

This item is held in Loughborough University's Institutional Repository (<https://dspace.lboro.ac.uk/>) and was harvested from the British Library's EThOS service (<http://www.ethos.bl.uk/>). It is made available under the following Creative Commons Licence conditions.



creative  
commons  
C O M M O N S D E E D

**Attribution-NonCommercial-NoDerivs 2.5**

**You are free:**

- to copy, distribute, display, and perform the work

**Under the following conditions:**

 **BY:** **Attribution.** You must attribute the work in the manner specified by the author or licensor.

 **Noncommercial.** You may not use this work for commercial purposes.

 **No Derivative Works.** You may not alter, transform, or build upon this work.

- For any reuse or distribution, you must make clear to others the license terms of this work.
- Any of these conditions can be waived if you get permission from the copyright holder.

**Your fair use and other rights are in no way affected by the above.**

This is a human-readable summary of the [Legal Code \(the full license\)](#).

[Disclaimer](#) 

For the full text of this licence, please go to:  
<http://creativecommons.org/licenses/by-nc-nd/2.5/>

A FLEXIBLE MANUFACTURING SYSTEM FOR  
LAWNMOWER CUTTING CYLINDERS

by

D.J. PARRISH

A Doctoral Thesis

submitted in partial fulfilment of the requirements

for the award of

The Degree of Doctor of Philosophy

of the Loughborough University of Technology

March 1983

Supervisor: Professor R.J. Sury, PhD, C.Eng.  
Department of Engineering Production

© by D.J. Parrish

## ACKNOWLEDGEMENTS

My grateful thanks are made to Dr J.W. Rourke and Professor R.J. Sury, of Loughborough University of Technology, for their help and guidance with the project. I am also indebted to Mr P.G. Phipps, Managing Director of Suffolk Lawnmowers Ltd, and his engineering staff, particularly Mr A.D. Perrot, Mr S.G. Buckle and Miss E. Fisher, for their assistance.

Further thanks are extended to Mr P.K. Wadsworth (LUT) and Mr J.E. Middle (LUT) for their assistance in a technological appraisal of robotic welding carried out in the Department of Engineering Production, Loughborough University of Technology, to Mr J. Norris (BOC) for his advice on welding gases and to Mr C. Winstanley (PERA) for his assistance in providing material for the literature survey.

	page number
CONTENTS	i - iv
List of Diagrams and Tables	v - vii
Abbreviations used in text	viii
Synopsis	ix
Section 1 <u>Introduction</u>	1
Section 2 <u>Literature Survey of FMS Concepts for Batch Production</u>	3
2.1    Introduction	3
2.1.1    The Future of Automation in Batch Production	3
2.1.2    The Influence of Batch Size on Automation	3
2.2    Flexible Automation	4
2.2.1    FMS definitions (expert opinions)	4
i)    Flexibility	
ii)   Flexible Manufacturing Systems	
iii) Flexible Manufacturing Cells	
2.2.2    Benefits of FMS	14
2.2.3    Incremental Implementation of FMS	17
Section 3 <u>Establishing the Form of the FMS</u>	20
3.1    Determining of the FMS design concept	20
3.2    FMS Planning and Design	20
3.3    Alternative FMS Designs	25
3.3.1    Early Designs	25
3.3.2    FMS with Robotic Transfer of Components	26
3.4    Benefits with Robotic Applications in FMS	28
3.5    Requirements of Robots for Welding and Transfer Processes	31
Section 4 <u>Controllers for Flexible Manufacturing Systems at SLM Ltd</u>	33
4.1    Computer Systems in Manufacturing	33
4.1.1    Process Computers	33
4.1.2    Minicomputers	33
4.2    Computers in Batch Production	35
4.2.1    Numerical Control	35
4.2.2    Direct Numerical Control	35
4.2.3    Integrated Control	36

	page number
4.3 Hierarchical Decentralised Control	36
4.4 Benefits of a Hierarchical System	38
4.5 Hierarchical Control for an FMS	38
4.6 Microcomputers and Programmable Controllers	40
4.6.1 Microcontrollers for Hierarchical Systems	40
4.6.2 Microcontroller Development	40
4.6.3 Programmable Controller Definitions	41
4.6.4 Programmable Controllers versus Mini-computers	45
4.6.5 Programmable Controller Configurations for Hierarchical Control	46
4.6.6 Applications of Programmable Controllers	47
Section 5 <u>Development of the Production Processes for Integration into the FMS</u>	48
5.1 The Company Structure	48
5.1.1 Birmid Qualcast	48
5.1.2 The Home and Garden Equipment Division	48
5.1.3 Suffolk Lawnmowers Ltd Market Analysis and Forecast	48
5.1.4 Existing Company Products	49
5.1.5 The Factory	53
5.2 FMS Part Spectrum Analysis	53
5.2.1 Product Mix	53
i) Cylinder Design Criteria	
ii) Total Cylinder Mix	
5.2.2 Process Mix	62
5.2.3 The Manufacturing System	64
i) The Total System	
ii) The Cylinder Manufacturing System	
5.2.4 The Variable Production Profile of Cylinder Manufacture	70
5.3 Technology of the present Manual Cylinder Production System	92
5.3.1 Assembly and Welding	92
5.3.2 Hardening	98
5.3.3 Grinding	100
5.3.4 Transfer	104

Section 6	<u>Technical Developments required to achieve FMS Objectives</u>	109
6.1	MIG and MAG Welding	109
6.2	Hardening	122
6.3	Grinding	131
Section 7	<u>The FMS Design for Cylinder Production</u>	139
7.1	Stepwise Cylinder Automation	139
7.1.1	Total Cylinder Production Automation	141
	i) Cell Modules	
	ii) Transfer	
	iii) Component Automation	
	iv) Finishing	
	v) Control	
7.1.2	Cylinder Machining Automation	151
7.1.3	Robot and Control Capabilities	152
	i) Robotic Welding and Transfer	
	ii) Control	
	iii) Machine Tools	
7.2	The Recommended System	158
7.2.1	Phase I	158
	i) Machine Hardware Specifications	
	a) Robotic Welding and Tooling	
	b) The Hardening Machine	
	c) The Grinding Machine	
	ii) Workpiece Transfer	
	a) Transfer Robot	
	b) Mechanical Gripper	
	iii) Control (Functions)	
	a) General Control Descriptions	
	b) Loading Operator Functions	
	c) Welding Station	
	d) Transfer Functions	
	e) Flame Hardening	
	f) Grinding Functions	
	g) Conveyor	
	h) Reporting	
	iv) Control (Hardware and Configuration)	
7.2.2	Phase II	186

<b>Section 8</b>	<b><u>Expected Benefits</u></b>	189
	8.1 Cell Capability and Capacity	189
	8.2 Labour Cost Savings	190
	8.3 Further Benefits	191
	8.4 The Cost of the FMS	193
	8.5 Financial Returns from the FMS	196
<b>Section 9</b>	<b><u>Discussion of FMS Implementation</u></b>	202
	9.1 Implementation	202
	9.1.1 Turnkey Development	202
	9.1.2 Implementation Programme	203
	9.2 Development Team	205
	9.3 Training	205
<b>Section 10</b>	<b><u>Conclusions - Requirements for FMS</u></b>	209
	10.1 General Conclusions	209
	10.2 Major Conclusions	209
	10.3 Further Recommendations	213
<b>Section 11</b>	<b><u>Discussion of Further Work</u></b>	215
<b>Appendices</b>		
	1 Review of Existing Flexible Manufacturing Systems	216
	2 Robotic Applications for Flexible Manufacturing Systems	230
<b>References</b>		244

LIST OF DIAGRAMS AND TABLES

page number

I DIAGRAMS

2.1	The FMS concept	5
3.1	Determining part spectrum requirements	23
3.2	FMS configurations	27
3.3	Levels of automation	29
4.1	FMS control	39
4.2	Poll processing in programmable controllers	42
4.3	PC programming languages	42
5.1	The factory production system	54
5.2	Cutting cylinder technology	58
5.3	Fabrication tolerances	59
5.4	Cutting cylinder components	61
5.5	Cutting cylinder variations	63
5.6	The factory system	66
5.7	Cylinder production system layout	67
5.8	Process flows through system	68
5.9	Annual volumes	75
5.10	Volume changes (1980 - 1981)	76
5.11	Annual production by cylinder type	77
5.12	Throughput/product mix analysis	78
5.13	Cylinder costs	79
5.14	Value produced analysis	81
5.15	Present operation process times	84
5.16	Batch runs - 1980	85
5.17	Cylinder types produced in a week	86
5.18	Cylinder production - 1980	90
5.19	Standard hours produced - 1980	91
5.20	Welding workstation	95
5.21	Welding section manning levels	96
5.22	Configuration of weld	97
5.23	Flame hardening concept	99
5.24	The method of grinding	102
5.25	Cylinder diameters for grinding	105
5.26	Transfer stillages	106
6.1	Cylinder QLM-A1 test	114
6.2	Cylinder QLM-B1 test	115
6.3	Cylinder ESAB/A test	116
6.4	Cylinder WIRS/1 test	118
6.5	Cylinder WIRS/5 test	119



	page number	
6.6	Cylinder Ginger/1 test	120
6.7	Robotic welding at Loughborough University	121
6.8	The effects of polymer quenchant concentration on quenching speed	127
6.9	The effects of polymer quenchant temperature on quenching speed	129
6.10	Hardening test results	130
6.11	Belt grinding m/c configurations	134
6.12	Grinding test in-feeds	138
7.1	Long term automation objectives	140
7.2	Short term automation objectives	142
7.3	Phases of FMS implementation	143
7.4	Paint spraying robot	147
7.5	DNC configuration	149
7.6	DNC configuration	150
7.7	Alternative layouts	153
7.8	FMS layout	159
7.9	Hall Automation welding robot	164
7.10	Assembly-weld turntable	166
7.11	Flame hardening m/c	170
7.12	Newall S.A. grinding m/c	172
7.13	Hall Automation transfer robots	174
7.14	FMS production cycle	176
7.15	Double gripper sequence	177
7.16	Configuration of controllers	182
7.17	Configuration of controllers (expanded)	187
7.18	Phase II layout	188
8.1	Project costs vs time	197
9.1	Stepwise implementation map	204
9.2	Development programme	206
9.3	FMS personnel	207
10.1	FMS layout (Phase I configuration)	212

II TABLES

5.1	UK sales of lawnmowers by type	50
5.2	Sales of rotary mowers by type	50
5.3	Total market shares	50
5.4	Ownership of mowers	50
5.5	Estimated unit sales of lawnmowers in UK	51
5.6	Estimated UK sales (1975-1979)	51
5.7	Estimated unit volume sales - 5 year forecast	52
5.8	Cutting cylinder product mix	55
5.9	Cutting cylinder process mix	69
5.10	Cutting cylinder work centre descriptions	71
5.11	Production levels of cylinders	72
5.12	Programmed and achieved production levels	73
5.13	Standard cylinder production times	83
5.14	Set-up periods	88
5.15	Potential machine utilisation	88
5.16	Subcontracted cylinders for welding	88
5.17	Percentage carbon content of component material	93
5.18	Grinding specification	103
5.19	Methods of manual transfer	108
6.1	Hardness test results	111
6.2	Welding test results	112
6.3	Induction hardening m/c specifications	113
6.4	Belt grinding test results	136
6.5	Wide-face grinding wheel test results	136
7.1	Alternative robots for the FMS	155
7.2	FMS capability specification	160
7.3	GEM80/245 microcontroller specification	184
7.4	GEM80/100 PC specification	185
8.1	Current system labour requirements	192
8.2	Material cost savings	194
8.3	Compilation of capital equipment costs	195
8.4	Progressive payments analysis	198
8.5	Financial payback analysis	199
8.6	Financial payback analysis	201
10.1	FMS functional specification	211

ABBREVIATIONS USED IN TEXT

CAM	Computer Aided Manufacture
CAD	Computer Aided Design
CNC	Computer Numerical Control
CP	Continuous Path
CPU	Central Processing Unit
DNC	Direct Numerical Control
FMC	Flexible Manufacturing Cell
FMS	Flexible Manufacturing System(s)
GT	Group Technology
HB	Brinell Hardness
IR	Industrial Robot
K	Kilobytes
MAG	Metal Active Gas
MDI	Manual Data Input
MIG	Metal Inert Gas
NC	Numerical Control
P(L)C	Programmable (Logic) Controller
PTP	Point to Point
SLM	Suffolk Lawnmowers Limited

## SYNOPSIS

The thesis is concerned with the conception and design of a FLEXIBLE MANUFACTURING SYSTEM (FMS) for the automation of the manufacture of lawnmower cutting cylinders at Suffolk Lawnmowers Ltd. A review of FMS definitions, planning methods and current systems is carried out for the development of a suitable FMS configuration for the final stages of manufacture of grass cutting cylinders having 21 different design specifications. This involves examination of the capabilities of robotics and microcontrollers to automate the technologies used in cylinder production.

The company's current manual batch production system is analysed to determine the suitable form and requirements of the FMS. This includes analyses of annual volumes, throughputs, batch sizes, product and process mixes. Long term objectives to automate the system are identified from which short term objectives are derived. The FMS recommended for immediate development encompasses the short term objectives for the welding, hardening, grinding and transfer processes of 8 cutting cylinder specifications.

It is shown that the MIG (Argon/CO<sub>2</sub>) arc welding, progressive flame hardening and wide-face cylindrical grinding processes can be developed successfully to automate cylinder production. The recommended system integrates these processes into an FMS through the automatic handling of cylinders (through three process routes) by a robotic manipulator utilising a double gripper. A robotic welding station, manually loaded, is also recommended. The system is controlled overall by a 32K micro-controller with the process machines individually controlled by programmable logic controllers with up to 6K of memory each.

The economic appraisal of the FMS indicates a 4.4 year payback based on direct labour and material cost savings. The company's application for grant aid to implement the FMS design has led to an offer of a Department of Industry grant to cover 50% of all capital and revenue costs. The grant of £166,943 reduces the payback period to 2.3 years.

## SECTION 1

### INTRODUCTION

Suffolk Lawnmowers Ltd manufactures lawnmower cutting cylinders by a batch production system with operations that are manually controlled. Attention has been directed at developing a production system with a high degree of automation, together with the flexibility to cater for the changing operational requirements of variable product, process and batch size mixes. The concepts of FLEXIBLE MANUFACTURING SYSTEMS (FMS) aim to automate batch production systems. The advent of microcontrollers and robotics opens potential opportunities for a cost-effective implementation of an FMS for automation of cutting cylinder production.

In order to develop a system design, the company, in collaboration with Loughborough University of Technology, initiated research into the appropriate forms of FMS which are suitable to SLM Ltd requirements. These requirements are based on an analysis of the present production system.

The initial statement of company objectives was set out as:-

- i) To automate the production of lawnmower cutting cylinders at SLM Ltd.
- ii) The automation must be cost effectively applied within a reasonable period of time. Therefore short and long term automation objectives, which differentiate between the potential for immediate implementation and the potential for future expansion of any automation, are to be identified.
- iii) The automated system must be maintainable, reliable and aim for an increase in component quality.
- iv) To reduce labour costs aiming at a minimum cost saving of £0.5 per cylinder through an appropriate reduction in manning levels.
- v) To explore and secure available forms of grant aid to minimise investment costs.
- vi) To meet the volumes of production outputs as achieved in 1980. Flexibility for increases from these levels is to be achieved by increases in the rate of throughput.

In order to achieve these objectives, a review of present flexible automation systems has been undertaken together with an analysis of the current cutting cylinder system; this is reported in Section 2 together with Appendix 1, which reviews a variety of forms of FMS. Technical development of the present processes has also been appraised and formulated; the present

processes are reported in Section 5 whilst the developments are reported in Section 6. The specification of the Flexible Manufacturing System scheme (Section 7) will enable a decision on implementation to be made relating the cost of automation and investment to the achievable economic benefits (Section 8).

## SECTION 2

### LITERATURE SURVEY OF FMS FOR BATCH PRODUCTION AUTOMATION

The applications of FMS technology for the automation of batch production systems are relatively new and costly. Consequently comparatively few systems have been implemented on a world-wide basis. This has resulted in the available literature frequently describing the same few systems that have been widely publicised. Commercial confidentiality restricts such descriptions to the physical layout, control, transfer and machine tool hardware of FMS, with descriptions of the product and process mixes involved. However, much academic research has developed linked to some of the major systems, particularly in Japan, the USA, Western Germany and the East European countries.

#### 2.1 INTRODUCTION

The FMS approach to automation is not revolutionary in its concept, but the result of a long evolutionary process of the mechanisation of the production processes.

##### 2.1.1 The development of automation in batch production

The degree of automation that can be applied has, to date, largely depended upon the type of production and the relevant batch sizes involved. Groover (1980) explains that "for extremely large quantities or volumes, the mass production or continuous flow processing methods are used, for medium volume batch sizes standard batch production is implemented, whilst for one-offs or small batches the job-shop method is practiced." The smaller the batches, the more difficult it has been to automate the production system. In fact, the only production methods approaching the truly computer integrated automatic factory are the processing plants as used, for example, in petro-chemical production.

##### 2.1.2 The influence of batch size on automation

The mid-volume batch range, which has been the hardest to automate due to the flexibility found in historically cheap manual transfer methods, has been suggested by Hutchinson (1979) as follows:-

<u>Parts in System</u>	<u>Required Production p.a.</u>	<u>Manufacturing System</u>
3-10	1000-10000	Dedicated or special
4-50	50-2000	FMS
30-500	20-500	Manufacturing cell

The objectives of mid-volume batch automation are to minimise the production costs per part whilst achieving a flexibility to produce various part designs. There are varying views as to the size of this range. Hughes (1975) classifies the mid-volume range as 200 to 20,000 components per annum, whilst the Machine Tool Task Force report (1980) more accurately defines a Batch Manufacturing System's typical lot size as between 10-300 for large complex parts and from 300-15,000 for small simple parts.

## 2.2 FLEXIBLE AUTOMATION

### 2.2.1 FMS definitions (expert opinions)

#### i) Flexibility

In the automation of batch production systems there is the problem of achieving both the flexibility and productivity objectives.

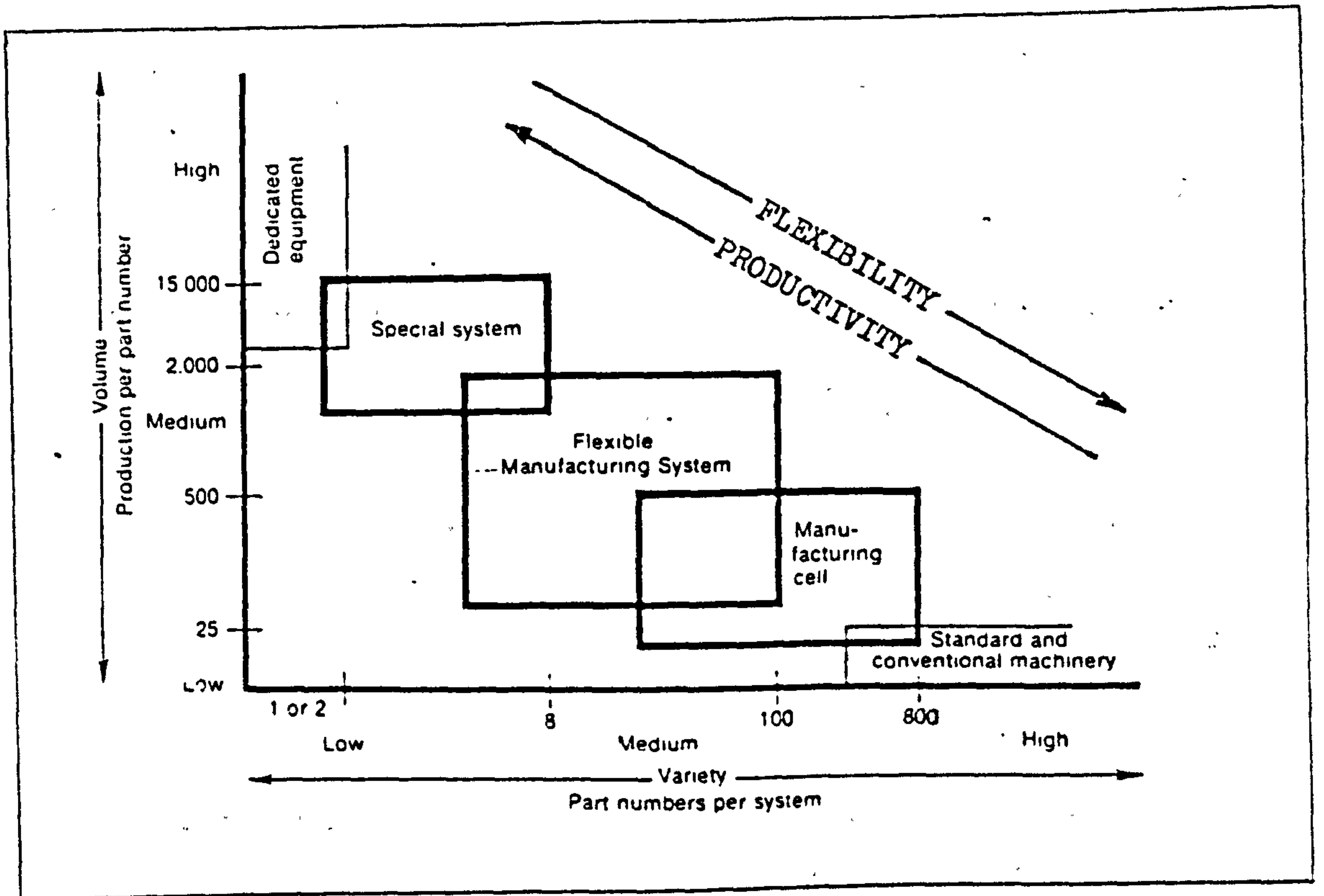
Hegland(1981) explains that the "classic" conflict between productivity and flexibility can be resolved by the application of a mid-volume mid-variety manufacturing systems concept. The seemingly contradictory natures of these two primary manufacturing objectives are illustrated in diagram 2.1:-

Hegland (1981) states:

"the productivity versus flexibility arrows denote the divergent paths of these objectives. An FMS allows the optimum level of each objective to be obtained so they are in harmony and therefore enhance each others qualities."

Flexibility has three levels:- complete flexibility, process specialisation and machine specialisation (process dedication). Each defines the degree of commitment to a process. Complete flexibility relies on universal machinery, tooling, fixtures and processes. In the next level, process specialisation shifts the emphasis to tooling, fixturing and processing to increase productivity. The machine specialisation level is even more restrictive. The machinery is tailored to its application like the tooling and fixturing of the previous level. Productive capacity starts with stand alone machinery and culminates with equipment dedication. However high volume production does not necessarily denote high efficiency. High machine efficiency is achieved by the unique command of machine, material handling and





DIAG. 2.1 THE FLEXIBLE MANUFACTURING SYSTEM CONCEPT

systems control. For example Bailey (1979) defines flexibility as the achieving of parts and run time variety with minimal loss in changeovers.

The flexibility in a machining system has been classified by Hutchinson (1979) in varying degrees:-

- a) Instantaneous flexibility is the choosing of the machine to work with.
- b) Very short term flexibility is the choosing of the parts mix in the system.
- c) Short term flexibility is the ability to change the design of the parts produced.
- d) Short to medium term flexibility is the choosing of the economic number of shifts to work on.
- e) Medium term flexibility is the ability to add or take away parts from the product mix.
- f) Medium to long term flexibility is the ability to add or take away machine tools.
- g) Long term flexibility is the ability to produce different products.

He states that the FMS choice of batch automation embraces all the above forms of flexibility enabling different parts, design changes, product mix changes and expandability in the system.

Hughes (1976) describes a job-shop as normally producing mid-volume batches with the manual labour providing the flexibility. However, the productivity is low in terms of output of parts produced per man.

Present widely applied technology does not enable unmanned factories without limiting these varying degrees of flexibility as is found when transfer lines are utilised. Wood (1981) takes the view that with the FMS approach this need not be so. Companies can learn to develop flexibility with FMS on the route to flexible unmanned factories.

As described by Lipp (1979) transfer machines are suitable for mass production on components with typical cycle times of one to one and a half minutes, whereas machining centres can execute small batches and one-offs on components with cycle times around one hour. In between, believes Lipp, there is a productivity gap that should be filled with flexible systems.

ii) Flexible Manufacturing Systems

There is no generally agreed-upon definition for what has come to be called "flexible manufacturing system" (FMS). Certainly any operable factory can be termed a manufacturing system and flexible is also a subjective adjective. However, the term is often associated with batch manufacturing. The new approach relies on three distinguishing characteristics according to Jablonowski (1980).

- a) Individual independent machine tools.
- b) A transport mechanism for tooling and components.
- c) An overall method of control to coordinate the functions of both machine tool and transfer system so as to achieve flexibility.

With this broad scope there have been a number of individual approaches to achieve the FMS objective of high variable output.

There are alternative ways of defining a manufacturing system and its degree and type of flexibility. Most experts agree on the above FMS concept with minor variations. Arndt (1977) considers the complexity (as well as the flexibility) of manufacturing systems at four levels:-

- a) The first order, and smallest, of systems consists of a lathe (say), or a machining centre and a man.
- b) The second order of system consists of several systems of the first order to complete the machining of a component.
- c) The third order of system consists of the second order with the additional functions of production control and planning.
- d) The fourth order completes the evolution with the addition of product development and design capabilities.

A manufacturing system, he defines, is the totality of all processes and means used to create from a given raw material a quantity of certain products of geometrically defined shape. With the third order the automation of the system can be developed leading to the FMS concept of production. The FMS concept applies only in the second order if only one component per set were being produced manually.

Arndt defines Flexible Manufacturing Systems as "a series of devices interconnected via a common control and transport system such that automatic production takes place by means of differing production processes (or machining operations) of workpieces differing within a

given range, i.e. a system automatically producing a range of components". He develops this description by explaining that "operations differing within the defined workrange may be performed on likewise differing workpieces in a continuous sequence without interruptions caused by resetting", (Arndt (1977)). He explains that existing FMS have been developed mainly for metal cutting or metal forming activities but may also apply to other "solid" workpieces.

The above general FMS definitions encompass the two basic types of FMS designed for:-

- a) ROTATIONAL components requiring turning, boring, drilling, reaming operations, etc., along 2 axes, or
- b) PRISMATIC, or box-like, components requiring all types of operations on up to 6 faces.

Integration of the various operations is required to achieve the FMS objectives. Szumanski (1980) defines this integration as the coherency of multilevel information flow. This enables the structural flexibility in a system, which he defines as the controllability in the form of the speed and regularity of a system's response to environmental changes.

Collins (1980) expresses the prime aim of integrating a manufacturing system to be the combining of a number of hereto separate manufacturing processes so that they can be controlled from a single source relative to each other. Such integration, he believes, has been possible since the 1960's with the advent of low cost controllers.

Integrated computer automated manufacturing provides systems for production with limited manpower (i.e. an unmanned nightshift and a minimally manned dayshift) according to Rathmill (1980). The generic term FMS describes the developments in the factory of the future which have the characteristics of a) product variety and b) highly automated production. To Rathmill (1976) the automatic factory is the DNC concept extended to its logical conclusion.

Hutchinson (1973, 1976) defines Advanced Batch Manufacturing Systems (ABMS) as where both work station and materials handling are under computer control to machine batches of components. The Flexible

Manufacturing System is a subset of the ABMS which can produce various parts in random order at multiple workstations. This is also supported by Hegland (1981) with the view that ABMS are also evolutionary and not revolutionary with the prime requirement to cut metal. The FMS concept is technically a reality with various systems already constructed, but there is the need to develop the design and management skills required.

Hutchinson (1979) analyses the possible construction of FMS as consisting of:-

- a) Machine tools - single spindle or multi spindle
- b) Materials handling - conveyors, cart, robotic, air cushion, stacker cranes or combinations  
Topology - straight line or loop
- c) Tooling - manual, local or automated
- d) Control - optimising, heuristics

He believes the materials handling system to be a small percentage of the total system cost and therefore should have excess capacity. The choice of handling is dependent upon each situation. Hutchinson (1979) expresses robots as being the best choice for ROTATIONAL FMS due to their ease of gripping rotary workpieces. Eversheim (1975) describes two types of FMS. The first type is a "single-stage" system which links one or more identical NC machines to a central store. He declares this is the simplest yet most technically involved type. Therefore with identical operation functions the workpiece is destined for one machine only. The second type is a "multi-stage" system which links different NC machines to complement each others' functions. As each machine has only one type of operation the workpiece must visit several machines. Temporary storages are therefore required as well as a main store. A third type is obviously the combination of the above two types and is more common. NC machining centres used in an FMS of the third type, allow fluctuations in the standard machines' capacities to be taken up.

