'Inexperienced' operators were classified as those who had had no (or very little) industrial experience in clothing making-up, and had little experience in the use of industrial lockstitch sewing machines, apart from instruction as to their use.

All experiments were carried out at Leicester Polytechnic and operators were selected from relevant members of staff or students.

5.6.1 Test equipment and methods

Two samples were used for experimentation, sample A and sample B, see plate 5.29. Samples were made from medium weight calico fabric (186.6 g/m²). Sample A was designed to assess the performance of operators and prototype machines on straight seams, and sample B to
assess their performance on contoured seams. The contour of sample B was designed bearing in mind the capabilities of the prototype machine. The positioning arm of the edge positioning device has a range of movement of 50 mm, therefore the overall range of contour of the sample was designed to be within this [40 mm]. The radii of the contour were determined such that; they were equal in curvature; met each other at a tangent at the midpoint of the sample; and span the specified contour range. This was determined to be a radius of 100 mm.
Experienced and inexperienced operators carried out the seam analysis tests on the same machine, the Singer model 591 industrial lockstitch machine. Each operator was given the following specification:

TEST PROCEDURE
MACHINE - SINGER 591 LOCKSTITCH

SEW 4 CONTINUOUS SEAMS ON SAMPLES A and B PROVIDED, AT EACH OF THE FOLLOWING SEAM WIDTHS:

2.5 mm, 5.0 mm, 7.5 mm, 10.0 mm.

ONE SET (A & B) TO BE SEWN AT A SLOW MACHINE SPEED, THE OTHER SET AT A FASTER MACHINE SPEED

```
<table>
<thead>
<tr>
<th>Sample</th>
<th>Stitch Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.5 mm</td>
</tr>
<tr>
<td>B</td>
<td>5.0 mm</td>
</tr>
<tr>
<td>A</td>
<td>7.5 mm</td>
</tr>
<tr>
<td>B</td>
<td>10.0 mm</td>
</tr>
</tbody>
</table>
```

a - s slow speed  b - s slow speed
a - f fast speed  b - f fast speed
Operators were not given specific machine speeds at which to produce the samples. It was not the main objective of the study to determine the effect of machine speed on seam width, such a study would call for a larger number of operators, which the constraints of time did not permit.

Rather, the main objective was to make an assessment of the operator's ability to control the fabric as it is being fed into the machine. At slow speed the operator would have greater control over the fabric (depending on their skill at making the machine operate at low speed). Each operator was monitored to make sure the second set of samples were produced at a higher machine speed than their first set. The range of machine speeds encountered for the operators were:

**Experienced operators**

- **Slow speed**
  - Minimum: 0
  - Maximum: 1500 spm

- **Fast speed**
  - Minimum: 3000 spm
  - Maximum: 5000 spm

**Inexperienced operators**

- **Slow speed**
  - Minimum: 0
  - Maximum: 400 spm

- **Fast speed**
  - Minimum: 2000 spm
  - Maximum: 3000 spm

[spm = stitches per minute]

Test samples were also produced on the prototype machine to the same specification as those for experienced and inexperienced operators. The range of prototype machine
speeds being:

**Slow speed**
- minimum - 0
- maximum - 500 spm
(Samples A & B).

**Fast speed**
- minimum - 1750 spm
- maximum - 2000 spm
(Sample A - continuous)
- minimum - 0
- maximum - 1600 spm
(Sample B - intermittent)

The prototype machine was not operated continuously at maximum speed for sample B, as it was found that problems were encountered with the fabric distorting at high manipulation rates. Portions of the contour were machined at maximum speed, whilst machine speed was reduced at various intervals.

Ten sets of samples were produced for experienced operators, inexperienced operators and prototype machine, at slow speed and fast speed.
Plate 5.29 Test Samples A and B
5.6.2 Analysis of samples

Each sample was analysed by measuring the seam widths at specific locations on the sample edge/profile, shown in figure 5.30. The mean seam width of each sample was then calculated for the seven locations, along with the standard deviation of the measurements.

Seam widths for the prototype samples were analysed over locations (1) to (6) sample A, and (2) to (6) sample B. This was due to the arrangement of the positioning roller in the prototype machine. The roller is positioned approximately 55 mm in advance of the sensors, so once the fabric has passed under the roller control is lost. Therefore readings at location (7) would not be consistent.
The curvature of sample B, and the arrangement of the emitters/detectors prevent accurate placing of the sample under the feeding foot. Readings for location (1) [sample B] are therefore excluded. The diagram below shows the type of error which could be encountered in placing sample B under the feeding foot:

A typical set of samples produced by an experienced operator at slow speed is shown in plate 5.31, and at fast speed in plate 5.32. A typical set of samples produced by an inexperienced operator at slow speed is shown in plate 5.33 (slow speed), and plate 5.34 (fast speed). Typical samples produced on the prototype machine at slow speed are shown in plate 5.35, and at fast speed in plate 5.36.
Figure 5.30 Locations for Measuring Seam Widths
Plate 5.31 Typical Set of Samples  
Experienced Operator - Slow Speed

Plate 5.32 Typical Set of Samples  
Experienced Operator - Fast Speed
Plate 5.33 Typical Set of Samples
Inexperienced Operator - Slow Speed

Plate 5.34 Typical Set of Samples
Inexperienced Operator - Fast Speed
Plate 5.35 Typical Set of Samples
Prototype Machine - Slow Speed

Plate 5.36 Typical Set of Samples
Prototype Machine - Fast Speed
5.6.3 Results obtained

The tables of results obtained can be found in Appendix J.

Key to graphs

[Diagram showing key to graphs: MAXIMUM VALUE, MEAN VALUE, TARGET VALUE, MINIMUM VALUE]
Graph 5.37 Experienced Operators
Slow Speed
Samples A and B
Graph 5.38 Experienced Operators
Fast Speed
Samples A and B
Graph 5.39 Inexperienced Operators
Slow Speed
Samples A and B

SEAM WIDTH (MM)

25
20
15
10
5
0

A
B
A
B
A
B
A
B

1
2
3
4

A
B
A
B
A
B
A
B

5 10 15 20 25
Graph 5.40 Inexperienced Operators

Fast Speed

Samples A and B
Graph 5.41 Prototype Machine
Slow Speed
Samples A and B
Graph 5.42 Prototype Machine
Fast Speed
Samples A and B
5.7 Conclusions and further work

5.7.1 Conclusions

Graph 5.37 shows that the experienced operators studied were able to produce seams close to the target seam widths [2.5 mm, 5.0 mm, 7.5 mm and 10 mm], within the range 1.5 mm to 4.55 mm for sample A, and 1.5 mm to 6.86 mm for sample B, at slow speed. The mean seam widths for sample B were approximately 1 mm over the target widths for each seam. The graph shows a trend for the range to increase with an increase in seam width.

In graph 5.38 it can be seen that as experienced operators increase the machine speed, the range of results increases to between 2.86 mm and 6.22 mm for sample A and 2.07 mm to 7.93 for sample B. The mean seams correlate closely to those for the slow machine speeds. As for the seams produced at slow speed there is a tendency for the range to increase as the seam width increases.

Graph 5.39 shows the results obtained for inexperienced operators at slow speed. In all cases it can be seen that the mean seam widths produced are in excess of the target seam widths, between 1.5 mm and 3.2 mm. As with the results obtained for experienced operators there is a tendency for the range to increase with increased seam width, the ranges being; 3.08 mm to 14.00 mm for sample A; and 4.0 mm to 15.07 mm for sample B.

The range of results obtained for inexperienced operators at fast speed can be seen in graph 5.40. It shows that the range of results is between 3.43 mm and 9.61 mm for sample A, and 3.57 mm to
11.28 mm for sample B. As with the samples produced at slow speed in all cases the mean seam value is in excess of the target value.

Graph 5.41 shows the range of results for samples produced on the prototype machine. It can be seen that at slow speed the mean seam values correlate closely with the target seam values [within 0.5 mm], and that the range of results is between 0.9 mm and 1.33 mm, for sample A. It can be seen that there is no significant trend for the range to increase as seam width increases. The mean results for sample B show the mean values to be approximately 1.0 mm less than the target values, with a range of 0.9 mm to 2.7 mm. The graph shows there is no evidence to suggest that the range depends on seam width.

The range of results obtained for samples A and B, produced on the prototype machine at fast speed, is shown in graph 5.42. It can be seen that the mean seam values for sample A seams correlate closely with the target seam values. The range of results being between 1.58 mm and 2.75. The mean values for sample B seams are again less than the target values, and the range of results lying between 1.3 mm and 3.4 mm.

Comparison of the results shows the results obtained for samples A and B, produced on the prototype machine, exhibit a smaller range than those produced by experienced and inexperienced operators. The difference between the mean values and target values for samples A (straight seams) produced on the prototype machine are comparable to those produced by an experienced operator. The difference is considerably less than those produced by an inexperienced operator. Although the mean values obtained for samples B on the prototype
machine are less than the target value, they are consistently so.

It was found during experimentation that some of experienced operators had no special perception of distances and that all tended to produce seams in excess of the target values. The prototype machine on the other hand was able to produce consistent seam widths at slow and fast speeds.

From the results obtained it can be seen that in principle the prototype machine can be used by an operator to produce accurate and consistent seams.

5.7.2 The need for further work

Although it has been shown that the principle of controlling the fabric being fed through an industrial lockstitch sewing machine can be achieved using the techniques outlined in this chapter, there are a number of areas which need further work to develop the prototype into a commercial viability. These being:-

(i) Increased contour seaming capabilities.
(ii) Greater fabric control.
(iii) Increased sensor resolution.
(iv) Multi-ply fabric control.

(i) Increased contour seaming capabilities

Results obtained for sample B, produced on the prototype machine, show that the standard deviation (SD) of the seam produced is high [1.75 - 2.11 SD (mean) - slow speed, 1.35 - 1.81 SD (mean) -
fast speed] compared with the standard deviation for sample A produced on the prototype machine [0.45 - 0.62 SD (mean) - slow speed, 0.51 - 0.62 SD (mean) - fast speed]. The large standard deviation exhibited for sample B suggests the seam width does not remain constant over its length.

In order to analyse the nature of the seam deviation, the results obtained for sample B on the prototype machine were analysed further. Figure 5.43 shows an analysis of the curved seam profiles at slow speed and figure 5.44 the analysis of the curved seam profiles at fast speed. From the figures it can be seen that the deviation in seam width is due to the manner in which the seam lines follows the edge. Between locations (2) and (4) [in both cases] the seam exhibits a greater degree of curvature than the concave edge, resulting in the seam lines passing close to the fabric edge. Between locations (4) and (6) the seam again exhibits a greater degree of curvature than the convex edge, this time resulting in seams being farther away from the edge.

The large deviation in seam width can therefore be attributed to the fact that the seam passes close to the sample edge at (2) and further away from the edge at (6). It can be clearly seen from the figures however, that the four seam lines are closely related in profile and maintain a consistent distance apart.

The nature of the seam produced on the prototype is governed by the physical positioning of the sensors relative to the needle. In the present arrangement, the sensors are positioned approximately 23 mm in advance of the needle. As a contoured seam is fed into the
machine the edge will pass over the sensors as shown:

A concave portion of the seam passing over the sensors is shown above. If the desired edge position is covering sensor no. 2, then as the fabric is fed into the machine the edge will be corrected in direction A. The degree of curvature of the fabric edge however will mean that the line of stitches pass closer to the edge than desired, this increasing as concave curvature increases. This explains why analysis of the curved seam profiles shows the seam passes closer to the fabric edge on concave profiles.
For convex sections of the profile, the reverse is true.

As the convex fabric edge passes over the sensor array, the edge will be controlled in direction B. The curvature of the seam will therefore mean the line of stitches will be farther from the edge than desired.

The combined effects of concave and convex edge profiles can be seen in figures 5.43 and 5.44. In order to eliminate or reduce this, it is necessary to position the sensor array closer to the needle. This would allow the fabric edge to be monitored closer to the point of stitching. The presser foot/top feed foot and feed dog arrangement of lockstitch machines however, prevents positioning of the sensor array extremely close to the point of stitching.

Another method of reducing the problem of curvature would be to
introduce a delay into the positioning device, such that, depending on the feed rate of the fabric through the machine, edge positioning would take place at a time after the edge has passed over the sensor array.

In its present configuration the prototype is limited to curved profiles over 100 mm radius.

(ii) Greater fabric control

During operation of the prototype machine it became evident that a greater control of the fabric being fed through the machine was necessary. Samples being fed through the machine had the tendency to drag on the table surface. This resulting in the fabric being fed through at a 'skew', the positioning device therefore has the additional function of correcting this 'skew' during fabric feeding.
The problem of fabric 'skew', especially with large pieces can be corrected by the use of additional feeding mechanisms situated to one side of the stitching head, and also behind the stitching head (puller feed) if required.

Another method of eliminating this 'skewing' effect would be to 'float' the fabric on a cushion of air to eliminate the frictional effects of the fabric on the sewing machine table. By incorporating 'directable' air jets into the table it would be possible to direct the fabric to have a forward motion. [similar to the principle outlined earlier for directing the fabric by compressed air against a fixed edge guide].

(iii) Increased sensor resolution

The present arrangement of emitters and detectors gives a theoretical seam width resolution of approximately 3.5 mm., due to the physical size of the components. The method of detecting the fabric edge passing between the infra-red emitter and phototransistor, using one sensor to indicate the desired edge location, can cause the seam produced to deviate as shown over.
As the fabric edge is being monitored, it is possible for it to travel between positions (1) and (2) (shown above), without any corrective action being taken by the positioning device. This distance varying between approximately 3.0 mm and 4.00 mm depending on the spacing of the emitter and phototransistor array. In practice the results obtained for the deviation in seam width, suggest seam deviation can be controlled within the range 0.9 to 2.75 mm [see Appendix J].

Further studies have been carried out under the supervision of the author[^129], to (a) investigate alternative methods of monitoring and controlling the movement of the fabric, and (b) reduce the resolution of seam width, by using the emitters and phototransistors in alternative arrangements. The study has led to the development of a system of using the emitters and phototransistors to provide a 0.8 mm to 1.00 mm resolution of seam width.
(iv) Multi-ply fabric control

At present the prototype machine can only be used to produce specific widths of seam on multi-ply fabric pieces in which the edges are of the same profile and positioned correctly one on top of the other. Such a system would require an operator to align the edges as the fabric is fed into the machine. Seam width however would be constantly monitored by the system, with any corrective actions being carried out automatically.

In order to extend the prototype to fully automated capabilities further research would need to be carried out to investigate methods of monitoring and positioning the individual plies of fabric during multi-ply feeding. This would also need to include an investigation into the monitoring and control of plies with differing edge profiles.
Analysis of Sample B Seam Profiles
Prototype Machine - Slow Speed

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>②</td>
<td>2.75</td>
<td>5.25</td>
<td>7.70</td>
<td>10.20</td>
</tr>
<tr>
<td>③</td>
<td>0.90</td>
<td>4.10</td>
<td>6.25</td>
<td>8.80</td>
</tr>
<tr>
<td>④</td>
<td>3.40</td>
<td>6.60</td>
<td>8.80</td>
<td>11.30</td>
</tr>
<tr>
<td>⑤</td>
<td>6.15</td>
<td>8.55</td>
<td>10.85</td>
<td>13.35</td>
</tr>
<tr>
<td>⑥</td>
<td>5.95</td>
<td>8.20</td>
<td>10.90</td>
<td>13.35</td>
</tr>
</tbody>
</table>
Figure 5.44 Analysis of Sample B Seam Profiles
Prototype Machine - Fast Speed

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>MEAN SEAM WIDTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.65</td>
</tr>
<tr>
<td>2</td>
<td>2.10</td>
</tr>
<tr>
<td>3</td>
<td>4.60</td>
</tr>
<tr>
<td>4</td>
<td>6.45</td>
</tr>
<tr>
<td>5</td>
<td>5.50</td>
</tr>
</tbody>
</table>
Chapter 6

Automated Handling of Fabrics and Other Flexible Materials
6.1 Automated ply separation and handling of fabrics

The situation of rising import penetration has led for a number of years to the automation of various operations such as collar stitching, pocket setting etc., in order to eliminate the human tasks of guiding and removing the fabric during the sewing operation. Very few of the developments, however, are able to pick up parts from a stack, assemble them, present them to the needle, guide them during sewing and dispose of them.

Over the years labour content reductions achieved by automated techniques have been sufficient to keep pace with imports. Recently, the situation has changed and many domestic markets in the developed countries have been put at risk. This has in turn led to companies seeking alternative ways of reducing the labour content other than that which can be achieved merely by de-skilling the sewing operation through mechanisation. These semi-automated machines still require an operator, and do very little to break the mould of one machine/one operator which keeps the clothing industry so labour intensive. It is felt in some circles that the labour content cost needs to be reduced by as much as 50% in order for domestic production to recapture its competitive position\textsuperscript{130}.

With a few exceptions among large specialist machines it is the materials handling problem which holds the key to breaking the one machine/one operator link and is a problem which has not yet been universally solved, although much research attention is being paid to this area.
The clothing industry as a whole has an extremely difficult task in trying to reduce or eliminate labour. One of the main reasons is due to the nature of the raw material used in producing finished products. The properties of textile fabrics combine to make a material which defies simple replacement of human hands with mechanical devices. Despite the difficulties facing the industry, much work has recently been carried out in developing 'operatorless' sewing stations\textsuperscript{131,132}. Although the development and introduction of these new technologies has not been as pronounced as other industries where the characteristics of the raw material are less of a problem.

The manufacture of large volume production apparel usually involves the 'laying up' of the fabric which is normally delivered in roll form up to 100 metres long and of a standard width. During this 'laying up' process, layers of fabric are placed on top of each other to form a stack. The height of the stack and number of plies it contains depend upon the particular method of cutting employed and the type of fabric being cut. Stacks can be in the order of 50 plies deep. Garment pieces are then cut from this 'layed up' stack either manually following a 'marker' or automatically using numerically controlled cutting equipment. The latter method having significant advantages as it can be directed by computer-aided lay planning systems.

In order to be able to cut a number of layers of fabric placed on top of each other in the form of a stack, a high degree of rigidity must be maintained. This is usually achieved by covering the entire stack with a non-porous or low air permeable material and
applying a vacuum to the under-side, producing a rigid vacuum-sealed stack which can then be cut.

After cutting it then becomes necessary to strip the waste material from the stack leaving the bundles of cut garment pieces. These are transported to the relevant work stations for subsequent assembly operations. During assembly each piece of the garment has to be separated from the bundle so that it can be handled for machining or matching with other pieces.

During the assembly of a garment the 'handling time' can be as high as 80% of the total time to complete that garment. Part of this 'handling time' is taken up with the manual separation and handling of the garment piece to position it for stitching. Automated ply separation has been introduced in certain operations such as pocket attaching but has yet to overcome many difficulties. One of the main difficulties can be attributed to the nature and properties of the material being handled. Textiles vary in porosity, have essentially no stiffness, have a non-homogeneous structure and are compressible. These properties combine to make a material whose orientation and absolute positioning are difficult to predict. Automated ply separation is further hindered by the multi-layer cutting operation described above. Vacuum sealing of the stack has the effect of compressing the layers together so that the fibres of each layer cling together causing an interface bond between plies (severity depends on the type of fabric). Simultaneous saw or knife cutting can cause the fibres at the edges of the stack to become entangled and form a mechanical inter-locking bond or strong friction bond, both of
which can make it difficult to separate individual layers. This problem can, however, be minimised by the use of sharp cutting tools. Thermoplastic yarns may have a tendency to fuse together during cutting, this problem must be carefully considered in the choice of cutting equipment.

The problems of automated ply separation have been tackled for many years, with many ingenuous and sophisticated devices being developed for this purpose. The advent of more affordable and available computer technology, and subsequent developments in robotics is now leading to a more universal approach to the task in hand.
6.2 Review and classification of devices for automatically separating plies of fabric from a cut stack

This section presents an abridged review of devices, both historical and state-of-the-art, for separating plies of fabric from a cut stack. The full review is presented in the published paper by the author, listed in Appendix S.

1. Pinch type devices

Pinch type devices are those which are designed such that the uppermost ply of fabric in a stack is picked up by the action of mechanically operated pinchers or grippers. The method is non-intrusive and techniques employed for disturbing the uppermost ply and securing it, differ widely.

The 'Clupicker', shown in figure 6.1, is an example of a pinch type device. This device uses a picking wheel to displace the top ply of fabric into a shoe, which then clamps and secures the top ply.

Pinch type devices in general are designed so as to pinch the fibres of the uppermost ply in a stack, avoiding the second ply by precision design. Correct setting of these devices is therefore critical to maintain a high level of reliability. Fabric fibres may become disturbed using this method.

2. Needle type pick-up devices

Needle type devices, whether single or multiple needle, linear or rotary action, are all what can be termed as 'intrusive' methods
for picking up a ply (or plies) of fabric. That is, they rely on needles (or similar) being inserted in the fabric in order to retain it. Needle type devices are 'positive' methods of picking up a ply of fabric, since a controlled force can be applied to the fabric. The main disadvantage with this method is that it can disturb the fibres of the material, and in handling some fine or delicate fabrics needle insertion may be totally unacceptable.

An early example of a needle type device was that patented by Oldroyd in 1971, see figure 6.2. Bijttebier employed the principle of pin engagement in the 'Jognatic' pick-up device, see figure 6.3. Rimoldi have used the principle in their 'Rimoldi-Robot', see figure 6.4, and the University of Durham have developed a device based on pin engagement, figure 6.5.

3. Vacuum pick-up devices

The use of vacuum devices to pick up articles is already widespread in many industries. The inherent porosity of some textile materials however, presents a limitation to the widespread application of the principle in the textile industry. Many vacuum type devices have been developed for use in the textile industry. These, in the main, have been used for single ply handling operations or for handling fabric with low air permeability.

A technique designed to overcome the problem of porosity in textile materials described as the 'wet vacuum' method was patented in 1973, see figure 6.6.
4. Adhesive pick-up devices

The principle of adhesive pick-up of fabric involves the use of temporary adhesion, as may be provided by an adhesive tape, see figure 6.7. This method has the advantage of being consistently able to pick up a single ply of fabric and provides positive location of the uppermost ply only. [This principle is discussed further in sections 6.6 and 6.7]

5. Air jet devices

This method of ply separation involves the use of an air jet, arranged so as to produce vibrations in the uppermost layer of fabric in a stack of material. The use of air-jets to disturb the top ply of fabric has previously been used with devices which grip or hook the disturbed ply or remove it by vacuum. Researchers at the University of Hull have developed a sensory gripper (used as a robot end-effector) which employs the air jet principle, see figure 6.8.

6. Other pick-up devices

(i) Combination devices

These devices do not fall into the broad categories outlined previously, but are combinations of similar principles. Needles have been used with pinch type devices, pinch type devices have been used with vacuum, and other such combinations. An example of a combination pick up device is the device patented by Mathias in 1985, which incorporates a pinch principle with vacuum, see figure 6.9.
(ii) 'Velcro' pick-up devices

'Velcro' is the registered trade mark of the original hook and loop fastener. The fastener consists of two nylon tapes, one covered in tiny hooks and the other in tiny loops, see figure 6.10. When the hooks are pressed into the loops they grip the loops tightly, forming a secure closure which resists lateral tensions.

The hooks can be used on their own for picking up fabrics, but they must be able to grip the surface structure. They are ideally suited to the open structure of knitted fabrics, but can cause the fabric to 'snag' (loops of yarns being pulled out of the fabric) on removal.

(iii) Cryogenic pick-up

This principle involves the adhesion of the fabric to the probes of a cryogenic device maintained at, or below, freezing point. Such a device was patented by Sutz in 1971 and is shown schematically in figure 6.11. The principle described involves a thin layer of water being applied to the probe tips, which descend and contact the fabric ply. The water then freezes on the tip of the probe forming a matrix of ice between the probe tip and the fabric. The fabric is then secured to the device.

(iv) Electrostatic attraction

Scope exists for the use of electrostatic attraction of fabrics to a device, as the phenomenon of 'static cling' is evident in everyday use of certain textile materials. To the consumer however, garments which are static prone present problems such as clinging of apparel, and dust attraction etc.
Figure 6.1 The Clupicker

Figure 6.2 Oldroyd Device

Figure 6.3 Bijsuebier Device
Figure 6.4
The Rimoldi Robot
(courtesy of Rockwell Rimoldi Ltd)

Figure 6.5 Durham Pick-up Device

Figure 6.6 'Wet Vacuum' Pick-up
Figure 6.7 Adhesive Pick-up

Figure 6.8 Hull Pick-up Device

Figure 6.9 Combination Pick-up Device
Figure 6.10 'Velcro' (courtesy of Selectus Ltd)

Figure 6.11 Cryogenic Pick-up
6.2.1 Discussion of review

Table 6.21 shows a comparison of the various types of pick up device in terms of cost, speed of operation, reliability, type of fabric, commercial availability and multi-ply separation. Many of the devices described earlier have been patented but not applied fully in the commercial sense. It is therefore only possible to attain an assessment of them from experimental and descriptive data.

The comparison highlights the problems encountered when handling fabrics. One particular device may perform to a high standard overall, but may then be totally unacceptable for handling a certain type of fabric. With devices which take a more universal approach to ply separation and fabric handling, the cost and complexity of the device tends to increase. The exception to this rule being adhesive pickup devices. These devices rely mainly on the performance of the adhesive in determining the reliability and cost, and type of fabric that can be handled.

Research in this chapter has concentrated on the use of adhesives in the handling of fabrics. The following sections outline; the problems involved in separating and manipulating fabrics; the requirements of a device for the automated handling of fabrics; and the influence of the fabric to be handled on the selection of suitable techniques for automated handling. This is followed by sections detailing research undertaken in the application of adhesives in the handling of fabrics, and the subsequent development of a robotically controlled device for automated ply separation and handling.
## Table 6.12 Relative Comparisons of Pick-up Methods

<table>
<thead>
<tr>
<th>Device</th>
<th>Cost</th>
<th>Speed of Operation</th>
<th>Reliability</th>
<th>Type of Fabric</th>
<th>Commercially Available</th>
<th>Multi-ply Separation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finch</td>
<td>Medium</td>
<td>Medium/high</td>
<td>Good (a)</td>
<td>Most</td>
<td>Widely</td>
<td>Limited</td>
<td>a) Dependent on fabric type</td>
</tr>
<tr>
<td>Needle</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Most (b)</td>
<td>Widely</td>
<td>Yes</td>
<td>b) Needles or pins may damage fine fabrics</td>
</tr>
<tr>
<td>Vacuum</td>
<td>Low</td>
<td>High</td>
<td>High (c)</td>
<td>Low Permeability Fabrics</td>
<td>Widely</td>
<td>Limited (not accurate)</td>
<td>c) With correct fabric type</td>
</tr>
<tr>
<td>Adhesive</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Most</td>
<td>Widely</td>
<td>No</td>
<td>May leave residue on fabric</td>
</tr>
<tr>
<td>Air Jet</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Most</td>
<td>No</td>
<td>No</td>
<td>Inherently slow</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination</td>
<td>Variable (d)</td>
<td>Variable (d)</td>
<td>Variable (d)</td>
<td>Variable (d)</td>
<td>Yes</td>
<td>Possibly</td>
<td>d) Device dependent</td>
</tr>
<tr>
<td>Velcro</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Limited (e)</td>
<td>No</td>
<td>No</td>
<td>e) Hooks must be able to grip</td>
</tr>
<tr>
<td>Cryogenic</td>
<td>Medium/high</td>
<td>medium/high</td>
<td>High</td>
<td>Most</td>
<td>No</td>
<td>No</td>
<td>Refrigeration must be available</td>
</tr>
<tr>
<td>Electrostatic</td>
<td>Medium/high</td>
<td>Variable</td>
<td>-</td>
<td>Static</td>
<td>No</td>
<td>No</td>
<td>Electrostatic problems</td>
</tr>
</tbody>
</table>
6.3 The problem to be solved

Unlike rigid mechanical parts, sheet material and the like, all textile materials are described as flexible or 'limp'. The degree of flexibility or limpness varies markedly from fabric to fabric, with extremes in sheer and limpness exhibited by silk through to extreme stiffness as with starched denims.