Stute (1975, 1976, 1977) characterises a flexible manufacturing system as a number of workstations linked together by a common transport and control system which, on the one hand permits automated production and on the other hand permits a range of different machining operations to be carried out on a variety of parts (with small changeover requirements and minimal changeover times). Hellmuth (1981) expands upon this adding that the linkage of NC machines with common control and work-

handling system allows operations to be carried out consecutively, automatically and uninterrupted on a specified range of workpieces. The essential feature of flexible integrated machining systems is the linking of the work and data flows of production, storage and inspection equipment. Such systems occupying a position in between production plants of maximum flexibility (i.e. NC machines) and maximum productivity (i.e. transfer lines). The dividing lines are not rigidly defined.

Barash (1979) explains two extremes in machine tool selection for an FMS. One method is to employ only identical machines, the other method is for each machine to be different and specialised. In the first case, machines duplicate one another, in the second they complement each other. The merit of the first approach is higher system reliability because a machine which is down can be replaced by another. However, some operations are not performed very efficiently. The second opposite approach offers variable routing for each operation but the system is very sensitive to machine failure. Another important aspect is the approach to materials handling. One approach is to allow for random access, with the parts circulating and "pulled out" from the handling system as required. The other is "addressable" delivery with the part being picked up at one machining station and delivered to another upon computer command.

Hitomi (1979) explains that the addition of automatic loading/unloading devices enhances a DNC system's efficiency and flexibility. Such systems are of two forms:-

- a) A tandem DNC system where the tandem layout of machines for similar parts with similar processes provides the productivity.
- b) A DNC system where NC machines with automatic handling randomly processing components (with on-line real-time computer control of information and material flow) provides the flexibility.

He defines the second type as the more flexible manufacturing system. He states that an FMS is the integration of machines and control by combining automation (the hard-technologies) with hierarchical computer systems (the soft technologies). Therefore, the unmanned factory is not a "dream" but a technological stand point.

The ability to switch batches quickly by computer programme rather than by laborious setting of tools emphasises the definition of flexibility

according to Nof (1979) and Leslie (1980). An FMS must provide a flexible range of operations in order to automate non-dedicatable low volume components. They compare an FMS to a flexible transfer line with the flexibility enabled by multiple operations and variable tool changes. The computer control is chiefly responsible for the flexibility as it maintains part programmes, monitors the availability of machines and their assignments, etc.

Yoshikawa (1980) differentiates between a flexible machining system and a flexible manufacturing system. Only the latter includes the assembly function. He classifies FMS as "systems used in general for prismatic components constructed with DNC machine tools for metal removal or surface finishing". He explains that there are three main moving elements:-

- a) The rotating tool holder
- b) The tool magazine
- c) The work table load/unload mechanism

He describes the formalisation of tasks, and their subsequent modularisation with the machines and components, as contributing to a system's flexibility.

Stute (1974) has analysed the characteristics of an FMS as

- a) The integration of material flow
- b) The adaptability of machine tools
- c) The capability of machining different workpieces
- d) System compatibility and expansibility

Spur (1979) believes there has not been much development to automate small to medium batch production except in the NC and DNC field. The basic function of a DNC system is the processing and issuing of NC data to the machines. This application is relevant to the small to medium batch range through the FMS concept of automation. He describes an FMS cell as a system of components necessary to machine different workpieces on one machine tool automatically with a minimum of human control. A flexible manufacturing system is the expansion of the cell to include numerous other machines.

Buzzacott (1980) explains that an FMS is a machining system where

production operations are performed linked by a material handling system under computer control. In contrast to transfer lines, the material handling system allows parts to follow a variety of routings. The FMS should be able to process a large total volume of small to medium batches of parts. The flexible routing is achieved by providing separate paths between each pair of machines where part movement might occur by use of a common material handling device through which all parts pass and which connects all machines.

### iii Flexible Manufacturing Cells - FMS subsets

One important factor in the FMS approach to production is its cellularisation of the manufacturing facilities thereby obtaining the benefits of Group Technology (GT). One of the major justifications for Group Technology has been the belief that it will reduce lead times and improve control (Cauldwell (1973), Collins (1980)). Collins describes GT cells with NC technology and transfer as the basis of the FMS concept.

Merchant (1977) believes that GT precedes an FMS. He suggests that the use of GT cellular organisation, as a forerunner of computer control, will have the eventual benefit of providing a compatible economic base for evolution of computer automation of the factory. This is through the increasing use of hierarchical computer control and multistation manufacturing systems, i.e. FMS, (Merchant (1975)). Much of the research and development in Europe and Japan is being directed to the advancement of CNC and DNC systems in such a way that it can be adapted to GT cells on the shop floor. This will aid the development of FMS. Merchant (1976) believes that of the various possible alternative architectural approaches to meeting FMS requirements, the one that has emerged as clearly much superior to others is that in which the lowest element in the hierarchy is the numerically controlled work station with the next higher element being the DNC cell. Such work stations have self-contained automated work, tool and information flows. In order for the stations to construct a self-contained cell, the cell must obviously be devoted to the manufacture of group technology part families. Thus by definition an FMS is in reality a GT cell that is fully automated.

The final step in the hierarchy is the placing of groups of these cells under DNC. This may result in a computer automated factory. His steps to a "Computer Integrated Automated Factory" are:-



- a) Integrated manual software system
- b) GT and cellular manufacturing
- c) Computer control of the cells
- d) Multistations manufacturing system
- e) Computer integrated automatic factory

GT and cellular manufacturing systems are defined as where part-families are being produced on a product line basis rather than in functionally layed out shops. Sinha (1980) advocates that this evolves FMS by increasing the use of DNC hierarchical control systems. A cell manufacturing system has three states of development. The first stage is a single machine system with the same shape or process components and is the simplest definition of group technology. The second stage is a cellular system with multiple machines to create a machining group for multiproduction flow lines. The third stage is the total cellular system which includes the production, personnel, environment and management functions.

The full potential of GT was first exploited in the USSR and publicised by Mitranov (1958) which created the first real world-wide interest in GT. By 1965 at least 800 Russian factories were using group technology (Grayson (1973)). Opitz's (1971) work on the statistics of workpieces was a most important development in the evolution of GT leading to the famous Opitz classification system. Since Burbidge (1975) has created great interest through his writings on the subject there are now over 150 GT cellular manufacturing systems in the UK.

A manufacturing cell, according to Spur (1976,1979,1980) is the sum of all components necessary for machining a family of parts on a machine tool without manual interruption. A flexible manufacturing cell (FMC) is a single CNC machine tool with integrated tool and work handling. Several integrated FMC s constitute a flexible manufacturing system and such FMS can be linked by a work transport system to create a flexible manufacturing factory (FMF). Therefore an FMC is a unit of an FMS. Chaining together FMC s for a manufacturing system is the recommended approach by Spur (1980) for the stepwise realisation of a modular integrated production concept.

As the labour cost versus automation influences investment he believes GT may be the vehicle for increased robotic use with FMS.

Allen (1974) describes Ferranti's famous GT cell for prismatic avionic equipment which has been automated with NC technology into a DNC cell. This grouping of parts, to be manufactured, into families with common features in terms of process technology (ie the original concept of GT) remains an essential method of planning an FMS according to Barash (1976). He believes it to be an essential component of improving batch manufacturing efficiency, and reasons that the combination of small batches of similarly processable parts achieves much larger batches which can be manufactured more efficiently and economically.

For Rathmill (1977) a GT cell becomes an FMS when operators and supervisors are aided in the operating rescheduling and optimising functions.

Lipp (1979) suggests the following criteria, which include GT principles, for FMS adoption:-

- Batch production repeating at intervals of different frequencies
- Components with a minimum of six different machining operations
- Each operation having a cycle time of between 0.5 and 1.0 minutes
- Family grouping possible, even in the loosest sense

If these conditions exist he recommends the adoption of the FMS principles for automation.

### 2.2.2 Benefits of FMS

Automation of manufacturing and information flows have the following benefits, as classified by Spur (1980).

- i) Continuous supply of components raises the utilisation of productive installations.
- ii) The work in progress levels can be decreased through the accurate control of materials flow.
- iii) By multishifting productivity can be raised
- iv) A rise in the consistency of quality is achievable.
- v) The labour costs can be reduced as the only manual production function is a loading station.

vi) Direct management control of the manufacturing processes is possible.

Spur believes that

- i) Successful implementation and achievement of these benefits is dependent upon the successful integration of an FMS with the production stages before and after the system
- ii) FMS productivity compares favourably with that of conventional job-shops which traditionally have high work-in-progress and low utilisation of much duplicated equipment
- iii) Automation is the freeing of human operators from machine bound work.

Spur (1976) considers that such automation of industrial processes should include all organising and technological measures to release people from direct linkage to the working cycle time of production machines and therefore from the execution of repetitive and monotonous operation.

The uncertainties in component mix and volume necessitates the trading off, in batch manufacturing, between manufacturing economies of scale, offered by process dedication, and the ability to respond quickly to the ever changing market place, offered by stand alone machines. Flexible manufacturing system concepts offer a number of advantages and benefits over these disadvantages in the mid-volume, mid-variety field.

Hegland (1981) argues that the flexibility alone in an FMS provides the justifications. The flexible system allows the mixing of parts randomly, at higher production rates than standalone machines. The parts handled can belong to a general family, or be a group of parts representing major components with options, or have nothing in common except similar size and processing requirements. A flexible system permits incorporation of engineering changes without major production losses, with minimum cost and without sacrificing system productivity.

In-process inventories are sharply reduced with flexible systems as the system can mix parts randomly and respond quickly to the needs of the assembly shop. This in turn reduces lead times. Work-pieces are processed as complete units so a batch does not have to be processed through all the operations before one workpiece is available. Economic order quantities are lower so production schedules can more closely reflect market demands.

An FMS'S inherent flexibility and the constant monitoring and optimisation by its computer control system help maximise the utilisation of the system. If one machine goes down production continues with work re-scheduled to a similar machine.

Flexible systems cut costs in several areas. The automated operation brings labour costs per part well below those for stand alone operations. Direct labour is only needed at the load/unload stations. Indirect labour in the form of material handling and inspection personnel is also minimised. Flexible systems eliminate the dedication of operators to individual machines and they do not require high levels of machining skill. Such systems can be installed on a minimum, modular basis and expanded or contracted as production dictates. The implementation and growth are therefore modular. This reduces risks associated with market forecast errors. The matching of investment to required capacity over a period of time is a definite economic benefit.

Hughes (1976) has argued that an FMS may reduce manufacturing costs by 70 per cent over conventional methods.

To balance this view Rathmill (1980) describes the characteristics of an FMS as:-

- i) high capital investment
- ii) high system complexity and therefore
- iii) high risks due to the nature of the technology.

The decision to build an FMS must be based on accurate data. However with the intrinsic variety of batch manufacturing the demand for batch automation will inevitably lead to the need for a great variety of FMS designs with their own characteristics.

Some of the difficulties with the FMS approach are described by Collins (1980) as:-

- i) the design of the components
- ii) the programming costs, checking etc
- iii) the lack of effective feedback control
- iv) the environmental shortfall.

He believes the approach will reduce inflationary effects as, with the capital being spent at the beginning of the system's life and with

decreased work in progress and labour levels, the future cost of components can be more easily forecast. Additionally, the decreased floor space required for the systems reduces fixed asset costs.

Despite the problems one must consider, according to Wynne (1974), the opportunity cost of not having an FMS when the competition does have one. This would be noticed through the potential or actual loss in sales of components etc. He recognises this fact despite the problems that would be encountered with the conversion of any present manufacturing system to that of an FMS.

Dronesk (1979) has quantified for a system the benefits of an FMS as a 44 per cent machining time reduction, a 39 per cent plant floorspace reduction, a 9 per cent reduced investment expenses reduction and a 25 per cent total running cost reduction for the system he has analysed.

### 2.2.3 Incremental Implementation of an FMS

Arndt's (1976) philosophy for the most prudent way to implement an FMS is to build the system from conventional machines. Initially the control need not be a computer even and need only cover a few workpieces in the parts spectrum. As FMS s are highly capital intensive he advocates the incremental stepwise approach to the introduction of an FMS. These principles should first be accepted which he believes should prove beneficial economically as well as a step towards more advanced systems.

Spur (1975,1979) also advises stepwise implementation as the approach can spread the investment capital and make the introduction of the technology easier. He prefers the initial automation to start at independant modules, ie flexible manufacturing cells. The real time monitoring of a computer based system with a flexible transport system, leads to the FMS.

The stepwise approach with small sets or cells is advocated by Leslie (1980). These cells would contain machines where the necessary software can be developed and improved. He believes that, with standardisation of the interfaces, several cells would build up to the automatic factory.

Hutchinson (1976) declares that CAM can allow the incremental acquisition of capacity and therefore recommends a stepwise implementation approach as a company must base its capacity on uncertain forecasts for products with uncertain life cycles. A company can postpone the capital expenditure for the manufacturing capacity until necessary.

To get from today's industrial methods and equipment to the computer automated factory requires an evolutionary and not a revolutionary process (Merchant (1976)). A stepwise approach is preferable as, whilst a complete system must be planned from the top down it must be implemented from the bottom up.

Few companies are going to build a computer automated factory or even very large FMS due to the cost. Therefore an approach is needed which allows them to build up their systems and factories step by step, with as little disruption as possible from each step. The hierarchical control of DNC and FMS permits such stepwise evolution from the bottom up. Merchant (1976) believes that the appropriate initial step is to lay a sound foundation for the gradual evolution of a factory to full computer control with the introduction of group technology cellular organisation. The resulting cells can operate first as stand alone machines. However they can be acquired with features such that as the percentage of such workstations increases complete automation and integration of the work, tool and information flow within the cell can become economically feasible. The automation of the work handling, etc, can be done through pallets or robots or combinations of these; that of the information flow by use of DNC. Thus in time each group technology cell can evolve into a multistation cellular manufacturing system operation under CNC/DNC.

Barash (1976) agrees that an integrated system represents a large outlay of funds. He believes the introduction of these systems will be aided by better understanding of their capabilities and by the possibility of installing them by stages. He argues that the latter can be achieved without difficulty if CNC machines are installed at first then integrated into DNC systems.

## Summary

The concepts of mid-volume batch production automation have evolved over fifteen years. The development of NC machines, with their wide range of machining applications, provides flexible machining capabilities. Flexibility and productivity have mutually opposing characteristics and are difficult to optimise in one system. Such systems have been achieved (Appendix 1) by adhering to the design principles of integrating NC machines and tool/part transfer under Direct Numerical Control to machine components of similar shape and/or process requirements.

The potential for modular implementation and expansion of an FMS are two concepts which can be beneficial with the introduction of automation.

These concepts are seen as relevant for the design of a system to automate Suffolk Lawnmowers Ltd cutting cylinder production system. The review of existing international FMS (Appendix 1), which pays particular regard to the design of systems that facilitate the automation of cylinder production, establishes the state of the art in FMS technology and provides pointers to indicate the form of FMS suitable for SLM Ltd.

## SECTION 3

### ESTABLISHING THE FORM OF THE FMS

The design concepts used in existing FMS can be employed specifically for the automation of SLM's cylinder production. It is necessary to plan the correct system from the many alternative system designs available and therefore the planning stages, with the control and transfer functions in particular, are examined.

#### 3.1 DETERMINING THE FMS DESIGN CONCEPT

The survey of existing FMS designs (Appendix 1) indicates how:-

- i) smaller sizes of system can be implemented
- ii) the modular stepwise approach can be applied to the implementation of a system
- iii) the use of robots has increased for automated transfer.
- iv) the size of the control hardware has decreased with increasing use of microcontrollers and programmable controllers
- v) hierarchical control configurations have been successfully employed

These FMS trends are instrumental in determining the method of automation for the cutting cylinder production system.

#### 3.2 FLEXIBLE MANUFACTURING SYSTEM PLANNING AND DESIGN

The complexity and high capital risk associated with the investment in implementing an FMS requires a high level of accuracy in planning to minimise the risks. Stute (1978) examines planning methods with respect to their validity in laying out flexible manufacturing systems. In order to aim at an optimal solution, several alternatives must be considered from which a choice can be made. The main points governing a system layout are:-

- i) material flow
- ii) control and monitoring
- iii) organisation
- iv) machining aids

It is the material flow consideration which chiefly affects a layout. A system's configuration depends upon the chosen conception design, time behaviour and costs of the material flow system. Stute's first analysis task is the determination of the planning's aims and requirements, before an analysis of the part mix characteristics and their limiting conditions is required. A subsequent design and outline of the system components, such as



function, equipment, structure and organisation gives rise to possible conceptions of the subsystems involved, i.e. work flow, tool flow and control systems. Stute (1975) has previously concluded that the requirements, deriving from the spectrum of parts to be machined, influences the work flow in a system. Different concepts of part flow, tool flow and control must be developed for optimisation. The design work is simplified by considering separately these subsystems of an FMS.

Stute lists the aims of an integrated manufacturing system as

- i) achieving flexibility
- ii) achieving high utilisation of equipment
- iii) achieving a degree of automation
- iv) creating a wide machining range
- v) integration into the existing production system
- vi) reliability
- vii) securing product quality
- viii) part spectrum

As small and medium batches very often cause changes in manufacturing requirements, a high degree of flexibility is necessary. When a new batch of parts is to be machined the aim is to make it possible to change over the manufacturing stations quickly with the least amount of interruption and to ensure that the changes in capacity loading due to downtime can be overcome by simple organisational measures. The extent of the measures which ensure a high degree of flexibility depends on whether complementary or interchangeable stations are integrated within the system. With interchangeable stations the parts in each case are finish-machined on one station. With complementary stations several stations may be necessary for finish-machining.

In an FMS the machining processes are performed automatically. The manual activities remaining concern only the work in the part-setting/loading area as well as the preparation of the control information, system monitoring and maintenance functions. The machining of parts should be as complete as possible as operations external to the FMS require additional set-ups which may lead to a lower part quality and higher throughput times. In considering the machining requirements of the part spectrum, a step-by-step implementation is beneficial with the high investment involved and the difficulties associated with the integration. A typical characteristic of an FMS is the linking of the stations with buffers by means of the transport system.

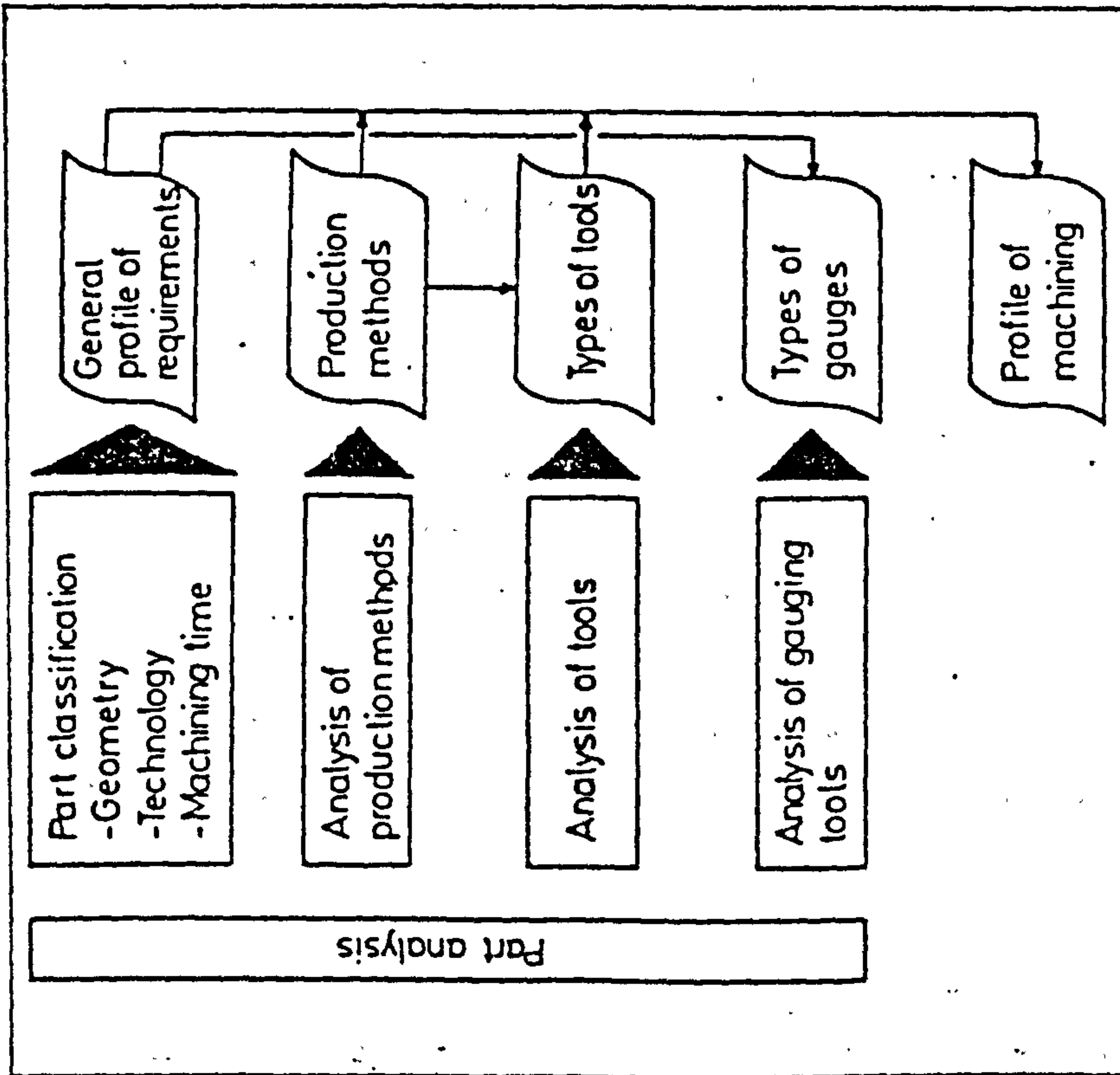
The positioning of machines in an FMS layout is very important in reducing cycle-times. This is true also of the reliability of any centralised transfer system.

Breakdown of centralised subsystems can bring the whole system to a standstill.

The part spectrum has to be preselected to generally correspond to the desired aims initially specified. According to Stute (1978) the grouping together of the part requirements leads to a profile in which the geometrical, technical and machining-time requirements are contained (diagram 3.1). This can be supported by an analysis of the manufacturing processes and tooling requirements. The resulting machine profile contains the major requirements of the part spectrum and thus represents a decisive foundation for the layout of the material flow. Further requirements may be formulated for the individual system components. They result, on the one hand, from the necessary interrelation of the individual devices and, on the other hand, from the demand for the simplest of possible solutions. The resulting catalogue of requirements provides the essential foundation for the design of an FMS.

As well as the system layout/model the relevant input and output parameters are of particular importance. For the input parameters the technical considerations include layout, type of system, potential extensions to the system and transfer type, whilst the organisational parameters include the number of shifts, store loading strategy, transport strategy, organisation of queues, batch sizes and part clamping. The output parameters include the loading of stations, loading of transport, pallet frequency, number of pallets, storage capacity and machining cycles. Stute (1978) explains that for the planning and layout of FMS it is necessary to co-ordinate the developed part flow options under conditions of efficient performance with the maximum loading of stations and transfer equipment.

One must compare various systems on a cost basis which includes the total purchase value, depreciation, interest, maintenance, floor space and energy costs. Hellmuth (1981) advocates a user of an FMS mastering both the hardware and software of the latest control technology. Special attention in the design phases must be given to extensive automatic fault diagnosis. It must be possible to superimpose software for DNC and production scheduling functions. The work spectrum must first be investigated during the planning stage ascertaining the number of workpieces to be machined. Where different types of workpieces are frequently worked on they have to be passed to the assembly shop by the most direct route without the need for large buffer stores. To achieve this the number of set-ups required,



DIAG. 3.1 DETERMINING PART SPECTRUM REQUIREMENTS

necessitated by the machining times, must be carefully investigated. After the throughput and machining sequences and their duration have been established the concept of the plant, i.e. machine numbers, type, allocation of operations, etc., can be established. Hellmuth states that the choice of handling also connected to these considerations resulting in the use of guided trolleys, conveyors, pallets and robotic systems. The next important planning phase is the determination of the control system. The hard and software system must be capable of controlling its operations automatically and have provision for an interface for production scheduling. The control system must be designed so as to enable the user to operate and service it himself subsequent to commissioning. Two prerequisites are essential for a successful operation of an FMS. They are a high degree of machine availability and unmanned operation.

In a flexible system the failure of a machining station not only reduces the rate of output but also results in an imbalance between the quantities of workpieces produced in parallel. This in turn results in difficulties in the assembly shop due to shortages. Consideration must also be given to the fact that the machining stations must run without an operator. A system should be served solely by people responsible for loading and unloading in the loading station and by setters. Therefore, all machining stations must be equipped with a maximum of safety devices. There are several ways to meet the requirements for the control system. Hellmuth (1981) has found that some FMS have, in the past, come to grief on the complexity of the control system, including the enormous software costs.

Where all functions of a flexible system (e.g. NC programme control, data management, machine loading scheduling, workhandling and data collection) are controlled by a centralised computer, very costly software development is necessitated. Such complex software can be modified by the use of CNC and standard freely programmable controllers (PCs). Each machining station has an independent CNC or PC unit. It must be possible to equip the controllers with extensive part programme stores (which decentralises the control). This not only makes it possible to operate machines completely independently of the workhandling system and to try out machining operations, but also enables correct part programmes to be called after integration with the workhandling system. The workhandling functions can also be controlled by a computer or programmable controller.

The planning function, as analysed by Björke (1979), should include detailed

technological planning as well as production planning. He advocates software modules being developed along two axes, horizontal and vertical. Björke's horizontal automation is the increasing of the range of processes included in an automation project (e.g. different machining processes, workpiece handling and measuring, tool supply, etc.) whilst vertical automation is the increasing and development of the process activities themselves (e.g. machining operations, sequence control, path control, data distribution, set-up and data transfer functions). This modular approach to automation enables an ultimate hierarchical computer system to be constructed. Björke has used the approach in Norway to build his three level system. The first (lowest) level consists of a dedicated computer for path and sequence control of the robot. The next level consists of a computer dedicated to cell handling, data distribution, set-up and verification, local planning and data transfer. The third level is the central "host" computer to carry out process and production planning (Section 4).

A basic question to be answered when planning an FMS is whether components already exist for which the system can be applied. The systems built in the USA, Japan, West Germany and Russia had products or groups of products already available or planned for which new production facilities were required. Barash (1978) proposes a method of planning with the following criteria:-

- i) selection of the group of parts to be manufactured
- ii) determination of machining content
- iii) identification of machine tool elements
- iv) configuration of station and systems
- v) detailing of system design and operating rules

Witte (1980) at Aachen University has established a method of choosing suitable workpieces for NC equipment which can be applied to the part spectrum analysis for an FMS. Eversheim (1975) of Aachen University recommends the construction of a pilot system to minimise the development cost risks whilst establishing a large FMS. This approach enables experience to be gained, demonstrations to be given, teaching and preparation to be carried out and enables motivation from manufacturers and users of the FMS to take place.