The limpness of textile materials is a necessary pre-requisite, as it renders these materials desirable as covering for the human body. Wearer comfort, ease of movement, and other important factors are required from most garments, although the degree to which garments exhibit these characteristics depend on the particular end-use e.g. underwear, sportswear, outerwear etc.

As more of the sewing operations become automated the industry is faced with the problem of substituting mechanical methods of manipulating flexible materials for the dexterity of a human operator. The human operator is an invaluable tool in the production of garments and despite recent attempts at full or semi-automation the services of the flexible production tool - the human, are very difficult to dispense with. While manipulating fabrics an operator can compensate for the variations associated with the properties and adapt accordingly, even during a continuous process.

Despite recent developments in robot gripper technology, they have not as yet even approached the capacity of humans in terms of sensory and tactile capabilities. The more 'intelligent' the gripper the more likely it is that the capital cost will rise accordingly.
Many developments and research projects are underway in respect of gripper technology in other industries notably mechanical engineering. It is not within the scope of this work to discuss these, although it can be stated that much work still has to be carried out in order to increase the current capabilities of robot grippers.

The problem facing the industry is how best to substitute the dexterity and tactile capabilities of the human operator with a mechanical device that can cater for a wide range of fabrics, operate reliably and above all be cost-effective. The four main areas associated with flexible fabric handling can be defined as:

(i) 1st stage - ply separation
(ii) 2nd stage - ply removal
(iii) 3rd stage - transportation
(iv) 4th stage - orientation, registration, and presentation.

Ideally an automated handling device should be able to carry out all the 4 stages, including disposal of the completed piece, as this is what is presently achieved by the operator. In practice however the stages or problem areas have tended to be tackled separately, although some devices which have been developed combine many of the stages into a single device.
6.4 Requirements of an automated device for handling fabric pieces

In order that devices for automated handling serve the needs of clothing assembly automation both in the present and in the future, they must meet the following requirements:

(i) Range of fabrics
(ii) Accuracy
(iii) Reliability
(iv) Non-impairing or contaminating
(v) Cost
(vi) Speed of operation

(i) Range of fabrics

The complete range of fabrics which can be encountered in the clothing industry could be represented by super-limp sheer fabrics such as silk through to stiff heavy fabrics such as starched denim. In practice however, it is more likely that sectors of the industry are handling a wide range of a particular material such as knitted fabrics, shirting fabrics, denims and the like. As the division of sectors increase the range is more likely to narrow. Any device(s) applied to a particular operation must therefore be able to cater for the range of material to be encountered. If the device is to have universal appeal then it must also be able to cater for the needs of different sectors, this greatly enlarges the range of materials that
must be catered for.

(ii) Accuracy

The device must be able to accurately distinguish between one ply, more than one ply or no plies at all. Depending on the fabric these differences could be from a few tenths of a millimetre to a number of millimetres. Special placement accuracy can either be achieved by the device itself or by ancillary positioning devices. Although not as critical as for some industries, placement accuracy must be consistently controlled.

(iii) Reliability

Simply automating an operation such as limp fabric handling is not enough to ensure that productivity gains and labour cost per unit reductions can be achieved if a person is still required to monitor the equipment. In order to justify its use a handling device must approach 100% reliability, otherwise excessive machine down-times will erode any benefits accrued. It has been suggested that reliability should ideally be upward of 98%\textsuperscript{135}, the device should also be incorporated in a system which warns of any breakdown on malfunctions.

(iv) Non-impairing or contaminating

Most clothing products are judged by the customer by their appearance and feel. Small imperfections due to pin holes, abrasions, snags etc. can be quite obvious to the consumer and reduce its value.
in their eyes. Once the garment has been made-up with imperfections it has to be sold off as seconds or 'mark-downs'. Contamination of the garment by the handling device e.g. lubricating oil, adhesives etc. must also be avoided as any additional processing (and hence labour cost) to remove the contaminant reduces the value added part of the garment to the producer. Permanent contamination such as staining presents the same problem as imperfections.

(v) Cost

The cost of the handling device is normally related to the total automated system cost as compared to the system productivity. Its economic viability is usually determined by the various methods of payback techniques. It has been stated that a basic device to separate plies from a small stack should be in the price range $50 - $100 (£25-£50). This is due to the fact that a number of such devices would be required for complex or large operations.

(vi) Speed of operation

The human operator can locate and pick up a single piece of fabric from a stack at a fairly high speed. Any automated device must therefore be able to work at a comparable speed and not spend time searching and attempting to locate a single ply. With many devices speed of operation is usually increased at the expense of accuracy and reliability.
The requirements outlined above are viewed as the basic requirements of an automated device for handling fabric. Other requirements may exist in relation to specific sectors of the industry. Any device for handling fabrics can be assessed by how well it meets the above requirements. Devices can also be compared in terms of these requirements to enable prospective users to determine the device best suited to fabric handling in a particular situation.
6.5 The influence of the fabric to be processed on the selection of suitable techniques for handling fabrics

The development of devices which are already effective in handling fabrics, and the enlargement of the area of application is influenced, in addition to technological and economic factors by:-

(i) The fabric being handled, and
(ii) The mechanical properties of the fabric.

6.5.1 The influence of the fabric being handled

Extensive research carried out at the Karl Marx Stadt in East Germany has involved an examination of the manufacturing ability of fabrics with respect to automated handling. The investigation was based on an examination of approximately 200 fabrics ranging from 50 g/m² up to 480 g/m² and leather up to 950 g/m². The physical and technical characteristics were also included in the investigation. It was concluded that the adhesion power relationship between two fabric plies are decisive factors in the selection of suitable separation techniques. Fabrics were classified under manufacturing classes to be considered for handling:-

Class 1

The fabrics in this class are relatively impermeable to air and have no adhesion power between each other. These fabrics have a thick smooth surface without any free filaments.
Class 2

This class contains textile fabrics permeable to air, but with no adhesion power between plies. In opposition to the fabrics in class 1 they have a loose structure with few filaments.

Class 3

This class contains air permeable fabrics with adhesion power between the plies. This adhesion power does not however exceed the weight per dimension of the fabric being manipulated. These fabrics are characterised by having a roughened surface.

Class 4

This class contains air permeable fabrics with significant adhesion-power between plies. These fabrics are characterised by a roughened surface and filament structure with a large number of compact free ends - typified by corduroy.

The above classifications were used by the research team as the basis for pre-selecting the basic principles. Basic principles for each class being:

Class 1 - Vacuum (pneumatic) pick-up

Class 2 - Mechanical pinch type devices

Class 3 - Needle type devices

Class 4 - Partial pick-up of the fabric structure and inference of strain tension.
Although the above investigation gives valuable guidelines as to the selection of suitable basic principles for separating fabric plies, it must be noted that the technical (and financial) expenditure for the basic principles increased from class 1 fabrics to class 4 fabrics. It is however possible to handle fabrics of a lower class with the basic principles of a higher class.

One of the basic principles overlooked in the investigation was the use of adhesives.
6.5.2 The mechanical properties of the fabric

There is increasing evidence that certain mechanical properties significantly influence the engineering behaviour of fabrics in spreading, cutting, sewing and pressing. With the increased introduction of automated handling of fabrics, and the elimination of the availability of skilled operators, there exists a problem which must be addressed, to compensate for the great range of the physical properties of woven and knitted fabric available.

A study made by Kawabata and Niwa in Japan, into the objective specification of fabric quality, mechanical properties and performance, has led to the development of a system known as the Kawabata Evaluation System (KES). Initially, KES was aimed at developing a correlation between the subjective evaluation of the aesthetics of 'hand' and drape of fabrics as measured by a panel of experts, and the objective Total Hand Value (THV) calculated from the mechanical properties of these same fabrics. ['Hand' or 'Handle' is normally judged subjectively and is related to the judges physiological perception of the fabric gained by touching and handling it].

KES was developed by inviting a number of experts, mostly from the wool fabric weaving and finishing industries in Japan to join the committee of the Hand Evaluation and Standardisation Committee (HESC) organised by Kawabata. The experts were asked to agree upon the properties they considered as important in assessing the 'hand' of the fabric. These are classified in table 6.13 as 'primary hand'. The next step was to have each expert judge each of approximately 500
fabric samples according to each primary hand. This eventually led to the standardisation of each sample according to a value known as 'hand value' (HV), in eleven grade ratings from 0 - 10.

The fabric handle concerned with fabric quality was also graded by the experts, according to six grades. This was called the 'total hand value' (THV). THV assessment was also carried out in collaboration with the University of New South Wales, Australia. The main purpose of the fabric handle standardisation was for technical communication about fabric handle.

Research into obtaining objective measurement of fabric handle, was carried out by Kawabata and Niwa in parallel with the fabric standardisation activities outlined above. The principle aim of the research was to use the fabric's basic mechanical properties, as measured by instrumentation, to determine hand values (HV's). The procedure for obtaining the Total Hand Values (THV) is shown below:

\[
\begin{align*}
\text{Basic mechanical properties and some of related fabric properties} & \\
\text{measurement} & \\
\end{align*}
\]

\[
\begin{align*}
\text{A} & \quad \text{HV's for primary hands} & \quad \text{B} & \quad \text{THV} \\
\text{Translation I} & \quad \text{Translation II} & \\
\text{calculation} & \\
\end{align*}
\]

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Six fabric properties were chosen for measurement to determine the basic fabric properties. These being: (i) tensile, (ii) shear, (iii) bending, (iv) compression, (v) surface (frictional and geometrical roughness), and (vi) fabric structure (weight and thickness). Each property was defined as completely as possible, leading to sixteen parameters used for characterising fabric properties, see table 6.14.

The mechanical data obtained using the KES-F measurement system, is transformed into hand values (HV) using conversion equations developed on the basis of experts' handle judgement. The equations for transformation I were developed from the statistical analysis of the relationship between the HV’s judged by experts and the mechanical data of a number of samples. The equations for translation II were also obtained by the analyses of the relationship between HV's and THV's, both of which being evaluated by the experts.139,140

Currently the major use of the KES instruments is with the correlation of the properties of fabrics in their compliance and conformation in seam formation and in converting two dimensional fabrics into three dimensional garments. A typical set of results obtained using the KES is shown in figure 6.15, this is referred to as a 'footprint' of the fabric and can be used to objectively compare different fabrics. Figure 6.16 shows typical criteria used by a Japanese suit factory, for tailoring process control based on fabric tensile and shear properties.

Much work in categorising the physical characteristics of
fabrics and the effects they have on fabric handle had been carried before Kawabata developed the system described above. Kawabata however recognised that in this area, progress was very slow and that much of the work was scattered in different sources. Since its development KES equipment has gained ever increasing importance in setting standards by which woven garment manufacturers select fabrics for particular applications. KES is also being used outside Japan by clothing manufacturers and academic institutions.

The suitability of KES for all type of fabric and its implications for the apparel industry have been in question for a number of years. Some are of the opinion that, KES is too expensive, the equipment is too intricate and there have been differences in the subjective assessment of 'handle' upon which KES is based. There is also concern that KES is unsuitable for some knitted fabrics.

Besides research being carried out to objectively assess the fabric properties important in finished fabric, research into the tailoring operations which influence garment appearance and clothing comfort have also been undertaken. Dhingra and Postle determined that the effect of sewing on fabric bending behaviour depends on the nature of the seam, the seam allowance and the seam direction. Further work carried out has shown:— (i) structural seam balance influences the tensile and bending properties of the seamed fabric composites; (ii) A natural curvature results from fabric overfeed during seaming; and (iii) It is possible to calculate the relative lengths of overfed fabrics required for a desired natural curvature.

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In their survey of the present status and future potential of some methods suitable for the goals of yarn and fabric engineering, Curiskis et al.\textsuperscript{145} concluded:

(i) By further developing and exploiting known methods, it is envisaged that current objective measurement programmes for fibres, yarns and fabrics can be extended and orientated towards the optimisation of fibre selection, processing and yarn and fabric design and construction for specified levels of mechanical and physical performance.

(ii) Although much research and development work is still to be done, the potential of these methods should lead to the attainment of the goals of yarn and fabric engineering.
<table>
<thead>
<tr>
<th>Hand</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. KOSHI</td>
<td>A stiff feeling coming from bending property. Springy properties promote this feeling. High density fabrics made by springy and elastic yarn usually possesses this feeling strongly.</td>
</tr>
<tr>
<td>2. NUMERI</td>
<td>A mixed feeling coming from smooth, limber and soft feeling. The fabric woven from cashmere fibre gives this feeling strongly.</td>
</tr>
<tr>
<td>3. FUKURAMI</td>
<td>A feeling coming from bulky, rich well formed fabrics. Springy properties in compression and the thickness accompanied with warm feeling are closely related with this feeling. (FUKURAMI means &quot;swelling&quot;).</td>
</tr>
</tbody>
</table>

**Men's summer suit fabric**

<table>
<thead>
<tr>
<th>Hand</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. KOSHI</td>
<td>Same as KOSHI in men's winter suit fabric.</td>
</tr>
<tr>
<td>2. SHARI</td>
<td>A feeling coming from a crisp and rough surface of fabric. This feeling is brought by hard and strongly twisted yarn. This feeling brings a cool feeling.</td>
</tr>
<tr>
<td>3. HARI</td>
<td>Anti-drape stiffness, no matter whether the fabric is springy or not. (This word means &quot;spread&quot;).</td>
</tr>
<tr>
<td>4. FUKURAMI</td>
<td>Same as FUKURAMI in men's winter winter suit fabric.</td>
</tr>
</tbody>
</table>
Table 6.14  The sixteen parameters describing fabric mechanical properties

| I  | Tensile   | 1  | LT | Linearity of load-extension curve (−) |
|    |           | 2  | WT | Tensile energy (gf cm/cm²)          |
|    |           | 3  | RT | Tensile resilience (%)              |
| II | Shear     | 4  | G  | Shear rigidity (gf/cm degree)       |
|    |           | 5  | 2HG| Hysteresis of shear force at 0.5 degrees (shear angle) (gf/cm) |
|    |           | 6  | 2HG| Hysteresis of shear force at 5 degrees (gf/cm) |
| III| Bending   | 7  | B  | Bending rigidity (gf cm²/cm)        |
|    |           | 8  | 2HB| Hysteresis of bending moment (gf cm/cm) |
| IV | Compression | 9  | LC | Linearity of compression-thickness curve (−) |
|    |           | 10 | WC | Compressional energy (gf cm/cm²)    |
|    |           | 11 | RC | Compressional resilience (%)        |
| V  | Surface characteristics | 12 | MTU | Coefficient of friction (−) |
|    |           | 13 | MMD | Mean deviation of MTU (−)          |
|    |           | 14 | SMD | Geometrical roughness (micron)     |
| VI | Fabric construction | 15 | W  | Fabric weight per unit area (mg/cm²) |
|    |           | 16 | T  | Fabric thickness (mm)              |
Figure 6.15 HESC Data Chart - Mens Winter Suit

<table>
<thead>
<tr>
<th>HESC DATA CHART - 101W</th>
<th>MEN'S WINTER SUIT (SAMPLE 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>/EM</td>
<td></td>
</tr>
<tr>
<td>/ILT</td>
<td></td>
</tr>
<tr>
<td>TENS</td>
<td></td>
</tr>
<tr>
<td>/WT</td>
<td></td>
</tr>
<tr>
<td>/RT</td>
<td></td>
</tr>
<tr>
<td>BEND</td>
<td></td>
</tr>
<tr>
<td>/B</td>
<td></td>
</tr>
<tr>
<td>/2HB</td>
<td></td>
</tr>
<tr>
<td>/G</td>
<td></td>
</tr>
<tr>
<td>SHEAR2HG</td>
<td></td>
</tr>
<tr>
<td>/2HG5</td>
<td></td>
</tr>
<tr>
<td>/LC</td>
<td></td>
</tr>
<tr>
<td>COMP1WC</td>
<td></td>
</tr>
<tr>
<td>/RC</td>
<td></td>
</tr>
<tr>
<td>/MIU</td>
<td></td>
</tr>
<tr>
<td>SUR1MD</td>
<td></td>
</tr>
<tr>
<td>FACE1SMO</td>
<td></td>
</tr>
<tr>
<td>/T</td>
<td></td>
</tr>
<tr>
<td>/W</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>H.V.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>KOSHI (STRENGTH)</td>
<td>6.085</td>
</tr>
<tr>
<td>NUMERI (STRAIGHTNESS)</td>
<td>6.238</td>
</tr>
<tr>
<td>FUKURAMI (FULLNESS)</td>
<td>7.257</td>
</tr>
<tr>
<td>T.H.V</td>
<td>3.416</td>
</tr>
</tbody>
</table>

16 Mechanical Properties

Primary Hand Values

Total Hand Value
Figure 6.16 Criterion Used by Japanese Suit Factory

TAILORING PROCESS CONTROL BASED ON FABRIC TENSILE AND SHEAR PROPERTY

DATE 88/06/06

<table>
<thead>
<tr>
<th>LT</th>
<th>-4</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>1.5</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>TENS EM1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>TENS EM2</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>ALPHA [°/°m/deg]</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>G</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>SHEAR 2HG5</td>
<td>.5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

MEN'S SUMMER SUIT (SAMPLE 1)

-especially difficult in the case LT<0.55 and RT>73 or LT<0.55 and RT>55

non-control zone operation on the basis of fabric mechanical properties is not required

for conventional tailoring process
6.6 The application of adhesives in the automated handling of fabric

Temporary adhesion of the fabric to a suitable device is a very efficient and easily implemented method of picking up single layers of fabric. It has the advantage of being consistently able to pick up a single piece of fabric at a time and provides positive location of the uppermost layer of a stack only. Other advantages include:-

(i) The ability to bond to a variety of materials, which may be dissimilar and of a different thickness.

(ii) Versatility of adhesive forms and methods of application permits their adaptation to many production processes.

(iii) Economic and rapid.

(iv) Uniform distribution of stresses over the entire bonded area.

In order to pick up and hold a piece of fabric, a strong adhesive to fabric bond is required. However a weak bond is required to release the fabric from the adhesive. The adhesive to fabric bond strength is therefore an important parameter in the selection and design of adhesive pick up devices. Until recently adhesive pick up devices have been used on several machines for the handling of small parts, labels etc. for presentation to the operator who then removes it for subsequent assembly. These devices in the main consist of a magazine type adhesive roll which has facilities for indexing the take-up roll to present an unused adhesive surface, either automatically or manually, after a number of uses. After the tape
roll has been fully utilised a new roll is exchanged. This method has proved extremely reliable and cost effective and is in concept a very good solution to the problem.

The disadvantages of using a tape dispenser are that although the cost of tape may be minimal it may need frequent replacement. Multiplying the cost over a number of rolls shows that if a reusable adhesive is utilised then a substantial cost saving could be made over a period of time.
6.7 Comments on adhesive pick-up devices

The review of patents covering adhesive pickup devices and commercial adhesive pickup devices, presented in Appendix K, shows that without exception all devices rely on the use of an adhesive tape. The arrangement of the tape differs from device to device, but what is common is that means are provided for the tape roll to be secured on/in the device. Means are also provided to take-up the used portion of the tape. Also some means by which the tape is indexed is also provided.

Adhesive tape is used because a fresh adhesive surface has to be presented once the 'tack' properties have deteriorated. Adhesive as supplied in tape roll form provide an economical means of obtaining a fresh adhesive surface. Liquid adhesive and adhesives supplied in block form have also been proposed, but have not found commercial applicability.

Research has been carried out at Clemson University USA\(^{146}\), into establishing some of the properties important in using commercial adhesive tapes to pick up plies of fabric. The research identified certain trends of adhesive properties, this being substantiated by laboratory tests.

Although adhesive techniques have been used successfully over the years, little fundamental research has been carried out in determining the performance characteristics of temporary fabric to adhesive bonding. Many of the techniques used by manufacturers of adhesive pickup devices have been developed by trial and error, with rough estimates as to a particular tape's performance being given.

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6.8 Theoretical considerations in using adhesives in fabric pick-up devices

6.8.1 Theory of adhesion

Definitions:\textsuperscript{147}

- **Adhesive** - A material which when applied to surfaces can join them together and resist separation.
- **Adhesion** - Refers to the attraction between substances whereby when they are brought into contact it is necessary to do work to separate them.
- **Adherend** - The solid on whose surface the adhesive is applied.
- **Substrate** - Where attraction for a body is exhibited by a surface, or when an adhesive or liquid is placed on a surface which is not part of a joint between two solid materials.

It is generally accepted that there exists three theories which explain adhesion - 'Adsorption', 'Electrostatic' and 'Diffusion'. Vasenin\textsuperscript{148} commenting on these theories stated "none of the theories under consideration can alone explain all the facts of adhesion phenomena, and therefore no claim to generality can be made. Applicability of each theory is limited to a given field".

It is not within the scope of this work to expound the theories of adhesion as applied to this study, as Wake\textsuperscript{149} states:
"It should be possible to study adhesives as materials and to observe empirically and discuss their interaction with the various substrate surfaces to which they are applied without any concern with adhesion. To know how to stick things together does not necessarily require a knowledge of why they stick."

This study concentrates on the class of adhesives referred to as 'pressure sensitive'. These adhesives have the properties of retaining their adhesive 'tack' or instantaneous adhesiveness for long periods of time, and bond to surfaces under light pressure. The tack should not greatly exceed the internal strength or cohesion of the adhesive, otherwise the adhesive will separate from the tape when it is pulled away [adhesive transfer].

Pressure sensitive adhesive tapes are widely available and offered with a wide variety of backing materials such as crepe paper, fabric, polyester film, plasticised poly vinyl chloride, and other flexible materials. 'Double-sided' pressure sensitive film is also available which features a removable release paper instead of the conventional backing material. Pressure sensitive tapes have a wide variety of industrial applications ranging from surgical tapes through to masking tapes for automobile finishing.

The property of the adhesive known as 'tack' is not a fundamental physical property, as is elastic modulus or viscosity. It can have different meanings in different situations. Wetzel shows that adhesive 'tack' is a direct function of the rheological properties of the material such as viscous flow, tensile strength or cohesion, yield value, modulus of elasticity, rate of elastic recovery, and deformability. Tack can therefore be used as a variable
which encompasses the adhesive's properties, so long as it is realised that tack is sensitive to temperature, pressure, rate of application and removal, and time of contact. In order to compare adhesive tack, identical testing conditions have to be maintained otherwise the results obtained will be meaningless.

6.8.2 Mechanism of adhesive to fabric (fibre) bonding

Making a bond by means of 'tack' relies on either viscous flow or deformability, for adequate wetting and contact. It has been shown that the nature of the bond strength developed is undoubtedly due to 'Van der Waals' forces and to a lesser extent, diffusion and chain entanglement. Failure of a bond made by 'tack' is cohesive.\textsuperscript{153}

The nature of temporary fabric bonding differs from that of solid surface bonding in that the fabric is made up of yarn which has been constructed from fibres. This results in a surface which has many loose fibres. Depending on the type of fabric, bonding to an adhesive usually takes place over a large number of fibres.
Light contact of the fibres with the adhesive causes an intimate molecular bond and 'wetting' is likely to occur, see figure 6.17. Heavy contact of the fibres with the adhesive causes fibre encapsulation, as shown in figure 6.18, where the adhesive deforms around the fibre.

Failure of a bond formed by light contact will be caused by either (i) cohesive failure of the bond, where the fibres/yarns separate cleanly from the adhesive, or (ii) the fibre being pulled from the fabric surface either completely or partially until cohesive failure occurs. Adhesive transfer will only occur if the bond strength developed by the adhesive and fibres greatly exceed the internal strength or cohesion of the adhesive. In the case of heavy fabric (fibre) to adhesive contact it is likely that fibres will be completely removed from the fabric surface, and become embedded in the adhesive surface. A certain degree of deformation in the adhesive surface will be evident.

Examination of the fabric surface after temporary bonding shows the fibres of the fabric are pulled away from the surface and a certain number of fibres become embedded in the surface of the adhesive. The degree to which this occurs depending on the contact force and the type of fabric.
Figure 6.17 Light Fabric to Adhesive Bonding

Figure 6.18 Heavy Fabric to Adhesive Bonding
6.8.3 Determination of fabric to adhesive bond strength

If an adhesive is used for temporary adhesion of the fabric, then neglecting the peeling effects of the fabric at the edges of the pick up element, the bond strength of the adhesive is directly proportional to the force required to separate the fabric from the adhesive, either by peeling or perpendicular separation.

\[ \text{bond strength} \propto \text{separation force}. \]

Now, if a piece of fabric is temporarily adhered to a pick-up element, and the draping effect on the fabric caused by gravity is negligible, then that piece of fabric will continue to be held so long as the force exerted on the fabric due to gravity (or its weight) does not exceed the bond strength.

The bond strength of the adhesive and fabric is determined by the adhesive properties of tack, thickness of film modulus, surface tension, density and viscosity. The strength of the bond between the adhesive is governed, along with the adhesive properties, by the type of fabric that is being adhered. In addition to the above factors, a number of other factors influence the adhesive to fabric bond strength, these are pressure of contact, time of contact, area of contact and number of times the adhesive has been used.

To summarise, the bond strength (or force required to separate fabric from the pick up element) is influenced by the following factors:
(a) **Adhesive properties** including:
   - Adhesive tack
   - Film thickness
   - Modulus
   - Surface tension
   - Density
   - Viscosity

(b) **Type of fabric being handled** including:
   - Structure
   - Finish

(c) **Operating conditions** including:
   - Contact force
   - Contact time
   - Area of contact
   - Number of times used
   - Rate of separation

6.8.4 **Dimensional analysis of fabric to adhesive bond**

The solution to any problem in the physical sciences is usually expressed in the form of a relationship between a number of variables. Normally, such a relationship is written as an equation which describes how the dependent variable varies with the independent variables\(^{154}\).
There are generally two methods for establishing such relationships:

(i) A mathematical model of the phenomenon is developed, which consists of a statement of the physical laws that are operating, expressed in the form of equations. Using this method, assumptions almost always have to be made so that the situation can be simplified to a point at which the resulting mathematics can be performed. This method can, in many instances, represent the situation quite accurately. However simplifying assumptions can sometimes be too drastic, to the extent that the model bears little or no relationship to the physical problem.

(ii) When the mathematical approach does not give good results, or when the problem is so complex that no model can be developed another method is required. One approach is to construct a physical model which is capable of reproducing the phenomenon. Measurements of parameters of interest can then be taken from this model and scaling laws (if necessary) can then be used to derive values applicable to the real situation.

The method of dimensions, or dimensional analysis, is concerned with the fundamental relationship between variables, such as velocity, length, acceleration, etc. These quantities although being fundamentally different from one another, possess certain qualities in common. The assumption is therefore made that all variables can be
derived from quite a small number of certain basic entities. These entities are referred to as 'dimensions'.

Dimensional analysis also establishes the fact that it is only possible to equate like things. Therefore, if a mathematical equation has been developed, a check can be made on its dimensional accuracy by ascertaining that all the terms in the equation have the same dimensions as one another and as the left hand side of the equation. This method can trap some of the errors which can occur in the process of developing equations. Equations which are dimensionally homogeneous are known as rational, some derived equations are not dimensionally homogeneous.

Buckingham Pi Theorem

The theorem states that if a situation can be described by 'n' variables and 'k' is the number of fundamental dimensions (ie MLT) involved, then there will be 'n - k' dimensionless groups.