### 3.3 ALTERNATIVE FMS DESIGNS

#### 3.3.1 Early Designs

It is usually possible, from the parts and machining requirement

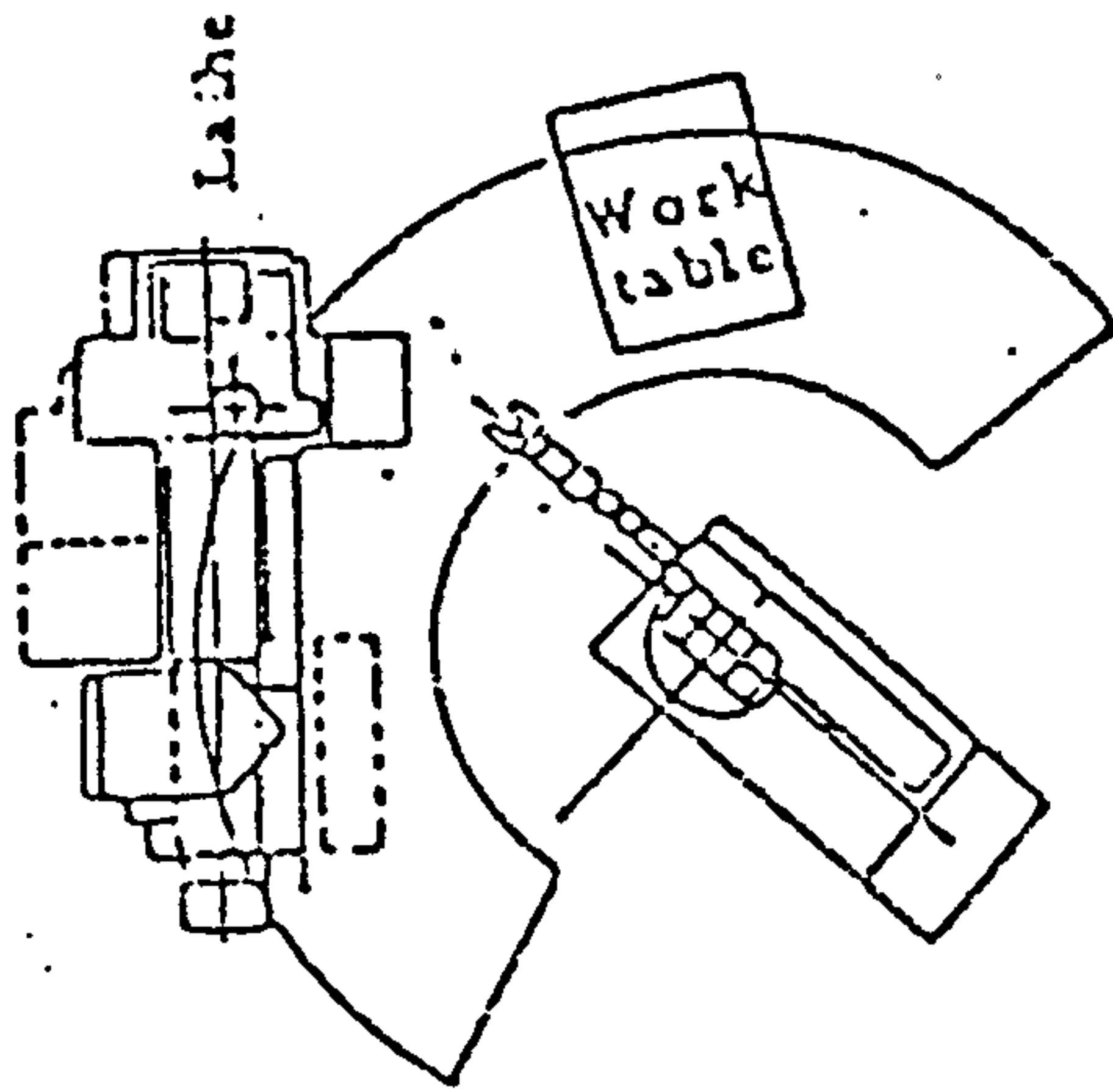
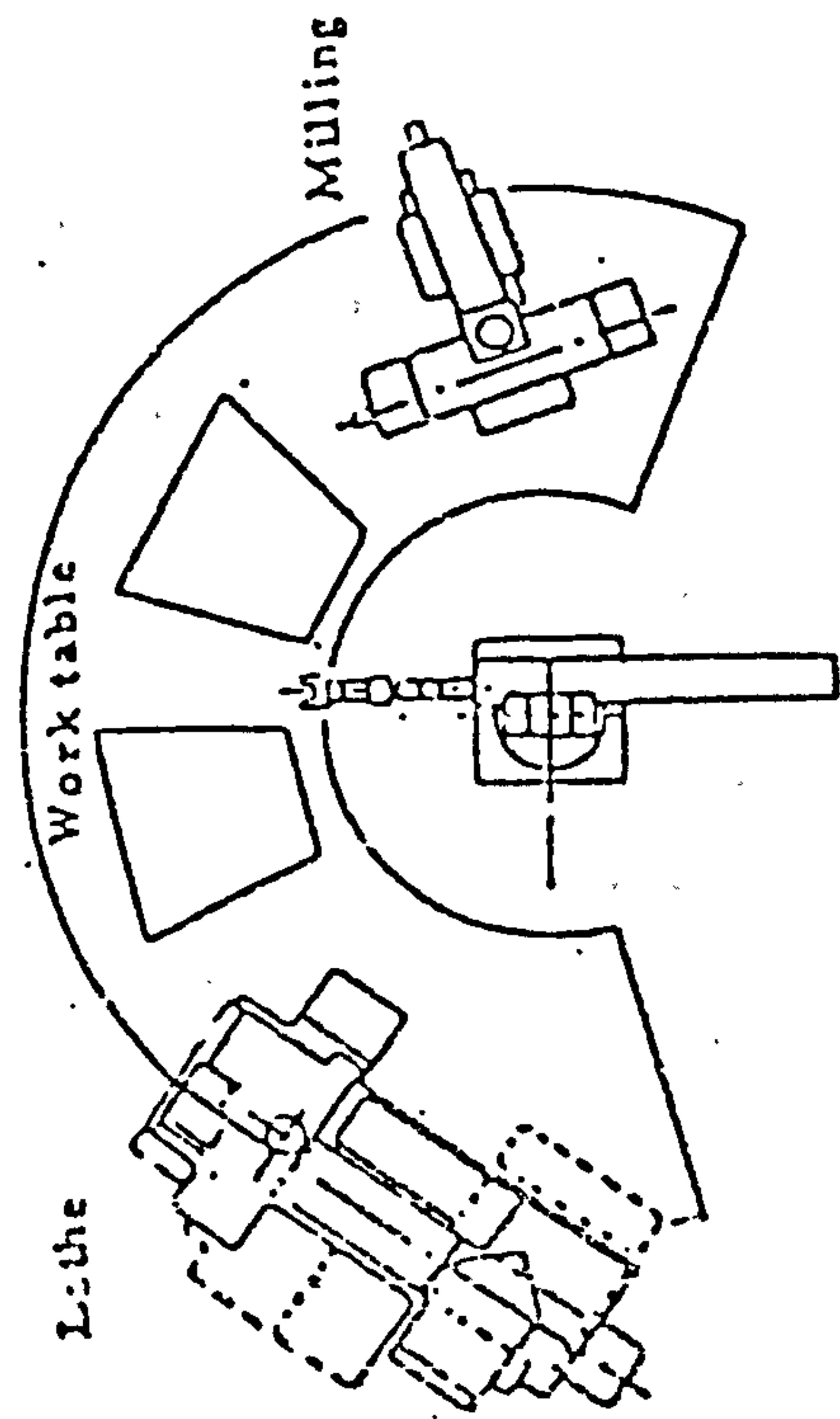
catalogue as proposed by Stute (1978), to arrive at several alternatives of FMS layout design and system structure. The analysis of the present systems (Appendix 1) shows the form of the major FMS structures, (diagram 3.2). These include the line and loop configurations using roller conveyors, carts, robots and stacker cranes, etc.

Flat and block-like stores are used for central storage. However, multi-level storage is the most common, which permits random access to the components. The simplest line structure is given when the central store and the machining stations are set up in line opposite each other and are serviced jointly by a single means of transport. Multi-level stores serviced by stacker cranes are used with this approach. Second stacker cranes have been used to reduce the workload on a single crane. Such a division of tasks enables one crane to service the store whilst the second services the machines. A looped structure arises from positioning the machine tools around a roller conveyor (say). The pallets move along the conveyor, which can also be used as a store, until they reach the required machines.

### 3.3.2 FMS with Robotic Transfer of Components

One or two machines such as lathes, drilling, milling machines, etc., can be combined with a robot to organise an automated integrated machining system. If the unmachined workpieces are placed at a specified position a robot can unload a machined workpiece from a machine, load an unmachined workpiece and issue a command to start operations. A robot can also perform automatic tool change operations. System configurations can be that of loading/unloading a machine to and from a table, to and from a work feeder and to and from a work feeder to several machines. A limitation of machines results from the work area available to a robot and the dimensions of the machine tools within this area. Beyond the capacity of one transfer robot a compound system consisting of several robot cells must be used. Unmachined workpieces are supplied to machines from a work feeder before being loaded to an intermediate work feeder or table (diagram 3.2). The conditions which determine a layout are

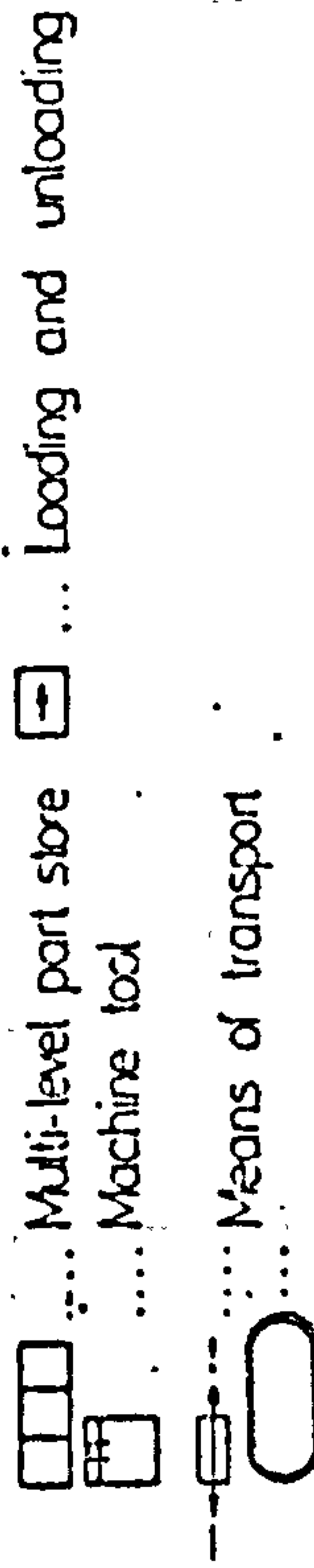
- i) the service area obtainable from a robot
- ii) the accessibility into a machine tool's work area by the robot, avoiding tail stocks, chucks, etc.
- iii) gripper manoeuvrability of workpiece into workholder chuck



(ROTATIONAL)

(PRISMATIC)

Option A1	Option A2	Option B1	Option B2



DIAG. 3.2 FMS CONFIGURATIONS

- iv) expulsion priorities of human personnel from robot service area
- v) efficient work loading/unloading with the service area of a robot
- vi) contingencies for tool loading/unloading

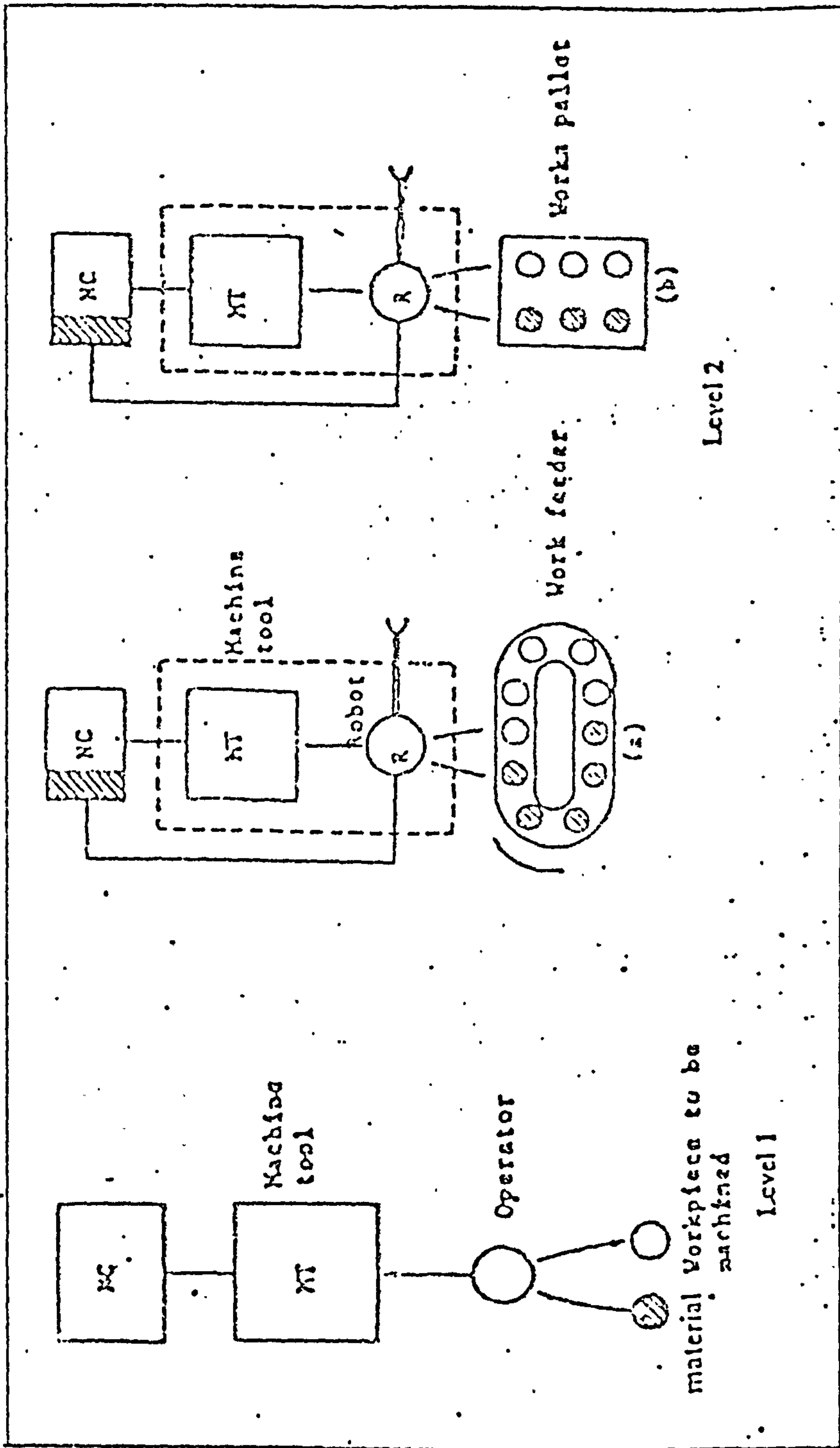
For a robotic system the workhandling characteristics are of extreme importance. The major considerations are those of the machining method, work loading, work supply and design of the workpiece. The machining method dictates the gripping (i.e. the work holding mechanism and jig and fixture design), machining accuracy and time, and lot size considerations. The loading and unloading criteria dictate the service space and time, and gripping and jig design, whilst the design of a workpiece governs handling by its shape prior to and after machining, its weight, centre of gravity, quality and surface conditions. The work supply is dictated by the use of work table and/or work feeder equipment.

#### 3.4 BENEFITS WITH ROBOTIC APPLICATIONS IN FMS

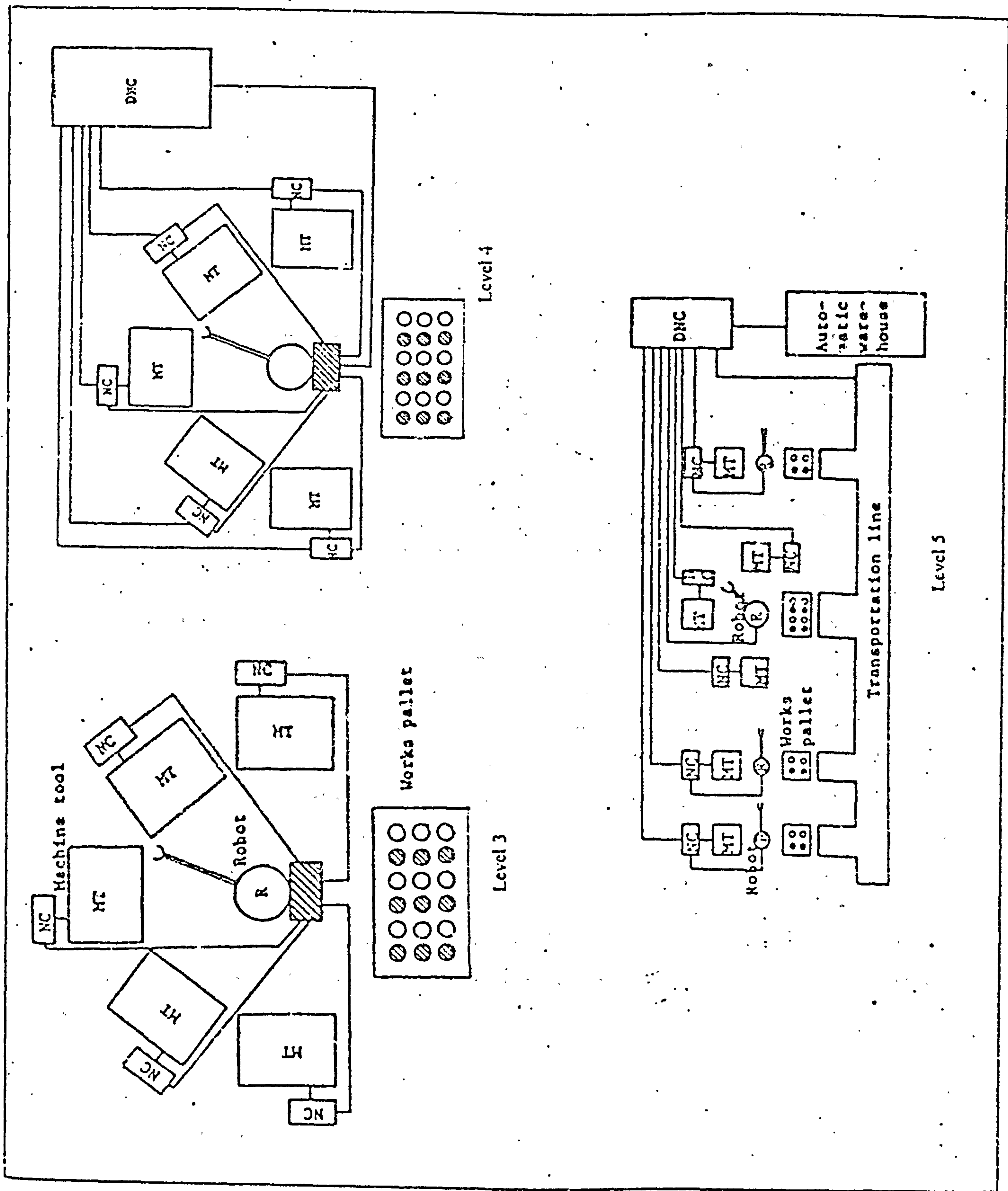
According to Brock (1980), the nations leading in FMS technology tend to occupy similar positions in robot implementation technology, as, for example, the USA, Japan, West Germany and Sweden.

Inaba (1976) advocates the use of robots in flexible manufacturing cells as it provides a significant step to automation when evolving systems. Inaba maintains that for flexible, computer controlled manufacturing systems, the use of the robot is the best means for automating the handling of work. A robot can be applied through a series of evolutionary levels of automation leading eventually to an unmanned factory. These levels are shown in diagram 3.3. Level one is the conventional NC machine with workhandling carried out by the operator. Level two is a system in which the loading and unloading of a workpiece on an NC machine is executed by one robot in place of the operator with the robot controlled by NC. Level three illustrates a system in which one robot loads and unloads workpieces on to a number of NC machine tools under commands from their individual NC controls. Level four describes the system in which DNC is introduced to control and co-ordinate the several machines and the robot in the cell. Level five approaches the unmanned factory in which centralised DNC is used to control and co-ordinate a variety of level three and four systems and also a transportation line, with an automatic warehouse.





DIAG. 3.3i LEVELS OF AUTOMATION



DIAG. 3.3ii LEVELS OF AUTOMATION

### 3.5 REQUIREMENTS OF ROBOTS FOR WELDING AND TRANSFER PROCESSES

A wide variety of industrial processes are amenable to robot applications as explained by Warnecke (1979). Some processes are better suited than others for different types of robots. Heginbotham (1980) divides typical processes into four categories in descending order of their natural suitability for robot applications, as follows:-

- i) Category A includes the processes necessitating low-accuracy curve-tracing with no gripping requirements, e.g. spray coating, shot peening and spot welding.
- ii) Category B are the processes requiring low-precision gripping operations or where standard gripping surfaces on the component or job holders are present, e.g. unloading of die casting and injection moulding machines, heat treatment operations, loading or unloading of machine tools with cylindrical or other regular prismatic workpieces.
- iii) Category C includes the processes involving more precise handling operations necessitating interstage tooling and special gripping facilities for each different operation, e.g. transfer between stations for hot and cold forging operations, loading/unloading of machine tools with general work, arc welding, deburring, etc.
- iv) Category D describes assembly operations and processes requiring a similar degree of positioning accuracy and versatility of manipulation and gripping.

Spur (1979) has studied the requirements imposed by a number of industrial processes on some of the performance parameters of robots, e.g. positioned scatter, velocity variation, etc.

For arc welding, Spur states the requirements as:-

Positional scatter	- medium (0.2 - 1.0 mm)
Velocity variation	- stepless
Velocity	- 100 mm/s - 1000 mm/s
Form of motion	- defined path
Program sequence	- continuous

For loading and unloading the requirements are :-

- Positional scatter - medium (0.2 - 1.0 mm)
- Velocity variation - single or multi step
- Velocity - high (>1000 mm/s)
- Form of motion - point to point
- Program sequency - discontinuous

To interface a robot into a DNC system a certain level of control sophistication is required.

The American National Bureau of Standards defines five levels of control for a hierarchical system. They are, in ascending order, servo control (i.e. the controlling of position and velocity actuators), primitive function control (i.e. the generation of trajectories and their modification due to sensory perceptions), elemental move control (i.e. the specification of trajectories), work station control (the control of a single work station), and system control (i.e. the control of a system of work stations). To achieve level four, the control of a work station with the monitoring and local reaction to sensors, Engleberger (1979) believes a robot must be capable of:-

- i) workspace command with six infinitely controllable articulations between the robot base and a hand extremity
- ii) fast hands-on instructive programming
- iii) local and library memory
- iv) random program selection by external stimuli
- v) positioning repeatability of 0.3 mm
- vi) weight handling capacity to 150 kg
- vii) compatible computer interfaces
- viii) high reliability

He states that these capabilities have been achieved in commercially available, first generation robots which have subsequently been applied to machine loading, hot handling, assembly, welding and fettling.

## SECTION 4

### CONTROLLERS FOR FLEXIBLE MANUFACTURING SYSTEMS

#### 4.1 COMPUTER SYSTEMS IN MANUFACTURING

The size and cost of computers used in manufacturing have continually decreased over the past twenty years whilst their capacity and performance have increased. Minicomputer and microcontrollers are capable of many of the functions that previously larger mainframe, process computers were required to do.

##### 4.1.1 Process Computers

The automotive companies were among the first to use process control computers in discrete parts manufacturing plants to control their massive production operations. Whereas the chemical and the primary metal industries have tried mainly to control continuous processes, the manufacturing industry is burdened with discrete processes of high complexity. Consequently, the automotive industry has developed programmable controllers, to serve as substitutes for conventional controllers for their transfer lines, leaving larger computers to carry out the more complex monitoring operations.

Large computers are often used to control and monitor several different functions whilst the smaller computers/controllers are used for functional specialisation.

##### 4.1.2 Minicomputers

A large computer can handle such applications easily though not economically. The dedicated smaller computer is simpler to programme and can be much more efficient and therefore economical. Rembold (1977) examines the trend towards the use of smaller satellite computers that are controlled and monitored by a central computer. These are less costly, more versatile, easier to programme and result in less complex installations.

The overall productivity of a plant is influenced by the efficiency of the machine tools and the ability of operating personnel to control the entire manufacturing process. The control computer can be employed to assist plant personnel in both of these areas.

In order to substantially improve the efficiency of an operation, it is necessary to approach both of these areas at the same time. Unfortunately, in most operations, this is not possible as many existing machine tools would have to be retrofitted for computer monitoring and control. It is not too difficult to attach sensors to an existing machine and then to monitor the operations of such equipment. However, to modify a machine tool for computer control is generally impracticable as the equipment has not been designed with a computer controller in mind. This problem can largely be overcome with the application of the inexpensive microcontrollers recently available.

The fundamental causes of machine tool inefficiencies have been listed in order of importance by Rembold (1977).

- i) Elapsed time necessary to adjust and change tools (setting)
- ii) Mechanical breakdown of equipment (maintenance)
- iii) Electrical malfunction of electrical components external to the main control panel (limit switches, motors control solenoids, etc.
- iv) Problems with hydraulic equipment
- v) Electrical malfunction of components inside the control panel

Wherever one of these problems arises a time penalty and repair cost occurs. Computer control tries to reduce the economic losses that are associated with these two phenomena.

The first machine monitoring systems were designed so that all inputs were monitored in sequence by the same computer. For large installations this kept the central processor very busy. As these systems evolved, input data evaluation was performed by exception analysis. The computer was programmed to service transducer inputs according to a hierarchical structure. With a high level scan of the inputs the computer investigates the proper functioning of a machine and goes to the next one if an acceptable signal was obtained. In the case of an abnormal signal, the computer initiates a low level scan investigating the input of numerous other transducers to determine the source of difficulty. With the advent of microprocessors, microcontrollers

were developed for dedication to each machine in order to report to the central control computer.

## 4.2 COMPUTERS IN BATCH PRODUCTION

The medium and small lot size industries have many problems that are similar to those of mass producers such as the automotive industry. Therefore, much of the computerised manufacturing technology is common to both. Due to the fact that batch producers are usually smaller companies, computerisation of these plants will take longer as a result of the high costs. NC equipment is very popular in this industry although, without DNC, it is not used to its fullest potential.

### 4.2.1 Numerical Control

The introduction of the Numerical Controlled (NC) machine has revolutionised many manufacturing operations producing small parts in small and medium size production runs. There is a wide variety of machine tools which are equipped with hardwired NC controllers. NC machines have found little application in mass production runs where it is difficult to compete with specially designed manufacturing equipment which continually produces the same parts. With the majority of NC machines, programs are entered by tape or manual data input (MDI). In the case of complex workpiece configurations, a larger computer is required, with a programming processor (e.g. APT - automatically programmed tools, ADAPT - air material command developed APT). These processors are special languages that facilitate programming considerably. Their features include easy description of parts, cutting tools, the motion of cutting tools and required tolerances. The output of the computer is a part programme which describes the tool selection, tool path, cutting speed, coolant flow, etc. The part programme is then translated into machine instructions via a post processor, which is a special programme describing the configuration of the controls of the machine to the computer.

### 4.2.2 Direct Numerical Control

In companies that employ a large number of NC machines, the preparation of programmes can be a major effort. In order to improve this situation, direct numerical control (DNC) has evolved. The programmes are developed on a large computer and sent via a direct communication line to a process control computer, which stores the programme on a disc. When the machine operator requires the programme he informs the computer and the programme is actuated to control the tool.

For less complicated parts, the programmes can be developed and debugged on process control computers. This eliminates the need for tapes. A further improvement of the machine tool is the adaptation of a mini-computer that takes control of all movement of the machine. This approach is known as soft-wired control. It is the sole function of the computer to monitor and control the machine tool. Programmes are often entered via a tape reader or transferred from a host computer.

#### 4.2.3 Integrated Control

Both NC and DNC systems can be part of a hierarchical computer structure. The total manufacturing programme of a factory can be stored on disc or magnetic tape. These programmes can be part of an integrated manufacturing system whereby workpieces are scheduled automatically onto different machine tools. The computer also performs piece counts, transfer of workpieces and scheduling of new parts.

The future of computers in manufacturing equipment is leaning towards the increased use of mini and microcomputers as control devices. There is more emphasis towards machine control rather than monitoring only. The machine tool controller is the lowest in the line of a hierarchical system with ever increasing use being made of the programmable controller, which is the latest development of microcontrollers as explained by Charnley (1977).

#### 4.3. HIERARCHICAL DECENTRALISED CONTROL

With the advent of minicomputers and microcontrollers, systems designers have a low-cost tool that, when interconnected into a network, can be as powerful as a larger computer. Bernard (1970) emphasises that control functions not requiring complex calculations are often much better accomplished by smaller systems. Most of the control tasks in industry are in the form of digital inputs and outputs which suit minicomputers. Control systems can be divided into numerous smaller and simpler control tasks in a hierarchical nature. Minicomputers can be used to assume the divided responsibility of the complex system whereby one processor would be responsible for one or more sections of the total control task. Hierarchical systems can contain up to four levels of control responsibilities. The computers of each level must be compatible to communicate with each other. Each level of control computer may need the software and hardware capability to communicate with adjacent levels. The top level only has to communicate downwards. It is not absolutely necessary that the chain of command has to be observed within the network with data from the first level being sent to the third



level or the second level could directly control a process. Required communication links may work in serial or parallel mode for direct communication. The individual computers should be provided with an automatic disconnect to isolate faulty hardware. Automatic powerfail and restart modules should be available and these should have the capability to automatically load programmes and perform diagnostics. It is of considerable advantage to use standardised hardware, communication and control software as well as modular programmes for each control level if possible. The complexity of a hierarchical system increases considerably if equipment from many different vendors is used. Particular attention needs to be given to the software as it has to perform a similar function as the supervisory system in a multi-processing environment. Computers on the higher levels of control hierarchy should be able to perform error diagnostics, programme loading, etc.