In general a situation can be expressed in the form:-

\[ \phi (V_1, V_2, V_3 \ldots ) = 0 \]

where \( V_1, V_2, V_3 \ldots \) are the variables and \( k \) is the number of fundamental dimensions involved M, L or T (ie 1, 2 or 3).

The situation can also be expressed using the \( \pi \)- theorem as:-

\[ \Phi (\pi_1, \pi_2, \pi_3 \ldots \pi_{n-k}) = 0 \]
Variables involved in fabric to adhesive bonding

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tack*</td>
<td>$T_k$</td>
<td>$ML^{2}T^{-2}$</td>
</tr>
<tr>
<td>Separation force</td>
<td>$F_s$</td>
<td>$MLT^{-2}$</td>
</tr>
<tr>
<td>Contact force</td>
<td>$F_c$</td>
<td>$MLT^{-2}$</td>
</tr>
<tr>
<td>Time (of contact)</td>
<td>$t$</td>
<td>$T$</td>
</tr>
<tr>
<td>Area (of contact)</td>
<td>$A$</td>
<td>$L^2$</td>
</tr>
<tr>
<td>Rate of separation</td>
<td>$V$</td>
<td>$LT^{-1}$</td>
</tr>
</tbody>
</table>

Dimensionless quantities

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of separations</td>
<td>$n$</td>
</tr>
<tr>
<td>Number of 'cleans'**</td>
<td>$c$</td>
</tr>
<tr>
<td>Type of fabric</td>
<td>$k$</td>
</tr>
</tbody>
</table>

* 'Tack has been classified as a quantity of energy. [see discussion of 'tack' in section 6.8.1].

** 'Cleaning' refers to the process of removing foreign bodies, or substances from the surface of the adhesive.

Analysis using Buckingham Pi Theorem

Variables $(T_k, F_c, F_s, t, A, V, n, n_c, k)$

Fundamental variables $(T_k, A, t)$.

$n = 9 \quad k = 3$

expect $9 - 3 = 6$ groups.
\[ \pi_1 = T_k^a, A^b, t^c, F_c \]

\[ 0 = (ML^2 T^{-2})^a (L^2)^b (MLT^{-2}) \]

equating exponents,

(M) \[ 0 = a + 1 \rightarrow a = -1 \]

(L) \[ 0 = 2a + 2b + 1 \rightarrow b = 1/2 \]

(T) \[ 0 = -2a + c - 2 \rightarrow c = 0 \]

\[ \pi_1 = F_c A^{1/2} \]

\[ t \]

\[ \pi_2 = T_k^a A^b t^c F_s \]

\[ 0 = (ML^2 T^{-2})^a (L^2)^b (T)^c (MLT^{-2}) \]

as above,

\[ \pi_2 = F_s A^{1/2} \]

\[ t \]

\[ \pi_3 = T_k^a b t^c v \]

\[ 0 = (ML^2 T^{-2})^a (L^2)^b (T)^c (LT^{-1}) \]

equating exponents,

(M) \[ 0 = a \rightarrow a = 0 \]

(L) \[ 0 = 2a + b + 1 \rightarrow b = -1 \]

(T) \[ 0 = 2a + c - 1 \rightarrow c = 1 \]

\[ \pi_3 = v.t \]

\[ \frac{t}{A} \]

\[ \pi_4 = n \]

\[ \pi_5 = n_c \]

\[ \pi_6 = k \]

\[ \text{(6.1)} \]

\[ \text{(6.2)} \]

\[ \text{(6.3)} \]

\[ \text{(6.4)} \]

\[ \text{(6.5)} \]

\[ \text{(6.6)} \]
6.8.5 Use of dimensionless groups

The dimensionless groups determined in the previous sub-section, suggest possible groupings of the variables under investigation. As the groups are dimensionally homogeneous it is possible to equate the various groups and develop equations.

From previous working it was shown:–

\[
\begin{align*}
\pi_1 &= \frac{F_c A^{1/2}}{t} \\
\pi_2 &= \frac{F_s A^{1/2}}{t} \\
\pi_3 &= \frac{v t}{A} \\
\pi_4 &= n \\
\pi_5 &= n_c \\
\pi_6 &= k
\end{align*}
\]

(6.1) (6.2) (6.3) (6.4) (6.5) (6.6)

Equating the dimensionless groups \( \pi_1 \) and \( \pi_2 \) we have:

\[
\frac{F_s A^{1/2}}{t} = f \left( \frac{F_c A^{1/2}}{t} \right)
\]

hence,

\[
F_s = f(F_c)
\]

(6.7)

To proceed further it becomes necessary to perform an experiment to find the effect on \( F_s \) [separation force] of varying \( F_c \) [contact force], all other variables being kept constant.
Equating the groups $\pi_2$ and $\pi_3$ gives

\[ \frac{F_s A^{1/2}}{t} = f\left(\frac{v \cdot t}{A}\right) \]

hence,

\[ F_s = \int \left(\frac{v \cdot t^2}{A^{3/2}}\right) \]  

Again to proceed further it is necessary to perform an experiment to find the effect of $F_s$ of varying $A$ [Area] keeping $V$ (velocity of separation) and $t$ (time of contact) constant.

Using the procedure outlined above it becomes possible to equate the variables under investigation and determine experiments necessary to find the relationship between the equated groups.
6.9 Experimental details

6.9.1 Testing equipment and procedures

Testing machine

The Instron model 4301 universal testing machine was used for experiments concerning separation force. The model 4301 is capable of tension and compression testing in the range up to 5KN. The machine consists of a standard load frame and drive unit, a load weighing system, and a console mounted (microprocessor based) control system.

The control console provides communication between the user and the machine frame, and any peripheral devices used for recording, printing or calculating the test results. This is interfaced to the host computer [Hewlett Packard HP85] via an IEEE-4888 port. Automatic calibration and balance facilities are built in and a self-identifying facility provides automatic recognition of the recommended load cells.

The specifications of the testing machine are shown over.
Capacity

5 KN

Force rating (Tension and compression below the moving crosshead)

5 KN up to 500 mm/min

Full-scale load range (using interchangeable 2518 load cells)

0.5 N to 5 KN

Load weighing system accuracy

BS 1610 Grade A
DIN 51221 class 1
AFNOR A03-501 class 1
ASTM E4

Strain measuring accuracy

BS 3846 Grades C & D
ASTM E 83, B-2, C & D

Position measurement accuracy (no load)

+/- 0.1 mm

Position measurement repeatability

+/- 0.05 mm

Crosshead speed range

0.5 to 500 mm/min

Crosshead speed accuracy

+/- 0.5% over 100 mm (no load)

+/- 0.75% over 100 mm (max load)

Crosshead travel

970 mm
Fabric

All experiments were carried out on untreated cotton interlock fabric, made to the following specification:

Knitted on: Mellor Bromley 3RL3 circular knitting machine M/c No RP4298/50
16" diameter, 20 npi
1008 needles in dial and cylinder.

Fabric thickness - 1.20 mm (6 20 gf/cm)
Fabric weight - 267 g/m²
Yarn count - 25.5 tex
Course length - 427.26 cm
Stitch length - 0.424 cm
Courses/cm - 10.4
Wales/cm - 11.6
Stitch density - 120.64

Adhesives

Experiments were carried out using four type of pressure-sensitive adhesives, three commercially available, the other currently under development. The four adhesives being:

1 - 'Selotape'
2 - Masking tape
3 - Electrical Insulating tape
4 - 'Magnatac' adhesive*
* During the course of the investigation the author made contact with the manufacturer of a pressure-sensitive adhesive 'magnatac', not yet commercially available. The adhesive has unique characteristics not possessed by commercial pressure-sensitive's, - the ability to regain its 'tack' after cleaning with water and drying. With commercial pressure sensitive adhesives (1 to 3 above), once the 'tack has deteriorated the adhesive has no further use. The full specification of 'magnatac' adhesive, as supplied by the manufacturer is detailed in Appendix L.

**Experimental procedures**

Experimentation has been carried out to determine (i) the effect of the number of separations on separation force [bond strength] of the four adhesives on cotton interlock fabric and (ii) to investigate the effects of a number of variables [outlined in section 6.8.4] on the fabric to adhesive bond strength.

(i) **Effect of the number of separations on separation force**

Two test blocks were used, a test block of surface area 600 mm² on which the adhesive tape was fixed or coated on in the case of 'magnatac'. The other test block consisting of a base plate to which interlock fabric is fixed.

The base plate with the fabric is fixed in the bottom jaw of the testing machine and a static load of 1 Kg applied to the adhesive test block resting on the fabric test block, for 1 second, see diagram over:
The adhesive test block was then clamped in the upper jaws of the testing machine, and the force required to remove the adhesive test block measured and recorded.

The adhesive test block was again placed on the fabric test block, with the static load being applied for the same time. The force required to remove the adhesive test block was again measured. This was repeated a number of times depending on the adhesive being tested. This procedure being repeated three times for each adhesive. For each set of tests a fresh adhesive surface was used and a new fabric sample attached to the base plate. Plate 6.19 shows the test blocks fixed in the testing machine.
(ii) Investigation of the effect of a number of variables on the adhesive to fabric bond strength [separation force]

This set of experiments were designed to fully assess the performance of the adhesive selected to be used in a prototype device for picking up and handling fabrics. The adhesive selected for further investigation being 'magnatac' adhesive, due to its unique characteristics of being able to regain its tack properties.

A test block was manufactured from perspex, which was a full-size model of the block to be used in the prototype pick-up device, see figures 6.20 and 6.21. The same fabric test block used in the previous experiment was used. The testing specifications can be found in Appendix M.

6.9.2 Results obtained

(i) The effect of number of separations on separation force

The table of results obtained [Results 1] can be found in Appendix N.

(ii) Investigation of the effect of a number of variables on the adhesive to fabric bond strength [separation force]

The table of results obtained [Results 2] can be found in Appendix N.
Plate 6.19 Test Blocks Fixed in Testing Machine
Figure 6.20 Test Block For Experiment
Figure 6.21 Adhesive Areas (sq. mm)

361.0

301.5

252.5

193.0

133.5

109.0

84.5

72.3

36.1

18.1

adhesive area removed
6.9.3 Analysis of results

Results obtained by experimentation were analysed using a general purpose statistics package - 'MINITAB'. It consists of a worksheet (rows by columns) where data is stored. There are a variety of commands available which allows the data to be analysed and 'explored'.

In order to find a model of the relationship between the separation force and number of separations for adhesive to fabric bonding, the results were manipulated to find an approximation for a straight line. Rather than fit a polynomial to the curved data a number of transformations were tried to see if a model could be found. Transformations were chosen starting with the weakest \( \sqrt{Y} \) or \( \sqrt{X} \), followed by \( \log_e Y \) or \( \log_e X \), and the strongest \(-1/Y\) or \(-1/X\). This was then followed by a combination of the above transformations, these are outlined as follows.
Transformations Tested for Separation Force against Number of Separations data

Plot of Separation Force [Y] vs. Number of Separations [X]

Transformation 1 - Plot of Sq. root of Y vs. X
Transformation 2 - Plot of $\log_e Y$ vs. $X$

Transformation 3 - Plot of $-1/Y$ vs. $X$

$s = 0.6841 \quad R^2 = 85.7\% \quad R^2(adj) = 85.2\%$
Transformation 4 - Plot of Y vs. Sq. root X

Transformation 5 - Y vs. Loge X

s = 0.07536    R-sq = 89.4%    R-sq(adj) = 89.0%
Transformation 6 - Y vs. -1/X

Transformation 7 - \(\log_e Y\) vs. \(\log_e X\)

\[ s = 0.1212 \quad R^2 = 95.2\% \quad R^2(adj) = 95.0\% \]
Transformation 8 - \(-1/Y\) vs. \(-1/X\)

Transformation 9 - \(\log_e(1/Y)\) vs. \(\log_e X\)

\[ s = 0.1212 \quad R\text{-sq} = 95.2\% \quad R\text{-sq(adj)} = 95.0\% \]
From the fore-going analysis it can be seen that the transformation \( \log_e(1/Y) \) versus \( \log_e(X) \) gives the strongest indication of a relationship between the two variables. The analysis was carried out on a typical set of results.

The regression equation is given as:

\[
\log_e(1/Y) = \log_e(a) + k \log_e(X)
\]

This is of the form \( Y = mx + c \)

Raising both sides by \( e^X \) gives,

\[
\frac{1}{Y} = a.X^k
\]

where \( a \) is the intercept and \( k \) is a constant.

The general law relating the separation force to the number of separations is given as:

\[
\text{Separation force} = \frac{1}{a \cdot \text{Number of separations}^k}
\]

The analysis of experimental data follows:
ANALYSIS OF SELOTAPE DATA

Plot of Mean Separation Force [Kg] (C2) vs. Number of Sepe. (C1)

- 0.50+ *
- 0.40+
- 0.30+ 2***
- 0.20+
- +---------+---------+---------+---------+---------+---
- 0.0 30 60 90 120 150

Transforming data on X and Y axes

Plot of Log of the Inverse of Mean Separation Force [Kg] (C4) vs. Log Number of Separations (C3)

- 1.50+
- 1.20+
- 0.90+
- +---------+---------+---------+---------+---------+---
- 0.0 1.0 2.0 3.0 4.0 5.0
The regression equation is:

\[ C_4 = 0.731 + 0.194 \times C_3 \]

Where,

- \( C_4 \) is \( \log_e \) of the Inverse of Mean Separation Force [Kg]
- \( C_3 \) is \( \log_e \) of Number of Separations

This gives,

\[ \text{Mean Sep. Force (Kg)} = \frac{1}{2.077 \times \text{Number of Separations}^{0.194}} \]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>Stdev</th>
<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.73076</td>
<td>0.03327</td>
<td>21.97</td>
</tr>
<tr>
<td>C3</td>
<td>0.19448</td>
<td>0.01012</td>
<td>19.21</td>
</tr>
</tbody>
</table>

\[ s = 0.07609 \quad \text{R-sq} = 92.3\% \quad \text{R-sq(adj)} = 92.0\% \]

Analysis of Variance

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DF</th>
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<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
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<td>2.1367</td>
<td>2.1367</td>
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<tr>
<td>Error</td>
<td>31</td>
<td>0.1795</td>
<td>0.0058</td>
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<tr>
<td>Total</td>
<td>32</td>
<td>2.3161</td>
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</tr>
</tbody>
</table>
ANALYSIS OF MASKING TAPE DATA

Plot of Mean Separation Force [Kg] (C2) vs. Number of Seps. (C1)

Transforming data on X and Y axes

Plot of Log_e of the Inverse of Mean Separation Force [Kg] (C4) vs. Log_e of Number of Separations (C4)
The regression equation is

\[ C_4 = -0.0889 + 0.487 \times C_3 \]

Where,

- \( C_4 \) is \( \log_e \) of the Inverse of Mean Separation Force [Kg]
- \( C_3 \) is \( \log_e \) of Number of Separations

This gives,

\[
\text{Mean Sep. Force (Kg)} = \frac{1}{0.915 \times \text{Number of Separations}^{0.487}}
\]

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<tr>
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<th>t-ratio</th>
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<tr>
<td>Constant</td>
<td>-0.08890</td>
<td>0.03454</td>
<td>-2.57</td>
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<tr>
<td>C3</td>
<td>0.48672</td>
<td>0.01051</td>
<td>46.30</td>
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</table>

\( s = 0.07901 \) \hspace{1cm} \text{R-sq} = 98.6\% \hspace{1cm} \text{R-sq(adj)} = 98.5\%

Analysis of Variance

<table>
<thead>
<tr>
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<td>Error</td>
<td>31</td>
<td>0.194</td>
<td>0.006</td>
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<td>Total</td>
<td>32</td>
<td>13.576</td>
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</table>
ANALYSIS OF ELECTRICAL INSULATING TAPE DATA

Plot of Mean Separation force [Kg] (C2) vs. Number of Sephs. (C1)

0.80+ * 
C2
- 
- 
- 
0.60+ *
- 
- 
- 
0.40+ 2*
- 
- 
- 
- 
0.20+ 
- 
- 
+----------------+-----------------+-----------------+-----------------+-----------------+------C1
0 30 60 90 120 150

Transforming data on X and Y axes

Plot of Log_e of the Inverse of Mean Separation Force [Kg] (C4) vs. Log_e of Number of Separations (C3)

C4
- 
- 
- 
1.50+ 
- 
- 
- 
1.00+ 
- 
- 
- 
0.50+ 
- 
- 
- 
+----------------+-----------------+-----------------+-----------------+-----------------+------C3
0.0 1.0 2.0 3.0 4.0 5.0
The regression equation is:
\[ C_4 = 0.328 + 0.280 \times C_3 \]

Where,

\( C_4 \) is \( \log_e \) of the Inverse of Mean Separation Force [Kg]

and,

\( C_3 \) is \( \log_e \) of Number of Separations

This gives,

\[
\text{Mean Sep. Force (Kg)} = \frac{1}{1.388 \times \text{Number of Separations}^{0.28}}
\]

<table>
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<th>t-ratio</th>
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</thead>
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<tr>
<td>Constant</td>
<td>0.32813</td>
<td>0.02549</td>
<td>12.87</td>
</tr>
<tr>
<td>C3</td>
<td>0.280225</td>
<td>0.007757</td>
<td>36.13</td>
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</table>

\( s = 0.05830 \quad \text{R-sq} = 97.7\% \quad \text{R-sq(adj)} = 97.6\% \)

Analysis of Variance

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<td>0.0034</td>
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<td>Total</td>
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</table>
ANALYSIS OF 'MAGNATAC' ADHESIVE DATA

Plot of Mean Separation force [Kg] (C2) vs. Number of Sepns. (C1)

Plot of Log_e of the Inverse of Mean Separation Force [Kg] (C4) vs. Log_e of Number of Separations (C3)

Transforming data on X and Y axes.
The regression equation is:-

\[ C_4 = -0.156 + 0.450 C_3 \]

where,

C4 is \( \log_e \) of the Inverse of Mean Separation Force [Kg]

and,

C3 = \( \log_e \) of Number of Separations

This gives,

Mean Sep. Force (Kg) =

\[
0.856 \times \text{Number of Separations}^{0.45}
\]

<table>
<thead>
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<th>Predictor</th>
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<th>Stdev</th>
<th>t-ratio</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.15621</td>
<td>0.05758</td>
<td>-2.71</td>
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<tr>
<td>C3</td>
<td>0.45022</td>
<td>0.01974</td>
<td>22.80</td>
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\( s = 0.1190 \) \hspace{1cm} R-sq = 95.2% \hspace{1cm} R-sq(adj) = 95.1%

Analysis of Variance

<table>
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<td>7.3631</td>
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<tr>
<td>Error</td>
<td>26</td>
<td>0.3682</td>
<td>0.0142</td>
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<td>Total</td>
<td>27</td>
<td>7.7312</td>
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</table>
ANALYSIS OF EXPERIMENT 1 DATA

Plot of Mean Separation Force (Kg) vs. Number of Separations

- *
- 0.60+
Mean - *
Sep. - *
Force - *
(Kg) - *
0.45+ *
- 22
- ** *
0.30+ *2*
- *
- *
0.15+ *
+---------+---------+---------+---------+---------+------
0 35 70 105 140 175
Number of Separations

Transforming data on X and Y axes

Plot of Loge of the Inverse of Mean Separation Force (C4) vs. Loge of Number of Separations (C3)

- 2.00+
- 1.50+
- 1.00+
- 0.50+
+---------+---------+---------+---------+---------+------
0.0 1.0 2.0 3.0 4.0 5.0 C3

417
The regression equation is:-

\[ C4 = 0.284 + 0.333 \times C3 \]

Where,

- \( C4 \) is \( \log_e \) of the Inverse of Mean Separation Force
- \( C3 \) is \( \log_e \) of Number of Separations

This gives,

\[
\text{Mean Sep. Force (Kg)} = \frac{1}{1.328 \times \text{Number of Separations}^{0.333}}
\]

<table>
<thead>
<tr>
<th>Predictor</th>
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<th>Stdev</th>
<th>t-ratio</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.28429</td>
<td>0.03799</td>
<td>7.48</td>
</tr>
<tr>
<td>C3</td>
<td>0.33325</td>
<td>0.01112</td>
<td>29.96</td>
</tr>
</tbody>
</table>

\( s = 0.08948 \)  \( \text{R-sq} = 96.5\% \)  \( \text{R-sq(adj)} = 96.3\% \)

Analysis of Variance

<table>
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<td>7.1896</td>
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<tr>
<td>Error</td>
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<td>0.2642</td>
<td>0.0080</td>
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<tr>
<td>Total</td>
<td>34</td>
<td>7.4539</td>
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</tr>
</tbody>
</table>
ANALYSIS OF EXPERIMENT 2 DATA

Plot of Initial Separation Force (Kg) vs. Number of 'Cleans'

Transforming data on X and Y axes

Plot of \( \log_{10} \) of the Inverse of Initial Separation Force (C4) vs. \( \log_{10} \) of Number of 'Cleans'
The regression equation is:

\[ C_4 = 0.100 + 0.425 C_3 \]

Where,

\( C_4 \) is \( \log_e \) of the Inverse of Mean Separation Force [Kg]

and,

\( C_3 \) is \( \log_e \) of Number of Separations

Predictor | Coef | Stdev | t-ratio
---|---|---|---
Constant | 0.1002 | 0.1927 | 0.52
C3 | 0.4246 | 0.1731 | 2.45

\( s = 0.2200 \) \hspace{1cm} R-sq = 66.7\% \hspace{1cm} R-sq(adj) = 55.6\%

Analysis of Variance

<table>
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<tr>
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<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
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<td>0.29128</td>
<td>0.29128</td>
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<tr>
<td>Error</td>
<td>3</td>
<td>0.14522</td>
<td>0.04841</td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
<td>0.43650</td>
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</table>

* The low value of the coefficient of determination (R-sq) suggests that this is a weak correlation.
Plot of Mean Separation Force (Kg) vs. Number of Separations
[Before cleaning]

Mean
Sep.
Force - *
(Kg) -
0.90+ *

Transforming data on X and Y axes

Plot of Log of the Inverse Mean Separation Force (C9) vs.
Log of Number of Separations (C8) [Before Cleaning]
The regression equation is:

\[ C9 = -0.163 + 0.458 \times C8 \]

Where,

- \( C9 \) is \( \log_e \) of the Inverse of Mean Separation Force [Kg]
- \( C8 \) is \( \log_e \) of Number of Separations

This gives,

\[
\text{Mean Sep. Force (Kg)} = \frac{1}{0.873 \times \text{Number of Separations}^{0.458}}
\]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>Stdev</th>
<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.16318</td>
<td>0.05866</td>
<td>-2.78</td>
</tr>
<tr>
<td>C8</td>
<td>0.45819</td>
<td>0.02012</td>
<td>22.78</td>
</tr>
</tbody>
</table>

\( s = 0.1212 \) \quad \text{R-sq} = 95.2\% \quad \text{R-sq(adj)} = 95.0\%

Analysis of Variance

<table>
<thead>
<tr>
<th>SOURCE</th>
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<th>MS</th>
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<tr>
<td>Regression</td>
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<td>7.6259</td>
<td>7.6259</td>
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<tr>
<td>Error</td>
<td>26</td>
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<tr>
<td>Total</td>
<td>27</td>
<td>8.0081</td>
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</tr>
</tbody>
</table>
Plot of Mean Separation Force (Kg) vs. Number of Separations
[After cleaning]

Transforming data on X and Y axes

Plot of $\log_e$ of the Inverse Mean Separation Force (C10) vs. $\log_e$ of Number of Separations (C7) [After Cleaning]
The regression equation is:

\[ C10 = 0.491 + 0.300 C8 \]

Where,

\( C10 \) is Log\(_e\) of the Inverse of Mean Separation Force [Kg]

and,

\( C8 \) is Log\(_e\) of Number of Separations

This gives,

\[
\text{Mean Sep. Force (Kg)} = \frac{1}{1.634 \times \text{Number of Separations}^{0.3}}
\]

\[
\begin{array}{cccc}
\text{Constant} & 0.49083 & 0.04859 & 10.10 \\
C8 & 0.29998 & 0.01666 & 18.00 \\
\end{array}
\]

\( s = 0.1004 \quad \text{R-sq} = 92.6\% \quad \text{R-sq(adj)} = 92.3\% \)

Analysis of Variance

\[
\begin{array}{ccc}
\text{SOURCE} & \text{DF} & \text{SS} \quad \text{MS} \\
\text{Regression} & 1 & 3.2688 & 3.2688 \\
\text{Error} & 26 & 0.2622 & 0.0101 \\
\text{Total} & 27 & 3.5310 & \\
\end{array}
\]
ANALYSIS OF EXPERIMENT 3 DATA

Plot of Mean Separation Force (Kg) vs. Number of 'Cleans'

Mean
Sep.
Force
(Kg)

0.80+

0.60+

0.40+

0.20+

- +---------+---------+---------+---------+---------+--

1.0 2.0 3.0 4.0 5.0 6.0

Number of 'Cleans'

Transforming data on X and Y axes

Plot of Log_e of the Inverse of Mean Separation Force (C4) vs. Log_e of Number of 'Cleans' (C3)

C4

1.80+

1.20+

0.60+

-0.00+

- +---------+---------+---------+---------+---------+------C3

-0.00 0.35 0.70 1.05 1.40 1.75

425
The regression equation is:
\[ C4 = 0.310 + 0.900 \times C3 \]

Where,

\( C4 \) is \( \log_e \) of the Inverse of Mean Separation Force and,

\( C3 \) is \( \log_e \) of Number of 'Cleans'.

This gives,
\[
\text{Mean Sep. Force (Kg)} = \frac{1}{1.363 \times \text{Number of 'Cleans'}^{0.9}}
\]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>Std Err</th>
<th>t-ratio</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.3097</td>
<td>0.2732</td>
<td>1.13</td>
</tr>
<tr>
<td>C3</td>
<td>0.8999</td>
<td>0.2181</td>
<td>4.13</td>
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</table>

\[ s = 0.3232 \quad \text{R-sq} = 81.0\% \quad \text{R-sq(adj)} = 76.2\% \]

Analysis of Variance

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<tr>
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<td>Total</td>
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ANALYSIS OF EXPERIMENT 4 DATA

Plot of Mean Separation Force (Kg) vs. Contact Time (sec)

The regression equation is:

Mean Separation Force = 0.716 + 0.0106 Contact Time

Analysis of Variance

<table>
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</table>

427
The following shows the transformations that were tested to find a stronger correlation of the data:

**Transformations Tested**

Plot of Mean Separation Force (Kg) vs. Square Root of Contact Time (C3)

The regression equation is:

Mean Separation Force = 0.553 + 0.0980 Sq. rt of Contact Time

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>Stddev</th>
<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.55299</td>
<td>0.05420</td>
<td>10.20</td>
</tr>
<tr>
<td>Sq. rt Time</td>
<td>0.09798</td>
<td>0.01559</td>
<td>6.28</td>
</tr>
</tbody>
</table>

s = 0.09718 R-sq = 79.8% R-sq(adj) = 77.8%

**Analysis of Variance**

<table>
<thead>
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<th>SOURCE</th>
<th>DF</th>
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<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.37292</td>
<td>0.37292</td>
</tr>
<tr>
<td>Error</td>
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<td>0.09443</td>
<td>0.00944</td>
</tr>
<tr>
<td>Total</td>
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<td>0.46735</td>
<td></td>
</tr>
</tbody>
</table>
Plot of Mean Separation Force (Kg) vs. Cubed Root of Contact Time (C4)

Mean -
Sep. -
Force -
(Kg) -

1.20+

1.00+-

0.80+-

0.60+-

-----+---------+---------+---------+---------+--------
C4 1.20 1.80 2.40 3.00 3.60

The regression equation is:

Mean Separation Force = 0.391 + 0.227 Cubed Root of Contact Time

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
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<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.39138</td>
<td>0.08201</td>
<td>4.77</td>
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<tr>
<td>C4</td>
<td>0.22665</td>
<td>0.03830</td>
<td>5.92</td>
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</table>

s = 0.1019 \quad \text{R-sq} = 77.8\% \quad \text{R-sq(adj)} = 75.6\%

Analysis of Variance

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<tr>
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<td>Error</td>
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<td>Total</td>
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</tbody>
</table>
ANALYSIS OF EXPERIMENT 5 DATA

Plot of Mean Separation Force (Kg) vs. Applied Load (g)

The regression equation is:

Mean Separation Force (kg) = 0.269 + 0.000653 Applied Load (g)

The regression equation is:-

Mean Separation Force (kg) = 0.269 + 0.000653 Applied Load (g)

<table>
<thead>
<tr>
<th>Predictor</th>
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<th>Stdev</th>
<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.26928</td>
<td>0.05417</td>
<td>4.97</td>
</tr>
<tr>
<td>AppLoad</td>
<td>0.00065289</td>
<td>0.00004829</td>
<td>13.52</td>
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</table>

s = 0.08179  R-sq = 97.9%  R-sq(adj) = 97.3%

Analysis of Variance

<table>
<thead>
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<th>SOURCE</th>
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<th>MS</th>
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</thead>
<tbody>
<tr>
<td>Regression</td>
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<td>1.2227</td>
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<tr>
<td>Error</td>
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<td>Total</td>
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<td>1.2494</td>
<td></td>
</tr>
</tbody>
</table>

430
ANALYSIS OF EXPERIMENT 6 DATA

Plot of Mean Separation Force (Kg) vs. Separation Rate (mm/min)

The regression equation is:

Mean Separation Force = 0.208 + 0.00149 Separation Rate

Predictor Coef Stdev t-ratio
Constant 0.20841 0.01403 14.86
Sep Rate 0.00148890 0.00006482 22.97

s = 0.02902 R-sq = 98.7% R-sq(adj) = 98.5%

Analysis of Variance

<table>
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<tr>
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<th>MS</th>
</tr>
</thead>
<tbody>
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<td>Regression</td>
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<td>Total</td>
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</tr>
</tbody>
</table>

431
ANALYSIS OF EXPERIMENT 7 DATA

Plot of Mean Separation Force (Kg) vs. Contact Area (mm²)

Mean Sep. Force = 0.0300 + 0.000641 Contact Area

The regression equation is:

Predictor Coef Stdev t-ratio
Constant 0.029992 0.004984 6.02
Area 0.00064110 0.00002606 24.60

s = 0.009105 R-sq = 98.7% R-sq(adj) = 98.5%

Analysis of Variance

SOURCE DF SS MS
Regression 1 0.050186 0.050186
Error 8 0.000663 0.000083
Total 9 0.050849
6.9.4 Discussion of analysed results

A general law relating the separation force to the number of separations has been found where,

\[
\text{Separation force} = \frac{1}{a \cdot \text{Number of separations}^k}
\]

where, 'a' and 'k' are constant.

The intercept 'a' and constant 'k' are found by experimentation. These have been shown for four pressure-sensitive adhesives; tape, masking tape, electrical insulating tape, and 'magnatac' adhesive.

Using the above law and applying the intercept [a] and constant [k] known for the particular adhesive, it is possible to predict the separation force required to remove the fabric from the adhesive for a given number of separations [for a given area of adhesive, applied at a given load, for a given time and separated at a given rate].

Further analysis of the adhesive chosen for further development, 'magnatac', establishes a number of relationships for the variables which affect the performance of the adhesive. Based on the experimental results it becomes possible to determine the theoretical maximum size of fabric sample that can be picked up and held given:-

(i) type of adhesive
(ii) number of separations (pick-ups)
(iii) time of contact
(iv) applied load
(v) separation rate
(vi) area of adhesive.

It is also possible to determine the force required to remove the fabric sample from the adhesive, for the given conditions i) - vi) above.

Theoretical size of fabric sample which can be picked up

If the fabric used has a weight of 267 g/m² and the force required to separate the fabric under certain conditions is 120 g. Then, the maximum area of piece that can be held would be:

$$3.75 \text{ cm}^2/\text{g} \times 120 \text{ g} = 450 \text{ cm}^2$$

for example a piece of fabric measuring 21.2 x 21.2 cm.
6.10 Research, design and manufacture of an adhesive device for automated ply separation and handling of fabrics

From the review presented in Appendix K, it was shown that without exception all devices, using pressure-sensitive adhesives, rely on the use of adhesive tapes. This restricts the design of such devices to provide means for incorporating the tape, and provide means to index the tape to present a fresh adhesive surface at certain times.

In using the pressure-sensitive 'magnatac' such restrictions are not imposed on the design. This is because the adhesive can be 'cleaned', allowing it to be used a number of times. Means of achieving this cleaning or replacing the adhesive however have to be provided. This can be achieved by either manual or automated means at some predetermined period during the operation of the device, or whilst a substitute device is operating. The working limits can be determined by analysis and experimentation, as shown in section 6.9.

The design of the prototype represents a departure from conventional pressure-sensitive adhesive devices. It has been designed for operation under robotic control. Achieving this aim enables the device, after the necessary modifications, to be used for semi-automated or manual purposes.

The following sub-sections detail the development of a prototype device for separating and handling fabric from a stack of cut parts.
6.10.1 Design criteria for the prototype device

With reference to the requirements of a device for the automated handling of fabrics, outlined in section 6.4, the design criteria are summarised as follows:-

(i) A device to reliably separate and hold a piece of fabric from a stack of cut parts.

(ii) The device to be reliable in operation and require very little maintenance.

(iii) The device should be lightweight and easily attached to a robot.

(iv) To operate at optimum speed and cater for changes in fabric.

(v) To prevent any damage or contamination of the fabric during operation.

(vi) To be safe in operation and present no risks to the operator(s).

(vii) The picking surface to be easily accessible for cleaning, and any replacement of parts should require the minimum of time.

(viii) The device to use components which are readily available.

(ix) To use existing power supplies, i.e. electricity compressed air.

(x) To be patentable and commercially exploitable.

6.10.2 Design and manufacture of the prototype

Figure 6.22 shows the detailed arrangement of the prototype pick-up device. It consists essentially of a dual-acting mechanism. One mechanism for registering the pressure applied to the fabric stack, and the other to separate the fabric from the pick-up device. Although specific components are shown for achieving this
(microswitch and solenoid), other means such as pressure transducers or pneumatic cylinders could be incorporated.

The mounting face provides a location for attaching the device to the robot, without interfering with the action of the device. When the device is applied to the fabric stack the applicator (5) coated with adhesive, mounted on a plate (4) causes the guide rods (11) to move through the base plate (2) acting against the springs (12). When the pressure applied to the fabric exceeds the spring force, the microswitch (14) is activated. Therefore the microswitch is activated after a predetermined pressure (controlled by spring force), see figure 6.23.

Once the fabric piece is located and transferred to the desired location, the solenoid (15) is activated. This causes the outer mechanism (consisting of the top guide (3), side plates (7), and release plate (6)) to move over the mounting plate (1), releasing the fabric from the applicator (5). The release plate consists of a matrix of wires which fit between the slots of the applicator. This arrangement improves release of the fabric from the applicator. This outer mechanism moves independently over the mechanism for registering the pressure applied to the fabric stack, see figure 6.23.

The surface of the applicator, coated with adhesive, is normally exposed below the surface of the release plate. This allows it to be cleaned periodically. If the applicator requires replacement, the release plate is removed, as shown in figure 6.24, allowing access to the applicator.
The main components of the prototype were manufactured from perspex, to make it as light weight as possible. Plate 6.25 shows the prototype device held by the robot gripper, and plate 6.26 shows a side view of the prototype. Plate 6.27 shows the under-side of the device, showing the face of the applicator with the wires of the release plate in the slots.
Figure 6.22 Prototype Adhesive Pick-up Device

Figure 6.23 Operation of Prototype Pickup Device

[Patent Pending]

1 - MOUNTING PLATE
2 - BASE PLATE
3 - TOP GUIDE PLATE
4 - APP. MOUNTING PLATE
5 - APPLICATOR (APP.)
6 - RELEASE PLATE
7 - SIDE PLATE
8 - ACTIVATING BLOCK
9 - GUIDE ROD
10 - SPRING
11 - GUIDE ROD
12 - SPRING
13 - NUT
14 - MICROSWITCH
15 - SOLENOID
16 - ACTUATING CORE
17 - CONICAL SPRING
18 - NUT
19 - HINGE
20 - CLASP
21 - SUPPORT PLATE
Figure 6.23 Operation of Prototype Pick-up Device

Solenoid activated at Station 2

Microswitch circuit completed in down position

Station 1
Single-ply pickup

Station 2
Single-ply placement
Figure 6.24 Removal of Adhesive Applicator
Plate 6.25 Prototype Pick-up Device
Plate 6.26 Side View of Prototype Pick-up Device
Plate 6.27 Under-side of Prototype Pick-up Device
6.11 Design of a robotic control system

This section outlines the design of a robotic control system for the prototype device detailed in the previous section. The aim of this particular area of research was to use a robot to control the prototype pick up device detailed in section 6.10.

The task involved was to separate one ply of fabric at a time from a stack of cut samples, transfer the ply to a new location and release the ply. This task to be carried out automatically without the need for human intervention. Provision was to be made for recording the number of plies picked up. Once the recommended number of pick-ups had been achieved, the robot was to move the prototype device to a 'cleaning' position, allowing the adhesive surface to be cleaned [manually] before the device is moved back to its initial position above the stack, ready to begin searching for a new piece to pick up.

The following sub-sections detail the hardware and software considerations in developing this system.

6.11.1 Hardware considerations

The robot used in the development of the system was the RTX robot, manufactured by Universal Machine Intelligence (UMI) Ltd. This is a low-cost, high performance robot arm of modified SCARA configuration. It has six axes of movement plus gripper, 2 Kg load capacity, +/-0.5 mm repeatability and a reach of 684 mm over full vertical travel of 915 mm. The technical specifications for the RTX
can be found in Appendix O.

The host computer used for controlling the RTX was an Olivetti M240 PC interfaced to the robot via the RS232-C serial port. The robot was not modified for use and the prototype device was held in the gripper of the RTX as shown in plate 6.25.

**Interfacing the prototype pickup device to the RTX robot arm**

The RTX features a user input/output (I/O) socket consisting of two I/O ports (IPO and IP1). Each I/O port has six lines which can be set to either input or output. The wiring of the socket is shown in figure 6.28. The I/O lines are TTL levels and need to be buffered.

Port 0 [IPO] is set for output and port 1 [IP1] is set for input. The prototype device incorporates a microswitch for registering pressure applied to the fabric stack, and a solenoid for activating the release (outer) mechanism to separate the ply of fabric from the device. The circuit developed for interfacing the microswitch and solenoid to the RTX is shown in figure 6.29. A 24 volt miniature solenoid was used in the prototype. The force exerted by the solenoid could be increased by increasing the voltage applied to the coil, according to the following:

<table>
<thead>
<tr>
<th>Duty (%)</th>
<th>10%</th>
<th>25%</th>
<th>50%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{Max}</td>
<td>77V</td>
<td>48V</td>
<td>34V</td>
<td>24V.</td>
</tr>
</tbody>
</table>

The solenoid was buffered to the input port using a 4104 logic level converter, and the current switched to the solenoid using a IRF510 transistor.
Figure 6.28 RTX User I/O Socket

Figure 6.29 RTX Interface Circuit

N/C

+15V

SOLENOID

IN4148

3K

12V

IPO

(BIT 0)

IP1

(BIT 0)

MICROSWITCH

+5V

1K

+5V

10K

+5V

15

16

4

2

+404

2

6

13

14

15

16

10

11

12

5

4

3

2

1

0

I/O PORT

0

1

2

3

4

5

0

1

2

3

4

5

0 V

VCC

0 V

VCC
6.11.2 Software considerations

A computer programme was developed using FORTH to control the robot. A flow chart of the programme is shown in figure 6.30. The programme begins by initialising the user input/output port, port 0 [IP0] to output and port 1 [IP1] to input. The search sequence is then begun. The picker is moved down one increment and the vertical position of the stack is checked. If the vertical position reaches the acceptable minimum position (at the bottom of the stack) then the picker is moved back to its initial position above the stack and waits for an acknowledgement signal to indicate that the stack has been replenished.

As the picker searches down towards the stack, the state of the microswitch is continually checked until it is closed. When this occurs it indicates that the picker has been applied to the stack at a given pressure. The ply is then lifted slightly and 'shifted' across the stack to break any edge entanglements see figure 6.31. It is then moved to the new position and the solenoid activated, causing the ply to be released from the device.

During the search routine when the ply has been found, the vertical position of the robot is recorded. The total number of pieces found is also incremented at this time. After the piece has been released from the device, it is returned to the position where the last position was found, and the search routine begun from this point. This procedure is repeated until the picker reaches its minimum acceptable position, in which case it is returned to the top of the stack. The number of pieces found is checked at this point. If
the number exceeds or equals the recommended number, the picker is moved to a 'cleaning' position. After cleaning it is then returned to its initial position ready for the search routine to start over. A programme listing is included in Appendix P.
Figure 6.30 Flow Chart For Robot Control Programme

1. **INITIALISE INTERFACE**
2. **START SEARCH**
   - **MOVE DEVICE DOWN ONE INCREMENT**
   - **CHECK IF DEVICE IS AT BOTTOM OF STACK**
     - **NO**
     - **CHECK IF MICROSWITCH CIRCUIT IS COMPLETE**
       - **NO**
       - **INCREMENT COUNT TOTAL**
         - **STORE POSITION OF FOUND PLY**
         - **SHIFT PLY**
         - **PICK UP PLY**
         - **MOVE PLY TO NEW POSITION**
         - **ACTIVATE SOLENOID**
           - **CHECK IF COUNT >= RECOMMENDED NUMBER**
             - **NO**
             - **MOVE DEVICE TO CLEAN POSITION**
               - **WAIT FOR ACKNOWLEDGEMENT**
               - **INITIALISE COUNT**
               - **MOVE TO START POSITION**
   - **YES**
   - **MOVE TO START POSITION**
   - **ACTIVATE SOLENOID**
     - **DISPLAY MESSAGE "STACK TOO LOW"**
     - **WAIT FOR ACKNOWLEDGEMENT**
     - **MOVE BACK TO STORED POSITION ABOVE STACK**
     - **SHIFT PLY**
     - **PICK UP PLY**
     - **MOVE PLY TO NEW POSITION**
     - **ACTIVATE SOLENOID**
       - **CHECK IF COUNT >= RECOMMENDED NUMBER**
         - **YES**
         - **MOVE DEVICE TO CLEAN POSITION**
           - **WAIT FOR ACKNOWLEDGEMENT**
           - **INITIALISE COUNT**
           - **MOVE TO START POSITION**

450
Figure 6.31 Ply Shifting

a) Top ply of fabric located

b) Ply lifted slightly above stack

c) Ply 'shifted' to right
6.11.3 Operation of the adhesive pick-up device

Samples were cut from cotton interlock knitted fabric and plain weave cotton fabric and placed together to simulate stacks of cut parts. The development of the system was carried out in parallel with the experimentation detailed in section 6.9. The object of the study in this area was to simulate the principle of small parts handling using the developed pick-up device under robotic control.

Plate 6.32 shows the complete system comprising the robot and pick-up device, along with the host computer. Plate 6.33 shows the picker device positioned above the stack of parts ready to begin the search routine. In plate 6.34 the picker has located the top ply and it is shifted to aid efficient ply separation. Plate 6.35 shows the piece securely held by the prototype device, and plate 6.36 shows the device releasing the piece in the desired location.

The recommended number of samples to be picked up before cleaning was set to fifty, after which the picker was moved to the 'clean' position. This number being determined on the basis of earlier experimental work. A number of test runs were made with the interlock fabric stack and the reliability was found to be in excess of 98%.

Plate 6.37 shows the device handling woven samples, the reliability of the device in handling these being of the same order as for interlock fabric.

The system operating at 50% full speed, takes approximately 45 seconds to locate the top ply of fabric of a stack approximately 55 mm high, with the prototype device positioned approximately 120 mm above
the stack. Once the first piece has been located, the cycle time to pick up the ply and transfer it to a location approximately 250 mm away is 17 seconds.
Plate 6.33 Pick-up Device Positioned Above Stack
Plate 6.36 Ply Released by Pick-up Device
6.12 Conclusions and further work

6.12.1 Conclusions

The research undertaken in the automated handling of fabrics has shown that pressure sensitive adhesives can be used successfully and reliably for separating and handling plies of fabric from a stack of cut parts. The use of pressure sensitive adhesives offers advantages over other forms of fabric handling devices, discussed in section 6.2, in being able to consistently and reliably pick up a single ply of fabric at a time. This method also provides positive location of the top ply of fabric in a stack of cut pieces. Other advantages in using adhesives include:

(i) The ability to bond to a variety of materials, which may be dissimilar and of different thicknesses.

(ii) Versatility of adhesive forms and methods of application permits their application to many fabric handling requirements.

(iii) Economic and rapid.

(iv) Uniform distribution of stresses over the entire bonded area.

Analysis of three commercial pressure sensitive adhesives (selotape, electrical insulating tape and masking tape) and one currently under development (‘magnatac’) has shown that a relationship between the force required to separate the fabric from the adhesive and the number of separations exists. This relationship
being of the form:

\[
\text{Separation force} = \frac{1}{a \cdot \text{Number of separations}^k}
\]

where 'a' and 'k' are constants.

[area of adhesive used, time of contact, contact force, separation rate and type of fabric are all assumed constant].

The derived relationship can be used to determine the performance characteristics of a particular pressure adhesive under certain operating conditions. The number of times the adhesive can be used under these conditions with a particular fabric can therefore be predicted using this relationship. This allows maximum use to be made of the adhesive before it requires replacement.

Further analysis, of the pressure sensitive tape currently under development, 'magnatac', has established relationships between a number of variables known to affect the adhesive to fabric bond strength. These relationships make it possible to predict the performance of a device using this particular adhesive. Analysis of this adhesive has shown that it will regain approximately 45 - 60% of its initial tack value upon cleaning, when used continually to pick up 100 plies of untreated cotton interlock fabric. This figure varying between 16% and 45%, if the adhesive surface is completely inhibited with chalk dust or fine talc and then cleaned. The analysis also shows the method used in cleaning the adhesive influences the regained tack value.
A low-cost prototype device based on the use of 'magnatac' has been developed, along with a robotic control system. The prototype pick-up device, under robotic control, can accurately and reliably (in excess of 98%) separate and handle pieces of fabric from a stack of cut parts, transfer the piece to a new location and release it. The system operating at 50% full speed takes approximately 45 seconds to locate the top fabric of a stack approximately 55 mm high, with the prototype device positioned approximately 120 mm above the stack. Once the first piece has been located the cycle time to pick up the ply and transfer it to a location approximately 250 mm away is 17 seconds.

6.12.2 The need for further work

It has been shown that pressure sensitive adhesives can be used successfully in the automated handling of fabrics. There are a number of areas which require further work which the constraints of time have not permitted, these being:-

(i) Further experimentation with different fabrics.
(ii) Increased prototype pick up device reliability.
(iii) Effect of fabric properties on fabric pick-up.
(iv) Determination of pick up area and points for large fabric pieces.
Further experimentation with different fabrics

There is a need to carry out further experimentation, based on the procedures outlined in section 6.9, for the different type of fabric likely to be encountered. This would establish performance characteristics for the adhesive with each type of fabric. The effect the types of fabric has on the variables can be determined by equating the results obtained using the theoretical analysis shown in section 6.8.

Increased prototype pick-up device reliability

One of the main problems encountered in developing the system for the automated handling of fabric, was that there were instances when more than one ply at a time was picked up by the device. This was caused by either (i) edge entanglement of the plies or (ii) attraction of the plies between the layers. There are a number of methods which can be used to reduce or eliminate this occurrence. The one chosen in this particular study was to incorporate a 'ply shifting' routine into the software control programme, whereby the ply was lifted slightly and 'shifted' to encourage single ply separation.

Other methods of preventing multiply picking need further investigation to eliminate this problem. Alternatively a sample weight sensor could be incorporated into the device to detect for this, in which case pick-up would be aborted. Additional transducers, sensors etc., would however increase the basic price of the pick-up device and require a more complex control programme.
(iii) Effect of fabric properties on fabric pick-up

The effect that the basic mechanical properties of the fabric have on the manner in which the fabric is picked up need further investigation. This would require greater fundamental knowledge of the effect basic mechanical properties have on the fabrics performance characteristics, enabling the optimum pick-up arrangement for a particular fabric to be determined.

(iv) Determination of pick-up areas and points for large pieces

At present a system has been demonstrated that can pick up small samples of fabric from a stack of cut pieces. The sample sizes are well within the holding capacity of the prototype pick-up device. Further research would need to be carried out to determine the ideal number and arrangement of the pick-up elements to achieve large fabric piece pick-up.

In section 6.9 it has been shown that the theoretical maximum size of a fabric piece (of a particular weight) can be calculated for a given area of adhesive, applied at a given load, for a given time. This data can be used in reverse for determining the area of adhesive required for picking up a piece of fabric of a given area. It would however be necessary to determine the optimum placement of the pick-up elements on the fabric piece.
Chapter 7

Summary of Conclusions and Further Work, Discussion and Commercial Applications
7.1 Summary of conclusions

In Chapter 3 a concept for an integrated system for garment manufacture is presented. Unlike many of the proposed research programmes and those currently active, it proposes an intermediate approach to integrated garment manufacture, based on human activity in the assembly area.

A number of key research areas have been identified which need to be addressed before such a proposed concept could become a reality. The areas being:

3. Automated handling of fabrics and other flexible materials.

Fundamental research has been carried out in each of the above areas, presented separately in Chapter 4, Chapter 5 and Chapter 6. A summary of the conclusions found in each area follows.
1. Computer-based generation of block patterns

The research has shown that by using appropriate modelling techniques, it is possible to create a reliable and consistent computer-based system for the generation of basic garment pattern blocks. A computer-based system has subsequently been developed for achieving this.

The system allows a designer to create an accurate garment pattern block on the visual display unit (VDU). This eliminates the need for manual drafting of the pattern and further digitising or scanning to convert the pattern into numerical co-ordinate information necessary for computer-based pattern design systems.

The system uses 'parametric' (macro) programming techniques, storing all instructions required for drafting the pattern in variable form. This eliminates the need for grading, as the 'parametric' retrieves all the necessary sizes from stored size charts or prompts for the relevant personal measurements before constructing the pattern. This technique ensures 100% repeatability when the same size block is drafted.

Geometric modelling techniques, for some common curves found on patterns, have been developed for use with the system. This allows accurate and consistent curve profiles to be produced automatically, without the need for inaccurate sketching techniques.
2. Automated fabric feeding to an industrial sewing machine

A low-cost system for controlling the edge of a piece of fabric being fed through an industrial sewing has been developed. The system uses a computer to direct a positioning device, controlling the fabric being fed into the machine. The edge of the fabric is continually monitored using infra-red emitters and phototransistors. Any deviation from the desired path causes a corrective signal to be issued to the positioning device controlling the fabric.

The system developed demonstrates that the principle of computer-based fabric edge control is technically feasible. Using software control techniques it is possible to produce a number of consistent seams on fabric samples, to specified widths.

The samples produced on the prototype machine, have been compared with those produced by experienced and inexperienced sewing machine operators. This has shown that the range in seam deviation is less than that which can be achieved by an experienced or inexperienced operator. It has also shown that accurate and consistent seams can be produced on the prototype machine.

A new 'top feed' feeding mechanism for an industrial sewing machine has also been developed, and incorporated into the system. This mechanism has been designed to facilitate efficient multi-ply feeding.
3. Automated handling of fabrics and other flexible materials

Fundamental research into the use of pressure-sensitive adhesives for handling fabrics has been undertaken. Analysis of three commercial pressure-sensitive adhesives and one new adhesive currently undergoing site testing has shown that a relationship exists between the force required to separate fabric from a pressure-sensitive adhesive and the number of times it is separated. This relationship can be used to predict the performance characteristics of a pressure-sensitive adhesive under certain operating conditions.

A low-cost fabric handling device has been developed, based on the use of the new pressure-sensitive adhesive. This particular adhesive having the ability to regain approximately 45 - 60% of its initial 'tack' upon cleaning.

A robotic control system has also been developed to control the prototype fabric handling device. The device, under robotic control can accurately and reliably separate (in excess of 98%) and handle pieces of fabric from a stack of cut parts, transfer the piece to a new location and release it.
7.2 Summary of further work

Further work in each area of study has been identified at the end of Chapters 4, 5 and 6. The following is a summary of the potential for further research identified in these chapters.

1. Computer-based generation of block patterns

(i) Further development of system

In order to fully develop the computer-based system for the generation of block patterns, a number of other blocks common to woven and knitted pattern making need to be investigated and adapted for use with this system.

(ii) Interfacing the system to commercial computer-based systems

There is a need to interface the developed system with a commercial system for garment pattern design. This will allow the developed system to be used alongside conventional and computer aided systems for garment pattern design.

2. Automated fabric feeding to an industrial sewing machine

(i) Increased contour seaming capabilities

The nature of the seam produced on the prototype machine is governed by the physical positioning of the sensors relative to the needle. Alternative methods of positioning the sensing devices closer to the point of stitching need further investigation. This will improve the quality of contoured seams produced.
(ii) Greater fabric control

Methods are required for controlling larger pieces of fabric being fed into the prototype machine. This will eliminate the problem of incorrect fabric feeding.

(iii) Increased sensor resolution

The present arrangement of infra-red emitters and phototransistors gives a seam width resolution of 3.5 mm. Further studies require to be undertaken to reduce the seam width resolution.

(iv) Multi-ply fabric control

The system has been demonstrated for producing specific widths of seam on multiple plies of fabric in which the edges are aligned. In order to extend the capabilities of the prototype, methods for monitoring and positioning the individual plies of fabric during multi-ply feeding require further investigation.

3. Automated handling of fabrics and other flexible materials

(i) Further experimentation with different fabrics

There is a need for further experimentation with different types and finish of fabric. This would establish performance characteristics for adhesive pick-up devices with each type of fabric.

(ii) Increased pick-up device reliability

Methods of preventing instances of multi-ply pick-up require
further investigation. This being achieved by either software control or hardware design.

**(iii) Effect of fabric properties on fabric pick-up**

The effect that the basic mechanical properties of the fabric have on the manner in which the fabric is picked up require further investigation.

**(iv) Determination of pick-up areas and points for large pieces**

The determination of the areas of adhesives required for picking up large pieces of fabric requires further investigation, along with the optimum arrangement and placement on the fabric piece for efficient pick-up.
7.3 Discussion

The U.K. clothing industry has for a number of years been facing many problems, largely associated with the increasing numbers of imports from the developing countries, and the fact that the industry is labour intensive with a high rate of labour turnover. The U.K. clothing industry along with those of the other industrialised countries, are seeking to improve their competitiveness in world markets, by automating many of the production processes. This is being done in a bid to decrease the expensive labour requirement and make the industry more capital-intensive.

The extent to which the industrialised countries are tackling the automation issue differ considerably, from a conceptualised system approach (FIGARMA) through to a sophisticated hardware approach (MITI). Research in this area is moving very rapidly as many research organisations in the developed countries have recognised the potential for a computer-integrated garment manufacturing system.

This particular project has sought to research a number of areas viewed as being key factors which need to be addressed before the concept of a computer-integrated garment manufacturing system can become a reality. The aims and philosophies of the undertaking have been to develop low-cost systems in which the human operator still has a valuable and worthwhile role to play in garment manufacture.