For the first level of control, a PC (say) will communicate directly with the process. Usually a number of controllers are located in the plant in close vicinity to the equipment or process to be controlled. Each controller is assigned a limited control task such as the monitoring and supervision of a machine tool. The operating system is usually small for the control of functions, which may include the scanning of process inputs from different sensors, counting, evaluation of critical test parameters, some data reduction and limited control of the process. At this level, the process needs continuous attention and immediate correction when 'out-of-control' conditions are encountered. Therefore, the controller will be in constant communication with the process elements. The controllers will be too small to support an optimisation programme which is executed at a higher level. Communication is required between the operator and controller at the first level. Therefore, plant personnel are able to obtain valuable computer experience at relatively low costs. The control system can be designed in a modular form with the inherent advantages of standardised hardware and software packages. By breaking a process into smaller sections, the risk of total plant shutdown due to a control failure can be reduced considerably.

A host computer supervises a number of level one controllers dependent upon the available input/output loops. This includes co-ordination of the activities between different controllers. Middle management can be supplied with necessary information to operate the plant efficiently on a daily basis. The information from machines and handling equipment is co-ordinated to assist communication between plant and production management. The hardware configuration of the host computer is more elaborate than the controllers.

It will have more memory and computing power with peripherals such as keyboards and visual display units. A third level of control is carried out by a central or executive computer. Information collected from several host computers enables management to form a data base which is necessary to operate the plant efficiently as part of the total corporate system.

Standardisation of equipment from the start of the system's implementation ensures that duplication of peripheral equipment is minimised. This is recommended by Branch (1971), Rembold (1973) and Chiantella (1976).

The demand for decentralised systems control has been discussed by Weck (1975) who describes the trend of inexpensive programmable controller systems enabling hierarchical systems to be easily constructed.

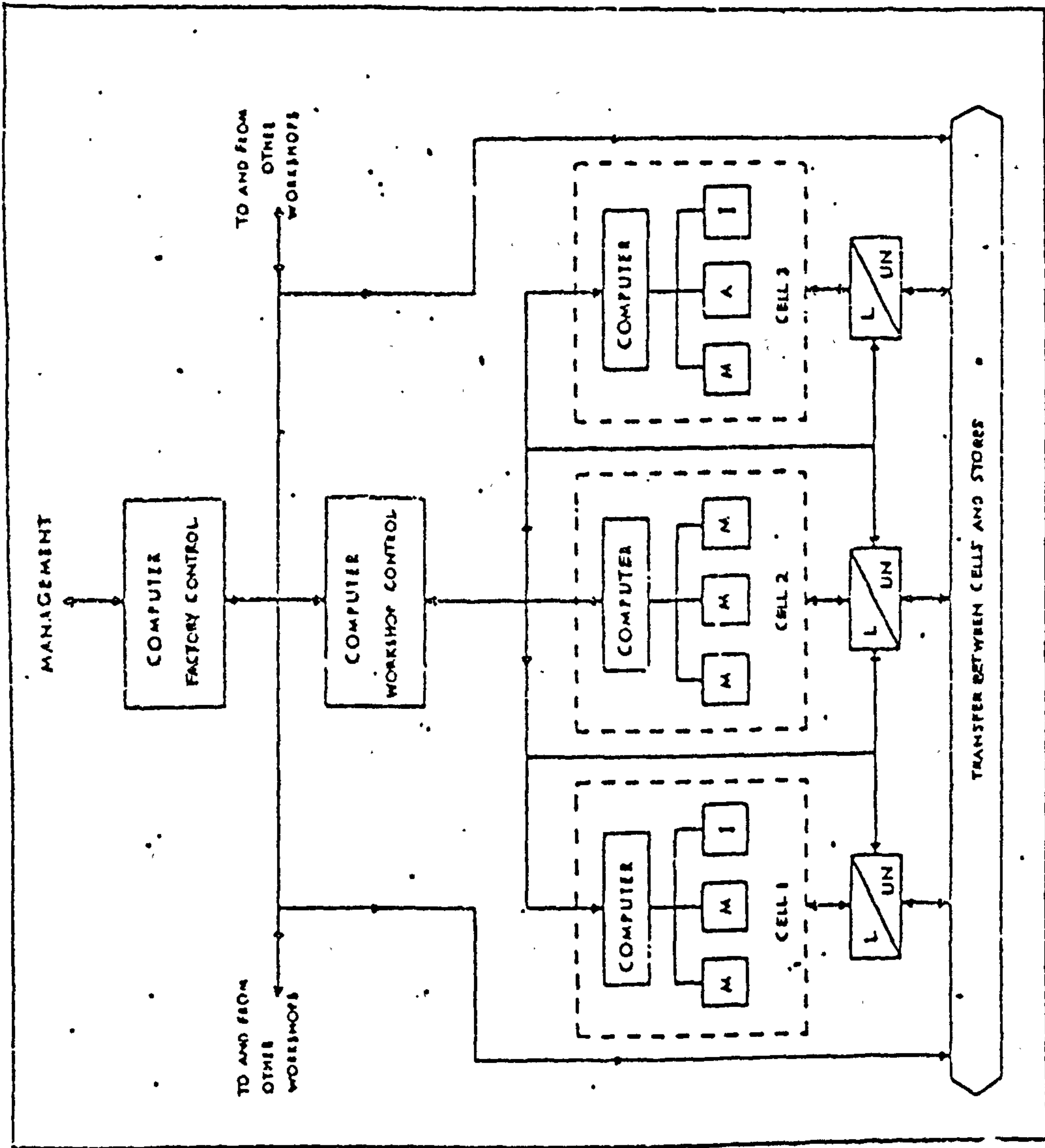
#### 4.4 BENEFITS OF A HIERARCHICAL SYSTEM

One of the main advantages of a hierarchical system is its modularity. If a controller should fail only a section of the machine tools is out of control. The software costs for smaller controllers is less than that of a main computer and is spread over the investment period. The controllers at level-one service transducers, solenoids, etc. of the machines more quickly as the control is executed by several controllers simultaneously. Software changes are more easily enabled as there is a minimised possibility of interference with all the machines in a system. A decentralised system is generally cheaper with hardware and software and wiring costs. It is also easier to expand the system due to the modularity. These benefits are explained by Schwarz (1976) and Garrett (1979).

#### 4.5 HIERARCHICAL CONTROL FOR AN FMS

The developments in computer technology have enabled the application of hierarchical control systems in flexible machining systems (diagram 4.1).

A major problem for any would-be FMS developer is the non availability of compatible hardware and software elements from which an FMS can be constructed (Rathmill (1981)). This is of crucial importance since, currently, considerable tailoring and special-purpose development work can be incurred by FMS builders. As the FMS market increases, and as engineers increasingly recognise the costs of special development work in this area, the availability of modular FMS elements will emerge. By choosing one supplier of micro-controllers such standardisation is achievable.



DIAG. 4.1 TMS CONTROL

## 4.6 MICROCONTROLLERS/PROGRAMMABLE CONTROLLERS

### 4.6.1 Microcontrollers for Hierarchical Systems

The new development in control computers, which economically enables the construction of a hierarchical computer controlled manufacturing system (small computers constructed with microprocessors), are better known as PROGRAMMABLE CONTROLLERS. They are microcontrollers which are specifically designed for industrial environments.

Groover (1980) has found that in a number and variety of production applications the microprocessor/microcontroller is being used to gain control over individual operations as they are cheap and reliable. He believes this use will grow tremendously.

Merchant (1976) discusses the (small) digital computers' potential and points out the advantages as being the versatility of automation as they can be programmed on-line. Additionally they may be capable of on-line moment by moment optimisation capabilities.

### 4.6.2 Microcontroller development

The programmable controller (PC) developed out of the needs of the automotive industry. The need was for a control system that was easily programmable and reprogrammable in the plant, highly reliable, small, able to communicate with a computer and inexpensive. Out of these requirements evolved the first PC s. These systems could be altered through a programming device to handle production changes without having to rewire relays. They were easier to maintain and repair (because of plug-in assemblies) and more reliable in a plant environment than relay control panels. They were also smaller thereby saving on expensive floor space. The PC s were designed to supply data to future computer monitoring and information gathering systems. They were cost-competitive with relay and solid state hardwired control panels and so originally proved to be effective "relay-replacers".

Through their early years PC s gained a good reputation and began to be accepted by other industries. For some applications, PC s even replaced some computers. The present PC designs are more flexible and reliable with additional features added to increase their capability due to present microprocessor technology. Arithmetic operations have been added to most PC s which makes it possible to interface with analytical instrumentation to obtain machine operation results, measure the tolerance of parts produced and perform required calculations. Three-mode analogue control functions (Proportional,

Integral and Derivative) to control analogue process variables enables a PC to go beyond purely digital analysis and approach the capabilities of a computer. PCs are literally computers designed for industrial environments with built in self-diagnostics for error detection and indication. For communication to hierarchical systems, PC systems include serial communication interfaces, based upon the E.I.A. standard RS-232C., with speeds up to 19,200 baud. The serial interface can be used for better man-machine interfaces by using printers to provide logs, alarm messages and management reports. The interface enables video screens to be used to give an operator immediate visual machine or process status and enables PCs to communicate with other PCs and central computers for the distribution of control throughout a plant, as explained by Jannotta (1980).

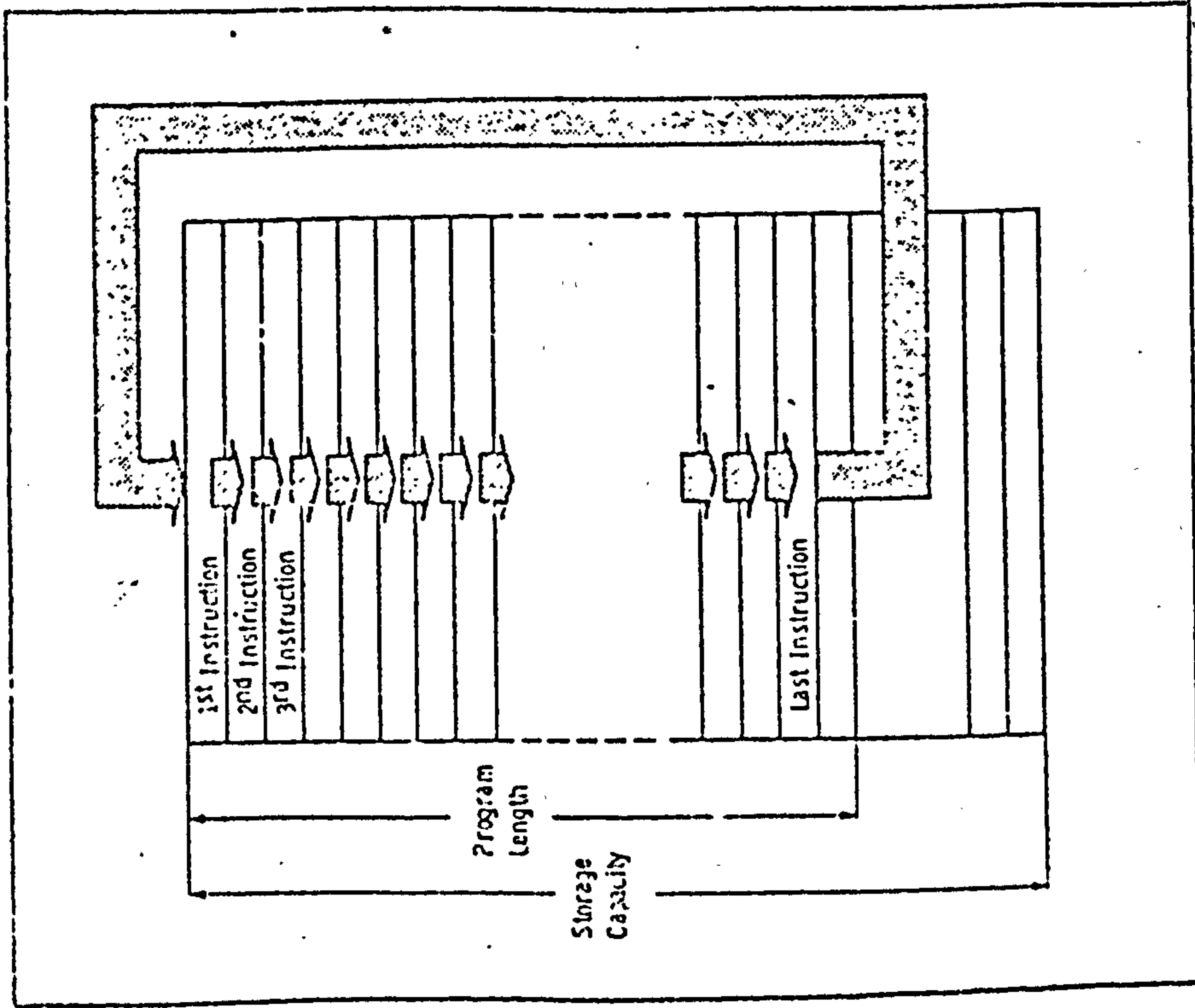
#### 4.6.3 Programmable Controller Definition

In 1978 the National Electrical Manufacturers Association (NEMA) of America, where PCs were originally developed, released a standard for programmable controllers. NEMA standard ICS3-1978, part ICS3-304, defines a programmable controller as "a digitally operating electronic apparatus which uses a programmable memory for the internal storage of instructions for implementing specific functions such as logic, sequencing, timing, counting and arithmetic control, through digital or analogue input/output modules, of various types of machines or processes. A digital computer which is used to perform the functions of a programmable controller is considered to be within this scope. Excluded are drum and similar mechanical type sequencing controllers".

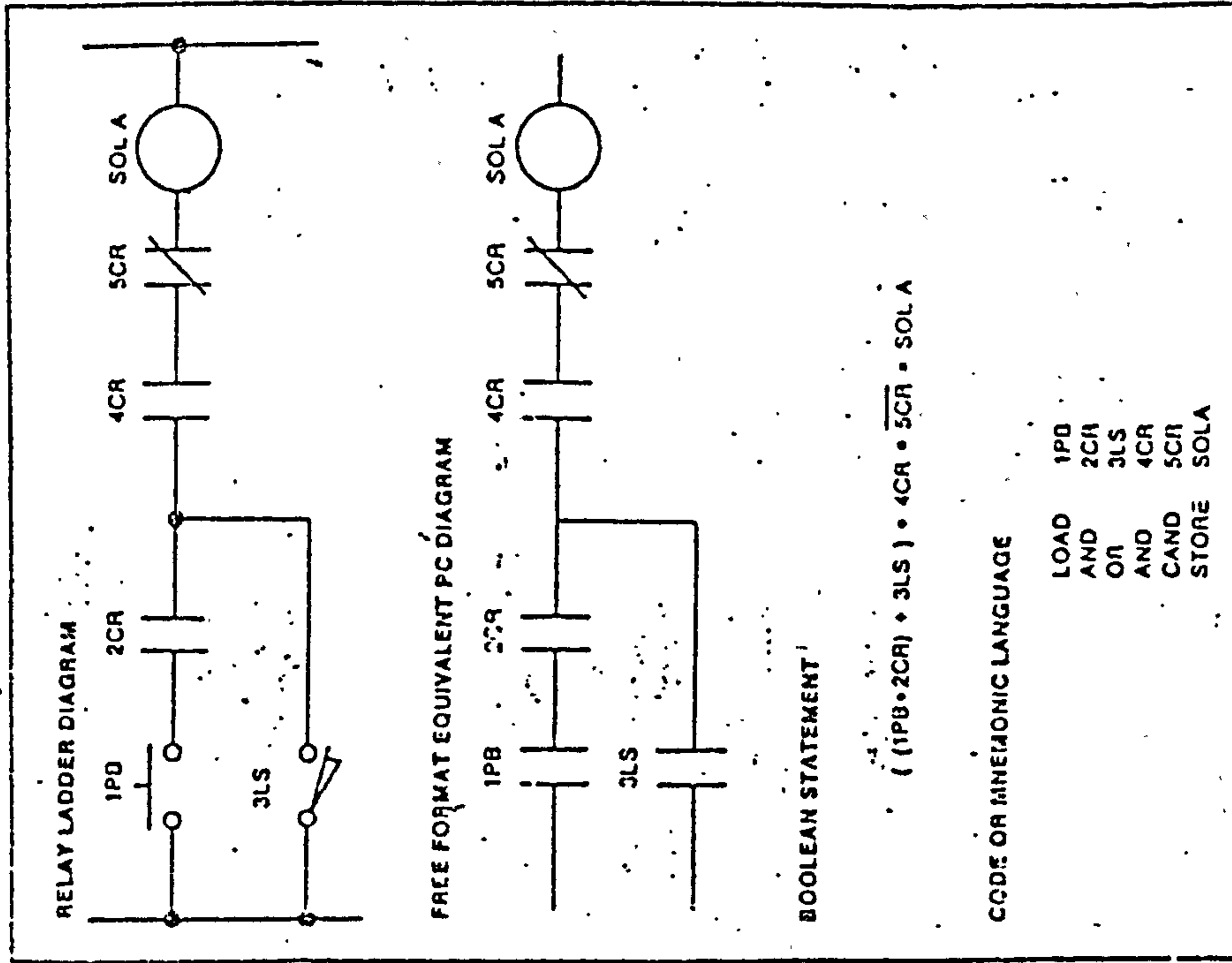
Regardless of size, cost or complexity, PCs all share the same basic parts and functional characteristics. A PC consists of

- i) input and output interfaces
- ii) memory
- iii) a processor
- iv) a programming language and device
- v) a power supply
- vi) housings

Functionally a PC examines the status of input interfaces and in response controls something through output interfaces. Combinations of input and output data are referred to as logic. Several logic combinations are usually needed to carry out a control plan (the program). This program is stored in memory using a programming device. All logic combinations stored in memory are periodically evaluated by the processor in a predetermined order. The period required to evaluate the logic combinations is called a "scan", (diagram 4.2).



DIAG. 4.2 POLL PROCESSING IN PROGRAMMABLE CONTROLLERS



DIAG. 4.3 PC PROGRAMMING LANGUAGES

Input interfaces, which are modular, accept signals from the machine or process pilot devices ( i.e. limit switches, thumbwheel, transducer, etc.) and convert them into signals to be used by the controller. Output interfaces, or modules, convert controller signals into external signals used to control the machine or process. The interfaces include A.C., D.C., pulse, binary coded, decimal, thermocouple and special purpose levels of signal.

The complexity of a control programme determines the amount of memory required. Most PC memories are expandable (in fixed increments) varying from 0.1K to 48K bytes. Most PC s use the Metal Oxide Semiconductor (MOS) integrated circuit memory, Random Access Memory (RAM). RAM, a read/write memory can be altered as easily as core memory but is more compact and less expensive. As RAM memory loses its stored data when power is removed, a back-up battery is required to retain the memory contents.

The processor organises all controller activity. The central processing unit (CPU) electronically scans the control plan logic along with the status of the inputs and executes a specified command to the appropriate output. A number or combination of numbers and letters is used to code data locations referred to as addresses. The processor uses addresses to fetch and sort input/output and memory data. The addresses are selected by assigning a specific interface circuit to a specific field device. In addition to straight logic processing the processor can perform other functions such as timing, counting, latching, comparison and retentive storage. It can also emulate stepping switches and shift registers. Hickey (1979) has found that the increasing use of microprocessors for the CPU function increases a PC's decision making capability including mathematical functions.

Programmable controller programming languages take one of the following forms:-

- i) Relay ladder diagrams and symbols representing normally open contacts, normally closed contacts and outputs, etc.
- ii) Boolean statements relating input and output data represented as logical "and", "or" and "invert" functions to a single output
- iii) A code or mnemonic language with instructions such as AND, OR, LOAD, STORE, etc., used with input and output addresses. Included in this form are assembly languages, (diagram 4.3).

Each programming language has its advantages. However, usually the relay ladder diagram is preferred as plant personnel are familiar with this format and it provides a convenient record. Programming is through an alpha/numeric

keyboard with a light-emitting-diode (LED) or cathode-ray-tube (CRT) display. After program entry has been completed the programming device continues to be used as a diagnostic tool.

The PC power supply may be integrated with the processor, memory and input/output units into a single housing, or may be a separate unit connected to the main housing through a cable. As a system expands to include more modules, additional or auxiliary power supply may be required. Power supplies are the first line of defence against electrical noise generated over power lines.

One of the most important features of a PC is its modularity which makes repairs easier, decreases downtime and facilitates expansion. Most major PC components are mounted on printed circuit boards that can be inserted into a housing or card rack. Housings are mounted in racks in a control console or mounted to a sub-panel in an enclosure. Most housings are designed to protect the circuits from the dirt, dust, electrical noise and vibration specifically found in industrial environments.

There are various sizes of microcontrollers (PC) as defined by Kumontis (1980). A "small" or "mini" PC is one having between four and 175 inputs and/or outputs. The memory module sizes range from 256 to 2096 word capacity. The capability is usually a basic instruction set consisting of relay logic, timers, counters and skip instructions.

A medium to large PC has 175 to 2000 inputs and/or outputs. These usually have an advanced instruction set of the basic functions plus arithmetic, data handling and other special functions. The memories are field expandable from 4K to 32K. These more sophisticated PC s have computer interfaces which accept and provide data at high baud rates. The interface connects into the processor and provides a switch selectable RS-232C or a 20 mA current loop port for direct communication to a host computer, or intelligent terminal for monitoring or control. Computer interfacing adds supervisory control to increase flexibility. The computer can load and monitor data within the PC enabling production reports to be compiled and PC parameters and programs to be varied by the computer, as described by Weck (1977) and Abbot (1979).



#### 4.6.4 Programmable Controllers versus Minicomputers

Programmable controllers have evolved from mere relay replacers to sophisticated microcontrollers as capable as computers. While all PCs are computers, by definition, not all computers are PCs. The difference is in the environmental design considerations, programming methods and maintenance. PCs are designed to operate in the industrial environment. Typical operating specifications include a temperature range from 0° to 60°C (32° - 140°F) and a relative humidity range of 0 to 95 per cent. Therefore airconditioning is not required and they are shielded so that they can operate in noisy electrical environments without being adversely affected. PC programming is intended for people familiar with relay logic (e.g. plant electricians and technicians) and standard symbols. Therefore, programmable controllers can be maintained by a plant electrician instead of highly trained electronics specialists. Usually maintenance is completed by replacing modules rather than components. Diagnostics are built into the PC to assist in locating bad modules.

The design to communicate directly with plant differentiates a PC from a general purpose computer. The plant or machine is wired directly to the controller's interface. The processor immediately recognises A.C. and D.C. signals and acts accordingly. A PC can be programmed on-line whilst the machine or process is running, thereby minimising downtime whilst control programmes are being enhanced. The costs of PC applications can be less than hardwired relay systems due to the latter's labour-intensive wiring costs. The modularity of construction also minimises supply lead times, (Hickey (1980)).

Shaw (1980) defines the areas of application in which different controllers may be suitable due to their characteristics. Whilst programmable controllers increase their capacities and capabilities they are continually encroaching into the general purpose computer area, which he defines as for calculation and recording uses.

Irwin (1980) has studied PC applications and found productivity increases of 98.5 per cent in comparison to 92 per cent and 96 per cent machine efficiency improvements for solid state and relay logic systems, respectively. Overall project times to install PC systems can be reduced 75 per cent due to shorter lead times in specification, design, purchase debugging and documentation functions.

#### 4.6.5 Programmable Controller Configurations for Hierarchical Control

Rosenof (1980) has analysed the approaches that can be implemented in order to achieve a system controlled by multiple PC s. Where it is advantageous to use several small inexpensive PC s rather than one large computer, he recognises two major systems which allow only one or two modules of a process going down, should a controller malfunction.

One method is to use a "daisy chain" configuraion. With this approach, an "in-use" signal is constantly transmitted around a loop from PC to PC. When one PC is scanning it prevents the other PC s from functioning. This is desirable should only one part of a process require a source of power, air (say), at a time. Thus, only one level of control is utilised. This method requires a manual start-up sequence and if one controller should fail, the whole system stops. This may be desirable from a safety point of view. The advantage of this approach is a minimisation of input/output hardware as a control PC is not used. However, the daisy chain system cannot prevent one PC from using a disproportionate amount of scanning time in relation to the other PC s.

The approach which eliminates this disadvantage is to assign one PC as a master controller in a master/slave configuration (i.e. hierarchical control). The master PC activates each of the slave PC s one at a time in sequence. When activated the slave PC turns on a "busy" output and then scans all the interfaces it is responsible for and activates any outputs if required. At the end of one scan, the PC turns off its "busy" signal which enables the master to monitor the next PC in sequence.

An improvement on this approach is the simultaneous scanning of all slave PC s with the master PC instructing them according to a priority programme within its memory. Thus, unless an "instruction-required" signal is sent to the master PC, all slave PC s continue scanning together.

Sherman (1979) defines the one level of control as "peer-to-peer" communication and defines a further approach to a PC system configuration; that of direct wiring to a foremans console. This is in fact a level of control below that of the daisy-chaining or peer-to-peer levels. A manual operator is directly in communication with all PC s. Therefore priority of control can be left to the human controller.

#### 4.6.6 Applications of PC s

Savelyev (1979) describes the use of PC s to control grinding machines, automatic welders, injection moulding machines, refractory and other hydraulic presses, etc. PC s have taken over whole assembly lines with many individual tools at each stage of the line, working in concert to produce a product from start to finish.

Programmable controllers to monitor and control machines in the heat treating industry are examined by Golden (1980). A PC can perform the functions of relays to sequence the mechanical movements of a heat treating machine, the quench valves, power sources, etc. It also provides the control circuitry for the hydraulic, waterquench and cooling systems.

Other PC applications include paint pigmentation control (Gault (1980)), energy management, waste disposal, paint spraying, data transfer and matrix handling, (Fox (1980)).

#### Summary

The concept of a system of machines (configured around a robot transferring cylinders from process to process) integrated together under hierarchical decentralised control is feasible for the automation of the production of cutting cylinders. Two levels of control are required ("host" and "local"). The present manual production system requires a detailed analysis to develop the concept into a workable system design specification.

## SECTION 5

### THE CURRENT CUTTING CYLINDER PRODUCTION SYSTEM

The planning methods of Stute (1978) provide a structured approach for the determination of the specification of an FMS to automate the cutting cylinder production system. A full analysis of the entire system's product mix, process mix, production technology and component geometry establishes practicable phases in which the system can be implemented.

#### 5.1 THE COMPANY STRUCTURE

##### 5.1.1 The Birmid Qualcast Group

Suffolk Lawnmowers Ltd is part of the U.K.'s largest foundry group - BIRMID QUALCAST. The group is divided into divisions of which the non-ferrous and iron foundry divisions perform the major operations of the group. The group specialises in precision castings in light alloys, sand and gravity die castings, high duty grey and spheroidal graphite iron castings, high volume sand and permanent mould castings and magnesium alloy castings.

##### 5.1.2 The Home and Garden Equipment Division

Suffolk Lawnmowers Ltd originally started business as an iron foundry and later merged with Qualcast of Derby, U.K., to obtain a stronger market position. The companies eventually produced only lawnmowers as these were the most profitable products (being originally manufactured from cast components). Upon merger with the Birmid foundry group, the division was created to produce furniture, ladders and greenhouses, as well as lawnmowers. In 1982, it was the most profitable division of the group. The division manufactures the world's largest range of lawnmowers.

##### 5.1.3 Suffolk Lawnmowers Ltd Market Analysis and Forecast

Suffolk Lawnmowers Ltd (SLM) is situated in Stowmarket, Suffolk, thirty miles from the East Coast international ports and eighty miles north east of London. Within the division the company produces the widest range of lawnmowers including hand and petrol powered lawnmowers of the cylinder, rotary and hover types. Electric motors, petrol engines, cultivators, welding rods/wire and professional heavy duty lawnmowers are also manufactured at Stowmarket.

The total United Kingdom market for lawnmower products within the division's range is approximately 1.26 million units per year. The division took 56 per cent of this market in 1981. Suffolk Lawnmowers Ltd exports a large percentage of its product range for the division. The biggest market for its products is in Western Europe where there is an annual consumption of 2.4 million units per annum. The company has strong representations in West Germany, France, Belgium, Holland and Ireland. Lawnmowers are also sold in South Africa, Australia and New Zealand. From 20 to 40 per cent of Suffolk Lawnmowers output has been sold abroad.