There are those who believe that the dream of producing a complete garment using robots and automated machinery is well within
the realms of possibility. Robotic sewing has indeed been
demonstrated but as yet the systems have not even approached
emulating the skills of a human operator. The cost of achieving this
aim is likely to dissuade their acceptance by the under-financed U.K.
clothing industry.

It is likely therefore that the human operator will continue,
at least in the near to mid-term future, to feature as an important
element in garment manufacture. The nature of the raw material -
fabric, is such that it presents many technical problems in
developing automated systems for garment manufacture.

The aim of the research has been to incorporate computers/
robotics into areas of garment manufacture which are best suited
to their introduction. Leaving the more complex areas, such as
creative intuition, three dimensional fabric manipulation etc., for
human operator control. Although certain tasks have been left for
human operator control, computers or robotics can still be used to
aid the operator in producing high quality consistent garments.

This research project has covered particular aspects
encompassing the process of garment manufacture, from pattern design
through to fabric handling and seaming. The next stage would have
been the integration of these various areas along the lines proposed
in Chapter 3. Financial resources and time constraints imposed on
this project would not however, permit this. It is hoped that the
research undertaken will be taken further with a view to achieving
this aim.

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7.4 Commercial applications

This sub-section outlines the steps which have been taken in order to attract commercial interest in the research areas undertaken.

Computer-based generation of garment pattern blocks

The developed system has been demonstrated to representatives of a major European manufacturer of computer-based pattern making systems - Lectra Systems Ltd. They have expressed their interest in the development, and further action is awaited (see Appendix Q).

Automated fabric feeding to an industrial sewing machine

The industrial collaborators of this research project, Rockwell-Rimoldi (GB) Ltd., have made an assessment of the system, see Appendix Q. Their assessment has shown that although it is technically viable, further development needs to be undertaken in order to make it commercially viable. Further development centres mainly on the areas of further work highlighted at the end of Chapter 5, particular emphasis being placed on the need for greater fabric control during feeding.

Automated handling of fabrics and other flexible materials

The research undertaken in this area and the subsequent development of a prototype pick-up device using the principle of temporary adhesion of the fabric, has led to interest by the
Department of Trade and Industry (DTI). The DTI were approached for funding under their Small Firm Merit Award for research and technology (SMART) scheme, to allow further research to be carried on the project. An award of £37,500 has subsequently been made by the DTI under this scheme, enabling the developer of the adhesive and the author to establish a business to exploit the use of the developed adhesive in the process of robotic fabric handling.
Appendices
Appendix A

Standard Industrial Classification (SIC)

This groups together economic activities to form industries. The first comprehensive (SIC) was in 1948 which was later revised in 1958 and 1968 to take account of the changes in the organisation and relative importance of a number of industries, also to take account of new industries. The principal objective of the 1980 revision was to examine and eliminate differences from the other European statistical offices such as the statistical office of the European Communities (SOEC) and the 'Nomenclature Generale des Activites Economiques dans les communautes Europeennes' (NACE).

The 1980 Standard Industrial Classification (SIC) has a decimal structure. The full range of activities are divided into 10 divisions (0-9). Divisions are sub-divided into classes (2nd digit). Classes are sub-divided into groups (3rd digit). Groups into activities (4th digit).

There are 10 divisions, 60 classes, 222 groups and 334 activities.

Activities associated with clothing and making-up are found in division 4. The relevant classes, groups and activities are shown over.
Division 4 :- Other Manufacturing Industries

Class

43 Textile Industry

Group

436 Hosiery and other knitted goods

Activity

4363 Hosiery and other weft knitted goods and fabrics.

45 Footwear and Clothing Industries

451 Footwear

4510 Footwear

453 Clothing, Hats and Gloves

4531 Weatherproof outerwear

4532 Men's and boy's tailored outerwear

4533 Women's and girl's tailored outerwear

4534 Work clothing and men's and boy's jeans

4535 Men's and boy's shirts, underwear and nightwear

4536 Women's and girl's light outerwear, lingerie and infants wear

4537 Hats, caps and millinery

4538 Gloves

4539 Other dress Industries.
Appendix B

Case Study

In the United States, the clothing industry is faced with similar problems as the U.K. clothing industry, that of low-cost, high-volume imports undermining the home produced goods. Due to this competition three streams of activity are emerging:-(i) investment in low cost labour areas (far east, 807 countries), (ii) higher technology investigation (Europe, U.S., Japan), and (iii) Investment in higher technology.

It is this first area that is at present attracting many U.S. clothing manufacturers with so called "Off-shore" or "Outward-processing" manufacturing plants where they make use of the lower costs and reduced overheads to be found in many overseas developing countries. The example below illustrates how reducing labour costs in conjunction with lower cost (or used) equipment can create a significant price edge.

<table>
<thead>
<tr>
<th></th>
<th>U.S. Product</th>
<th>Asian Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>$ 6.00</td>
<td>$ 0.45 *</td>
</tr>
<tr>
<td>Material</td>
<td>8.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Overhead</td>
<td>10.00</td>
<td>5.00 **</td>
</tr>
<tr>
<td></td>
<td>$ 24.00</td>
<td>30% Frt/Duties 4.04</td>
</tr>
<tr>
<td></td>
<td>$ 17.49</td>
<td>73%</td>
</tr>
</tbody>
</table>

* Allows for lower productivity

** Allows for accelerated depreciation and some U.S. administration costs.
In addition to low cost labour, many overseas or 807 locations may offer inducements to relocate, such as tax benefits or low cost buildings on favourable terms. The above example shows that even taking into account the duties imposed on using overseas locations the product can still be produced at three quarters of the cost of a U.S. product.

In a situation where a company finds its business growing, it may hypothetically be faced with the option of establishing a 500 operator plant using the latest equipment available, or moving into a foreign trade zone and using second hand equipment with a lower level of labour productivity.

<table>
<thead>
<tr>
<th></th>
<th>U.S.</th>
<th>Overseas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land</td>
<td>$535,000</td>
<td>99 Year lease @ $500 per year</td>
</tr>
<tr>
<td>Building</td>
<td>2,000,000</td>
<td>$255,000</td>
</tr>
<tr>
<td>Equipment</td>
<td>2,750,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td>(550 machines)</td>
<td>(1500 machines)</td>
<td></td>
</tr>
<tr>
<td>Computer Activity</td>
<td>1,000,000</td>
<td>0</td>
</tr>
<tr>
<td>Investment</td>
<td>$6,285,000</td>
<td>$1,755,000</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>27.9%</td>
</tr>
<tr>
<td>Estimated Annual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator Payroll</td>
<td>$6,240,000</td>
<td>$608,400</td>
</tr>
<tr>
<td>(Excludes Fringes)</td>
<td>(Includes Fringes - Sri Lanka)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>9.8%</td>
</tr>
</tbody>
</table>
The above comparison shows that the capital investment in the U.S. is approximately double that overseas. The operating capital requirement is approximately ten times higher for the U.S. than for overseas. At current interest rates, these differences may be more significant than just the labour costs.

Many U.S. apparel firms use the 807 Tariff convention to reduce control problems and improve turnaround time. They may cut garments in the U.S., sew in the Caribbean area and finish the product in the U.S.\(^1\)

Reference

Appendix C

Classification of Industrial Robots

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Manual manipulator</td>
<td>A manipulator which is operated by human beings.</td>
</tr>
<tr>
<td>B. Fixed sequence robot</td>
<td>A manipulator which performs a plurality of steps of motion one after another in accordance with the predetermined order, conditions and positions which are not easy to change.</td>
</tr>
<tr>
<td>C. Variable sequence robot</td>
<td>A manipulation which performs a plurality of steps of motion one after another in accordance with the predetermined order, conditions and positions which are easy to change.</td>
</tr>
<tr>
<td>D. Play back robot</td>
<td>A manipulation which memorises the order of work, positions and other information taught by man operating it for a first cycle of work and repeats the work by playing back the information.</td>
</tr>
<tr>
<td>E. Numerical control robot</td>
<td>A manipulator which works in accordance with the numerical instructions representing the order or work positions and other information.</td>
</tr>
<tr>
<td>F. Intelligent robot</td>
<td>A robot which has the functions of feeling and recognition and makes a decision for action for itself.</td>
</tr>
</tbody>
</table>

Note:

The manipulator is an apparatus which can hold an object and move it in space [as the forelimb of human beings does], and which holds it by gripping or attraction.
Appendix D

Members of the Technology Research Association

Automated Sewing System (TRAASS)

Aisin Seiki Co. Ltd.
Asahi Chemical Industry Co. Ltd.
Asics Corp.
Kind Wear Corp.
Kao Corp.
Kashijania & Co. Ltd.
Kayaba Industry Co. Ltd.
Kimuratan Co. Ltd.
Ginza Yamagataya Co. Ltd.
Sanyo Shokai Ltd.
Daiwa Dyeing Co. Ltd.
Tsuyakin Kogyo Co. Ltd.
Tokyo Juki Industrial Co. Ltd.
Toyama Goldwin Inc.
Toyo Electric MFG Co. Ltd.
Toyobo Co. Ltd.
Toray Industries Inc.
Nippon Kayaka Co. Ltd.
Japan Vilene Co. Ltd.
Hitachi Ltd.
Brother Industries Ltd.
Pegasus Sewing Machine MFG Co. Ltd.
Renown Inc.
Matasushita Electric Industrial Ltd.
Mitsubishi electric Corp.
Yamato Sewing Machine MFG Co. Ltd.
Wacoal Corp.

Textile Industry Rationalization Agency
Appendix E

1986 Sponsors of (TC)$^2$

Apparel Automation Research and Development

Labour Union

* Amalgamated Clothing and Textile Workers Union (ACTWU)

Textiles

Alice Mfg. Co.
American & Efird Mills
Atlas Yarn Co.
Brawer Bros.
* Burlington Industries
* Collins & Aikman Corp.
Cone Mills Corp.
FAB Industries
Glen Raven Mills
Macfield Texturing
* Milliken & Co.
National Spinning Co.
Parkdale Mills
Reeves Brothers
* Russel Corp.
* J.P Stevens & Co.
Swift Textiles
United Yarn Products Co.

Apparel

The Fechheimer Brothers Co.
* Grief Companies, Div. of Genesco
* Hartmarx Corp.
The Joseph & Feiss Co.
* Palm Beach Inc.
* Surgikos, a Johnson & Johnson Co.
West Mills Clothes.

Dyes and Chemicals

Amoco Chemicals Corp.
Badische Corp.
BASF Wyandote Corp.
Buffalo Color Group
Ciba - Geigy Corp.
Crompton & Knowles Corp.,
Dyes and Chemical Div.
ICI Americas  
Mobay Chemical Corp.  
Sandoz  
Union Carbide Corp.

Paper  
Dillard Paper Co.  
Star Paper Tube

Fibres  
Allied Corp.  
American enka Co.  
Autex Fibre  
* Celanese Fibre Operations  
* El du Pont de Nemours & Co.  
Eastman chemical Products  
Monsanto Co.  
PPG Industries

Equipment  
American Dornier Machinery Corp.  
American Schlafhorst Co.  
Gaston County Dyeing Machine Co.  
Keltex Corp.  
Morrison Textile Machinery Co.  
Saurer Corp. Textile Machinery Co.  
Steel Heddle Mfg. Co.  
Stork Screens America.

Banking  
NCNB Corp.  
Wachovia Bankand Trust Co.

Others  
American Sheep Producers Council  
Cotton Foundation  
Cotton Inc.  
Daniel International Corp.  
National Cotton Council  
* U.S Dept of Commerce

* Original Participants.
Appendix F

Use of computers in pattern making survey

Scope of the survey

The major objective of the survey was to make an assessment of the level to which computers are currently being utilised as aid to pattern making in the clothing industry. The survey was limited to companies operating in Leicestershire, as it was felt that some useful indications of general working practices could be obtained.

A recent survey carried out at Trent Polytechnic\(^{(1)}\) has looked in detail at the application of new technology to the clothing industries of the East Midlands. This survey does however have different principal aims and covers a larger geographical area including Derby, Nottingham and Leicester. The survey covers assessment of computer aided design (CAD) and computer aided manufacture (CAM) in a wide range of clothing manufacturing companies.

The present survey is more specific and was defined as "The use of computers in pattern making", 484 companies in Leicestershire connected in some way to the clothing industry were selected for survey. No attempt was made to classify the companies in terms of sector of the industry or type of products manufactured, as it was felt that companies not specifically involved in pattern making would either indicate so or fail to reply. No attempt has also been made to classify the companies involved in terms of size (annual turnover or number of employees). This was not considered necessary as it was a

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particular practice ie pattern design/making that was of major interest.

Specific method used

A postal questionnaire was used to gather the specific information required from the large number of scattered sources, it was used for:

1. Assessing the methods currently and previously being used in making pattern.
2. Making a minor assessment of the use of computers in this activity.

A pilot questionnaire was prepared and tested to refine the final postal questionnaire.

This survey in no way sets out to be a statistical record of the use of computers in Leicestershire clothing companies. Rather it is a means of looking at the methods currently being used in pattern making and attempting to determine the extent to which new technology, in particular computer aided design (CAD) systems, is being incorporated and utilised in the industry.

Survey findings

Response

A total of 71 replies were received from the 484 sent (a 14.67% response). Some sources(2) indicate that a response of 11% is very
good and suggest a strong interest in the survey. This is qualified by Oppenheim (3) who states that mail questionnaires suffer from the disadvantage of producing a very poor response. Scott (4) covers the subject of mail questionnaires in greater detail.

Possible reasons for low response

(1) A stamp was not included on the self addressed envelope.
(2) Hosiery manufacturing were included in the survey hence much of the terminology would have been meaningless.
(3) The choice of title 'Use of computers.' may have put off many people.
(4) Work demands at the time.

Survey findings not applicable

Of the 71 replies received 50 (70.4%) felt that the questionnaire was not applicable to their particular company. A break-down of the replies revealed that:-

18 (36%) were knitwear companies who manufactured body blanks or fully fashioned knitwear, or were commission knitters.
23 (46%) were hosiery or other companies in no way connected with pattern designing or making.
9 (18%) offered no explanation or simply stated that they do not use computers.

Survey findings applicable

The survey showed that in answer to the first question of what methods are used for creating a block pattern from scratch, 20 out of
21 (95%) stated that manual techniques of drafting were being used and that present practice is much the same as previous practice. Only one respondent said a computer was now being used where previously the job had been carried out manually.

Only one respondent stated that drafting aids such as 'Flexicurves', 'Patternmasters', 'Varyform curves', etc., were regularly used, 5 (23.8%) stated that they used them occasionally and the remainder (71.4%) stated they were never used.

All respondents stated that they were not aware of any methods which involved calculations for drawing curves on pattern blocks.

Questions 5 & 6 were designed to quickly determine how many companies were using computers in pattern making. When asked if a computer system was being used in the pattern making process, 6 (28.6%) said that one was now being used. All those that were using a computer system stated that patterns were first created manually before being digitised/ scanned into the computer system. Also, all stated that a manual method was used because it had always been done that way. One respondent (who was not using a computer system) stated that he thought the method of drafting was more accurate than a computer.

18 (85.7%) respondents did not adopt any standard method for drafting pattern blocks and 17 (80.9%) did not consult any form of literature when draughting pattern blocks. Conclusion

From the survey findings it was clear the vast majority of pattern cutters and designers sampled construct patterns using traditional techniques of modelling on work stands or point paper
drafting. Those who have access to a computer system, still prepare the pattern manually before it is converted to computerised graphical information. The reasons for this practice are many, one of the main reasons may be pattern cutting and designing is still very much regarded as being a craft aspect of the manufacturing process. The pattern designer uses personal experience and knowledge to create patterns which, only when the final draft has been completed, will then be digitised into the computer system, if one is available.

Many pattern cutters appear to be unaware of the commercial availability of computer aided design software packages, many running on relatively inexpensive micro-computers, and instead prefer to work on paper using the traditional tools of the trade. One of the main drawbacks with computer aided system for designing appears to be the problem of scale. Most patterns are developed full size where the pattern cutter can easily visualise the finished garment. The graphic display units of many computer systems are relatively small in size and designers can lose the 'feel' for a garment on a much reduced scale.

Many useful comments were received from respondents, one stated that if a computerised system was used "the job of pattern cutting would lose the skill element and become a monotonous, tiring job". A view not endorsed by the author.

On a more positive note many respondents said that they would be happy to carry out their job on a computer, the proviso being that proper training on such systems was received.

The views outlined above are further echoed in the survey.
carried out by Trent Polytechnic\(^{(1)}\) which states:

"...Pattern cutting has been available for sometime on the production systems, but very few companies, including those who have the software, have made use of it even for their production patterns. The designers have not! The fundamental gap between the graphics and construction of a first sample was identified in earlier research at Trent Polytechnic, this gap was seen as one element in the alienation of designers.....".

References

(1) TRENT POLYTECHNIC, Dept. of Fashion, "How knowledge of new technology can be made available to the clothing industry", Local collaborative project No 703, 1986.

(2) MURRAY, "Stitchless joining for apparel", KSA report, p.5.

(3) OPPENHEIM A N, "Questionnaire design and attitude measurement", Heinmahn Educational Books Ltd. ISBN 0435 826751, 1972.

Head of Design Section, School of Textile & Knitwear Technology

Head: Dennis Munden, BSc, FTI
Professor of Textile Technology

F. H. Carrotte, CEng, MIMechE, FTI
Professor of Knitting Engineering

Date January, 1988

Dear Sir/Madam,

I am writing to your company to ask for assistance with some research that is being carried out into the use of computers in the making of patterns in the clothing industry. The research is for a Ph.D. project concerning automation and computers in the industry, which is being sponsored by the Drapers' Company, London.

Enclosed is a questionnaire that has been designed to ascertain the level to which computers are currently being used in the making of patterns. I would be extremely grateful if you could circulate this to the person/s responsible for pattern making within your company and ask them to complete it as fully as possible, adding any comments they feel necessary about the use of computers or about the questionnaire itself. If more than one person is involved, please photocopy the questionnaire and ask each individual to complete a separate one.

I have also enclosed an addressed envelope for the return of the questionnaire. The results of this survey will be very important and will be used only in connection with the research which is being carried out at the Polytechnic.

I thank you in anticipation of your kind assistance and hope to receive your reply shortly. If there are any queries concerning the questionnaire, please do not hesitate to contact me, my telephone extension is 2253.

Yours sincerely,

Michael K. Hall, B.Sc.,
Research Assistant.
Use of Computers in Pattern Making Questionnaire

Name .................................. Company .............................................

Position .................................

1) What methods do you use for creating a block pattern from scratch?
   i) presently ...
   ii) previously ...

2) For drafting curves, how widely do you use aids such as :- flexicurves, 'Patternmaster', 'Varyform' curves, etc.?
   - Very often
   - Occasionally
   - Never

3) Do you use any other method for drawing curves?
   - Yes .... which
   - No

4) Are you aware of any methods which involve calculations for drawing curves on pattern blocks?
   - Yes .... which
   - No

5) Do you create basic blocks on the screen without digitizing or scanning?
   - Yes .... how?
   - No

6) Do you use your computer system primarily for generating patterns which have been drafted manually and then digitized / scanned?
   - Yes
   - No .... explain
7) If a manual system of drafting is used why is it preferred?
   - More accurate than computer
   - Always been done that way
   - Other .... explain

8) Do you adopt a standard method for drafting blocks?
   - Yes ... which
   - No

9) Do you consult any literature when drafting blocks?
   - Yes ... which
   - No

10) Do you keep basic pattern blocks in an archive form in the computer?
    - Yes
    - No

11) Would you be happy to carry out your job using only a computer?
    - Yes
    - No ..... why?

12) Do you use computers in any other aspect of your job?
    - Yes ..... how?
    - No

Comments

Prepared by: Michael Hall BSc, Research Assistant,
Leicester Polytechnic   January 1988
START/3.1
REM * PARAMETRIC SYMBOL TO FIT A CONTINUOUS *
REM * CURVE TO GARMENT PATTERN PIECES *
REM * PAR. SYMBOL NAME : CRV.PR *
REM * (C) MICHAEL K HALL *
REM * CREATED 30 MAY 1987 *
REM ** ** ** ** ** ** ** ** ** ** ** ** **
* START
PR ENTER WIDTH
ST/N C
PR ENTER OVERALL HEIGHT
ST/N D
PR ENTER CURVE DEPTH
ST/N R
PR ENTER TOP WIDTH
ST/N M
* CALCS
ME1
N=3
LET F=.3*D
LET N=D-F
LET J=1.8*R
LET H=(J+R)*SIN(41)
LET P=(J+R)*COS(41)
LET Z=P-C
IF(Z.GE.0)GOTO START
REM * FIRST RAD
LET E=C-((J+R)*COS(41))
LET R1=(H**2+E**2-J**2)/(2*(H-J))
LET GA=ARCTAN(E/(R1-H))
LET Y1=R1-(R1*COS(GA))
LET GA2=GA/2
LET X1=C-(R1*SIN(GA))
LET X4=C-(R1*SIN(GA2))
REM *SECOND RAD
LET R2=(P**2+(F-H)**2-J**2)/(2*(P-J))
LET AL=ARCTAN((F-H)/(R2-P))
LET Y2=F-(R2*COS(AL))
LET AL2=AL/2
LET X5=R2-(R2*COS(AL2))
LET Y5=F-(R2*COS(AL2))
REM * MIDPOINT
LET X3=R*COS(41)
LET Y3=R*SIN(41)
REM * CURVE PLOT *
FA2
IN/C
LT2
LN2
X=0,Y=0
X=C,Y=0
AC
X=0,Y=0
X=0,Y=F
LT1
LN3
X=0,Y=F
X=X5,Y=Y5-F
494
X = X2 - X5, Y = Y2 - Y5
X = X3 - X2, Y = Y3 - Y2
X = X4 - X1, Y = Y4 - Y1
X = C - X4, Y = Y = −Y4
AC
LT2
LN5
X = 0, Y = 0
X = R, Y = 0
A = 90
LN2
X = 0, Y = F
X = 0, Y = N
AC
X = 0, Y = D
X = M, Y = 0
AC
LT1
LN3
X = 0, Y = F
X = 0.25 * M, Y = N / 2
X = M − (0.25 * M), Y = N / 2
AC
* AGAIN
PR MORE (Y/N)
ST/T ANS
IF(ANS.EQ./Y/) GOTO START
* FINISH
END
IF (ANS.EQ./Y/) GOTO START
* FINISH
END

START/3.1
REM * PARAMETRIC SYMBOL TO CONSTRUCT *
REM * BASIC CASUAL JACKET BLOCK - BODY *
REM * 9 STANDARD SIZES AVAILABLE *
REM * SYMBOL NAME - BCJ.PAR *
REM * (C) MICHAEL HALL 1987 *
REM * CREATED 12 MAY 1987 *
REM
REM TITLE
PR BASIC CASUAL JACKET BLOCK - VERSION 1.1
PR STANDARD SIZES AVAILABLE - 88 92 96 100 104 108 112 116 120
REM TURN PROMPTS OFF
FA 29
REM CREATE ANOTHER VIEW
VS16
N=2
AC
N=1/1
REM
FA5
FA13
ME1
N=2
REM SET PROMPTS TO NOVICE
FA 29
*BEGIN
REM * PROMPT USER FOR SIZES *
PR IS CHEST SIZE STANDARD (Y OR N)
ST/T ANS
IF(ANS.EQ.\N/) GOTO SPECIAL
REM SET CHECK FOR LEGAL STANDARD SIZE
LET LG=1;
PR ENTER CHEST SIZE (CM)
ST/N CS
IF(CS.EQ.88) PCALL CHS88.PAR
IF(CS.EQ.92) PCALL CHS92.PAR
IF(CS.EQ.96) PCALL CHS96.PAR
IF(CS.EQ.100) PCALL CHS100.PAR
IF(CS.EQ.104) PCALL CHS104.PAR
IF(CS.EQ.108) PCALL CHS108.PAR
IF(CS.EQ.112) PCALL CHS112.PAR
IF(CS.EQ.116) PCALL CHS116.PAR
IF(CS.EQ.120) PCALL CHS120.PAR
IF(LG.EQ.1) GOTO ILLEGAL
GOTO DRAW
*ILLEGAL
PR ILLEGAL STANDARD SIZE INPUT - TRY AGAIN
GOTO BEGIN
*SPECIAL
PR ENTER CHEST SIZE (CM)
ST/N CHS
PR ENTER SCYE DEPTH (CM)
ST/N SCD
PR ENTER NATURAL WAIST LENGTH (CM)
ST/N NWL
PR ENTER NECK SIZE (CM)
ST/N NS
PR ENTER HALF BACK (CM)
ST/N HB
PR ENTER JACKET LENGTH (CM)
ST/N JL
PR ENTER SLEEVE LENGTH (CM)
ST/N SLO
*DRAW
TLET NAME = MEAST(USER)
TLET DATE = MEAST(DATE)
TLET DNAME = MEAST(NAME)
REM SET PROMPTS TO EXPERT
FA29
REM TITLE OF BLOCK
TE10
TE21
N=0
TE29
TE18
X=1,Y=3
T=/DRAWN - /+NAME
T=/ DATE - /+DATE
TE16
TE17
X=19, Y=1
T=/DRAWING FILENAME - /+DNAME
TE30
TE6
TE18
X=60,Y=80
T=/* VIEW 1 */ BASIC CASUAL JACKET BLOCK - BODY SECTION/
T=/CHEST SIZE (CM) - /+CHS
AC
REM RESET PROMPTS TO NOVICE
FA29
TE15
TE9
LT9
LN1
X=0,Y=5
X=17,Y=0
X=0,Y=-5
REM * VARIABLES FOR REPEAT DIMNS. *
LET QA=(JL+1)
LET QB=(.5*CHS)+7.5
LET QC=(.2*NS)+1
LET QD=SCD+3
LET QE=(.3333*CHS)+.5
LET QF=(.25*NS)-2
LET QG=(.25*NS)-1.5
LET QH=MB+2
LET QJ=(QH+(QE-QH)/2)+1
REM * DRAW BASIC BLOCK *
FA2
X=18,Y=5
REM DRAW GARMENT BLOCK
LT9
LN2
X=0,Y=0
X=0,Y=QG
X=0,Y=QG
X=-2,Y=0
X=QD,Y=0
497
REM DRAW BACK SHOULDER
LET AA=(.5*(.5*(SCD+1)))
LT1
LN2
X=AA-2,Y=QH
X=QA-QD,Y=0
REM DRAW OUTLINE
LT11
LN1
X=0,Y=0
X=QA,Y=QH
X=0,Y=QJ
X=-(QA-QD),Y=0
LN2
X=-2,Y=QG
X=AA,Y=(QH+2)-QG
REM DRAW SCYE (ARMHOLE) CURVE
REM CALL PAR- CRV9.PAR
FA2
X=QA,Y=QH
LET C=((QE-QH)/2)+1
LET D=QA-(AA-2)
LET M=2
LET R=.4*C
PCALL CRV9.PAR
LET TT=TO
REM STORE CALCS FOR LATER ****
LET C11=C1
LET C21=C2
LET C31=C3
LET C41=C4
LET C51=C5
LET EF1=EF
LET R11=R1
LET R21=R2
LET F1=F
LET D1=D
LET M1=M
REM DRAW BACK NECK CURVE
REM CALL PAR- CRV10.PAR
LET A=QQ
LET B=2
LET R=1.35
LET AL=30
LET BE=0
FA2
X=-QD,Y=-QH
PCALL CRV10.PAR
REM SET PROMPTS TO EXPERT
REM FRONT SHOULDER
LET BA=(QB-QF-QH)
LET BB=(QB-QF-QE)
LET BC=((AA*BB)/BA)+1.75

REM DRAW FRONT SCYE (ARMHOLE) CURVE
REM CALL PAR- CRV9.PAR
FA2-
X=GD,Y=QB-(QE+2)
LET C=QE+2-QJ
LET D=OD-BC
LET R=.4*C
FCALL CRV9.PAR
LET TT=TT+TO
LET SP=TT/3
LET SP2=SP/2
LET SP3=F1-SF2.
LET EP2=ARCSIN(SP3/R21)
LET C71=2*R21*(EP2*(3.142/360))
LET BF0=C11+C21+C31-C71
LET BP5=C41+C71
REM CALC LENGTH OF STRAIGHT LINE BP-5
LET BPX=R21-(COS(EP2)*R21)
LET BPA=M1-BPX
LET BPB=D1-F1+SP3
LET FPS=((BFA**2+BPB**2)**.5)
LET FP0=PO
LET FP4=P4
LET FPS=D-YC
REM DRAW FRONT NECK CURVE
REM CALL PAR- CRV11.PAR
FA2
X=QC-QD,Y=QF-(QB-(QE+2))
LET C=QF
LET R=.4*C
FCALL CRV11.PAR
FA2
X=-QC,Y=-QF
REM SET PROMPTS TO EXPERT
FA 29
REM ADD TEXT TO GARMENT FRONT
LT9
TE21
N=0
TE17
X=QD+((NWL+1)-QD)/2,Y=.5
T=/CENTRE FRONT/
AC
TE17
X=NWL+10,Y=.5
T=/NO SEAM ALLOWANCE/
AC
TE21
N=90
TE6
TE18
X=.5*QD,Y=QH/2
T=/FRONT/
T=/CHEST - /+CHS
T=/CUT 2/
AC
TE5
TE17
X=NWL+.5,Y=QJ/2
T=/WAISTLINE/
AC
TE17
X=JL+.5,Y=QJ/2
T=/NO HEM ALLOWANCE/
AC
TE21
N=180
TE17
X=QD+((NWL+1)-QD)/2,Y=QB-(QJ+.5)
T=/NO SEAM ALLOWANCE/
AC
TE17
X=NWL+10,Y=QB-(QJ+.5)
T=/SIDE SEAM/
AC
LN2
X=QD-YC,Y=QB-QE
L=1,A=-45
TE21
N=90
TE17
X=QD-YC,Y=QB-(QE+4)
T=/FP/
FA2
X=0,Y=-(QJ+10)
LN2
X=QD-F1+SP3,Y=QH+BPX
L=1,A=-90
TE17
X=QD-F1+SP3,Y=QH-3
T=/BP/
REM ** CALC. CHECK **
TE6
TE21
N=0
TE18
X=-10; Y=55
T=/TT = +TT
T=/SP = +SP
T=/FPO = +/-FPO
T=/FPS = +/-FPS
T=/BPO = +/-BPO
T=/BPS = +/-BPS
T=/YC = +/-YC
T=/SLO = +/-SLO
T=/BCL = +/-BCL
T=/FCL = +/-FCL
AC
REM RESET USER ORIGIN
FA2
AC
FA1
REM RESET PROMPTS TO NOVICE
FA29
LT9
REM PR DRAW SLEEVE NOW
PR DRAW SLEEVE (Y OR N)
ST/T ANS
IF(ANS.EQ./N/) GOTO FINISH
REM SELECT VIEW 2
FA29
VS1
N=2
FA29
FCALL SLO1.PAR
*FINISH
RND
START/3.1
START/3.1
REM * PARAMETRIC SYMBOL TO FIT A CONTINUOUS *
REM * CURVE TO GARMENT PATTERN PIECES *
REM * PAR. SYMBOL NAME = CRV9.PAR *
REM * (C) MICHAEL K HALL *
REM * CREATED 12 MAY 1987 *
REM * * * * * * * * * * * * * * * * * * * * * *
* START
* CALC
LET F=.4*D
LET N=D-F
LET J=1.8*R
LET H=(J+R)*SIN(41)
LET F=(J+R)*COS(41)
LET Z=F-C
IF(Z.EQ.0)GOTO START
REM * FIRST RAD
LET E=C-(J+R)*COS(41))
LET R1=(H**2+J**2-J**2)/(2*(H-J))
LET GA=ARCTAN(E/(R1-H))
LET X1=C-(R1*SIN(GA))
LET Y1=R1-(R1*COS(GA))
LET GA2=GA/2
LET X4=C-(R1*SIN(GA2))
LET Y4=R1-(R1*COS(GA2))
REM * SECOND RAD
LET R2=(F**2+(F-H)**2-J**2)/(2*(F-J))
LET AL=ARCTAN((F-H)/(R2-F))
LET X2=R2-(R2*COS(AL))
LET Y2=F-(R2*SIN(AL))
LET AL2=AL/2
LET X5=R2-(R2*COS(AL2))
LET Y5=F-(R2*SIN(AL2))
REM * MIDPOINT
LET X3=R*COS(41)
LET Y3=R*SIN(41)
REM CURVE LENGTH CALC
LET C1=2*R1*(GA*(3.142/360))
LET C2=2*R2*(AL*(3.142/360))
LET C3=((90-AL-GA)*(3.142/360))*2*J
LET R3=(4+N**2)/4
LET EP=ARCSIN(N/R3)
LET C4=2*R3*(EP*((3.142/360)))
LET TO=C1+C2+C3+C4
REM *** POSITION OF FP ***
LET XB=F-2
LET TH=ARCCOS(XB/J)
LET YC=H-(SIN(TH)*J)
REM *** CURVE LENGTH FP-O ***
LET CO=90-TH
LET C5=2*J*((CO-GA)*(3.142/360))
LET P0=C5+C1
LET F4=(C1+C2+C3+C4)-P0
REM DRAW CURVE
LT1
LN3
X=0,Y=C
X=-Y4,Y=X4-C
X=Y4-Y1,Y=X1-X4
X=Y1-Y3,Y=X3-X1
503
x = Y3 - Y2, y = x2 - x3
x = Y2 - (5, y = x5 - x2
x = Y5 - F, y = -x5
x = -N/2, y = 0.25 * M
x = -N/2, y = 0.75 * M
AC
*FINISH
END
START/3.1
REM * PARAMETRIC SYMBOL TO FIT NECK *
REM * CURVE TO BASIC BLOCK *
REM * PAR. SYMBOL NAME - CRV10.PAR *
REM * (C)MICHAEL HALL *
REM ****************************************
* START
*CALCS
LET R1 = (B**2 - R**2) / (2*(R+(B*COS(90+AL)))
LET X1 = A - (R1*COS(AL))
LET Y1 = B + (R1*SIN(AL))
LET C = X1 + ((R+(R1*SIN(AL)))*(TAN(BE)))
LET D = (B+(R1*SIN(AL)))/COS(BE)
REM *SECOND RAD
LET R2 = (D**2 + C**2 + (2*D*COS(90+BE)) - R1**2) / (2*(D-R1+(C*COS(90+BE))))
LET X2 = -R2*SIN(BE)
LET Y2 = R2*COSCBE)
LET GA = ARCTAN((Y2-Y1)/(X1-X2))
LET X3 = X1 + (R1*COS(GA))
LET Y3 = Y1 - (R1*SIN(GA))
LET A2 = GA/2
LET Y4 = Y1 - (R1*SIN(A2))
LET X4 = X1 + (R1*COS(A2))
REM MEASURE CURVE LENGTH
LET CL1 = (2*R1* (GA-AL) * (3.142/360)))
LET AM = 90-GA
LET CL2 = (2*R2* (AM*(3.142/360))
LET BCL = CL1 + CL2
LN3
X=B-Y4, Y=X4-A
X=Y4-Y3, Y=X3-X4
X=Y3, Y=-X3
AC
END
START/3.1
REM * PARAMETRIC SYMBOL TO FIT A CONTINUOUS *
REM * CURVE TO GARMENT PATTERN PIECES *
REM * PAR. SYMBOL NAME : CRU11.PAR *
REM * (C) MICHAEL K HALL *
REM * CREATED 08 MAY 1987 *
REM * *********************************************************
* START
* CALCS
LET J=1.8*R
LET H=(J+R)*SIN(41)
LET P=(J+R)*COS(41)
LET Z=F-C
IF(Z.GE.0)GOTO START
REM * FIRST RAD
LET E=C-((J+R)*COS(41))
LET R1=(H**2+J**2-J**2)/(2*(H-J))
LET GA=ARCTAN(E/(R1-H))
LET X1=C-(R1*SIN(GA))
LET Y1=R1-(R1*COS(GA))
LET GA2=GA/2
LET X4=C-(R1*SIN(GA2))
LET Y4=R1-(R1*COS(GA2))
REM * SECOND RAD
LET R2=(P**2+(F-H)**2-J**2)/(2*(P-J))
LET AL=ARCTAN((F-H)/(R2-P))
LET X2=R2-(R2*COS(AL))
LET Y2=F-(R2*SIN(AL))
LET AL2=AL/2
LET X5=R2-(R2*COS(AL2))
LET Y5=F-(R2*SIN(AL2))
REM * MIDPOINT
LET X3=R*COS(41)
LET Y3=R*SIN(41)
REM CURVE LENGTH
LET LC1=(2*R1*(GA*(3.142/360))
LET LC2=(2*R2*(AL*(3.142/360))
LET LC3=(*90-GA-AL)*((3.142/360))*2*J
LET FCL=LC1+LC2+LC3
REM * CURVE PLOT *
*LCURE
LT1
LH3
X=0,Y=-C
X=-Y4,Y=C-X4
X=Y4-Y1,Y=X4-X1
X=Y1-Y3,Y=X1-X3
X=Y3-Y2,Y=X3-X2
X=Y2-Y5,Y=X2-X5
X=Y5-F,Y=X5
AC
END
SET PROMPT TO EXPERT
FA29
ADD TITLE TO BLOCK
TE16
TE30
TE6
TE18
X=60,Y=80
T=/* VIEW 2 * BASIC ONE-PIECE SLEEVE BLOCK/
T=/TO MATCH CHEST SIZE (CM) - /+CHS
TE15
TE9
*DRAW
LET SP2=SP/2
LET S2=((FP0+.75)**2-YC**(2)**.5
LET TS=ARCSIN(YC/(FP0+.75))
LET HS2=SIN(TS)*((FP0+.75)/2)
LET HS21=COS(TS)*((FP0+.75)/2)
LET T31=90-TS
LET S21=SIN(T31)*.75
LET S22=COS(T31)*.75
LET S31=SP-YC
LET S3=((FPS+2)**2-S31**2)**.5
LET TS31=ARCSIN(S3/(FPS+2))
LET TS32=ARCCOS(S3/(FPS+2))
LET S34=(FPS+2)/3
LET S37=SIN(TS32)*S34
LET S38=COS(TS32)*S34
LET T33=90-TS32
LET S35=SIN(TS33)*2
LET S36=COS(TS33)*2
LET S32=SIN(TS31)*4
LET S33=COS(TS31)*4
LET S311=S3-S38-S34-S32
LET S312=S31-S37+S35-S33
LET S313=((S311**2)+(S312**2))**.5
LET TS34=ARCSIN(S312/S313)
LET S314=COS(TS34)*((S313/2)
LET S315=SIN(TS34)*((S313/2)
LET S4=ARCSIN(SP2/(FPS+1.5))
LET S41=COS(TS4)*((FPS+1.5)
LET S44=SIN(TS4)*((FPS+1.5)/2)
LET S45=COS(TS4)*((FPS+1.5)/2)
LET T5=ARCSIN(SP2/(FPS+.75))
LET S5=COS(TS5)*((FPS+.75)
LET S51 = SIN(TS5) * ((BFO+.75)/2)
LET S52 = COS(TS5) * ((BFO+.75)/2)
LET TS51 = 90 - TS5
LET S53 = SIN(TS51) * .75
LET S54 = COS(TS51) * .75
REM DRAW SLEEVE CONST LINES
FA2
X = 90, Y = 40
LT9
LN1
X = 0, Y = 0
X = 0, Y = S3 + S2
X = -(SLO - SP), Y = 0
X = -YC, Y = -S2
X = -S31, Y = -S3
X = SP2, Y = -S41
X = SP2, Y = -S5
X = SLO - SP, Y = 0
X = 0, Y = S5 + S41
LN2
X = 1, Y = -((S5 + S41 - 5)/2)
X = -10, Y = 0
X = -4, Y = -((S5 + S41 - 5)/2) + 1
X = 0, Y = 2
X = -((SLO - SP)/2), Y = -S5 + S41
X = 0, Y = S5 + S41 + S3 + S2
X = SLO + SP2, Y = -S41
L = 1, A = 45
X = SLO + SP - YC, Y = S3
L = 1, A = -45
X = 0, Y = 0
X = -SLO, Y = 0
X = -SLO + SP, Y = -S41 - S5
X = 0, Y = S5 + S41 + S3 + S2
X = SLO + SP - HS2, Y = S3 + S2 - HS2
X = S21, Y = -S22
X = SLO + S37, Y = S38
X = -S35, Y = S36
X = SLO + S44, Y = -S45
X = -S42, Y = -S43
X = SLO + SP2 + S51, Y = -S41 - S52
X = -S53, Y = S54
X = SLO + SP2 + S51, Y = -S41 - S52
X = S53, Y = S54
REM SLEEVE OUTLINE
LT11
LN2
X = SLO + SP, Y = -S41 - S5
X = SLO - SP, Y = 5
LN1
X = 0, Y = 0
X = 0, Y = S3 + S2 - 5
X = -SLO + SP, Y = 5
REM CONTINUOUS CURVE
LN3
X = 0, Y = -S41 - S5 + 5
X = 1, Y = (S5 + S41 - 5)/2
X = -1, Y = (S5 + S41 - 5)/2
AC
LH2
X = -SL0 + S31, Y = S3
X = -S33, Y = -S32
AC
LN3
X = -SL0 + SP, Y = S3 + S2
X = -HS2 + S21, Y = -HS21 - S22
X = -S21 + HS2 - YC, Y = S22 + HS21 - S2
AC
LN3
X = -SL0, Y = 0
X = S37 - S35, Y = S38 + S36
X = S312 - S315, Y = S311 - S314
X = S315, Y = S314
AC
REM ADD TEXT
LT9
TE15
TE5
TE29
TE21
N = 90
TE17
X = -((SL0 - SP)/2) - 1, Y = 1
T = /ELBOW LINE/
X = -SL0 + SP2 + 2, Y = -S41 + 2
T = /BP/
X = -SL0 + SP - YC, Y = S3 - 4
T = /FP/
TE30
TE6
TE18
X = -SL0 + SP + 2, Y = 0
T = /ONE-PIECE SLEEVE/
T = /TO FIT CHEST - /+CHS+//
T = /CUT 2/
REM RESET PROMPTS TO NOVICE
FA29
REM RESET USER ORIGIN
FA2
AC
FA1
END
START/3.1
REM *PARAMETRIC -CHS88.PAR *
LET CHS=88
LET SCD=22
LET NWL=43.4
LET NS=37
LET HB=18.5
LET SLO=63.6
LET SLT=78
LET CPT=27
PR ENTER JACKET LENGTH (CM)
ST/N JL
REM SET LG TO 2 - LEGAL STANDARD SIZE
LET LG=2
END
START/3.1
REM *PARAMETRIC -CHS92.PAR *
LET CHS=92
LET SCD=22.8
LET NWL=43.8
LET NS=38
LET HB=19
LET SLO=64.2
LET SLT=79
LET CFT=28
PR ENTER JACKET LENGTH (CM)
ST/N JL
REM SET LG TO 2 - LEGAL STANDARD SIZE
LET LG=2
END
START/3.1
REM *PARAMETRIC -CHS96.PAR *
LET CHS=96
LET SCD=23.6
LET NWL=44.2
LET H5=39
LET HB=19.5
LET SLO=64.8
LET SLT=81
LET CFT=29
PR ENTER JACKET LENGTH (CM)
ST/N JL
REM SET LG TO 2 - LEGAL STANDARD SIZE
LET LG=2
END
START/3.1
REM *PARAMETRIC -CHS100.PAR *
LET CHS=100
LET SCD=24.4
LET NWL=44.6
LET NS=40
LET HB=20
LET SLO=65.4
LET SLT=82
LET CFT=30
PR ENTER JACKET LENGTH (CM)
ST/N JL
REM SET LG TO 2 - LEGAL STANDARD SIZE
LET LG=2
END
START/3.1
REM *PARAMETRIC -CHS104.FAR *
LET CHS=104
LET SCD=25.2
LET NWL=45
LET NS=41
LET HB=20.5
LET SL0=66
LET SLT=83
LET CFT=30
PR ENTER JACKET LENGTH (CM)
ST/N JL
REM SET LG TO 2 - LEGAL STANDARD SIZE
LET LG=2
END
START/3.1
REM *PARAMETRIC -CHS108.FAR *
LET CHS=108
LET SCD=26
LET NWL=45
LET NS=42
LET HB=21
LET SLO=66
LET SLT=83.5
LET CFT=31.6
PR ENTER JACKET LENGTH (CM)
ST/N JL
REM SET LG TO 2 - LEGAL STANDARD SIZE
LET LG=2
END
START/3.1
REM  *PARAMETRIC -CHS112.PAR *
LET CHS=112
LET SCD=26.4
LET NWL=45
LET NS=43
LET HB=21.5
LET SL0=66
LET SLT=84
LET CFT=32.2
PR ENTER JACKET LENGTH (CM)
ST/N JL
REM  SET LG TO 2 - LEGAL STANDARD SIZE
LET LG=2
END
START/3.1
REM #PARAMETRIC -CHS116.PAR#
LET CHS=11.4
LET SCD=26.8
LET NWL=45
LET NS=44
LET HB=22
LET SLO=66
LET SLT=84.5
LET CFT=32.8
PR ENTER JACKET LENGTH (CM)
ST/N JL
REM SET LG TO 2 - LEGAL STANDARD SIZE
LET LG=2
END
START/3.1
REM *PARAMETRIC -CHS120.FAR *
LET CHS=120
LET SCD=27.2
LET NWL=45
LET NS=45
LET HB=22.5
LET SLO=66
LET SLT=85
LET CFT=33.4
PRINT ENTER JACKET LENGTH (CM)
ST/N JL
REM SET LG TO 2 - LEGAL STANDARD SIZE
LET LG=2
END
R.C.S. MICROSYSTEMS ELEVEN-Q MICROCOMPUTER BLOCK DIAGRAM
**User 6522 Address Assignment**

$0800$  Port B  Data Register

$0801$  Port A  Data Register  Controls Handshake

$0802$  Port B  Data Direction Register  $0 = $ Input

$0803$  Port A  Data Direction Register  $1 = $ Output

R/W = L  R/W = H

$0804$  Write T1LL  Read T1CL,Clr.Int. Flag

$0805$  Write T1L-H & T1CH  Read T1CH

T1LL T1CL,Clr. Int.Flag

$0806$  Write T1LL  Read T1LL

$0807$  Write T1LL,Clr. Int.Flag Read T1LL

$0808$  Write T2CH  Read T2CH,Clr.Int.Flag

$0809$  Write T2CH  Read T2CH

T2LL T2CL, Clr.Int.Flag

$080A$  Shift Register

$080B$  Auxiliary Control Register

$080C$  Peripheral Control Register

$080D$  Interrupt Flag Register

$080E$  Interrupt Enable Register

$080F$  Port A Data Register. No effect on handshake

For a detailed description of the VIA refer to Rockwell R6522 data sheet, document number 29000 D47.
<table>
<thead>
<tr>
<th>IDC</th>
<th>37 Way 'D' Type Socket</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CB2</td>
<td>1</td>
</tr>
<tr>
<td>3 CB1</td>
<td>2</td>
</tr>
<tr>
<td>5 PORT B7</td>
<td>3</td>
</tr>
<tr>
<td>7 PORT B6</td>
<td>4</td>
</tr>
<tr>
<td>9 PORT B5</td>
<td>5</td>
</tr>
<tr>
<td>11 PORT B4</td>
<td>6</td>
</tr>
<tr>
<td>13 PORT B3</td>
<td>7</td>
</tr>
<tr>
<td>15 PORT B2</td>
<td>8</td>
</tr>
<tr>
<td>17 PORT B1</td>
<td>9</td>
</tr>
<tr>
<td>19 PORT B0</td>
<td>10</td>
</tr>
<tr>
<td>21 PORT A7</td>
<td>11</td>
</tr>
<tr>
<td>23 PORT A6</td>
<td>12</td>
</tr>
<tr>
<td>25 PORT A5</td>
<td>13</td>
</tr>
<tr>
<td>27 PORT A4</td>
<td>14</td>
</tr>
<tr>
<td>29 PORT A3</td>
<td>15</td>
</tr>
<tr>
<td>31 PORT A2</td>
<td>16</td>
</tr>
<tr>
<td>33 PORT A1</td>
<td>17</td>
</tr>
<tr>
<td>35 PORT A0</td>
<td>18</td>
</tr>
<tr>
<td>37 CA2</td>
<td>19</td>
</tr>
<tr>
<td>39 CA1</td>
<td>20</td>
</tr>
</tbody>
</table>

Even pins 2 to 40
GROUND except 2 and 40
which may optionally be +5v.

21 to 37 GROUND except 21
and 37 which may
optionally be +5v.
Programme Listing

SENSOR AND MOTOR CONTROL PROGRAMME

$1000  A9  00  LDA #$00  Initialise
1002   8D  01  08  STA DRA  Ports A & B.
1005   A9  C0  LDA #$C0
1007   8D  03  08  STA DDRA
100A   A9  03  LDA #$01
100C   8D  00  08  STA DRB
100F   8D  02  08  STA DDRB
1012   20  12  F8 .read  JSR KEY  Check for any
1015   C9  00  CMP #$00  key pressed.
1017   F0  03  BNE again
1019   4C  00  11  JMP $1100
101C   A9  08  .again  LDA #$08
101E   20  15  F8 JSR DISPL
1021   A2  00  LDX #$00  Init. counter.
1023   A9  FE  LDA #$FE  Enable bit 0
1025   8D  00  08  STA DRB  Port B.
1028   AD  01  08  LDA DRA  Read port A.
102B   29  3F  AND #$3F  Mask out bits 7&8
102D   C9  00  CMP #$00
102F   D0  0A  BNE out
1031   EA
1032   EA EA
1034   EA EA
1036   EA EA
1038   4C  12  10  JMP read
103B   EA EA EA .out
103E   8D  BF  10  STA $10BF  Store port value.
1041   EA EA
1043   A9  3F  LDA #$3F
1045   CD  BF  10 .loop1  CMP $10BF  Loop checks which
1048   F0  0A  BNE display sensors are
104A   E8  INX  covered.
104B   E0  06  CPX #$06
104D   F0  C3  BNE read
104F   18  CLC
1050   96  ROR A
1051   4C  45  10  JMP loop1
1054   EA EA EA .display
1057   EA EA
1059   EA EA
105B   BD  C0  10  LDA $10C0,X  Load sensor
105E   20  15  F8 JSR DISPL  number from
1061   EA EA EA  look-up table and
1064   EA EA EA  displays character

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INITIALISATION ROUTINE

1100  A9 0D .start LDA #$0D Clear display.
1102  20 15 F8 JSR DISPL
1105  A2 00 LDX #$00
1107  20 15 F8 .al JSR DISPL
110A  BD A0 11 LDA $11A0,X Display 'Enter
110D  EB INX seam width (1-4)'.
110E  C9 00 CMP #$00
1110  DO F5 BNE al
1112  20 12 F8 .wait JSR KEY Wait for key to
1115  38 SEC be pressed
1116  F9 31 SBC #$31 check that it is
1118  30 F8 BMI wait range 1-4.
111A  C9 04 CMP #$04
111C  BO F4 BCS wait
111E  8D FF STA $11FF Store key value
1121  18 CLC
1122  0A ASL A Double key value.
1123  8D FE 11 STA $11FE Store value.
1126  A9 0D LDA #$0D Clear display.
1128  20 15 F8 JSR DISPL
112B  A9 0A LDA #$0A
A2 00  LDX #$00  Set X to zero.
20 15 F8  a2  JSR DISPL
BD B2 11  LDA $11B2,X  Display
C9 00  CMP #$00  'seam width'.
D0 F5  BNE a2
AE FE 11  LDA $11FE
AD FF 11  LDA $11FE
C9 00  CMP #$00  Compare key value
to zero.
F0 0C  BNE double
EA EA
EA EA
EA EA
4C 55 11  JMP single
A9 31  LDA #$31
20 15 F8  JSR DISPL  Display no. '1'.
BD C0 11  LDA $11C0,X  Display first
20 15 F8  JSR DISPL  value from look-
A9 2E  LDA #$2E  up table.
B0 2F  JSR DISPL  Display a point ' \('.
E8  INX
BD C0 11  LDA $11C0,X  Display 2nd value
20 15 F8  JSR DISPL  from look-up table.
A9 6D  LDA #$6D
20 15 F8  JSR DISPL  Display "mm".
A9 6D  LDA #$6D
20 15 F8  JSR DISPL
A9 6D  LDA #$6D
20 15 F8  JSR DISPL
A2 00  LDX #$00  Clear X register.
A9 11  LDA #$11  Store acwise codes
9D B0 10  STA $10B0,X  at memory locations
EC FF 11  CPX $11FF  starting at $10B0
F0 04  BNE ocl  When X value equals
E8  INX  key value branch to
4C 75 11  JMP ac  ocl.
E8  .ocl  INX
A9 00  LDA #$00  Store value 00.
9D B0 11  STA $10B0,X
E8  .cl  INX
9D FF  LDA #$FF  Store clwise codes
9D B0 10  STA $10B0,X  at remaining
E0 06  CPX #$0E  memory locations.
F0 03  BNE fin
4C 87 11  JMP cl
4C 00 10  JMP $1000  Jump to sensor
    motor control
    routine at $1000.
### Look-Up Table Memory Addresses

<table>
<thead>
<tr>
<th>$10B0</th>
<th>XX</th>
<th>RESERVED</th>
<th>$10C0</th>
<th>36</th>
<th>SENSOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10B1</td>
<td>XX</td>
<td>FOR</td>
<td>$10C1</td>
<td>35</td>
<td>NUMBER</td>
</tr>
<tr>
<td>$10B2</td>
<td>XX</td>
<td>MOTOR</td>
<td>$10C2</td>
<td>34</td>
<td>DISPLAY</td>
</tr>
<tr>
<td>$10B3</td>
<td>XX</td>
<td>DIRECTION</td>
<td>$10C3</td>
<td>33</td>
<td>INDICATOR</td>
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<tr>
<td>$10B4</td>
<td>XX</td>
<td>CODES</td>
<td>$10C4</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>$10B5</td>
<td>XX</td>
<td></td>
<td>$10C5</td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$11FF</th>
<th>XX</th>
<th>RESERVED FOR KEY NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>$11FE</td>
<td>XX</td>
<td>DOUBLE KEY VALUE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$11A0</th>
<th>45</th>
<th>E</th>
<th>$11B2</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>$11A1</td>
<td>6E</td>
<td>n</td>
<td>$11B3</td>
<td>20</td>
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<tr>
<td>$11A2</td>
<td>74</td>
<td>t</td>
<td>$11B4</td>
<td>53</td>
</tr>
<tr>
<td>$11A3</td>
<td>65</td>
<td>e</td>
<td>$11B5</td>
<td>65</td>
</tr>
<tr>
<td>$11A4</td>
<td>72</td>
<td>r</td>
<td>$11B6</td>
<td>61</td>
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<tr>
<td>$11A5</td>
<td>20</td>
<td></td>
<td>$11B7</td>
<td>6D</td>
</tr>
<tr>
<td>$11A6</td>
<td>57</td>
<td>w</td>
<td>$11B8</td>
<td>20</td>
</tr>
<tr>
<td>$11A7</td>
<td>69</td>
<td>i</td>
<td>$11B9</td>
<td>57</td>
</tr>
<tr>
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<td>64</td>
<td>d</td>
<td>$11BA</td>
<td>69</td>
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<tr>
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<td>74</td>
<td>t</td>
<td>$11BB</td>
<td>64</td>
</tr>
<tr>
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<td>$11BE</td>
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<td>00</td>
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<tr>
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<td>$11C0</td>
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</tr>
<tr>
<td>$11B0</td>
<td>29</td>
<td>)</td>
<td>$11C1</td>
<td>35</td>
</tr>
<tr>
<td>$11B1</td>
<td>00</td>
<td>stop</td>
<td>$11C2</td>
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</tr>
<tr>
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<td></td>
<td></td>
<td>$11C3</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>$11C4</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>$11C5</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$11C6</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$11C7</td>
<td>30</td>
</tr>
</tbody>
</table>
SIEMENS

FEATURES

- Low Cost
- Miniature Size
- Available as Single Unit, LD 261 and Arrays:
  - Two Diodes, LD 262
  - Three Diodes, LD 263
  - Four Diodes, LD 264
  - Five Diodes, LD 265
  - Six Diodes, LD 266
  - Seven Diodes, LD 267
  - Eight Diodes, LD 268
  - Nine Diodes, LD 269
  - Ten Diodes, LD 260
- Medium Wide Beem, 30°
- High Power, 8 mW Typical
- High Intensity, 10 mW/sr

DESCRIPTION

The LD 261 series, GaAs infrared emitting diodes, emit radiation at a wavelength in the near infrared range. This miniature device comes in a grey plastic package and is available as a single emitter as well as two through ten element arrays. The terminals are solder pins with 10° lead spacing. The LD 261 series is designed for use with the BPX 81 series phototransistor when the spacing between each is approximately 10mm. These devices can easily be mounted on PC boards and in thick film circuits for simple or complex scanning systems.