The major product type is the cylinder mower. During 1980 the company, with the assistance of a firm of consultants, identified the major strengths as being the production of cutting cylinders and bottom blades for their range of cylinder machines. Additionally, the manufacture of the small four-stroke petrol engine is a major strength of the company. All other activities are relatively standard or low technology processes. Major investments have already been undertaken to automate the engine production lines. The future corporate policies of the company are to reduce the size and manning levels of the Stowmarket factory to create a more productive manufacturing site. Manning levels have already been reduced from 800 to 500 personnel. The company is therefore engaged on a programme of investigating methods to minimise production costs on cylinder and bottom blade output to enable them to maximise the benefits of their specialist technology. The factory site is planned to be reduced in size by 50 per cent and the concepts of FMS will be applied to their cylinder batch manufacturing processes to assist this aim of increasing productivity. Tables 5.1 to 5.7 summarise an independent market survey of the lawnmower market (Mintel (1980); Market Assessment (1980)), and cylinder production anticipated for the next 3 years.

#### 5.1.4 Existing Company Products

The full range of products produced at Suffolk Lawnmowers Ltd is as follows:-

##### 1 Handmowers

Two types of handmowers are manufactured at Stowmarket; the older 'H' type with cylinder lengths of 14 and 16 inches and the newer 'metric' type with cylinder lengths of 12, 14 and 16 inches. They are small, lightweight mowers with an adjustment of cutting height of 1/4 inch to 1<sup>1</sup>/<sub>16</sub> inch.

	(x 1000) units	% of Total
Light mains electric	910	67
Power petrol/electric	310	22
Handmowers	120	8
Heavy duty mowers	50	3

Table 5.1 UK Sales of Lawnmowers by type : 1979

	(x 1000) units
Light mains electric	510
Power petrol	115
Power electric	55
Heavy duty	20

Table 5.2 Sales of Rotary Mowers by type : 1979

	%
Qualcast	50
Black & Decker	25
Flymo	15
Mountfield	3
Others	7

Table 5.3 Total Market Shares (Volume) : 1979

	1975 %	1979 %
Electric cylinder	2	1
Electric cylinder (flex)	10	12
Electric rotary	1	1
Electric rotary (flex)	16	19
Hand propelled (sidewheel)	13	5
Hand propelled (roller)	35	16
Petrol (cylinder)	11	10
Petrol (rotary)	6	6

Table 5.4 Ownership of Mowers

(Source: BRMB/Mintel January 1980)

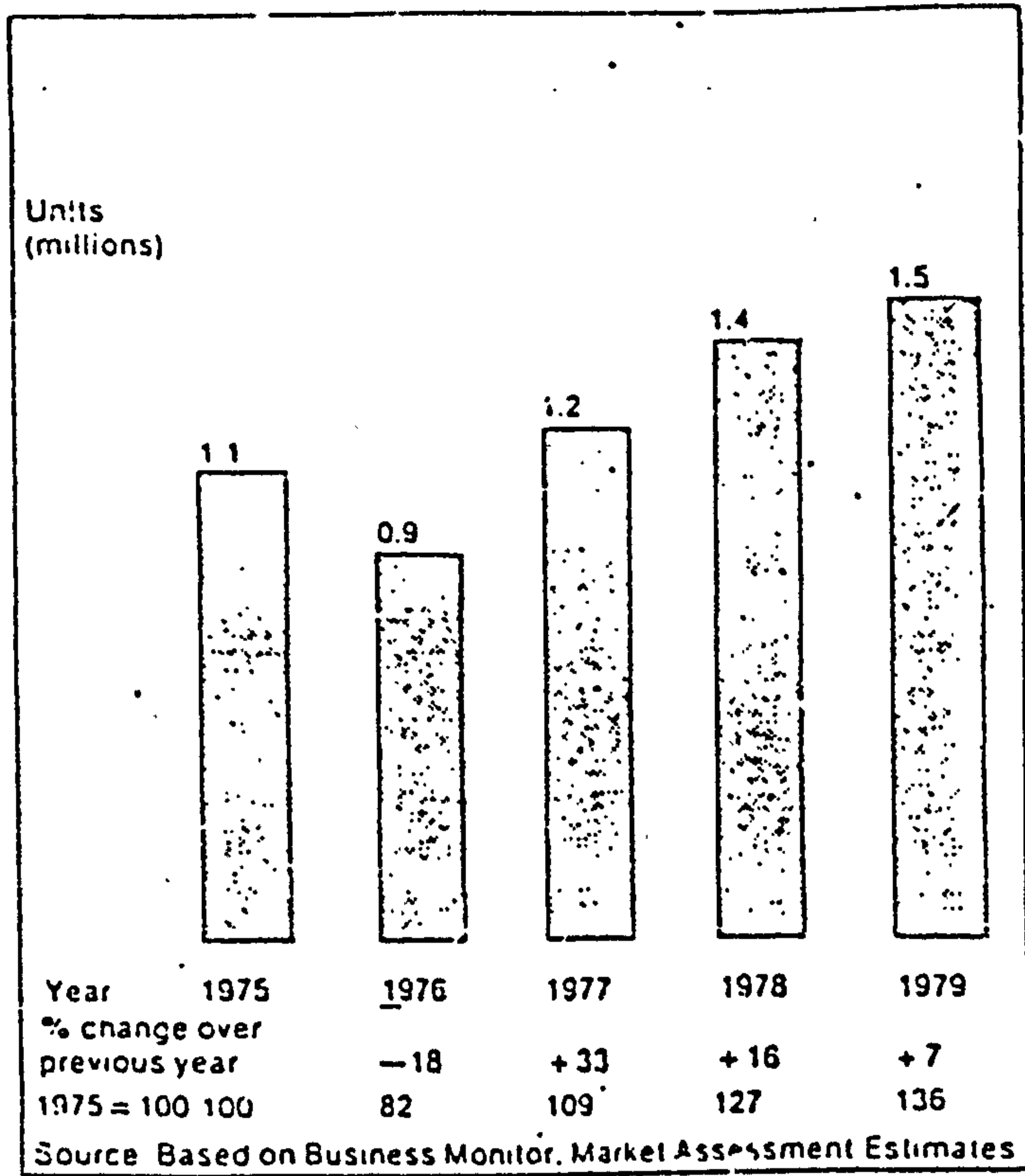


TABLE 5.5 UNIT SALES OF LAWNMOWERS IN THE UK

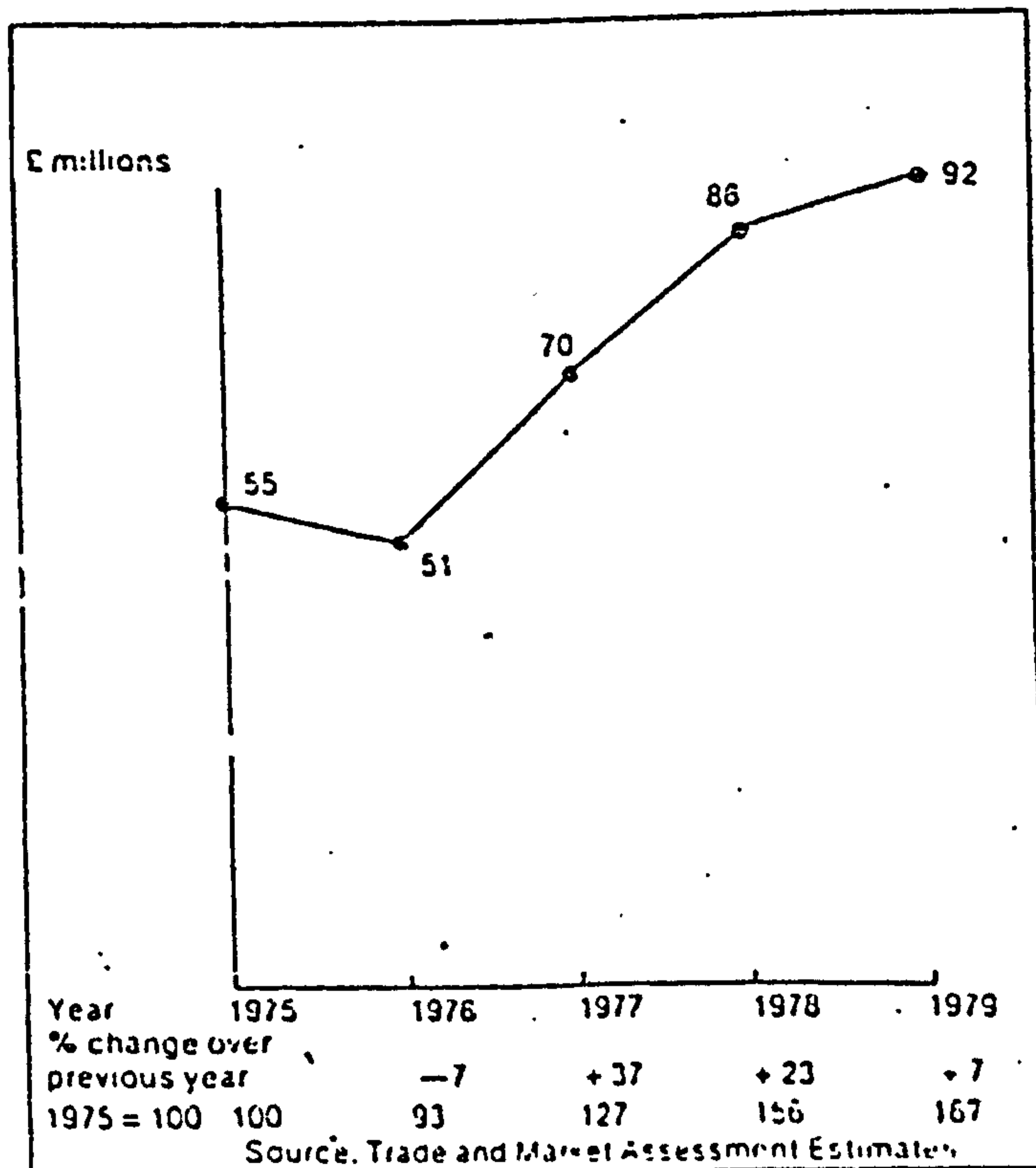


TABLE 5.6 UK SALES OF LAWNMOWERS (£ millions)

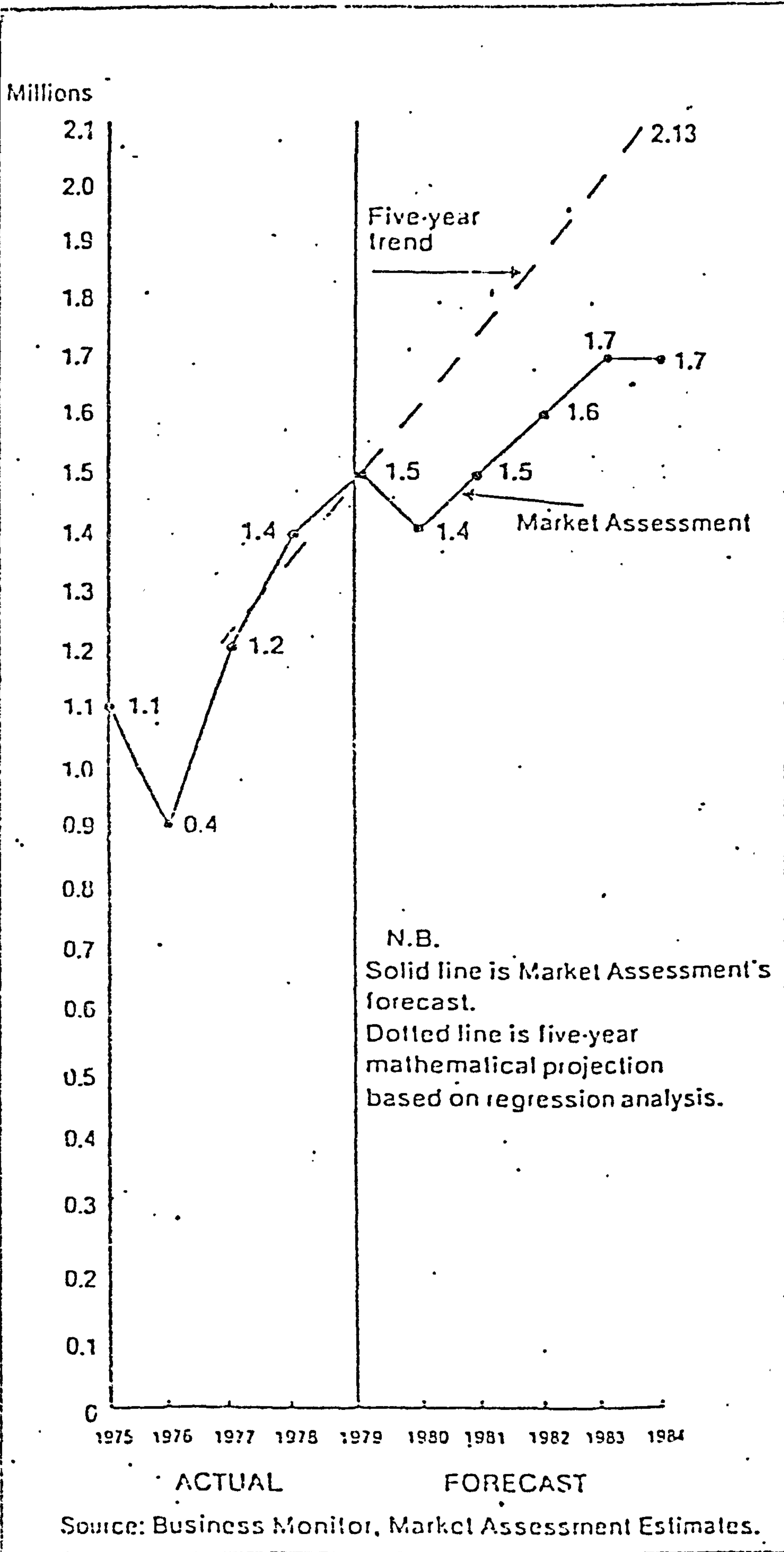


TABLE 5.7 ESTIMATED ANNUAL UNIT VOLUME SALES OF LAWNMOWERS IN THE UK - FIVE YEAR FORECAST



## 2 Powermowers

The powered cylinder mowers manufactured at Stowmarket are petrol driven rather than the electric motor driven mowers produced at Derby. They include a 12, 14 and 17 inch "Punch" range, a 12, 14, 17 and 20 inch "Atco Domestic" range and a 20, 24, 28, 30 and 34 inch "Atco Heavyduty" range. These are five or six bladed cylinder mowers with a height of cut adjustment from 1/4 inch to 1<sup>1</sup>/<sub>4</sub> inch. They are powered by a 98 cc 'Suffolk' four-stroke engine, or a 4 H.P. model, with an automatic clutch and recoil or instant electronic ignition.

## 3 Rotary Mowers

Six models of rotary mowers are produced in the range of 380 mm to 450 mm length blades.

### 5.1.5 The Factory

The factory layout is shown in diagram 5.1. Raw materials enter the system at A (for engines) or B (for mower chassis components) and are machined at C and/or D (A2 for engines), degreased at E, painted at F and assembled at G(A3 for engines). The mowers are stored at H and despatched at I. This layout is in the process of being rationalised. Cylinders, which are assembled and machined at D1, are discussed in more detail below.

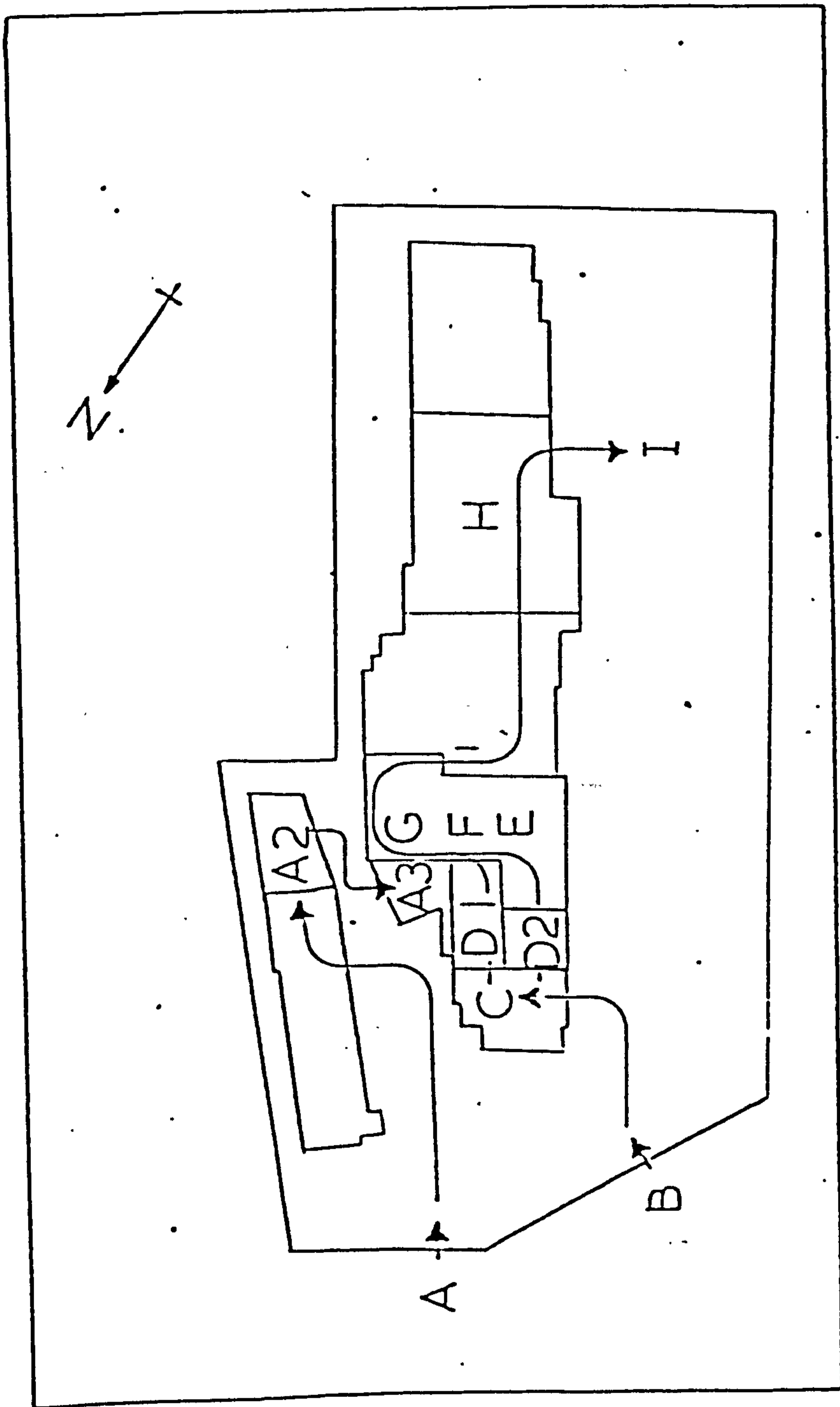
## 5.2 FMS PART SPECTRUM ANALYSIS

As discussed in section 3.2, (the design stage of an FMS) the system can be either developed for a completely new set of components or applied to a range of suitable existing products. The cutting cylinder product mix provides such a range of existing components at Suffolk Lawnmowers Ltd.

### 5.2.1 Product Mix

#### 1 Cylinder design criteria

The total product range for cutting cylinders at SLM includes five discrete types of handmower cylinder designs and sixteen petrol powered cylinder designs - a total of twentyone current requirement models. Two models have recently been de-rated to 'spares-only' models for a current total of eighteen spares models that may be required for production. This analysis concerns the current models only (table 5.8.) as



DIAG. 5.1 THE FACTORY PRODUCTION SYSTEM

No.*	Cylinder	Length	Blades	Spiders	Diameter	Type	
						Handmower	Metric
1	Panther	12"	5	3	5"	Handmower	Metric
2	Panther	14"	5	3	5"	"	"
3	Panther	16"	5	4	5"	"	"
4	Clipper	14"	5	4	5.3/4"	"	H
5	Clipper	16"	5	4	5.3/4"	"	"
6	Punch	12"	5	3	5.1/8"	Powermower	Domestic
7	Punch	14"	6	4	5.1/8"	"	"
8	Punch	17"	10	4	5.3/4"	"	"
9	Punch (Prof)	17"	6	4	5.3/4"	"	"
10	L40	16"	5	4	5.3/4"	"	"
11	Demon	19"	5	5	5.3/4"	"	"
12	Atco Deluxe	14"	6	3	5.3/8"	"	Heavy Duty
13	Atco Deluxe	17"	6	4	5.3/8"	"	"
14	Atco Deluxe	20"	6	4	5.3/8"	"	"
15	Atco HD	20"	6	4	5.3/8"	"	"
16	Atco (Golf)	20"	12	4	5.3/8"	"	"
17	Atco HD	24"	6	6	5.3/8"	"	"
18	Atco HD	30"	6	7	5.3/8"	"	"
19	Atco HD	28"	6	8	5.3/8"	"	"
20	Atco HD	34"	6	9	5.3/8"	"	"
21	Minigang	20"	5	5	6.1/8"	"	"

\* These numbers are the standardised key for cylinder descriptions used in diagrams and tables

Table 5.8 Cutting Cylinder Product Mix

the annual production quantities of spares are negligible. These designs provide the basic cylinder mix for the "ATCO", "QUALCAST" and "SUFFOLK" brand of mowers. The above two definitions of cylinders (hand or power) are further differentiated into the "Metric" or "H-type" handmower cylinder ranges and the "Punch", "Domestic" and "Heavy Duty" ranges of powered cylinder ranges. Thus, the major cylinder types are

- i) HANDMOWERS
- ii) POWERMOWERS (DOMESTIC)
- iii) POWERMOWERS (HEAVY DUTY)

The design range of the cylinder mix is a result of various factors:-

- i) the length of a cylinder determines the time to cut a given area of grass,
- ii) the cost of hand versus powered mowers determines the high or low price market that the product is aimed at,
- iii) power mowers are designed for larger lawn sizes,
- iv) heavy duty mowers are required for very large lawns or where grass is to be cut to a uniform length and standard (e.g. tennis courts or cricket pitches, etc.),
- v) sidewheel mowers provide a more effective cut for longer grass,
- vi) rear-roller mowers permit grass cutting over lawn-edges.

Petrol powered mowers enable variations in cutting speed for variable lawn conditions. Subsequently a robust cylinder design suited for the application dictates the product mix parameters. This ultimately reduces wear on the power source, i.e. the petrol engine. The length of a cylinder design depends upon the average lawn size of the market being aimed for. The following general criteria apply:-

<u>Lawn Area</u>	(equivalent tennis court size)	<u>Mower Width</u>
up to 75 sq yds	1/4	12"
75 to 150 sq yds	1/4 - 1/2	12" or 14/15"
150 to 300 sq yds	1/2 - 1	14/15"
300 to 600 sq yds	1 - 2	15/15" or 17/18"
over 600 sq yds	2+	17/18"+

The cutting width affects the speed of mowing. Research (PERA (1979)) has shown that approximately one inch is lost in overlap when mowing. Therefore, if a 14" cylinder takes 30 minutes to cut a lawn, then the time taken with various other cutting cylinder widths is:-

Cutting width (ins)	10	11	12	14	17
Time taken (mins)	43	39	35	30	24

Cylinder mowing is the most efficient method (hand and powered mowing) with the least loss of power from the power source. Power losses result from

- i) the efficiency of the motor (electric or petrol)
- ii) the power lost in the transmission system
- iii) power required for work other than cutting (e.g. for hover mowing as much as two thirds of the power available is required for motion).
- iv) the relative efficiencies of different cutting methods

Such cutting efficiency depends upon the design of a cylinder and its CUTTING GEOMETRY. The concept of a spiral blade cylinder cutting grass is analogous to a pair of scissors wherein two blades come together to shear the material being cut (i.e. the top, spiral blade and the flat bottom blade). By using a multi-spiral blade cylinder the efficiency of the process is raised as more cuts per cylinder rotation are made. The geometrical relationship between the cylinder with its spiral blades and the fixed bottom blade is therefore critical (diagram 5.2). The major parameters are:-

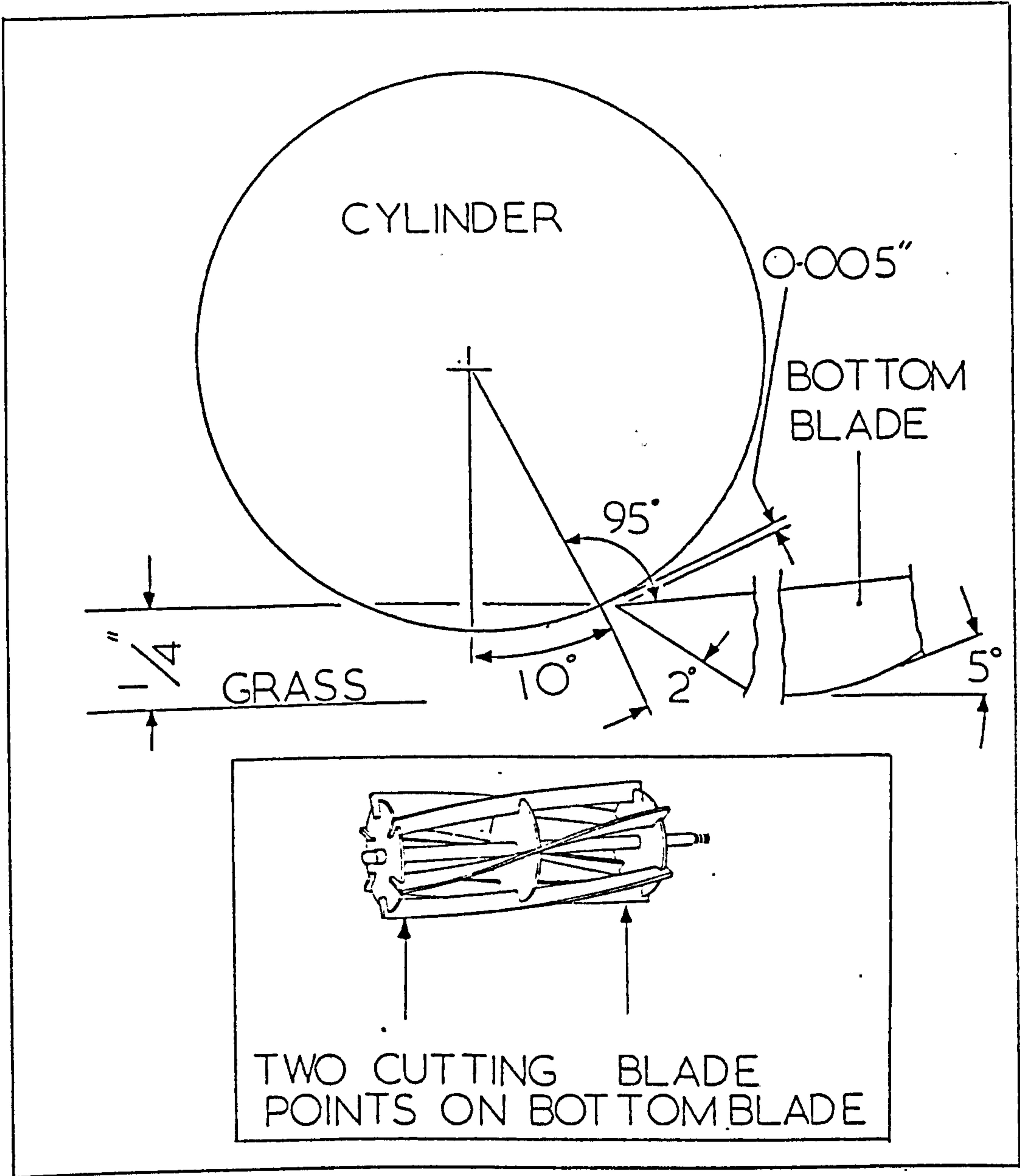
- i) the helix angle of each spiral blade to ensure a "lead-in" action onto the bottom blade for gradual blade contact.
- ii) the helix angle, number of blades and cylinder diameter relationship to ensure one blade finishing its traverse along the fixed blade after the next blade has started its traverse.
- iii) the dimensional accuracy of the cylinder to ensure fidelity of mechanical motion.

These parameters ensure an even cut of grass rather than a "chopping" action resulting in a segmented grass level. Other factors influencing quality of cut are revolutions per minute, blade rake angles and clearances. Too fast an r.p.m. (a result of cylinder diameter and/or drive r.p.m.) will brush the grass aside. Too large a clearance will tear the grass and blade wear will give an uneven cut.

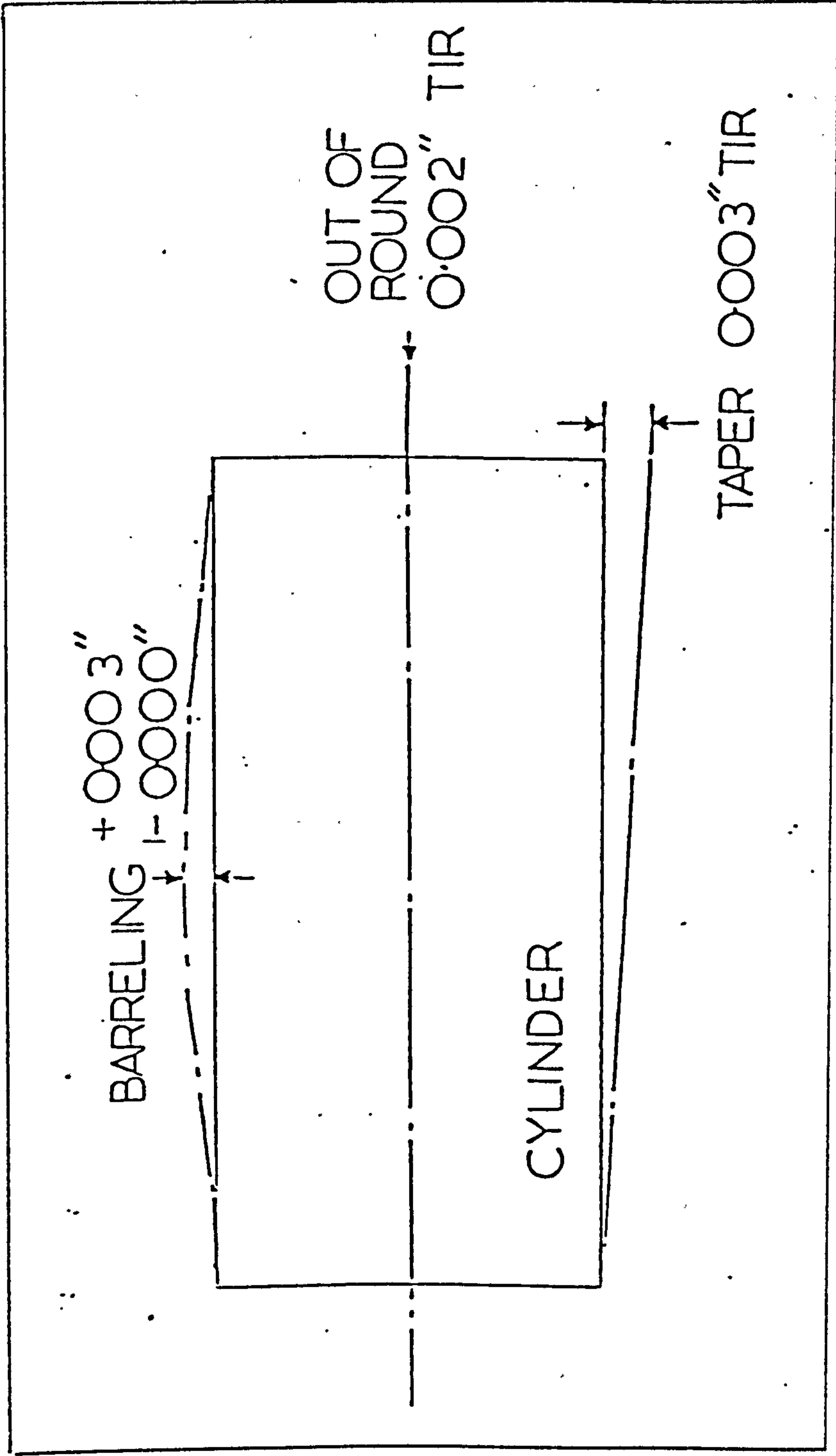
The cylinders' dimensional accuracies are most critical with:-

- i) the diameters concentricity with the spindle ends
- ii) the taper of the diameter

The cylinders' form may bow outwards (never inwards) a few thousandths of an inch as this assists the lead-in onto the fixed blade, (diagram 5.3). The relevant tolerances on dimensions are:-



DIAG. 5.2 CUTTING CYLINDER  
TECHNOLOGY



DIAG. 5.3 FABRICATION TOLERANCES

- i) OUT OF ROUND - 2 THOU. inch (T.I.R.)
- ii) TAPER - 3 THOU. inch on radius

The spiral blades need to be hardened as the bottom blade, a hardenable steel, is mounted onto a cast iron sole plate which will resist the impact and shock loading encountered when mowing over stones, etc. The hardened bottom blade with the sole plate combines shock resistance and wear resistance. This fixed blade is a "stiff member" in the mower design. Therefore the spiral blades must also be hardened for wear resistance although not as hard as the bottom blade.

Such factors, and others such as economic and market considerations, etc. dictate the final part mix that SLM must produce to achieve a feasible marketable cylinder mower product range.

## 2 Total Cylinder Mix

A cylinder is assembled and machined from three major component types (diagram 5.4),

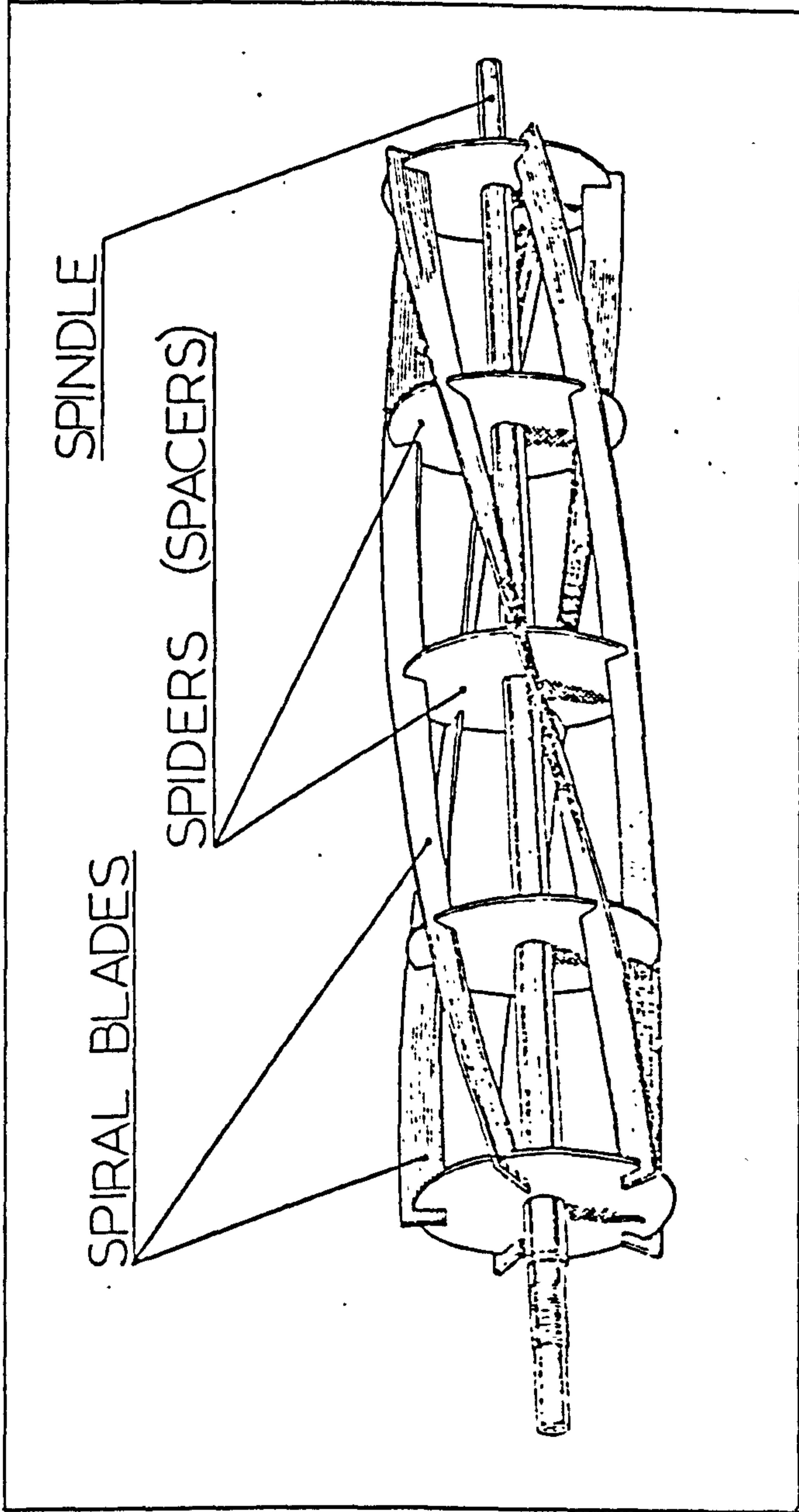
- i) spindles
- ii) spiders (i.e. blade spacers)
- iii) spiral blades

The handmower blades are manufactured from a high carbon steel and do not require a hardening process, unlike the power mower cylinders. The power mower blades are produced from "32 Carbon" hardenable steel. A "drawing" or "ordinary" quality mild steel, hot rolled from narrow strip mills, is used for the spiders, whilst "20 carbon" steels are used for the spindles.

<u>Materials:</u>	SPINDLES:	070M20 (EN3B) BMS
		220M07 (EN1A) BMS
		080M15 (EN32C) BMS
	SPIDERS:	BS1449 HR4
		BS1449 HR15/PO
		BS1449 HS4B/PO
	BLADES:	070A72/070A78 (EN42) High tensile low alloy (C-Mn) spring steel
		080A32 (EN5C)

The twentyone cylinder type range is the result of extensive product rationalisation over recent years. The handmower range, divided into





DIAG. 54 · CUTTING CYLINDER COMPONENTS

"H-type" or "Metric" cylinders is differentiated by the final-product design. The older "H-type" cylinders are assembled into die-cast aluminium body sides which permit two positions for the cylinder bearings to be assembled into. Therefore, the cylinder can be either 5<sup>1</sup>/<sub>8</sub> inch or 5<sup>3</sup>/<sub>4</sub> inch diameter. The "Metric" cylinders are assembled into a pressed steel side for which a 5 inch diameter cylinder only has been designed.

The powered cylinder range diameters vary from 5<sup>1</sup>/<sub>8</sub> inch for the Punch cylinders, to 5<sup>3</sup>/<sub>8</sub> inch for the Domestic and Heavy Duty cylinders.

The cylinders are either 5 or 6 bladed with the corresponding number of spiders, for the necessary rigidity, depending upon the cylinders length (3 to 9 spiders). The full design range is detailed in table 5.8. All three types of components are made at SLM. The spindles are turned and ground in a functionally organised batch production machine shop from bar-stock. The spiders are pressed in the company's press shop from coil or strip material. The blades are produced from 18 feet special-section lengths of steel. The blades are fluted for a smaller cutting edge cross-section. The strip is rolled into a radius and cropped to length before the helix spiral is applied by twisting the blade between special rollers. Correct batch sizes of these completed components are despatched to a machine shop dedicated to cylinder production. Typical cylinder variations are shown in diagram 5.5.

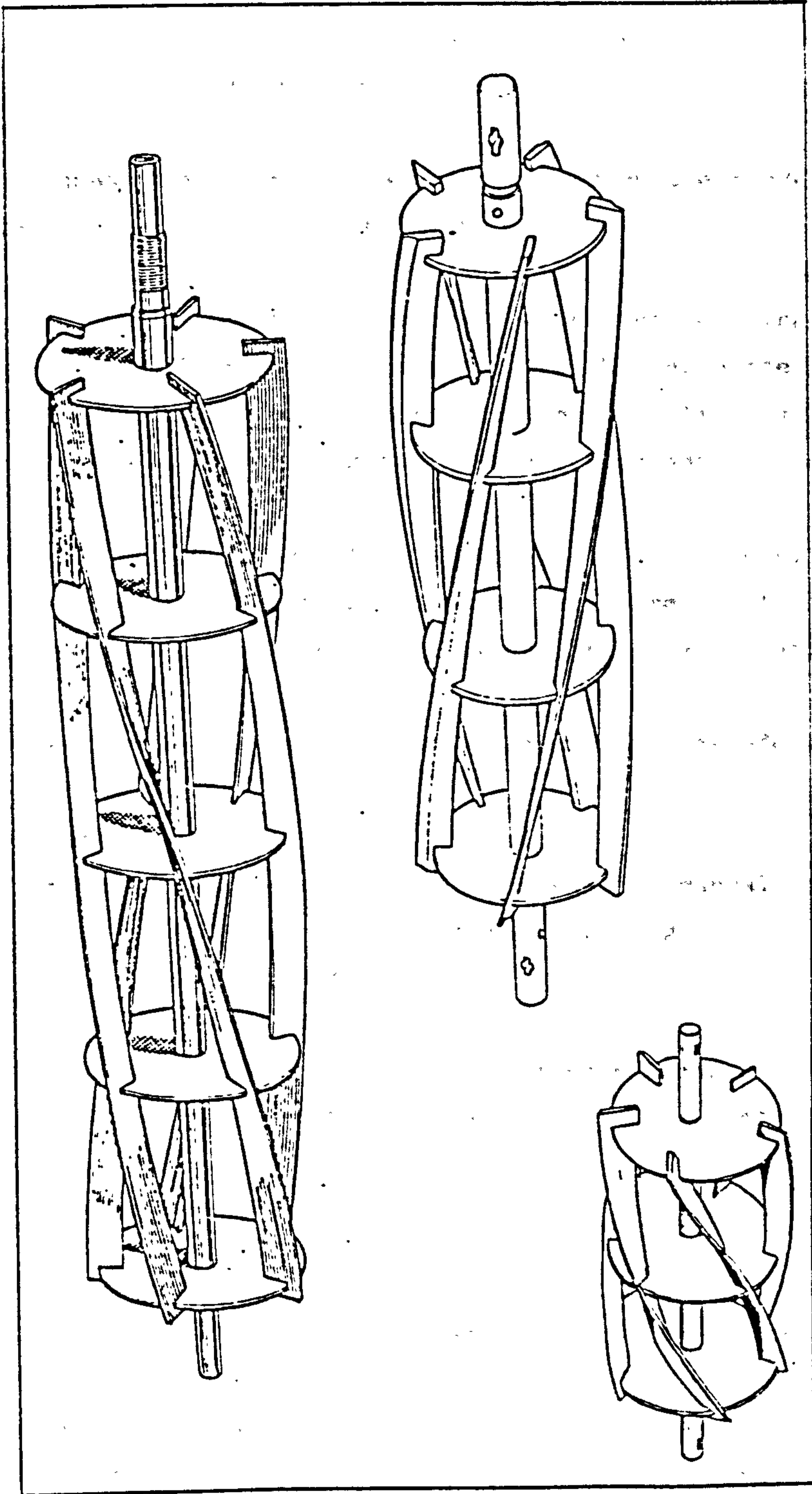
### 5.2.2 Process Mix

Subsequent to the component manufacturing processes, the basic processes for the final stages of production of a cutting cylinder are, in sequence,

- i) assembly of components
- ii) welding of components
- iii) hardening of blade edges
- iv) grinding of cylinder diameter
- v) degrease cylinder assembly
- vi) paint cylinder assembly

Thereafter, the cylinder can be assembled into the mower chassis or sold as a spare part. The complete process mix is detailed in table 5.9.

All cylinder parts are assembled manually using loose fixtures before being welded into a subassembly (i.e. a cylinder). The method of fabrication is Manual Metal Arc (MMA) stick electrode welding for handmowers and Metal Inert



DIAG. 5.5 CUTTING CYLINDER VARIATIONS

Gas (MIG)/Metal Active Gas (MAG) CO<sub>2</sub> arc welding for power mower cylinders.

Handmower cylinders are subsequently ground between cone-bearing supports. The "rough" and "finish" grinding operations are completed at the same machine in one operation. Degreasing and painting prepares the cylinder for final assembly into the end-product.

Domestic power mower cylinders are hardened on the blade tips by a flame hardening process before being ground.

The heavy duty cylinders are "rough" ground before being hardened, as a greater amount of material removal on the thicker blade sections is required. For a superior finish on these more expensive cylinders they are degreased and painted before receiving their "finish" grinding to size.

As a result of the different lengths, number of spiders, number of blades and cylinder diameters of the product mix, there are twenty different welding operations, fifteen hardening and twenty grinding operations.

The present technologies of the process mix are therefore:-

- i) manual assembly
- ii) manual arc welding
- iii) automatic (relay-control) flame hardening/manual loading
- iv) manual cylindrical grinding/manual loading
- v) manual loaded degreasing booth
- vi) manual wet-spray painting
- vii) manual transfer of components between processes

The control is manual throughout due to the high degree of flexibility required.

### 5.2.3 The Manufacturing Systems

#### 1 Total System

The total factory at the Stowmarket site may be considered as a discrete system, for the production of the full range of cylinder, hover, rotary mowers and cultivators, etc. This system in itself is the aggregation of a set of sub-systems. Within the factory (diagram 5.1) the main sub-systems concerned with cylinder manufacture are

- i) the "general machining shop" (m/c shop 1)
  - ii) the press shop
  - iii) "number 2" machine shop

In the "general machining shop", bar material is sawn to length, turned to diameter, centreless ground to size and drilled and knurled at one end in order to produce the spindles. The press shop produces the spiders to space the blades in a cylinder. These sub-systems supply "machine shop 2" with the required components for cylinder manufacture. They also supply other sub-systems, such as the grass-box manufacturing system, with their components.

Machine shop 2 is one of the major production systems in the factory. It also produces gears, cams and crankshafts for the production of the 'Suffolk' 4-stroke engine. Within this machine shop is a further integral sub-system which is tooled for the production of the complete cylinder mix up to the stage of grinding. The relationship of these systems is shown in diagram 5.6.

## 2 The Cylinder Manufacturing System

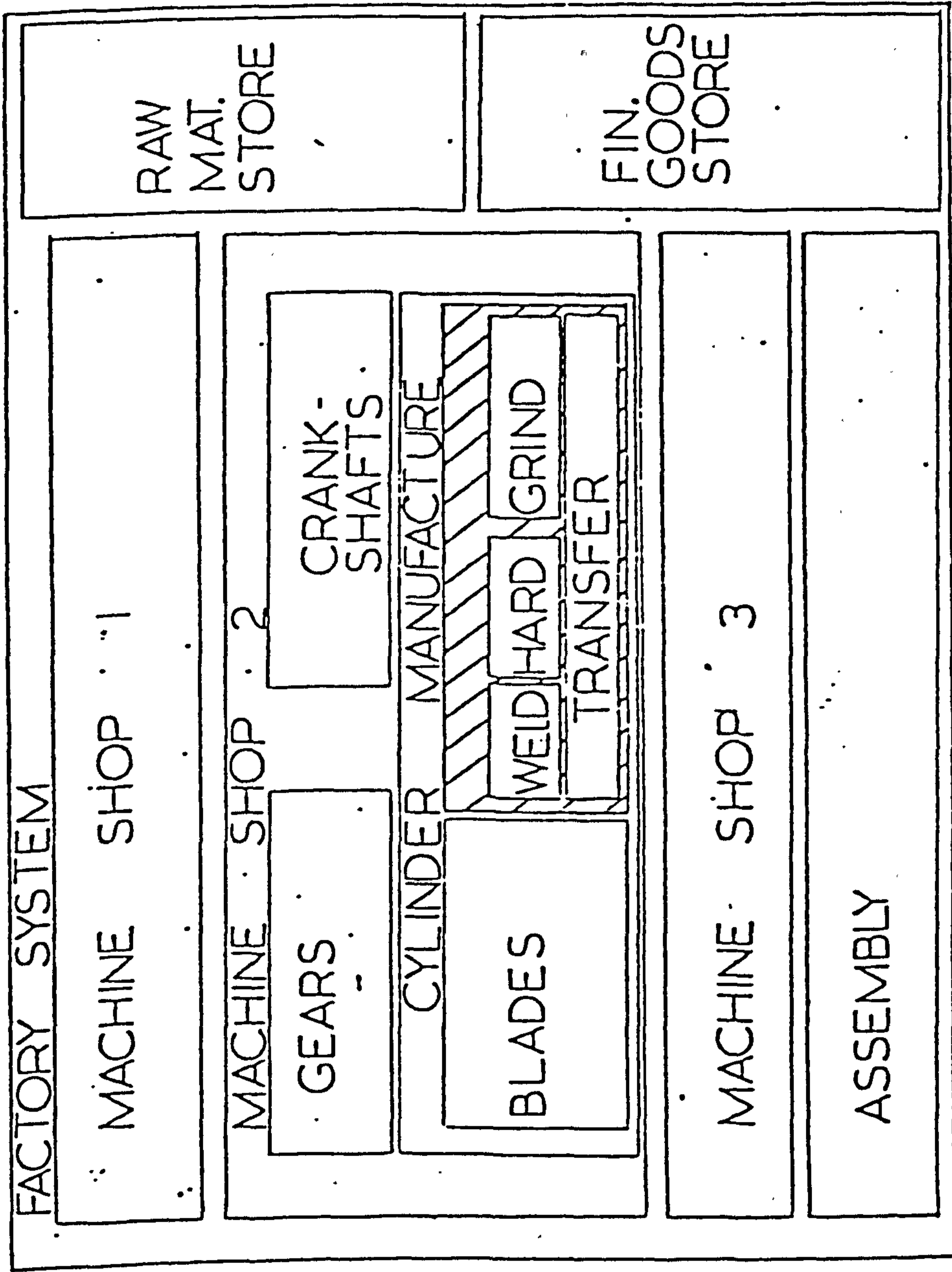
The present cylinder manufacturing system, part of machine shop number 2, is organised into machining centres consisting of similar process machines. Blades are produced on machining centres:-

- B5627/a (3 x rolling machines)
- B5627/b (3 x cropping machines)
- B5382 (3 x spiral twist machines)

The blade components, together with the spider components from the press shop and the spindles from machine shop number 1, provide the input into the CYLINDER ASSEMBLY/MACHINING SYSTEM. It is this system that has the highest need, and is most readily available for automation. The physical layout of this system, shown in diagram 5.7, has been designed to accommodate the major process routings and flows to minimise the required manual (work in progress) transfer. It is easier to show these flows pictorially (diagram 5.8).

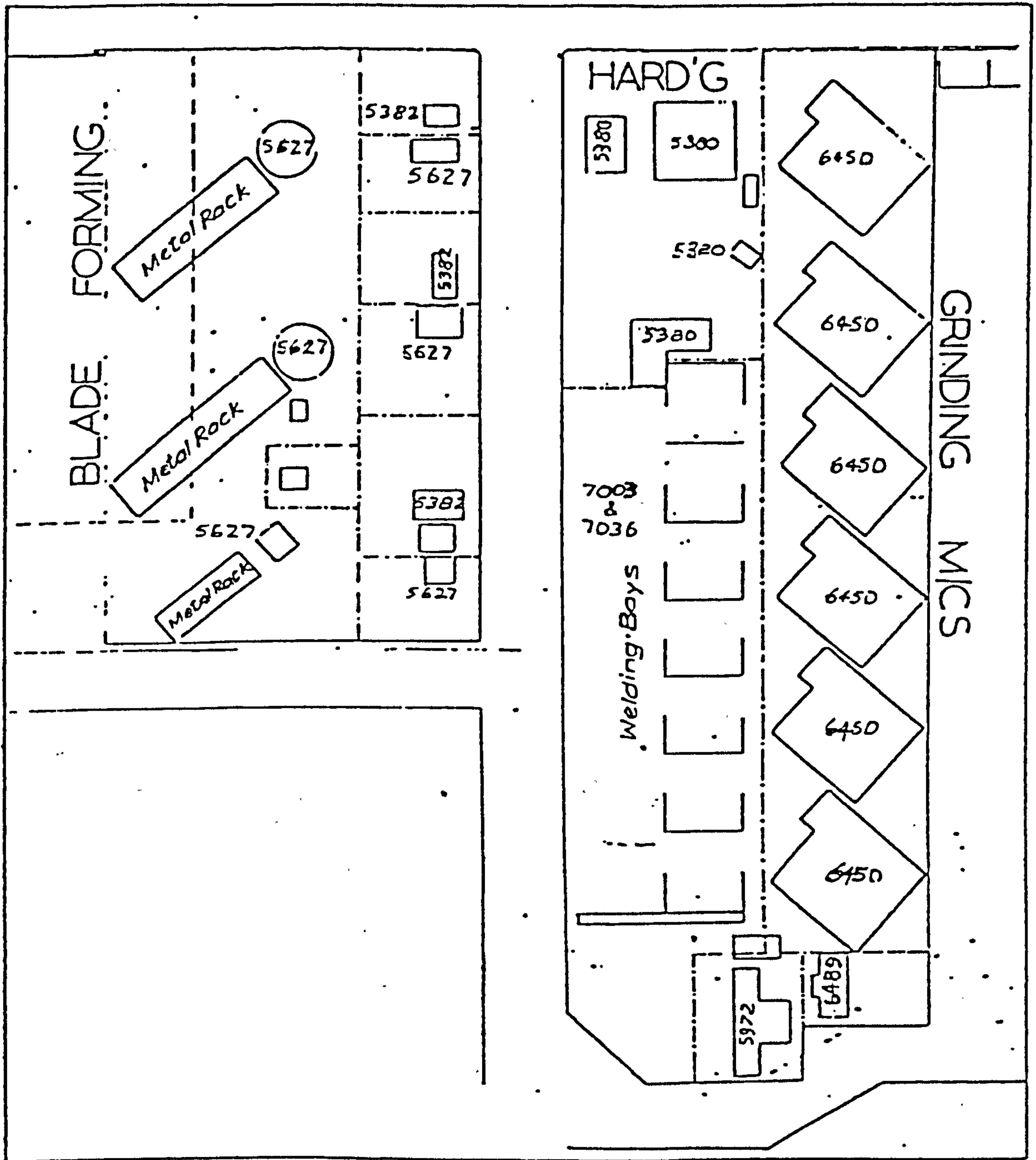
The required equipment to fabricate the cylinders are:-

<u>Process</u>	<u>Cylinders</u>	<u>Quantity</u>	<u>Work Centre No.</u>
i) Welding, Manual Metal Arc;	hand mower	6	B7003
ii) Welding, MIG/MAG Arc;	power mower	8	B7036
iii) Hardening, flame;	power mower	3	B5380
iv) Grinding, cylindrical;	hand and power mower	6	B6450
(see table 5.9)	(see table 5.8)		