Supplied by:

NORBAIN TECHNOLOGY

Norbain House, Boulton Road,
Reading, Berkshire RG1 0LT
Tel: (0734) 864411 Telex: 847203
Fax: (0734) 751464

LD 261 SERIES
INFRARED EMITTER
SINGLE AND ARRAYS

Package Dimensions in Inches (mm)

Maximum Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Single Unit</th>
<th>Arrays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength ((\lambda) = 50 mA, (I_p) = 20 ms)</td>
<td>950 ± 20 nm</td>
<td></td>
</tr>
<tr>
<td>Spectral Bandwidth</td>
<td>55 nm</td>
<td></td>
</tr>
<tr>
<td>Half Angle</td>
<td>± 30 Deg</td>
<td></td>
</tr>
<tr>
<td>Active Area</td>
<td>0.25 mm²</td>
<td></td>
</tr>
<tr>
<td>Active Area per Die</td>
<td>0.5 x 0.5 mm</td>
<td></td>
</tr>
<tr>
<td>Distance Die Surface to Package Surface</td>
<td>1.3 ± 0.1 mm</td>
<td></td>
</tr>
<tr>
<td>Switching Time ((I_s) from 10% to 90% and from 90% to 10%) at (I_s) = 50 mA</td>
<td>1, 1</td>
<td>μs</td>
</tr>
<tr>
<td>Capacitance ((V_o) = 0 V)</td>
<td>40 pF</td>
<td></td>
</tr>
<tr>
<td>Forward Voltage</td>
<td>1.25 ± 0.4 V</td>
<td></td>
</tr>
<tr>
<td>Breakdown Voltage ((I_s) = 10 μA)</td>
<td>30 ± 2 V</td>
<td></td>
</tr>
<tr>
<td>Reverse Current ((V_o) = 10 V)</td>
<td>0.01 (≤ 10) mA</td>
<td></td>
</tr>
<tr>
<td>Temperature Coefficient of (I_s) or (P_s)</td>
<td>-0.55 °C/k</td>
<td></td>
</tr>
<tr>
<td>Temperature Coefficient of (V_o)</td>
<td>-1.5 mW/K</td>
<td></td>
</tr>
<tr>
<td>Temperature Coefficient of (I_p)</td>
<td>0.1 °C/mW</td>
<td></td>
</tr>
</tbody>
</table>

Radiant Intensity \(I_o\) in Axial Direction Measured at a Solid Angle of \(θ = 0.01\) sr

<table>
<thead>
<tr>
<th>Group</th>
<th>LD261-4</th>
<th>LD261-5</th>
<th>LD261-6</th>
<th>260, 262-269</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiant Intensity ((I_s) = 50 mA, (I_p) = 20 ms)</td>
<td>2 to 4</td>
<td>3.2 to 6.3</td>
<td>≥ 5</td>
<td>2.5 to 8 mW/mm²</td>
</tr>
<tr>
<td>Radiant Power ((I_s) = 50 mA, (I_p) = 20 ms)</td>
<td>5</td>
<td>6.5</td>
<td>8</td>
<td>5 to 8 mW</td>
</tr>
</tbody>
</table>

Specifications are subject to change without notice.
**SIEMENS**

**BPX 81 SERIES**

**PHOTOTRANSISTOR**

**SINGLE AND ARRAYS**

---

**FEATURES**
- Silicon NPN Planar Phototransistor
- Low Cost
- Miniature Size
- Available As Single Unit, BPX 81 and Arrays:
  - Two Chip, BPX 82
  - Three Chip, BPX 83
  - Four Chip, BPX 84
  - Five Chip, BPX 85
  - Six Chip, BPX 86
  - Seven Chip, BPX 87
  - Eight Chip, BPX 88
  - Nine Chip, BPX 89
  - Ten Chip, BPX 90
- Narrow Acceptance Angle, 18°
- High Gain, Up to 5 mA

**DESCRIPTION**

The types BPX 80 to BPX 89 are plastic encapsulated phototransistor arrays consisting of an arrangement of max. 10 silicon NPN epitaxial planar phototransistors. The individual photodetectors are spaced apart according to the standard lead spacing of 2.54 mm (1/10`). A small angle of the lens-shaped light window avoids optical "cross modulation" from the adjacent system. The collector terminals are marked by small projections arranged at the sides of the solder pins. The phototransistor is suitable for versatile applications in conjunction with filament lamps and infrared light. The BPX 81 can be mounted on PC boards and is also provided for use as detector of the light emitting diode LD 261 (same type as BPX 81) in miniature light barriers.

Supplied by:

**NORBAIN TECHNOLOGY**

Norbain House, Boulton Road, Reading, Berkshire RG2 0LT
Tel: (0734) 864411 Telex: 847203
Fax: (0734) 751464

---

**Maximum Ratings**

- Operating and Storage Temperature: T from -40 to +80 °C
- Soldering Temperature:
  - Distance from soldering point to package ≥ 2 mm
  - Dip Soldering Time t ≤ 5 s
  - Iron Soldering Time t ≤ 3 s
- Collector Emitter Voltage V_{CE} ≤ 32 V
- Collector Current I_{C} = 50 mA
- Collector Peak Current (t < 10 μs) I_{P} ≤ 200 mA
- Power Dissipation (T_{amb} = 25 °C) P_{D} ≤ 100 mW
- Thermal Resistance R_{θJA} ≤ 750 K/W
- R_{θJG} ≤ 650 K/W

**Characteristics (T_{amb} = 25 °C)**

- Wavelength of Max. Photosensitivity: \( \lambda_{\text{max}} \) = 850 nm
- Spectral Range of Photosensitivity: \( \lambda \) from 440 to 1070 nm
- Radiant Sensitivity Area A = 0.17 mm²
- Die Area \( L \times W \) = 0.6 x 0.6 mm
- Distance Die Surface to Package Surface H = 1.3 x 1.9 mm
- Half Angle \( \Phi \) < 18° Deg
- Capacitance \( C_{CE} \) = 6 pF
- Collector Emitter Leakage Current (V_{CE} = 35 V, E = 0 V) \( I_{CEO} \) ≤ 25 (≤ 200) nA

**Group**

<table>
<thead>
<tr>
<th>Group</th>
<th>BPX81-2</th>
<th>BPX81-3</th>
<th>BPX81-4</th>
<th>BPX82-89</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photocurrent of the Transistor, Collector to Emitter (Note 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( (E_v = 1000 \text{ ix}) )</td>
<td>( I_p )</td>
<td>1.0 to 2.0</td>
<td>1.6 to 3.2</td>
<td>≥ 2.5</td>
</tr>
<tr>
<td>( (E_v = 0.5 \text{ mW/cm}^2 )</td>
<td>( I_p )</td>
<td>25 to 50</td>
<td>40 to 80</td>
<td>≥ 63</td>
</tr>
<tr>
<td>Rise/Fall Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( (t_{on} = 1 \mu s, V_{CE} = 5 \text{ V}) )</td>
<td>( I_p )</td>
<td>5.5</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Collector Emitter Saturation Voltage ( (I_{C} = I_{CEO} = 0 \text{ mA}) )</td>
<td>( V_{CEO} ) = 0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collector Emitter Current Gain (E = 1000 kV)</td>
<td>( I_{CEO} )</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Collector Emitter Voltage (E = 5 V)</td>
<td>( I_{CEO} )</td>
<td>190</td>
<td>300</td>
<td>450</td>
</tr>
</tbody>
</table>

The illuminances refer to unfiltered radiation of a tungsten filament lamp at a color temperature of 2856 K (standard light A in accordance with DIN 5033 and IEC 306-1). Irradiance \( E_v \) measured with HP radiant flux meter 8334A with option 013

1 Measured with LED \( \lambda = 950 \text{ nm} \), \( V_{CEO} = \) Photocurrent of transistor \( I_{CEO} = \) Photocurrent of Collector Base Diode

Specifications are subject to change without notice.

---

525c
Appendix J

OPERATOR - EXPERIENCED

SPEED - SLOW SAMPLE - A

<table>
<thead>
<tr>
<th>SEAM</th>
<th>1</th>
<th>SD</th>
<th>2</th>
<th>SD</th>
<th>3</th>
<th>SD</th>
<th>4</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.07</td>
<td>0.32</td>
<td>4.07</td>
<td>0.32</td>
<td>6.07</td>
<td>0.18</td>
<td>7.59</td>
<td>0.45</td>
</tr>
<tr>
<td>2</td>
<td>2.21</td>
<td>0.25</td>
<td>4.14</td>
<td>0.64</td>
<td>6.43</td>
<td>0.50</td>
<td>8.43</td>
<td>0.62</td>
</tr>
<tr>
<td>3</td>
<td>2.50</td>
<td>0.38</td>
<td>4.64</td>
<td>0.35</td>
<td>6.64</td>
<td>0.52</td>
<td>8.57</td>
<td>0.42</td>
</tr>
<tr>
<td>4</td>
<td>2.57</td>
<td>0.42</td>
<td>5.07</td>
<td>0.42</td>
<td>6.57</td>
<td>0.56</td>
<td>8.50</td>
<td>0.54</td>
</tr>
<tr>
<td>5</td>
<td>3.57</td>
<td>0.68</td>
<td>5.79</td>
<td>0.65</td>
<td>7.79</td>
<td>0.80</td>
<td>10.36</td>
<td>0.74</td>
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<tr>
<td>6</td>
<td>3.07</td>
<td>0.32</td>
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<td>0.44</td>
<td>8.43</td>
<td>0.42</td>
<td>10.79</td>
<td>0.43</td>
</tr>
<tr>
<td>7</td>
<td>3.21</td>
<td>0.25</td>
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1st SEAM MIN - 2.07mm MAX - 3.57mm RANGE - 1.5mm
MEAN - 2.88mm (SD 0.48)
SD MIN 0.25 SD MAX 0.68 MEAN 0.37 (SD 0.13)

2nd SEAM MIN - 4.07mm MAX - 6.21mm RANGE - 2.14mm
MEAN - 5.23mm (SD 0.69)
SD MIN 0.32 SD MAX 0.65 MEAN 0.45 (SD 0.12)

3rd SEAM MIN - 6.07mm MAX - 9.21mm RANGE - 3.14mm
MEAN - 7.64mm (SD 1.05)
SD MIN 0.18 SD MAX 0.80 MEAN 0.49 (SD 0.15)

4th SEAM MIN - 7.59mm MAX - 12.14mm RANGE - 4.55mm
MEAN - 9.87mm (SD 1.44)
SD MIN 0.42 SD MAX 0.74 MEAN 0.56 (SD 0.12)
## OPERATOR - EXPERIENCED

### SPEED - SLOW  
### SAMPLE - B

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MIN - 2.43mm  MAX - 3.93mm  RANGE - 1.50mm  
MEAN - 3.32mm (SD 0.48)  
SD MIN 0.23  SD MAX 1.02  MEAN 0.58 (SD 0.22)

2nd SEAM  
MIN - 4.00mm  MAX - 7.21mm  RANGE - 3.21mm  
MEAN - 5.86mm (SD 0.89)  
SD MIN 0.36  SD MAX 1.19  MEAN 0.67 (SD 0.24)

3rd SEAM  
MIN - 5.64mm  MAX - 10.57mm  RANGE - 4.93mm  
MEAN - 8.41mm (SD 1.40)  
SD MIN 0.36  SD MAX 1.15  MEAN 0.78 (SD 0.27)

4th SEAM  
MIN - 7.21mm  MAX - 14.07mm  RANGE - 6.86mm  
MEAN - 10.95mm (SD 1.92)  
SD MIN 0.69  SD MAX 1.45  MEAN 0.97 (SD 0.26)
OPERATOR - EXPERIENCED

SPEED - FAST

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1st SEAM
MIN - 1.57mm  MAX - 4.43mm  RANGE - 2.86mm
MEAN - 2.99mm  (SD 0.95)
SD MIN 0.27   SD MAX 1.06   MEAN 0.57 (SD 0.23)

2nd SEAM
MIN - 2.79mm  MAX - 7.50mm  RANGE - 4.71mm
MEAN - 5.47mm  (SD 1.39)
SD MIN 0.35   SD MAX 0.96   MEAN 0.59 (SD 0.23)

3rd SEAM
MIN - 4.65mm  MAX - 10.29mm  RANGE - 5.64mm
MEAN - 7.73mm  (SD 1.82)
SD MIN 0.25   SD MAX 1.84   MEAN 0.71 (SD 0.84)

4th SEAM
MIN - 6.71mm  MAX - 12.93mm  RANGE - 6.22mm
MEAN 10.09mm  (SD 2.22)
SD MIN 0.32   SD MAX 1.85   MEAN 0.77 (SD 0.47)
### OPERATOR - EXPERIENCED

#### SPEED - FAST  
#### SAMPLE - B

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1st SEAM MIN - 2.29mm  
MAX - 4.36mm  
RANGE - 2.07mm  
MEAN - 3.38mm (SD 0.66)

SD MIN 0.23  
SD MAX 1.18  
MEAN 0.58 (SD 0.20)

2nd SEAM MIN - 3.93mm  
MAX - 7.43mm  
RANGE - 3.50mm  
MEAN - 5.91mm (SD 1.0)

SD MIN 0.44  
SD MAX 1.12  
MEAN 0.79 (SD 0.19)

3rd SEAM MIN - 5.00mm  
MAX - 10.86mm  
RANGE - 5.86mm  
MEAN - 8.24mm (SD 1.66)

SD MIN 0.52  
SD MAX 1.27  
MEAN 0.90 (SD 0.24)

4th SEAM MIN - 6.57mm  
MAX - 14.50mm  
RANGE - 7.93mm  
MEAN - 10.80mm (SD 2.36)

SD MIN 0.56  
SD MAX 1.64  
MEAN 1.11 (SD 0.33)

529
OPERATOR - INEXPERIENCED

SPEED - SLOW    SAMPLE - A

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1st SEAM
MIN - 2.92mm  MAX - 6.00mm  RANGE - 3.08mm
MEAN - 4.1mm  (SD 1.18)
SD MIN 0.17  SD MAX 0.60  MEAN 0.45 (SD 0.14)

2nd SEAM
MIN - 5.43mm  MAX - 12.14mm  RANGE - 6.71mm
MEAN - 7.4mm  (SD 2.04)
SD MIN 0.17  SD MAX 1.16  MEAN 0.57 (SD 0.29)

3rd SEAM
MIN - 7.57mm  MAX - 18.14mm  RANGE - 10.57mm
MEAN - 10.34mm (SD 3.15)
SD MIN 0.27  SD MAX 1.38  MEAN 0.67 (SD 0.38)

4th SEAM
MIN - 9.79mm  MAX - 23.79mm  RANGE - 14.00mm
MEAN - 13.21mm (SD 4.31)
SD MIN 0.17  SD MAX 1.88  MEAN 0.71 (SD 0.51)
## Operator - Inexperienced

### Speed - Slow  Sample - B

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1st SEAM  MIN - 2.57mm  MAX - 6.57mm  RANGE - 4.0mm
          MEAN - 4.03mm  (SD 1.17)
SD MIN 0.49  SD MAX 1.21  MEAN 0.71  (SD 0.21)

2nd SEAM  MIN - 4.43mm  MAX - 10.50mm  RANGE 6.07mm
          MEAN - 7.19mm  (SD 1.93)
SD MIN 0.52  SD MAX 1.38  MEAN 0.95  (SD 0.27)

3rd SEAM  MIN - 6.00mm  MAX - 16.43mm  RANGE - 10.43mm
          MEAN - 10.15mm (SD 3.29)
SD MIN 0.56  SD MAX 1.83  MEAN 1.09  (SD 0.36)

4th SEAM  MIN - 7.57mm  MAX - 22.64mm  RANGE - 15.07mm
          MEAN - 13.33mm (SD 4.75)
SD MIN 0.68  SD MAX 2.08  MEAN 1.29  (SD 0.51)
### OPERATOR - INEXPERIENCED

**SPEED - FAST **

**SAMPLE - A**

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1st SEAM

MIN - 3.14mm  MAX - 6.57mm  RANGE - 3.43mm

MEAN - 4.64mm (SD 1.06)

SD MIN 0.42  SD MAX 1.36  MEAN 0.8 (SD 0.24)

2nd SEAM

MIN - 5.07mm  MAX - 13.29mm  RANGE - 8.22mm

MEAN - 7.91mm (SD 2.5)

SD MIN 0.52  SD MAX 6.50  MEAN 1.63 (SD 1.67)

3rd SEAM

MIN - 7.29mm  MAX - 15.00mm  RANGE - 7.71mm

MEAN - 10.06mm (SD 2.43)

SD MIN 0.45  SD MAX 1.73  MEAN 1.19 (SD 0.40)

4th SEAM

MIN - 10.25mm  MAX - 19.86mm  RANGE - 9.61mm

MEAN - 12.75mm (SD 3.14)

SD MIN 0.35  SD MAX 2.66  MEAN 1.34 (SD 0.71)
OPERATOR - INEXPERIENCED

SPEED - FAST   SAMPLE - B

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SD MIN 0.49  SD MAX 2.15  MEAN 1.1  (SD 0.5)

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           MEAN - 7.3mm  (SD 2.01)  
SD MIN 0.86  SD MAX 2.28  MEAN 1.39  (SD 0.43)

3rd SEAM  MIN - 7.71mm  MAX - 16.07mm  RANGE - 8.36mm  
           MEAN - 10.23mm  (SD 3.0)  
SD MIN 1.05  SD MAX 2.66  MEAN 1.82  (SD 0.51)

4th SEAM  MIN - 10.29mm  MAX - 21.57mm  RANGE - 11.28mm  
           MEAN - 13.19mm  (SD 3.54)  
SD MIN 0.82  SD MAX 3.49  MEAN 1.93  (SD 0.73)

533
### OPERATOR - PROTOTYPE MACHINE

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MEAN - 8.00mm  (SD 0.23)  
SD MIN 0.37  SD MAX 0.69  MEAN 0.53 (SD 0.1)

3rd SEAM  MIN - 9.5mm  MAX - 10.83mm  RANGE - 1.33mm  
MEAN - 10.44mm  (SD 0.37)  
SD MIN 0.24  SD MAX 0.94  MEAN 0.62 (SD 0.18)

4th SEAM  MIN - 12.25mm  MAX - 13.25mm  RANGE - 1.0mm  
MEAN - 12.79mm  (SD 0.27)  
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- RANGE - 1.55mm
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- SD MIN 1.66
- SD MAX 3.13
- MEAN 2.11 (SD 0.5)

**2nd SEAM**

- MIN - 6.2mm
- MAX - 7.3mm
- RANGE - 1.10mm
- MEAN - 6.57mm (SD 0.30)
- SD MIN 0.95
- SD MAX 2.11
- MEAN 1.75 (SD 0.32)

**3rd SEAM**

- MIN - 8.4mm
- MAX - 9.3mm
- RANGE - 0.9mm
- MEAN - 8.91mm (SD 0.27)
- SD MIN 1.5
- SD MAX 2.31
- MEAN 1.86 (SD 0.23)

**4th SEAM**

- MIN - 9.1mm
- MAX - 11.8mm
- RANGE - 2.7mm
- MEAN - 11.19mm (SD 0.73)
- SD MIN 1.5
- SD MAX 2.23
- MEAN 1.83 (SD 0.27)
### OPERATOR - PROTOTYPE MACHINE

**SPEED - FAST**

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**MEAN** - 7.66mm  (SD 0.78)
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3rd SEAM
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**MEAN** - 10.04mm  (SD 0.74)
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## OPERATOR - PROTOTYPE MACHINE

**SPEED - FAST**

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MEAN 1.81 (SD 0.5)

2nd SEAM  
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MEAN - 7.12mm (SD 0.62)  
RANGE - 2.4mm  
SD MIN 0.8  
SD MAX 2.18  
MEAN 1.53 (SD 0.37)

3rd SEAM  
MIN - 8.70mm  
MAX - 10.3mm  
MEAN - 9.41mm (SD 0.59)  
RANGE - 1.6mm  
SD MIN 0.86  
SD MAX 2.24  
MEAN 1.35 (SD 0.40)

4th SEAM  
MIN - 11.1mm  
MAX - 12.4mm  
MEAN - 11.58mm (SD 0.39)  
RANGE - 1.3mm  
SD MIN 0.86  
SD MAX 2.73  
MEAN 1.57 (SD 0.52)
Appendix K

Review of adhesive pick-up devices

Review of patents


Sheet feeding mechanism

This is one of the earliest known inventions relating to a paper feeding mechanism. It covers a means for removing one sheet at a time from a stack and delivering the sheets to a predetermined location. Mention is made of earlier attempts at sheet feeders utilising liquid glue or adhesive (no references), and states that liquid adhesive is subject to temperature changes and the quantities required are difficult to control.


Sheet feeding machine

This invention relates to a device for successive removal of individual sheets of material from a stack of sheets, and the successive delivery of the sheets to a desired location. The patent states that attempts had been made in the paper industry to feed sheets of material with the use of an adhesive material. It states that whilst devices used in the paper industry had been satisfactory for that type of industry, the machines are not suitable for delivery of textile materials because the means of stripping the sheet material from the adhesive are not positive and consequently do not provide a certainty of operation.

Pick-up device for use in feeding mechanism and the like

Assignee: G M Pfaff AG

This invention relates to pick-up devices for use in feeding mechanisms for advancing work pieces from one work station to another in the course of fabrication or processing operations. The pick-up device consists of an adhesive tape which passes around rollers so that the adhesive surface is exposed through the device to engage the material. In order to provide a fresh supply of adhesive to each piece or unit being fed, the tape may be advanced intermittently or step-by-step in synchronisation with the pick-up or feeding operation.


Garment working Apparatus

Assignee: Vanity Fair Mills, Inc.

This invention relates to apparatus for handling and performing operations on garments and sections thereof, and is directed more particularly to a novel and improved apparatus for automatically assembling and performing seaming operations on garments. The pick-up unit for this invention consists of a frame bar upon which a roll of pressure sensitive tape (commercial tape suggested "Scotch") is attached.

Automatic feeding, sewing, cutting and stacking apparatus

This invention relates to a sewing apparatus and has as its objective the provision of the automatic sewing machine assembly. The feeding of stacked pieces from a platform is achieved by an adhesive such as a tape. Means is provided for the tape to be wound from one roll to another.

6. AG Beazley US Patent 3,589,320 June 29 1971

Pocket blank sewing machine

Assignee: Farah Man. Co. Inc

This invention relates to a repetitive sewing machine operation and apparatus. More specifically it relates to a sewing machine in combination with apparatus and means to sew back pocket blanks used in pants whereby this limpid blank is automatically advanced, positioned, sewn separated, and removed during this operation.

The pick-up and transfer of the pocket blank is effected by a transfer device consisting of an adhesive tape reel.


Automatic feeder for workpieces of fabric or the like

Assignee: Kellwood Company

This invention relates to automatic feeders for workpieces of fabric or the like, and more particularly to apparatus for automatically feeding such workpieces one after another from a stack thereof to and through a sewing machine for a sewing operation along
an edge of each workpiece.

Other pick-up devices

ARF Demonstration rink

This was a study of automated handling of limp fabrics for the Apparel Research Foundation Inc. (ARF) carried out by Arthur D Little Inc. (ADL). These study was carried out in a number of phases. Phase I being a state-of-the-art investigation and Phase II being split into two parts:-

A - An experimental program, and
B - The development of a demonstration rink.

In dealing with the task of separation and pick-up of a single ply from a stack of cut parts ARF and ADL believed, as a result of the Phase I study¹, that the problem of separation and pick-up from the top of a stack was resolved by existing techniques, such as the Pfaff pressure-sensitive pick-up². They did however investigate and develop a top feeding device that would separate a single ply from the top of a stack of cut pieces by different principle than that used in the Pfaff device which relied on needle hold-back of the other plies. It was found that problems were being encountered with edge-strand entanglement as well as interfibre entanglement between plies. This led to the incorporation of a card cloth device used in conjunction with the pressure sensitive tape pick-up. The card cloth was used to stretch the cloth on the bias to eliminate the problem of edge and strand entanglement.

A bottom feed was also developed which again relied on securing
the ply by the use of a pressure sensitive adhesive tape. The stack of pieces were positioned on a V-shaped trough which had a two inch gap running the length of the bottom. The corner of the bottom ply came into contact with a strip of pressure sensitive tape, which subsequently pulled the ply through the gap. A roller was used at the bottom edge of the feeder to ensure that the bottom ply would be pulled down into the gap without folding up. They found that by using a bottom feeder work could be fed in from the top allowing the feeder to be used continuously.

Adhesive tape pickup devices have been used commercially for a number of years. Many machine manufacturers have developed their own adhesive pickup devices for their own particular picking operations. This has meant that very little published information concerning the commercial availability of such devices exists.

One device which is currently available is that produced by Maschinenfabrik Herbert Meyer GmbH of W.Germany. This device is used in the 'Robot-Tex' robotic system for single ply picking of fabric pieces from a stack. It consists of an adhesive tape roll incorporated into the device.

References


(2) Ibid. "Phase II : Automated handling of limp fabrics".
Appendix L

'MAGNATIC' Adhesive - Manufacturer's Specification

Manufacturer: Mr. Carl Shimmin
53 Kingsway Road
Leicester.

7000 series (High Tack) Adhesive

Water washable PPS adhesive. (Pressure sensitive). Non plasticized, non-shine, non-swelling, non-toxic.

*Temperature ranges

Cured film - 45°C ---- 70°C
Curing range - 0°C ---- 95°C (Do not boil)
Storage range - 0°C ---- 70°C (Do not freeze)

*Shelf life

emulsion - 12 months

cured film - greater than 5 years

*Tensile strength at break (Standard climatic conditions

23°C, 50% RH ; DIN 50014)

- approx. 0.15 N/mm²

*Elongation at break (Standard climatic conditions

23°C, 50% RH ; DIN 50014)

- 2000%

*Drying improvers - III Trichlorethene (up to 5%),

methyalted spirits.