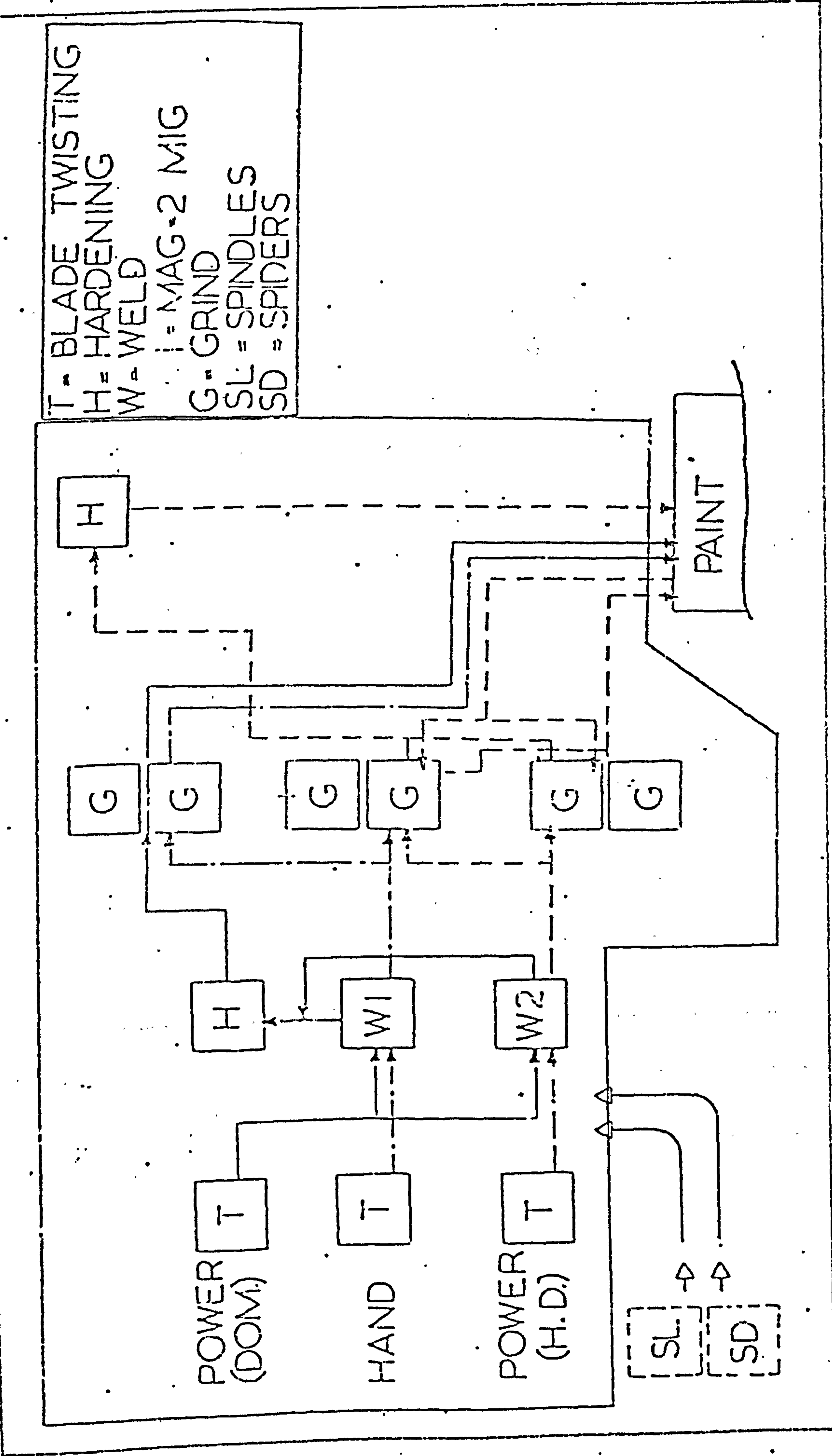
 AREA FOR AUTOMATION

DIAG. 5.6 THE FACTORY SYSTEM



DIAG. 5.7

CYLINDER PRODUCTION  
SYSTEM LAYOUT



DIAG. 5.8 PROCESS FLOWS THROUGH PRODUCTION SYSTEM  
(SEE DIAG. 5.7 & TABLE 5.9)



PROCESS MIX		Weld	Harden	Grind (Rough)	Grind (Finish)	Degrease	Paint
PRODUCT MIX	12" Panther	1	-	2	3	4	5
	14" Panther	1	-	2	3	4	5
	16" Panther	1	-	2	3	4	5
	14" Clipper	1	-	2	3	4	5
	16" Clipper	1	-	2	3	4	5
	12" Punch	1	2	3	4	5	6
	14" Punch	1	2	3	4	5	6
	17" Punch	1	3	2	4	5	6
	17" Punch Prof	1	3	2	4	5	6
	16" L40	1	-	2	3	4	5
	19" Demon	1	2	3	4	5	6
	14" Atco DL	1	3	2	6	4	5
	17" Atco DL	1	3	2	6	4	5
	20" Atco DL	1	3	2	6	4	5
	20" Atco HD	1	3	2	6	4	5
	20" Atco HD	1	3	2	6	4	5
	24" Atco HD	1	3	2	6	4	5
	28" Atco HD	1	3	2	6	4	5
	30" Atco HD	1	3	2	6	4	5
	34" Atco HD	1	3	2	6	4	5
20" Minigang	1	-	2	-	4	5	

Table 5.9 Cutting Cylinder Process Mix

These highly labour intensive activities provide a large degree of flexibility in the system. As there is no automation, however, the system labour costs are high in relation to the output (Section 8). The present policy and practice is to man every machine required with one single operator. This equates to four grinding operators utilising four machines leaving two for spare capacity. A floating operator utilises one of the three hardening machines as required or the cone or straightening presses. Each welding set is manned by a skilled welder. Table 5.10 details the full system specification. Constraints that exist on the present system's total flexibility, by enforcing various work-in-progress routings are:-

- i) The capability and set-up deviation of the three groups of blade forming machines. The three groupings are a) domestic cylinder mower blades (left hand spiral), b) domestic and heavy duty blades (right hand spiral), c) Metric and "H-type" blades (i.e all handmowers).
- ii) Three pairs of grinders used mainly for a) handmower cylinders, b) domestic power mower cylinders, c) heavy duty mower cylinders.
- iii) The requirement for heavy duty cylinders to leave the system for painting before receiving a finish grinding operation.
- iv) A hardening machine (work centre No. 6514) being reserved for cylinders of 20 inch length or more only.
- v) The grouping of MMA equipment and MIG/MAG equipment separately for hand and power mower cylinders.

#### 5.2.4 The Variable Production Profile of Cylinder Manufacture

##### 1 Volumes

The analysis carried out by Parrish (1980) provides the figures for the last 'typical' year of production levels. These relate to the production levels of cylinder mowers during the year 1980, (1.11.79 to 31.10.80). Subsequent to this manufacturing year the lawnmower industry (as nearly all other industries) faced the decreased demands attributable to the 1980-1982 economic recession. This is reflected in the data in tables 5.11 and 5.12. The required production volumes (lower than the programmed levels of volume) were set during the year 1981 to 15 per cent less than the previous year's achieved output. As the lawnmower market is highly seasonal with the major selling period in January/February (mainly to the major mail order companies stocking up for spring) with a secondary period in April/May (depending upon the weather and therefore the mail-order companies' successes with their first sales)

Process	Cylinder Types	Work Centre No.	No. of Machines in Work Centre
Welding (MMA)	Handmower (all)	7003	4
Welding (MIG)	Power Mower (all)	7036	6
Hardening (flame)	Power Mower (< 20")	5380	3
Hardening (flame)	Power Mower (> 20")	6514	1
Grinding (cylindrical plunge)	Hand and Power Mowers	6450	6

Table 5.10 Cutting Cylinder Work Centre Descriptions

Cylinder Type (Key Table 5.10)	1980		1981		1982		1983
	Achieved	Programmed	Achieved	Programmed	Programme (1)	Programme (2)	Programmed
	1	82.4	96.8	58.3	74.9	47.0	34.4
2	25.5	30.4	31.8	27.6	28.3	22.7	18.3
3	8.0	10.3	8.4	11.3	9.0	8.6	6.0
4	3.1	3.0	8.6	6.3	7.7	7.5	7.7
5	3.2	2.0	13.5	10.8	8.3	5.7	8.3
6	31.9	32.8	24.0	28.1	16.9	9.5	16.9
7	26.9	34.2	16.3	16.0	19.5	21.4	19.5
8	5.9	6.1	1.5	4.2	7.5	9.2	7.5
9	1.2	1.2	0.3	0.6	-	0.3	-
10	1.7	5.8	2.8	2.6	-	-	-
11	0.4	0.5	0.8	1.5	-	0.2	-
12	4.4	5.9	4.8	6.1	4.0	2.5	4.0
13	7.4	7.5	2.6	2.9	2.7	-	2.7
14	3.8	3.8	2.1	1.8	2.0	0.6	2.0
15	1.0	1.2	0.3	0.4	0.7	0.6	0.7
16	0.1	0.5	0.3	0.3	0.2	0.1	0.2
17	2.2	2.9	1.2	2.0	1.2	0.1	1.7
18	0.3	0.3	0.3	0.3	0.2	0.1	0.2
19	0.3	0.3	0.2	0.1	0.1	0.1	-
20	0.3	0.5	0.2	0.1	0.1	0.1	-
21	0.2	0.2	0.2	0.3	0.2	0.1	0.1
TOTAL	210.8	246.7	178.5	199.1	156.0	124.4	139.5

Units = 1000's (rounded to nearest 100)

Table 5.11 Production Levels of Cylinders (1980 - 1983)

Type	1980		1981		1982		1983
	Programmed	Achieved	Programmed	Achieved	Programme 1	Programme 2	Programme
Handmowers	142,581	122,390	131,100	120,875	100,350	79,074	83,850
Power Mowers Domestic	97,998	83,902	64,285	55,511	52,755	44,111	52,755
Power Mowers Heavy Duty	6,214	4,593	3,723	2,807	2,919	1,210	2,955
<b>TOTAL</b>	<b>246,793</b>	<b>210,885</b>	<b>199,108</b>	<b>179,193</b>	<b>156,024</b>	<b>124,395</b>	<b>139,560</b>

**Table 5.12 Programmed and Achieved Production Volumes**

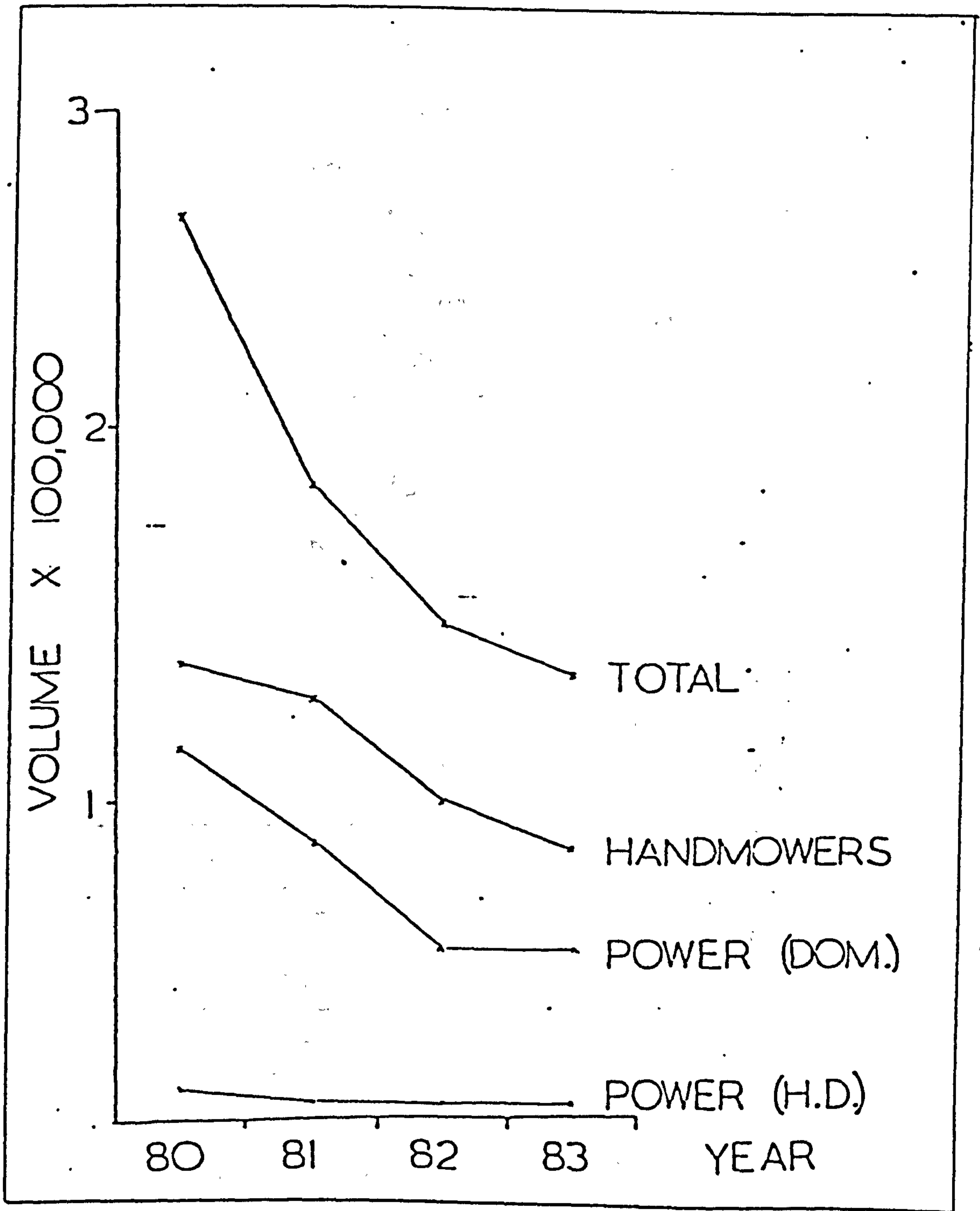
the whole production system is geared to produce to an annual sales forecast plan. When it is clear that the selling season is not going according to the plan, the manufacturing (production level) programmes are revised. During the period analysed (1980) the achieved volumes of cylinders produced in the system dropped 14 per cent from the programmed volumes of 1980. A similar reduction of a further 15 per cent in achieved volumes compared to the programmed levels of 1980, occurred for the year 1981 (1.11.80 to 31.10.81). For the year 1981, the programmed volumes had dropped 19 per cent from the 1980 programmed levels. Eventually the achieved volumes produced in 1981 dropped some 10 per cent below 1981's programmed volumes. These figures are shown in diagram 5.9. Present market forecasts show an upward trend in future sales and therefore production volumes.

Whilst ten products actually increased due to demand, in 1981, the remaining cylinder mower production levels (when analysed by cylinder types) were reduced by 43 per cent in volume, on average.

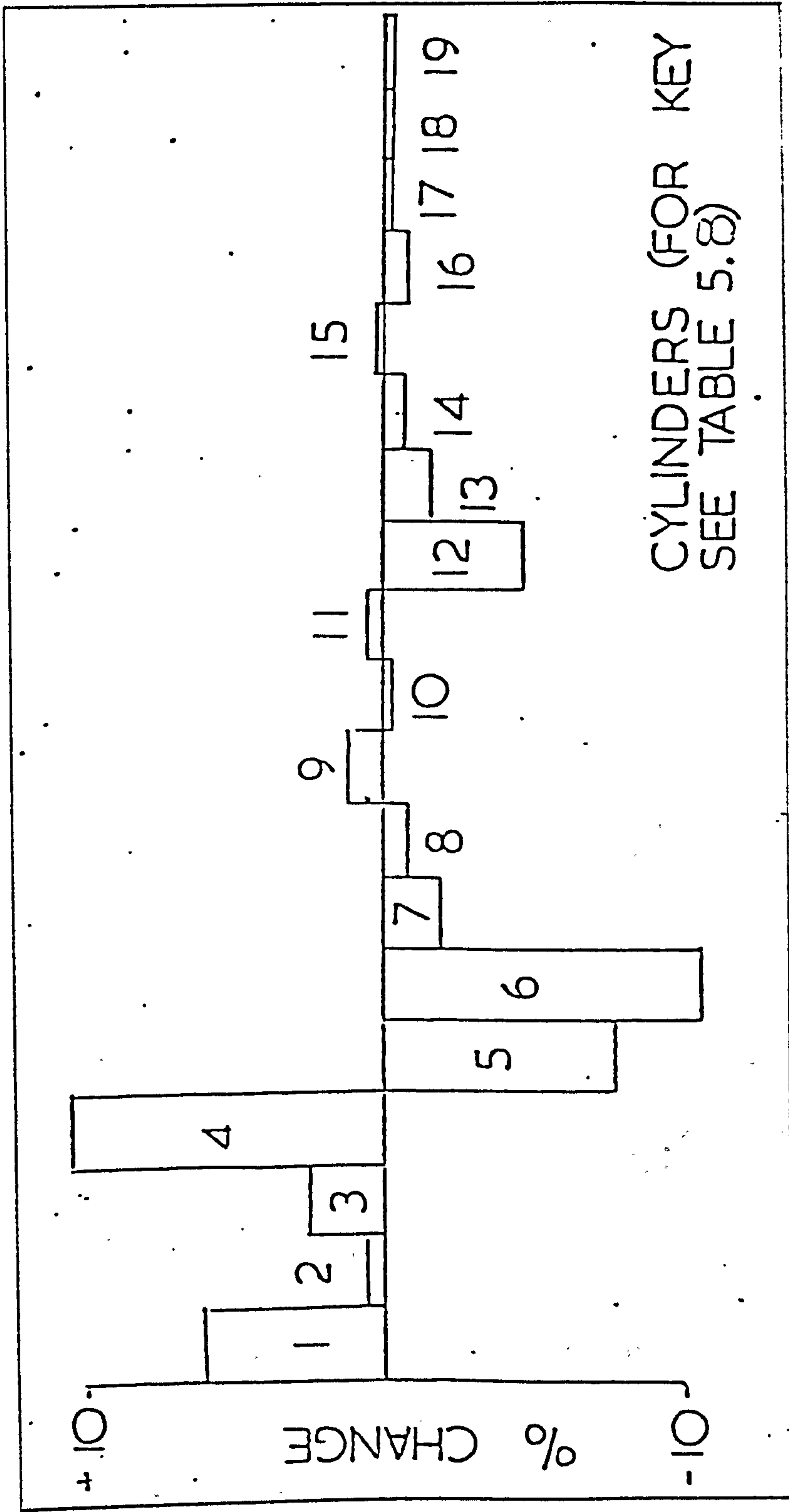
A 12 per cent increase is programmed for the year 1983 over the 1982 programmed production levels. Diagram 5.10 shows the percentage volume changes throughout the cylinder range for the two years from 1979 to 1981. Some models experienced reductions and increases in volume changes whilst the majority have mainly been decreased.

The percentage volumes of the individual cylinder types, however, measured against the total annual throughput, remained very similar. In 1980 the major four cylinders (20 per cent of the 21 cylinder types) accounted for 68.5 per cent of the programmed volume throughput. These were the 12 and 14 inch 'metric' handmower cylinders and the 12 and 14 inch domestic power cylinders. The percentage volumes (achieved) equated to 20 per cent of the mix accounting for 78.9 per cent of the throughput volume. These volumes are illustrated in diagram 5.11.

The Pareto curves (resulting from the analysis) of product variety versus percentage unit throughput is shown in diagram 5.12. Thus, physically automating a 'few' types of cylinders (i.e. the major four cylinder varieties) greatly affects the automation of the total, i.e. the 'many' units of throughput. In terms of cost, the analysis is slightly different. This is shown in diagram 5.13 where the longer, heavy duty cylinders (with more blades and spiders and longer machining times) accrue a larger manufacturing cost. In 1980 the value of the

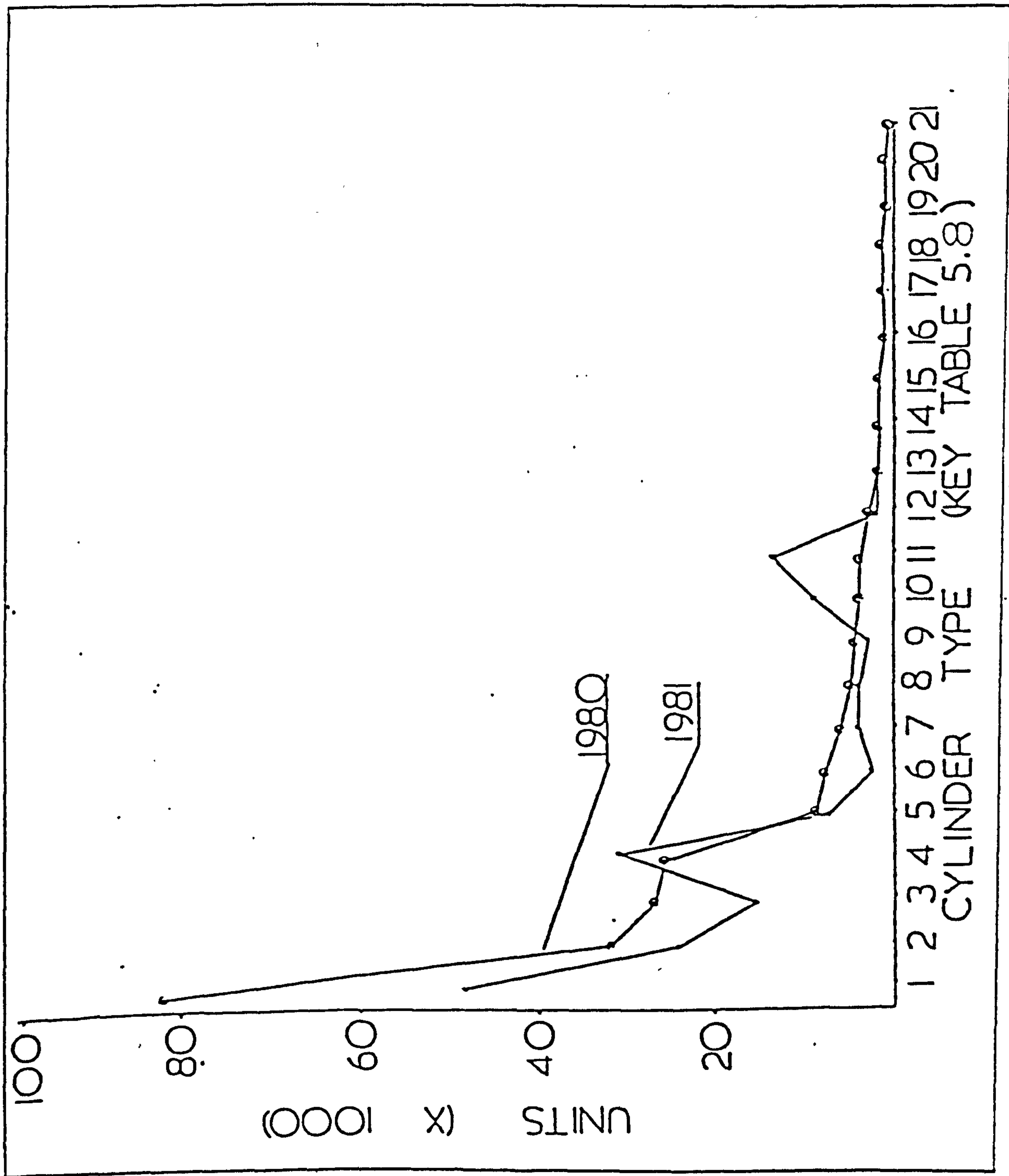


DIAG.5.9 ANNUAL VOLUMES

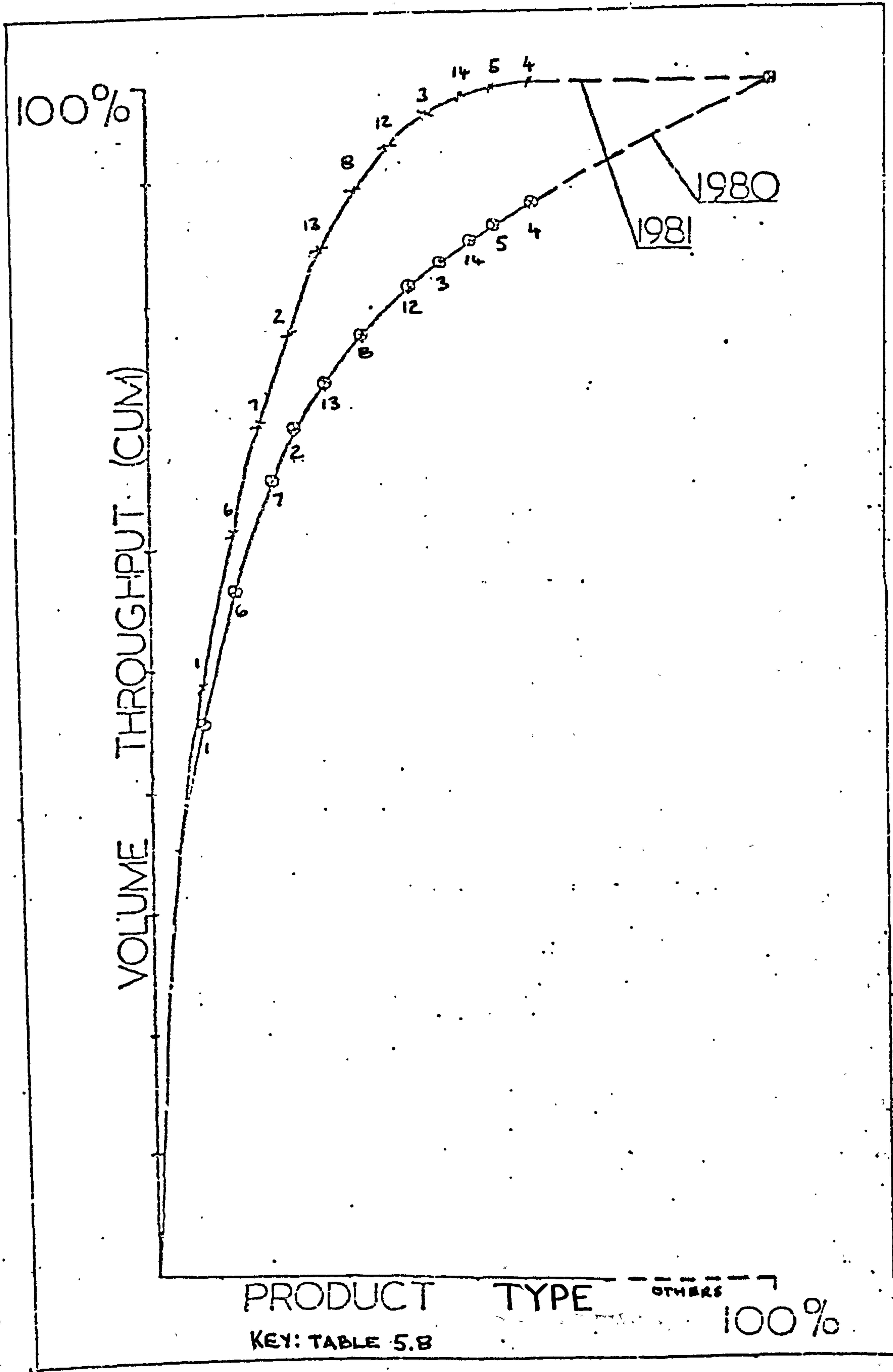


DIAG. 5.10 VOLUME CHANGES (1980 - 1981)

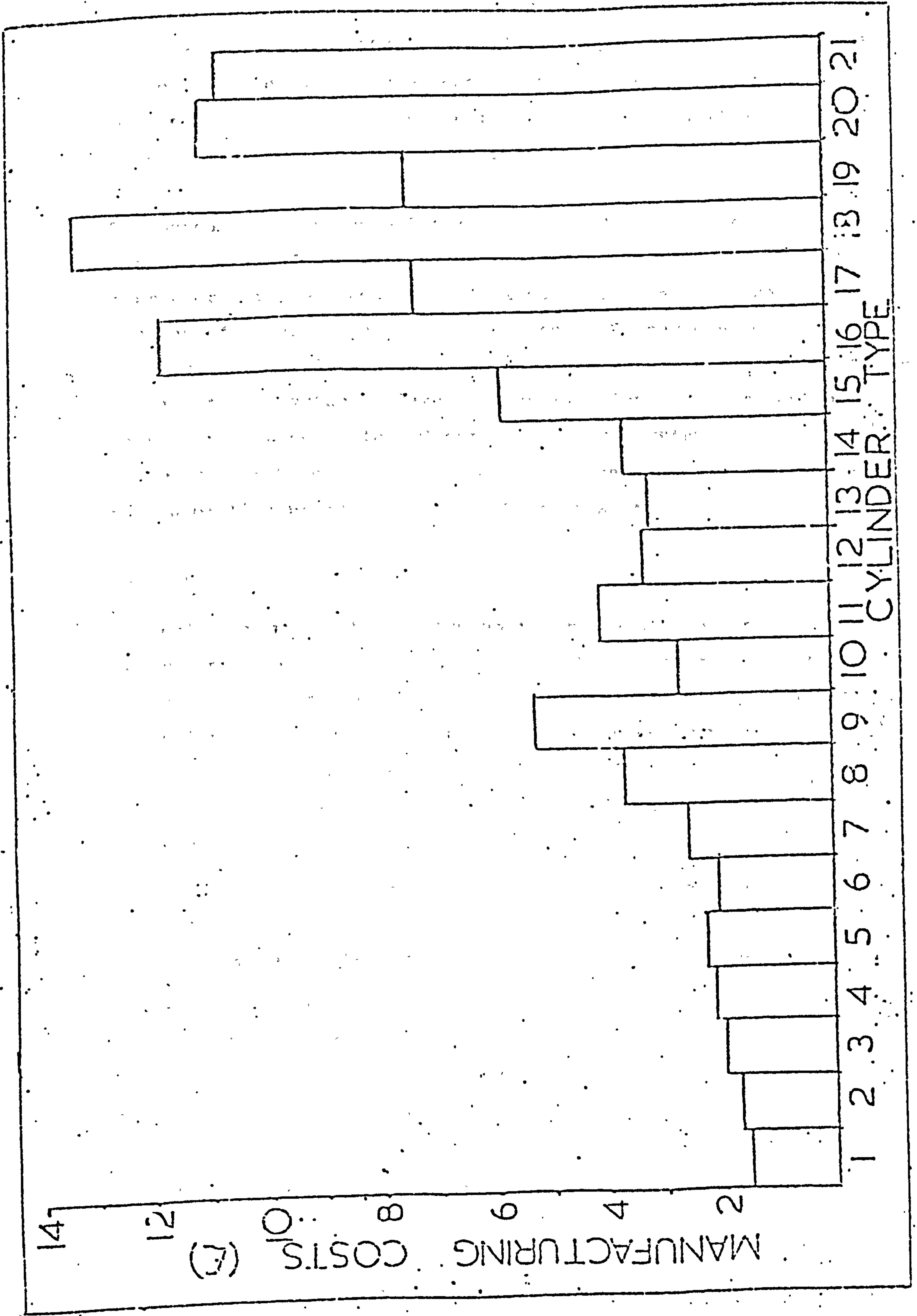




DIAG. 5.11 ANNUAL PRODUCTION  
BY CYLINDER TYPE



DIAG. 5.12 THROUGHPUT/PRODUCT-MIX ANALYSIS



DIAG. 5.13 CYLINDER MANUFACTURING COSTS. (KEY ON TABLE 5.8)

cylinders produced to the "as-ground" state amounted to £468,243. This was reduced to £396,315 in 1981, a drop of 15 per cent. The value added in the cylinder manufacturing system accounted for 70 per cent of the cylinder value in 1980 (i.e. a total of £329,014). This percentage level was maintained in 1981 (69.1 per cent).