*Application areas - Holding (temporary adhesion),

cleaning.
Analysis of water take-up

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The regression equation is:

Mass Uptake (%) = 1.29 + 1.56.\sqrt{\text{Time (in hours)}}

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s = 0.5768  
R-sq = 98.7%  
R-sq(adj) = 98.6%
Appendix M

Testing Specifications

TESTING SPECIFICATION 1

Experiment 1 - Effect of number of separations on the separation force

A performance test for Magnatac high tack adhesive, to determine the working limits for the adhesive under repeated pickup conditions without cleaning.

Test Specimens

Interlock fabric as supplied, specimen size 40 x 40 mm firmly attached to base plate.

Test block 25 x 25 mm as supplied, coated with adhesive.

Test Procedure

1. Instron testing machine setting:
   - Test Method: 9
   - Load Cell: 10 N
   - Sample Rate: 10 pts/sec
   - Crosshead Speed: 200 mm/min

2. Fix base plate in bottom jaw, directly under load cell.

3. Position test block squarely on base plate so that it can be gripped by the top jaws.

4. Apply a 500g load to the test block for 1 second.

5. Clamp test block in top jaw and balance load on Instron.

6. Take the first 20 readings and thereafter every 10th (remove the test block manually between readings).

7. Repeat until a significant reduction in performance is experienced.

8. Test 5 times with new fabric and adhesive surface.
TESTING SPECIFICATION 2

Experiment 2 - Effect of cleaning and number of separations on the separation force

A performance test for Magnatac high tack adhesive, to determine the working limits for the adhesive under repeated pickup conditions with cleaning.

Test Specimens

Interlock fabric as supplied, specimen size 40 x 40 mm firmly attached to base plate.

Test block 25 x 25 mm as supplied, coated with adhesive.

Test Procedure

1. Instron testing machine setting:
   Test Method - 9
   Load Cell - 10 N
   Sample Rate - 10 pts/sec
   Crosshead Speed - 200 mm/min

2. Fix base plate in bottom jaw, directly under load cell.

3. Position test block squarely on base plate so that it can be gripped by the top jaws.

4. Apply a 500g load to the test block for 1 second.

5. Clamp test block in top jaw and balance load on Instron.

6. Take the first 20 readings and thereafter every 10th (remove the test block manually between readings).

7. After 100th separation clean adhesive surface as instructed and repeat experiment.

8. Test until a significant reduction in performance is found.
TESTING SPECIFICATION 3

Experiment 3 - Effect of cleaning on the separation force

A performance test for Magnatac high tack adhesive, to determine the working limits for the adhesive under repeated cleaning conditions.

Test Specimens

Interlock fabric as supplied, specimen size 40 x 40 mm firmly attached to base plate.

Test block 25 x 25 mm as supplied, coated with adhesive.

Test Procedure

1. Instron testing machine setting:
   Test Method - 9
   Load Cell - 10 N
   Sample Rate - 10 pts/sec
   Crosshead Speed - 200 mm/min

2. Fix base plate in bottom jaw, directly under load cell.

3. Position test block squarely on base plate so that it can be gripped by the top jaws.

4. Apply a 500g load to the test block for 1 second.

5. Clamp test block in top jaw and balance load on Instron.

6. Take reading.

7. Remove test block and inhibit the tack with fine talc or chalk dust.

8. Clean adhesive surface as specified and repeat experiment.

9. Test until a significant reduction in performance is found.
TESTING SPECIFICATION 4

Experiment 4 - Effect of contact time on the separation force

A performance test for Magnatac high tack adhesive, to determine the effect contact time has on the bond strength.

Test Specimens

Interlock fabric as supplied, specimen size 40 x 40 mm firmly attached to base plate.

Test block 25 x 25 mm as supplied, coated with adhesive.

Test Procedure

1. Instron testing machine setting:
   Test Method - 9
   Load Cell - 10 N
   Sample Rate - 10 pts/sec
   Crosshead Speed - 200 mm/min

2. Fix base plate in bottom jaw, directly under load cell.

3. Position test block squarely on base plate so that it can be gripped by the top jaws.

4. Apply a 500g load to the test block for stated time.

5. Clamp test block in top jaw and balance load on Instron.

6. Take 5 readings.

7. Repeat experiment for each of the following contact times:-
   1s, 2s, 3s, 4s, 5s, 6s, 7s, 8s, 9s, 10s, 30s, 1min.
Experiment 5 - Effect of applied load on the separation force

A performance test for Magnatac high tack adhesive, to determine the effect applied load has on the bond strength.

Test Specimens
Interlock fabric as supplied, specimen size 40 x 40 mm firmly attached to base plate.
Test block 25 x 25 mm as supplied, coated with adhesive.

Test Procedure
1. Instron testing machine setting:
   Test Method - 9
   Load Cell - 10 N
   Sample Rate - 10 pts/sec
   Crosshead Speed - 200 mm/min
2. Fix base plate in bottom jaw, directly under load cell.
3. Position test block squarely on base plate so that it can be gripped by the top jaws.
4. Apply stated load to the test block for 1 second.
5. Clamp test block in top jaw and balance load on Instron.
6. Take 5 readings.
7. Repeat experiment for each of the following loads:
   100g, 200g, 500g, 1Kg, 1.5Kg, 2Kg.
Experiment 6 - Effect of separation rate on the separation force

A performance test for Magnatac high tack adhesive, to determine the effect separation rate has on the force required to separate fabric from adhesive.

Test Specimens
Interlock fabric as supplied, specimen size 40 x 40 mm firmly attached to base plate.
Test block 25 x 25 mm as supplied, coated with adhesive.

Test Procedure

1. Instron testing machine setting:
   Test Method - 9
   Load Cell - 10 N
   Sample Rate - 10 pts/sec
   Crosshead Speed - As Stated

2. Fix base plate in bottom jaw, directly under load cell.

3. Position test block squarely on base plate so that it can be gripped by the top jaws.

4. Apply 500g load to the test block for 1 second.

5. Clamp test block in top jaw and balance load on Instron.

6. Take 5 readings.

7. Repeat experiment for each of the following crosshead speeds:
   10, 25, 50, 75, 100, 150, 200, 300, 400, and 500 mm/min.
Experiment 7 - Effect of adhesive area on the separation force

A performance test for Magnatac high tack adhesive, to determine the effect the area of adhesive has on the force required to separate the fabric from adhesive.

Test Specimens

Interlock fabric as supplied, specimen size 40 x 40 mm firmly attached to base plate.

Test block 25 x 25 mm as supplied, coated with adhesive.

Test Procedure

1. Instron testing machine setting:
   Test Method - 9
   Load Cell - 10 N
   Sample Rate - 10 pts/sec
   Crosshead Speed - 200 mm/min

2. Fix base plate in bottom jaw, directly under load cell.

3. Position test block squarely on base plate so that it can be gripped by the top jaws.

4. Apply 500g load to the test block for 1 second.

5. Clamp test block in top jaw and balance load on Instron.

6. Take 3 readings.

7. Repeat experiment for each of the following adhesive areas:-

   361, 301.5, 252.5, 193, 133.5, 109, 84.5, 72.3, 36.1, and 18.1 mm²
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553
"Magnatac" Adhesive

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Results 2

Experiment 1

'Magnatac' Adhesive

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* missing data
Experiment 2

'Magnatac' Adhesive

(i) Effect of cleaning on initial separation force

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(ii) Effect of cleaning on separation force

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Experiment 3
'Magnatac' Adhesive

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* indicates no separation occurred.
Experiment 4
'Magnatac' Adhesive

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Experiment 5
'Magnatac' Adhesive

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Experiment 6
'Magnatac' Adhesive

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Experiment 7

'Magnatac' Adhesive

<table>
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RTX PERSONAL ROBOT ARM

- control — high level software control means easy programming
- installation — no special installation necessary. RTX is easily transportable
- maintenance — simple to maintain
- safety — programmable force control eliminates need for safety cages
- performance — modified SCARA format offers six axes plus gripper, 2kg load capacity, ±0.5mm repeatability, and a reach of 684mm over full vertical travel of 915mm
- flexibility — RTX is part of a range of fully integrated, upgradeable robotics products from UMI

FEATURES

- enhanced SCARA configuration
- seven degrees of freedom (including gripper)
- 0.8m cubic metre (33 cubic feet) work envelope
- 7 24V DC servo motors
- optical incremental encoder feedback
- PID control system running on 2 Intel 8031 microprocessors
- 2kg lifting capacity
- controlled from IBM PC or compatible via RS232C serial link
- programmable force control

SPECIFICATION

Power supply: 110-240V, 50-60Hz, 125VA (mains)
Height: 1252mm (49in)
Weight: 28kg
Base width: 316mm (12 1/2in)
Base depth: 285mm (11 1/4in)
Maximum reach: 684mm (27in) — possible over entire vertical travel
Vertical travel: 915mm (36in)
Lifting capacity: 2kg
Repeatability: ± 0.5mm
Maximum velocity: 1.1m/sec (combined shoulder/elbow movement)

Maximum speed:
- Shoulder 0.72 rad/sec
- Elbow 1.44 rad/sec
- Yaw 2.15 rad/sec
- Pitch 1.55 rad/sec
- Roll 1.55 rad/sec
- Zed 125mm/sec
- Gripper 66mm/sec

Maximum angular displacements:
- Shoulder ±90°
- Elbow ±180°, — 151°
- Yaw ±110°
- Pitch ±4°, — 98°
- Roll ±181°, — 132°
- Zed ±90°
- Gripper ±90°

Drive modes:
- numeric (relative and absolute); manual (drive until stop command received); interpolation at 62.5 Hz; force (programmable).

WORKING AREA

Dimensions in mm

RTX is available from:

UMI LTD.
Tel: 01-399 5211
UMI House
Fax: 01-399 0846
St. James Road
Surbiton
KT6 4QH

UMI Inc.
Metropolitan Centre for High Technology
2727 2nd Avenue
Suite 159
Detroit, Michigan 48201, U.S.A.
Tel: 313-9630616
Fax: 313-9637606
Appendix P

Programme Listing

30 ( LOAD SCREEN FOR FABRIC PICK-UP MKH 13JAN88)
31 VARIABLE HEIGHT
32 : SOL-TEST
33 : SEARCH 2
34 : PICK-UP
35 : 3FPICK

SCR 30
0 ( LOAD SCREEN FOR FABRIC PICK-UP MKH 13JAN88)
1 36 35 34 33 32 31 6 NLOAD
2
3
4
5
6
7
8
9
10
11
12
13
14
15

SCR 31
0 VARIABLE HEIGHT
1 VARIABLE COUNT
2
3 : TITLE
4 25 1
5 DO
6 10 EMIT
7 LOOP CR
8 :" *************************************************************************** "
9 CR :" * FABRIC PICK-UP PROGRAM VERSION 1.1  * "
10 CR :" * (C) M K Hall  Leicester Polytechnic 1988  * "
11 CR :" *************************************************************************** "
12 CR
13 ;
14
15
SCR 32
0 : SOL-TEST
  1 0 0 1BIT
  2 0 0 1BIT
  3 ;
  4 : STACK-TOP
  5 526 -625 -2119 -1221 -1241 0 152 GOTO>POS
  6 ;
  7 : POS1
  8 526 -1424 -2119 -1221 -1241 0 152 GOTO>POS
  9 ;
 10 : CLEAN
 11 526 -1970 -2119 -228 -289 0 152 GOTO>POS
 12 CR 7 EMIT "RECOMMENDED NO. OF PICK-UPS EXCEEDED!! CR CR"
 13 "CLEAN SURFACE... THEN PRESS <RETURN> WHEN FINISHED" CR CR
 14 "....TYPE 3FPICK TO RE-RUN" CR KEY STACK-TOP
 15 ;

SCR 33
0 : SEARCH2
  1 BEGIN
  2 -2 ZED MOVE NGO UNTIL DONE
  3 ZED ABSOLUTE MODE ZED @POSITION 2119 + -440 <
  4 IF
  5 CR CR 7 EMIT 7 EMIT "WARNING...STACK TOO LOW!!"
  6 STACK-TOP POS1 SOL-TEST STACK-TOP COUNT @ 50 >
  7 IF
  8 CR CR 0 COUNT ! CLEAN ABORT" SEQUENCE HALT "
  9 ELSE
 10 CR CR "TO RERUN... TYPE 3FPICK AND PRESS <RETURN>"
 11 CR CR 0 COUNT ! ABORT" SEQUENCE HALT " THEN
 12 THEN ZED RELATIVE MODE
 13 0 1 @BIT
 14 UNTIL
 15 ;

SCR 34
0 : PICKUP3
  1 ZED RELATIVE MODE
  2 HEIGHT @
  3 ZED MOVE NGO UNTIL-DONE
  4 SEARCH2
  5 7 EMIT COUNT @ 1 + DUP COUNT !
  6 "***** PIECE NO. " . " FOUND ....SEARCHING "
  7 13 EMIT 20 ZED MOVE NGO UNTIL-DONE
  8 ZED ABSOLUTE MODE
  9 ZED @POSITION 2119 + DUP HEIGHT !
 10 ZED RELATIVE MODE 30 ZED MOVE NGO UNTIL-DONE
 11 ZED ABSOLUTE MODE
 12 ELBOW RELATIVE MODE 35 ELBOW MOVE NGO UNTIL-DONE

564
13  \textbf{ELBOW ABSOLUTE MODE}
14  \textbf{STACK-TOP POS1 SOL-TEST SOL-TEST STACK-TOP}
15  ;

\begin{verbatim}
SCR 35
0 : 3FPICK
1  TITLE CR CR ." SEQUENCE STARTED....SEARCHING FOR PIECE "
2    0 HEIGHT ! CR CR
3    BEGIN
4       PICKUP3
5        -430 <
6    UNTIL
7     STACK-TOP
8  ;
9
SCR 36
0 : FPICK-INIT1
1  1 INPUT MODE 0 OUTPUT MODE
2  0 0 0 4BIT
3  0 HEIGHT ! 0 COUNT !
4  ZED ABSOLUTE MODE
5  STACK-TOP
6  TITLE
7    CR CR ."Fix pick-up device in RTX gripper.... "
8    CR CR 7 EMIT ."PRESS ANY KEY " CR CR
9    ." then type 3FPICK to run sequence "
10 KEY
11  ;
12
\end{verbatim}
3 July 1987

Mr M Hall
Leicester Polytechnic
Mechanical & Production Eng Dept
Hawthorne Building
Newark
Leicester LE1 9BH

Dear Mike

We should like to express our thanks for the demonstration of your computer based garment block design programme.

It is obvious that you have given a great deal of time and effort to learning the peculiarities of the clothing industry and developing a programme which will no doubt be of great benefit to it in the future.

Congratulations for developing a means to create accurate basic block patterns whilst dispensing with the traditional digitising procedure.

Be assured that other personnel at Lectra will be made aware of your project.

Yours sincerely

Stephen Uttley
OUR REF: AAM/RF

3rd May 1989

Dr W Blackwood
Director of Studies
Leicester Polytechnic
School of Textile and Knitwear Technology
P O Box 143
Leicester
LE1 9BH

Dear Bill

SUBJECT: - Mike Hall

Further to my visit to Leicester Polytechnic in connection with Mike Hall's project, I found my visit very interesting and Mike Hall's progress remarkable, in just three years he has achieved so much in different aspects of computer controlled/automatic and semi-automatic equipment. I shall give my impressions and comments on each aspect as follows:-

1. The edge guiding system working in conjunction with a sewing machine. - The concept was very impressive indeed and the electronic side worked well, perhaps let down by the mechanical side, but of course we were only looking at principle rather than the end result. Further studies will be required to ascertain how the guiding system would perform at high speeds and on a variety of fabrics.

2. Pattern creation through computer software. - This proved to be by far the most interesting aspect of the project and I am sure it could have an excellent commercial prospect if a specialist company, ie., Gerber, Investronica or Lectra, were to become involved. It probably could be further expanded to embrace all aspects of the fashion industry for the design of a variety of garments.

3. The pick and place Robot. - Although well thought out, it proved from a personal point of view the least interesting, as there are so many other similar devices being projected by others ie., commercial, and educational institutes. Furthermore, I feel that Robots do not have, at least for the foreseeable future, a role in the apparel industry as they are still too inflexible and rather costly.

.../...
I hope that my observations will prove useful to Mike Hall and of course I remain at your disposal should you need any further clarification on my comments, on any other subject.

Thanking you for involving me in this extremely interesting project.

I remain,

With kind regards,

Yours truly

RIMOLDI (GB) LIMITED

[Signature]

MANAGING DIRECTOR
Polytechnic Carol Singing

In place of the traditional Carol Service, we are holding informal carol singing in the Students' Union Arena on Monday 12th December from noon onwards. All are welcome.

From the Chaplains

Visit Strengthens Links with Local Industry

A recent visit to Fison’s Safety Evaluation Unit at Belton, near Loughborough has strengthened links between the School of Life Sciences and this local pharmaceutical company. Second year HND Applied Biology students studying the Toxicology special option were treated to a most interesting day at the Unit. The programme for the visit included a tour of the facilities, lunch and a series of seminars explaining how toxicological safety evaluation studies are carried out in order to guarantee the safety of newly marketed pharmaceuticals. Plans for the visit were conceived earlier this year when Bill Lawrence, the Toxicology option subject leader, visited two of last year’s second year HND Toxicology students who were working at the Unit for their seven week industrial experience. Fisons regularly offer such places to students who have completed the Toxicology option and a number have continued the association through temporary employment in the summer or by obtaining a permanent job in the Unit. One particularly pleasing aspect of the visit was that the programme was organised by Sally Robinson who graduated from the HND Applied Biology course in 1982.

SMART Competition

Mr Michael Hall, who gained an Upper Second Degree in the School of Mechanical and Production Engineering in 1985, and is now a research student, in the Polytechnic, was one of those who received an award from the DTI within its scheme to pump-prime the exploitation of innovation in small firms. The SMART competition engages small businesses and individuals in the Small Firms Merit Award. for Research and Technology, which is a competitive award which aims to encourage innovation. Awards are made to successful applicants in any technology marketed by DTI and are made specifically to develop feasibility studies to get to the point at which venture capital might be attracted for full exploitation. Seven awards were made in the East Midlands: the majority from companies with a close association with the University of Nottingham and the Nottingham Science Park. It was particularly important, therefore to recognise the achievement of Mike Hall in obtaining significant support (£37,500) with his industrial collaborator, Mr C. Shimmin for the exploitation of an adhesive which has a capability to significantly advance the process of robotic handling of materials. This can and will have an important place in the automated processes leading to garment assembly.

Student Exchanges: Leicester Polytechnic and the Universidad Complutense de Madrid

Members of the school of ASSPA were funded under the ERASMUS program to undertake a visit in the Spring of this year to the Universidad Complutense de Madrid, one of the oldest and most prestigious of the universities in Spain which enrolls some 150,000 students annually. It is anticipated that there will be regular flow of some three to five student exchanges between the BA Degree in Public Administration and its counterpart in the Complutense. Leicester Polytechnic students will spend some time at the University but will also work in one of the Spanish ministries or in Madrid City Council. The Spanish students studying in England will take courses in British Public Administration, including Information Technology.

The relationship has already borne fruit with three students from the Complutense who are engaged upon their year of study in Leicester. Pictured are the three Spanish students together with members of the ASSPA staff who are organising the exchange arrangements. From left to right: Meg Hart (ASSPA), Reyes Herrera, Laura Roman, Salvador Parrado (Complutense), John Greenwood, Mike Hart and Professor David Wilson (ASSPA).
### Glossary of clothing terms and definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALLOWANCE</td>
<td>The extra dimensions allowed on garment measurements over body measurements. See also &quot;seam allowance&quot;.</td>
</tr>
<tr>
<td>BALANCE</td>
<td>The adjustment of the relation of one section of a garment to another, in harmony with the natural attitude of the figure, especially that of back and front lengths.</td>
</tr>
<tr>
<td>BALANCE MARKS (PITCH POINT)</td>
<td>Notches, nips or threads in garment parts, which help to preserve the balance of the garment by serving as guides during assembly. They are generally put at side seams, in the scye, shoulder seams, hind arm and forearm seams and elsewhere as necessary.</td>
</tr>
<tr>
<td>BESPOKE</td>
<td>Bespoke clothes are those which are made to order for an individual.</td>
</tr>
<tr>
<td>BIAS</td>
<td>An oblique direction to warp and weft. True bias is at an angle of 45 degrees to both warp and weft.</td>
</tr>
<tr>
<td>BIAS CUT</td>
<td>A cut at an oblique angle to warp and weft. Also known as cutting on the cross.</td>
</tr>
<tr>
<td>BLOCK PATTERN</td>
<td>See &quot;pattern&quot;</td>
</tr>
<tr>
<td>BLOCKING OUT</td>
<td>The process of cutting many layers of material into manageable blocks which may incorporate one or more parts of a garment.</td>
</tr>
<tr>
<td>BUNDLE</td>
<td>A number of similar garment parts temporarily kept together for convenience of handling (see &quot;conventional bundle system&quot;, &quot;progressive bundle system&quot;).</td>
</tr>
<tr>
<td>CLOTH</td>
<td>Any fabric may be described as a cloth, but in the tailoring trade the word is usually applied only to the principal or outside fabric of a garment.</td>
</tr>
<tr>
<td>C.M.T.</td>
<td>An abbreviation of &quot;cut, make and trim&quot;. A section of the industry in which a contractor is supplied with materials and designs in order to produce garments for a supplier.</td>
</tr>
<tr>
<td>AUTOMATIC STITCHING</td>
<td>Automatic sewing along or near the edge of a garment part. The shape may be predetermined or edge following.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>CONVENTIONAL</strong></td>
<td>A production system in which bundles pass from storage to an operator and then back to storage for allocation to the next operation.</td>
</tr>
<tr>
<td><strong>BUNDLE</strong></td>
<td></td>
</tr>
<tr>
<td><strong>SYSTEM</strong></td>
<td></td>
</tr>
<tr>
<td><strong>DART</strong></td>
<td>A wedge shape removed from the surface area of a garment by stitching or alternatively by cutting and stitching.</td>
</tr>
<tr>
<td><strong>DRAFT</strong></td>
<td>A constructed plan of a garment, the application body or garment measurements to a flat plane.</td>
</tr>
<tr>
<td><strong>DRAPE</strong></td>
<td>An adjective describing the way fabric falls when hung. The draping quality varies with the structure, composition and finish of the fabric.</td>
</tr>
<tr>
<td><strong>EASING-IN</strong></td>
<td>The manipulation of an additional amount of one of the fabrics into a seam in order to create fullness.</td>
</tr>
<tr>
<td><strong>FELLING</strong></td>
<td>The operation of over-sewing a piece of material by its edge (raw or turned in) upon the body material.</td>
</tr>
<tr>
<td><strong>FLAGGING</strong></td>
<td>The rising and falling of material caused by the needle movement on the sewing machine.</td>
</tr>
<tr>
<td><strong>FULLNESS</strong></td>
<td>The additional amount of one of the fabrics joined at a seam which is allowed in order to create the desired shape in a part of a finished garment, e.g. a sleeve head (see &quot;easing-in&quot;)</td>
</tr>
<tr>
<td><strong>GRADING</strong></td>
<td>The process of producing a range of patterns of different sizes from a master pattern.</td>
</tr>
<tr>
<td><strong>GRAIN</strong></td>
<td>The direction of the warp of the fabric.</td>
</tr>
<tr>
<td><strong>HANDLE (HAND)</strong></td>
<td>The feeling of a fabric to the hand.</td>
</tr>
<tr>
<td><strong>LAY</strong></td>
<td>An assembly of cloths placed in identical lengths one on top of the other in preparation for cutting.</td>
</tr>
<tr>
<td><strong>LAY MARKER</strong></td>
<td>See &quot;marker&quot;.</td>
</tr>
<tr>
<td><strong>LAY PLANNING</strong></td>
<td>The arranging of patterns of the component parts of a garment, within a given width of fabric in order to obtain the most economical use of the material. Also called &quot;layout planning&quot;.</td>
</tr>
<tr>
<td><strong>LAYING UP</strong></td>
<td>The process of spreading cloth to form a lay. Often called &quot;spreading&quot;.</td>
</tr>
<tr>
<td><strong>LINKING</strong></td>
<td>The process of joining knitted garment parts on a linking machine, in which individual loops from two parts are run onto a series of regularly spaced points</td>
</tr>
</tbody>
</table>
and then joined by chain stitches.

**MAKING UP**
Converting fabric into garments.

**MARKER**
The representation or drawing of the final arrangement of the patterns of the component parts of a garment or garments in the form of a master plan for cutting, intended to make the best use of the fabric. The marker is placed on top of the lay prior to cutting. Also called marker.

**OVEREDGING**
The use of an overedge stitch, either by hand or machine to bind an edge so as to avoid fraying. Can also be used as a decoration. Also referred to as "overlocking".

**PATTERN**
A replica of a garment piece in flat card or paper. A template used for marking out the parts of a garment or material prior to cutting. Block Pattern A template of the basic pattern shape upon which design details can be super-imposed.

**PLY (FABRIC)**
A single thickness of fabric in a lay or seam. The number of plies in an assembly is the number of fabric thicknesses.

**PRESSING**
The removing or creating of creases or shape into garments and fabric by heat and/or steam and/or vacuum, or a combination of these with pressure.

**PROFILE STITCHING**
Automated sewing following a predetermined profile e.g. by jig or cams. Usually applied to the automatic stitching of small parts.

**PROGRESSIVE BUNDLE SYSTEM**
A production system in which bundles pass from one operator to the next with some work in hand at each operation. The operations are laid out in sequence with the required number of machines for approximate balance allocated to each.

**SCYE**
The armhole of a garment.

**SEAM**
The line of junction between two or more plies of fabric. (Covered by BS3870).

**SEAM ALLOWANCE**
A pre-determined amount of material between the edge of component parts of the garment and the seam line. Also called "seam margin" or "seam width".

**SEAM MARGIN**
See "seam allowance".
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEAM PUCKER</td>
<td>Puckering or &quot;rucking&quot; of the fabric along the line of stitching at a seam.</td>
</tr>
<tr>
<td>SEAM SLIPPAGE</td>
<td>The pulling away of fabric from a seam under tension.</td>
</tr>
<tr>
<td>SEAMING</td>
<td>Joining together the component parts of a garment at a given distance from the edge of the material.</td>
</tr>
<tr>
<td>SELVEDGE</td>
<td>The longitudinal edges of a fabric formed during manufacture in such a way that the component threads are interlaced to prevent them from unravelling or fraying.</td>
</tr>
<tr>
<td>SERGING</td>
<td>The operation of neatening the cut edge to avoid fraying, by means of an overedge stitch.</td>
</tr>
<tr>
<td>SHIRRING</td>
<td>A type of gathering which is usually done with multi-needle chain stitch machines using elastic thread in the looper.</td>
</tr>
<tr>
<td>SLACK COURSE</td>
<td>The row of loops used for linking. The loops are knitted slightly larger than most of the other loops.</td>
</tr>
<tr>
<td>SLEEVE HEAD</td>
<td>The part of the top sleeve which is joined to the scye.</td>
</tr>
<tr>
<td>SPOT AND CROSS PAPER</td>
<td>Paper printed with a design of alternate spots and crosses used for making master markers.</td>
</tr>
<tr>
<td>STITCH</td>
<td>One of a series of units of conformation of threads resulting from the thread or threads being repeatedly passed through or into the material during sewing. (See BS3870)</td>
</tr>
<tr>
<td>TRIMMINGS</td>
<td>The components of a garment other than the main fabrics and sewing threads.</td>
</tr>
<tr>
<td>UNDERPRESSING</td>
<td>The pressing operations carried out during assembly of the garment. Usually refers to seam opening.</td>
</tr>
</tbody>
</table>
Appendix S

List of Published Papers


Papers presented:

Paper presented to the Leicester Textile Society 17th November 1988 - "Clothing Research".
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