The products of the annual throughputs and unit costs, as shown in diagram 5.14, of the various cylinder designs, show the two distinct characteristics of the product mix values. The 12 inch and 14 inch lengths of power and hand mower cylinder (20 per cent of the product mix) account for 63 per cent of the added value in the cylinder assembly and machining system. Seven cylinder designs (33 per cent of the product mix) account for 80 per cent of the system's added value. These factors have a large influence on the stepwise implementation of the automation programme for the total system.

## 2 Batch Sizes

The cylinder manufacturing system is programmed to supply the painting department prior to supplying the assembly department. As these two latter systems are involved in the factory's total range of products the cylinder system is decoupled from these departments with buffer stocks between them to enable an even supply of painted cylinders to the assembly lines. However a lead time to manufacture the cylinders is required, as follows:-

Handmower cylinders	40 hours
Domestic power mower cylinders	40 hours
Heavy duty cylinders	60 hours

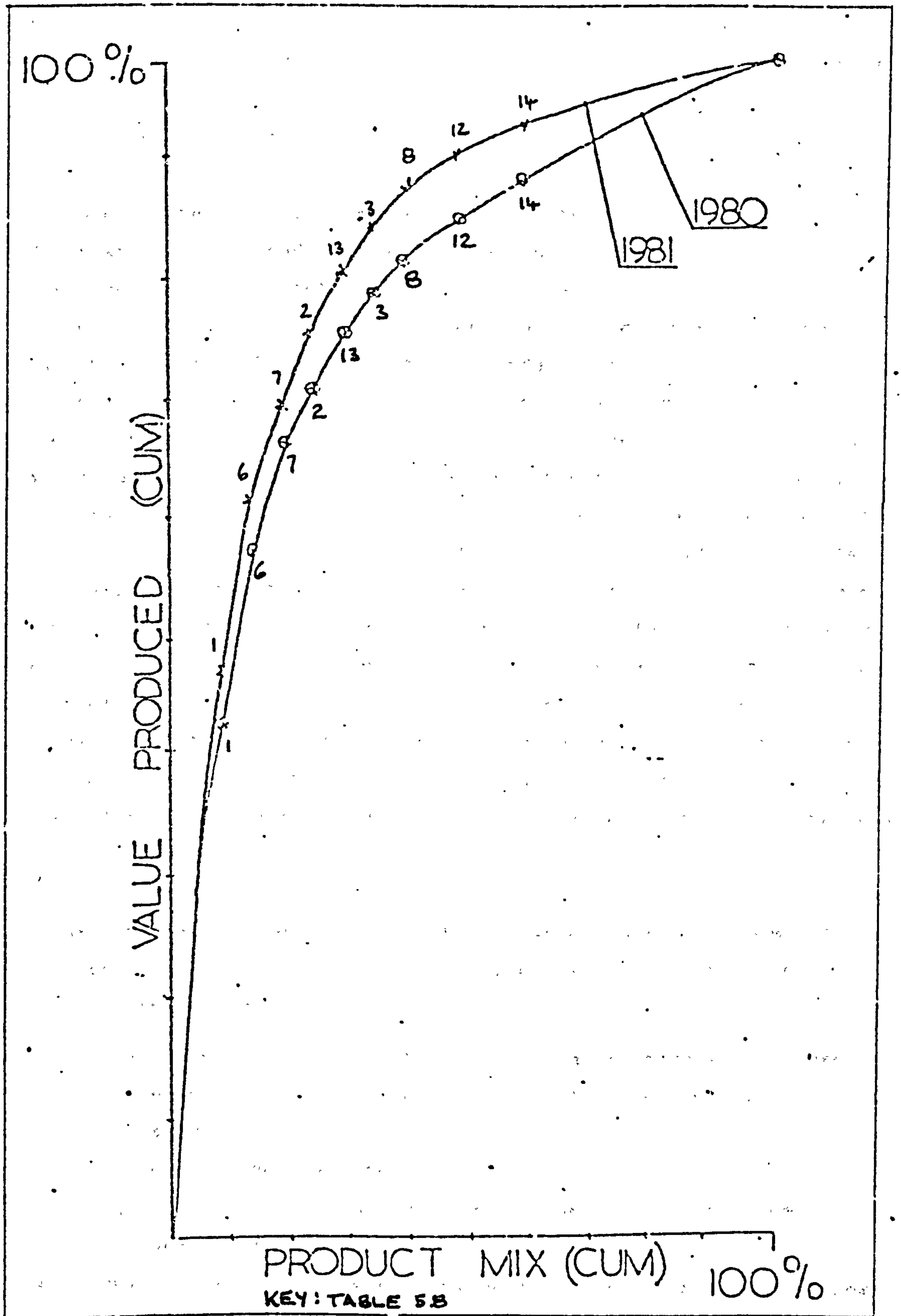
There are three painting/assembly lines to be supplied, divided into:-

- i) Handmowers (Metric and H-type)
- ii) Domestic power mowers (Suffolk)
- iii) Heavy duty mowers and Domestic (Atco)

The average demand for cylinders for these lines is:-

- i) Handmowers - 255 cylinders per 8 hour shift
- ii) Domestic power mowers - 109 cylinders per 8 hour shift
- iii) Heavy duty mowers - 50 max. cylinders per 8 hour shift

These are average figures as flexible manning of the assembly lines is practised according to the peaks and troughs in the mower assembly demand. This demand also influences the stepwise implementation of



DIAG. 5.14 VALUE PRODUCED ANALYSIS

the cylinders' automated system. The supply of cylinders from the mixed manual/automated production system is being studied by Painter (1982). This study also includes the supply of component parts to the automated system.

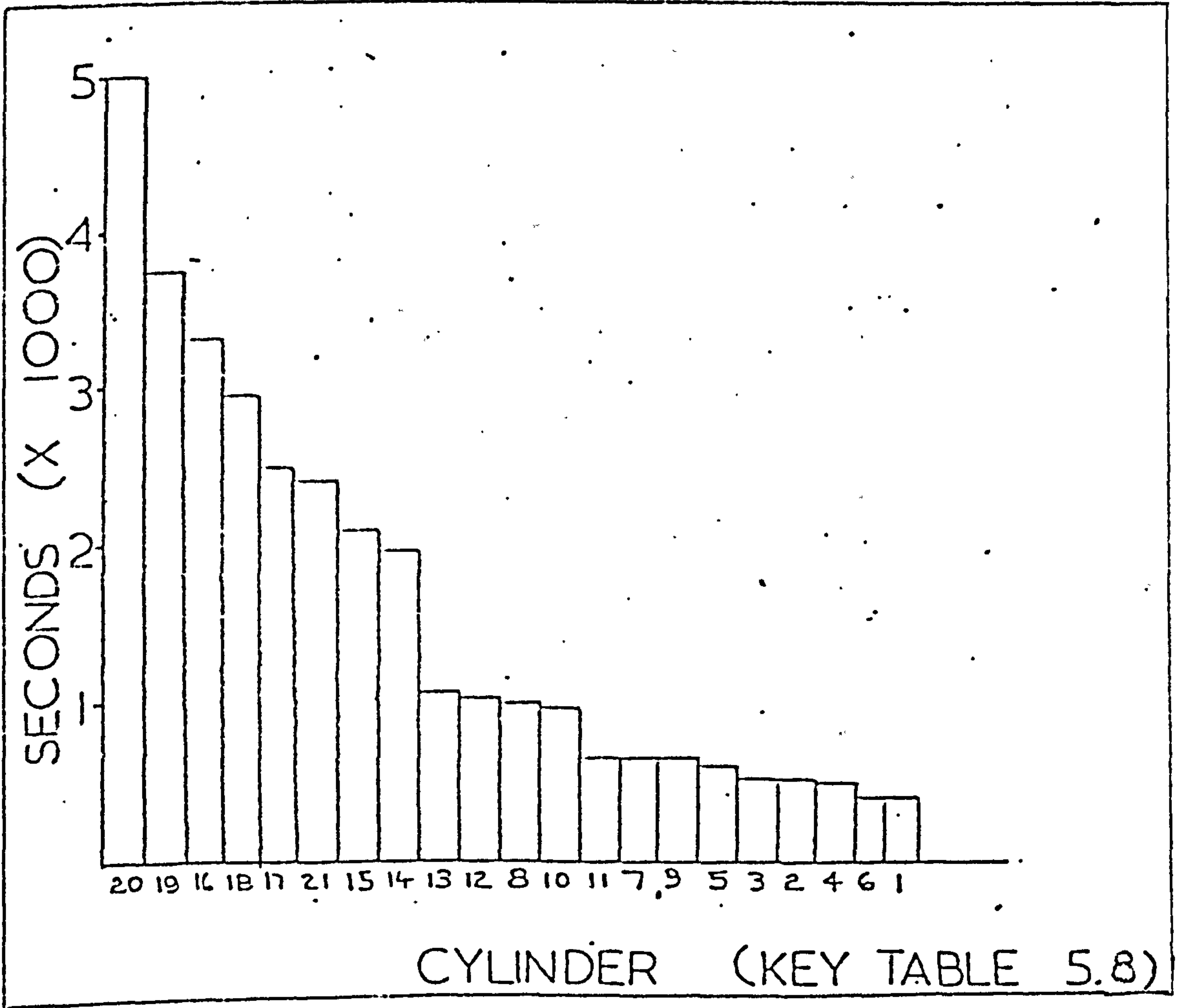
The present manual cylinder production system has to allow for the above fluctuations in demand for the variable product mix. This it presently does due to the inherent flexibility of the totally manual system. The processing times, or machining times, for each cylinder, are also highly variable. Table 5.13 shows the individual process times for each cylinder which build up to the total floor-to-floor machining time for the cylinders. As shown by Parrish (1980), the major process is that of assembling the cylinders and welding them manually, diagram 5.15. The process times range from 7.63 minutes for the handmower cylinders to 85.35 minutes for the largest of the heavy duty cylinders. Again, the Pareto distribution occurs with the major four cylinders accounting for 65.5 per cent of the manufacturing system's loading. The seven major cylinders (33 per cent of cylinder types) account for 79.8 per cent of the loading. The costs of the cylinders are evaluated upon these labour times. A component's manufacturing cost is evaluated by the absorption costing method of standard labour time per cylinder multiplied by 299 per cent to obtain the overhead content, being added to the material and labour costs.

A complete analysis of the production system's batch programme for the last year of stable production levels, diagram 5.16, indicates the variability of the system:-

- i) The number of different types of cylinder being manufactured during any one week varied from 2 to 12 types (diagram 5.17). The average number of types was 5 in order to supply the three different assembly lines.
- ii) The run lengths of batches varied from one to seven weeks with an average of three weeks.
- iii) The number of batches per cylinder type per annum varied from one to seven batches.
- iv) The changes in the forecasts and production programmes resulted in the number of set-ups for batches varying from the original programme. Set-ups were 12 less than were originally programmed (i.e. from 80 to 68). Whilst the number of set-ups varied, the resulting time allowed for changeover remained constant at 139 hours.

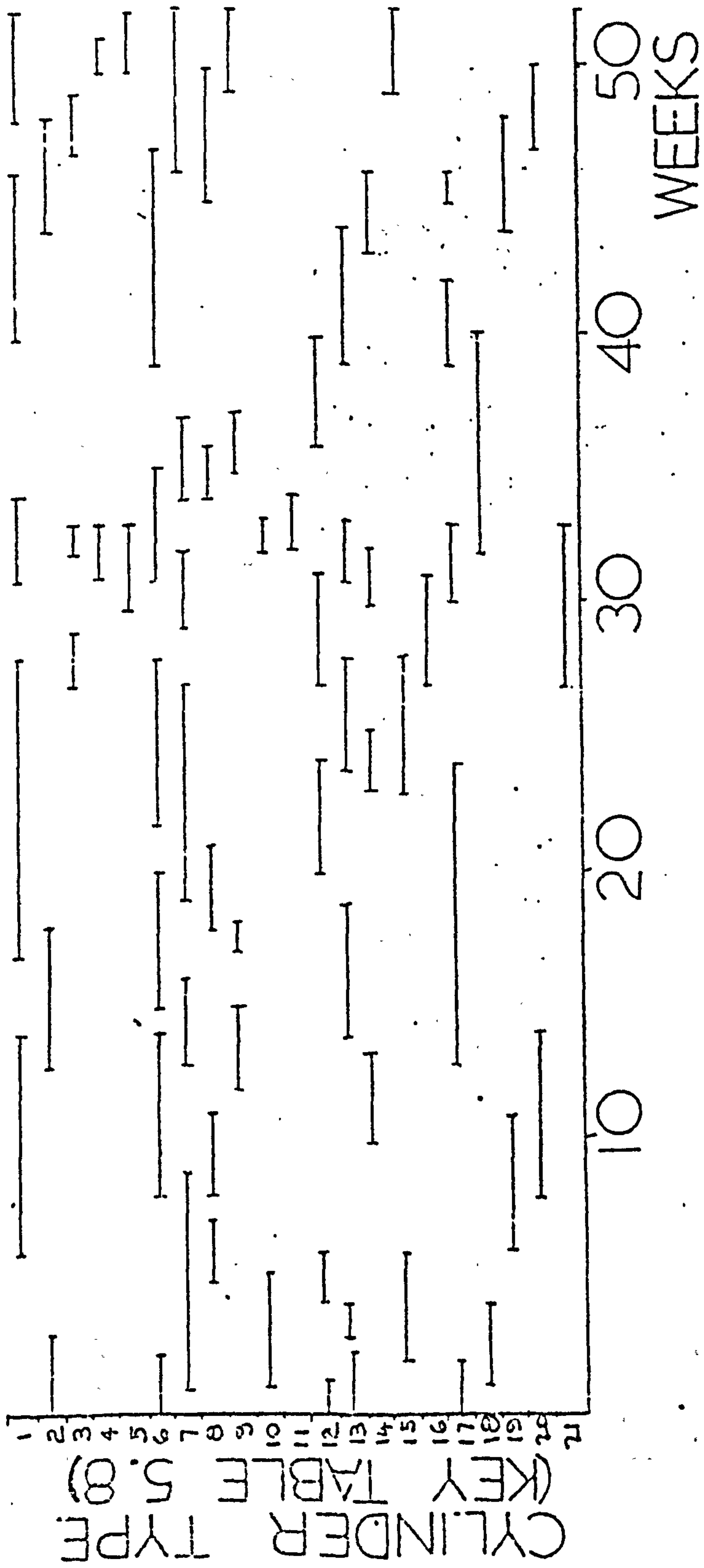
Cylinder Type (Key Table 5.10)	Assemble and Weld (secs)	True (secs)	Cones (secs)	Harden (secs)	Grind (secs)	True (secs)	Total (mins)
1	285	-	26	-	147	-	7.63
2	302	-	26	-	159	-	8.11
3	360	-	26	-	179	-	9.41
4	365	-	26	-	159	-	9.16
5	365	-	26	-	179	-	9.50
6	319	-	-	53	137	-	8.48
7	455	-	-	54	137	-	10.76
8	651	-	-	61	140	-	14.20
9	1494	-	-	132	140	-	29.43
10	463	-	22	-	153	-	10.63
11	688	-	47	78	166	-	16.31
12	372	-	-	54	223	-	10.81
13	572	-	-	126	327	-	17.08
14	572	-	-	130	367	-	17.81
15	1250	167	-	182	553	150	38.36
16	2104	210	-	105	892	150	57.68
17	1676	146	-	105	529	163	43.65
18	2197	87	-	270	1193	120	64.45
19	1573	166	-	264	933	152	51.63
20	3115	266	-	517	1040	183	85.35
21	1320	376	-	116	597	141	42.50

Table 5.13 Standard Cylinder Production Times (Floor to Floor)

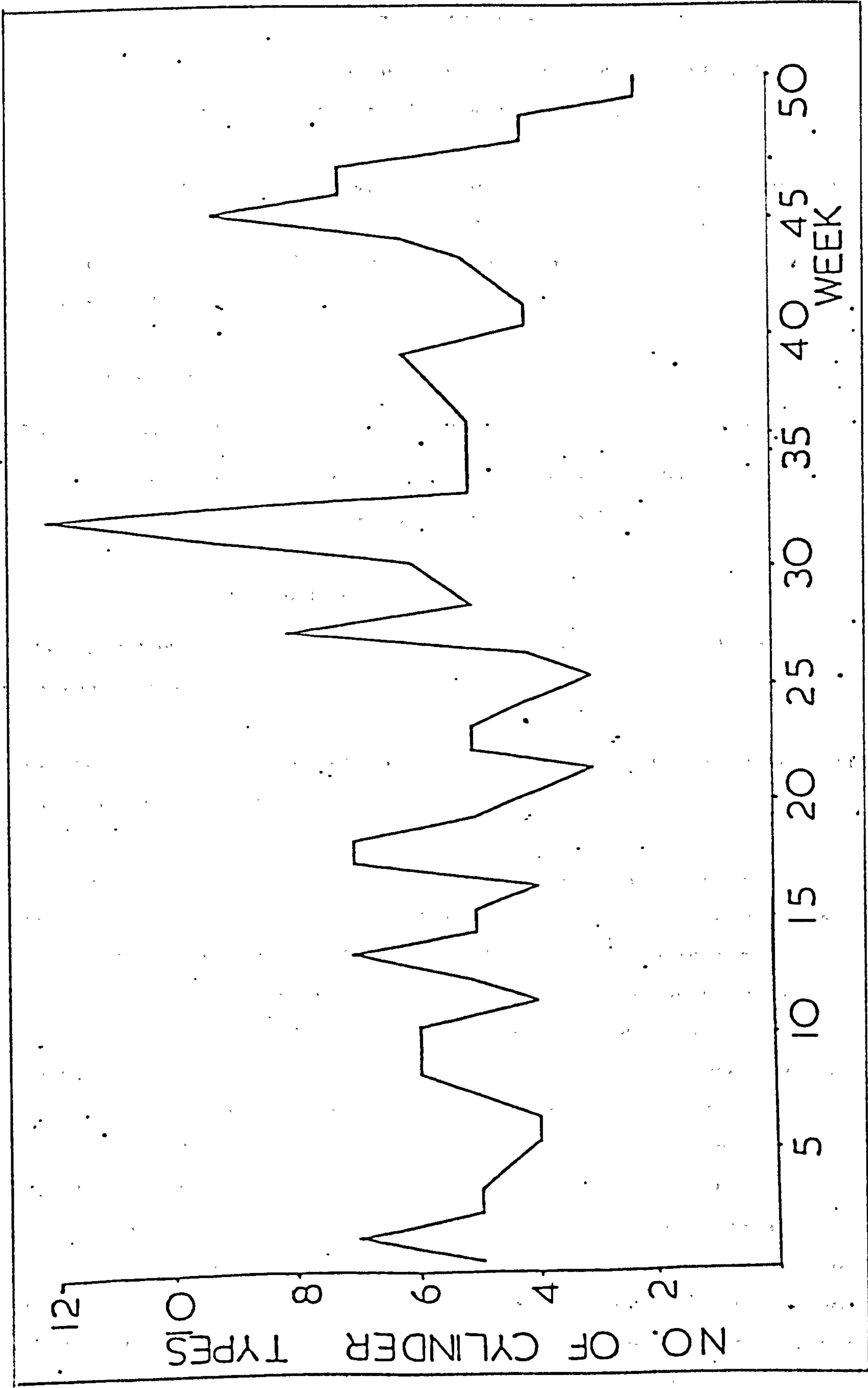


DIAG. 5.15 PRESENT OPERATION PROCESS TIMES





DIAG. 5.16 BATCH RUNS (1980)



DIAG. 5.17 CYLINDER TYPES PRODUCED IN A WEEK

v) The number of set-ups in the year 1981 increased to 119 as a result of smaller but more frequent batches.

In comparison to the actual process and machining times, the set-up/changeover times are very small (0.4 per cent).

All materials handling between processes is carried out manually by one single labourer employed for the task. Thus, the total handling and set-up time is 1978 hours (5.6 per cent). Table 5.14 details the process set-up times.

### 3 Manning Levels

The available labour in the cylinder machining system consisted of:-

12 welding operators (including 2 on night shift)

4 grinding operators (including 2 on night shift)

1 hardening operator

1 labourer (handling)

The operators on hardening and welding have the capability to change between these two operations should the situation arise.

Two setter/chargehands were also employed to set machines and ensure supplies of materials, tools and instructions.

During the manufacturing year analysed (1980) capacity was dictated by the labour available as the machines in the system exceed the manning levels of the system. There was a 25 per cent spare capacity of machines (setters can set unattended machines to avoid machines being unavailable). Two of the grinding personnel operated on a night shift. Thus, two grinding machines were always available. One operator for hardening operated the two available hardening machines. Two welders also worked during a night shift. Thus, time consuming downtime such as grinding wheel changeover set-ups did not affect the productive hours available. Table 5.15 details the available hours for production. For a 46 week year, 5 day week, 8 hour shift, the total system over two shifts was utilised only 40 per cent of the total machine hours available. As the company policy was that of employing only one shift with only four people on the night shift, to provide capacity during the peaks in production demand, it is more accurate to define the shift utilizations. They are:-

Day shift                    75.0 per cent

Night shift                 16.6 per cent

<u>Process</u>	<u>Set-up Time (hrs)</u>
Hardening (< 20" cylinders)	3.50
Hardening (> 20" cylinders)	3.00
Grinding	0.50
Welding	0.25
Grinding (wheel change)	4.00

Table 5.14 Set-up Periods

<u>Process</u>	<u>No. of machines</u>	<u>Available m/c hours</u>	<u>Available operators</u>	<u>Available std.hrs.</u>	<u>Utilisation (potential)</u>
Weld	14	25,760	12	22,080	85%
Grind	6	11,040	4	7,360	66%
Harden	3	5,520	3	5,520	100%
Transfer	1(man)	1,840	1	1,840	100%
	<u>24</u>	<u>44,160</u>	<u>20</u>	<u>33,120</u>	

Table 5.15 Potential Machine Utilisation

<u>Cylinder Type</u>	<u>Quantity Subcontracted</u>
12" Handmower	18,750
14" Handmower	5,000
16" Handmower	2,000
12" Power mower	6,029
14" Power mower	1,500
17" Power mower	2,375

Table 5.16 Subcontracted Cylinders for Welding (1980)

The quantities of cylinders produced, and the standard hours of production required for the quantities, are shown in diagrams 5.18 and 5.19, respectively. The first diagram clearly shows the seasonal cycle in production with the peaks of production appearing during and just after the major selling period when customers and stocks have to be supplied. The handmower range is the most volatile due to the large numbers of production required. Such seasonality is also reflected in the standard hours produced by the manual system. The manning levels are optimally set for the minimum of under utilisation of labour but without incurring too large a shortfall of production during the mid-season. This did in fact occur, requiring cylinders to be welded by sub-contracted companies. Detailed in table 5.16, the requirements for sub-contracted assembly and welding of cylinders necessitated an added on cost of £17,000.

#### 4 System Losses

During the 1979/80 period a manpower turnover in the arduous welding section of 75 per cent occurred. The related recruitment costs amounted to £4,200. Absenteeism averaged  $2\frac{1}{2}$  per cent for the department although it reached 5 per cent again in the arduous welding section. Rejection levels were negligible (0.1 per cent) as rework (i.e. an extra weld pass or an extra grinding pass) were often carried out during the work cycles.

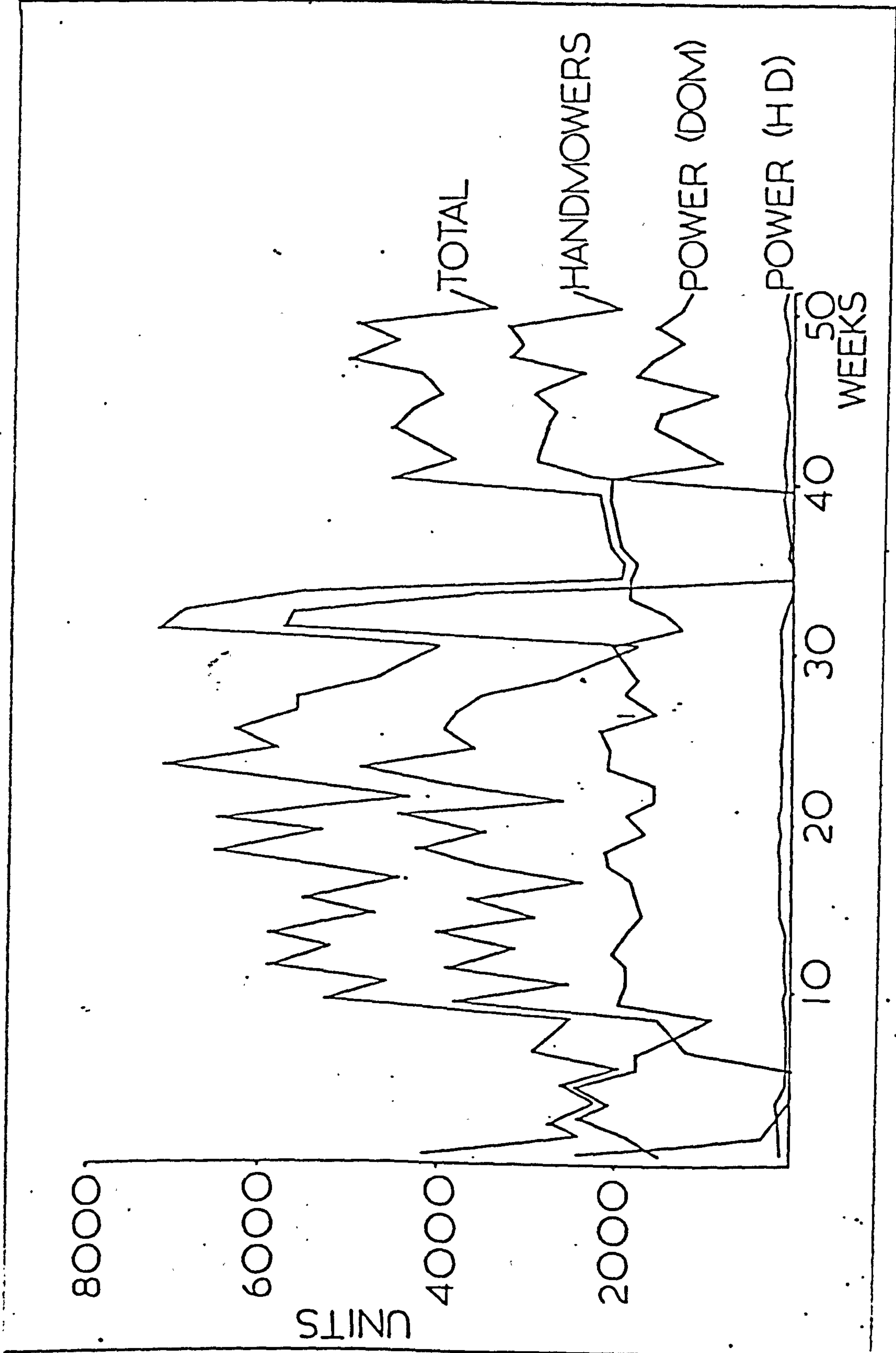
Downtime due to maintenance and repair, had a negligible affect on production due to the 25 per cent spare capacity of the machine tools. The relevant downtimes were:-

Welding	1 per cent
Hardening	5 per cent
Grinding	20 per cent

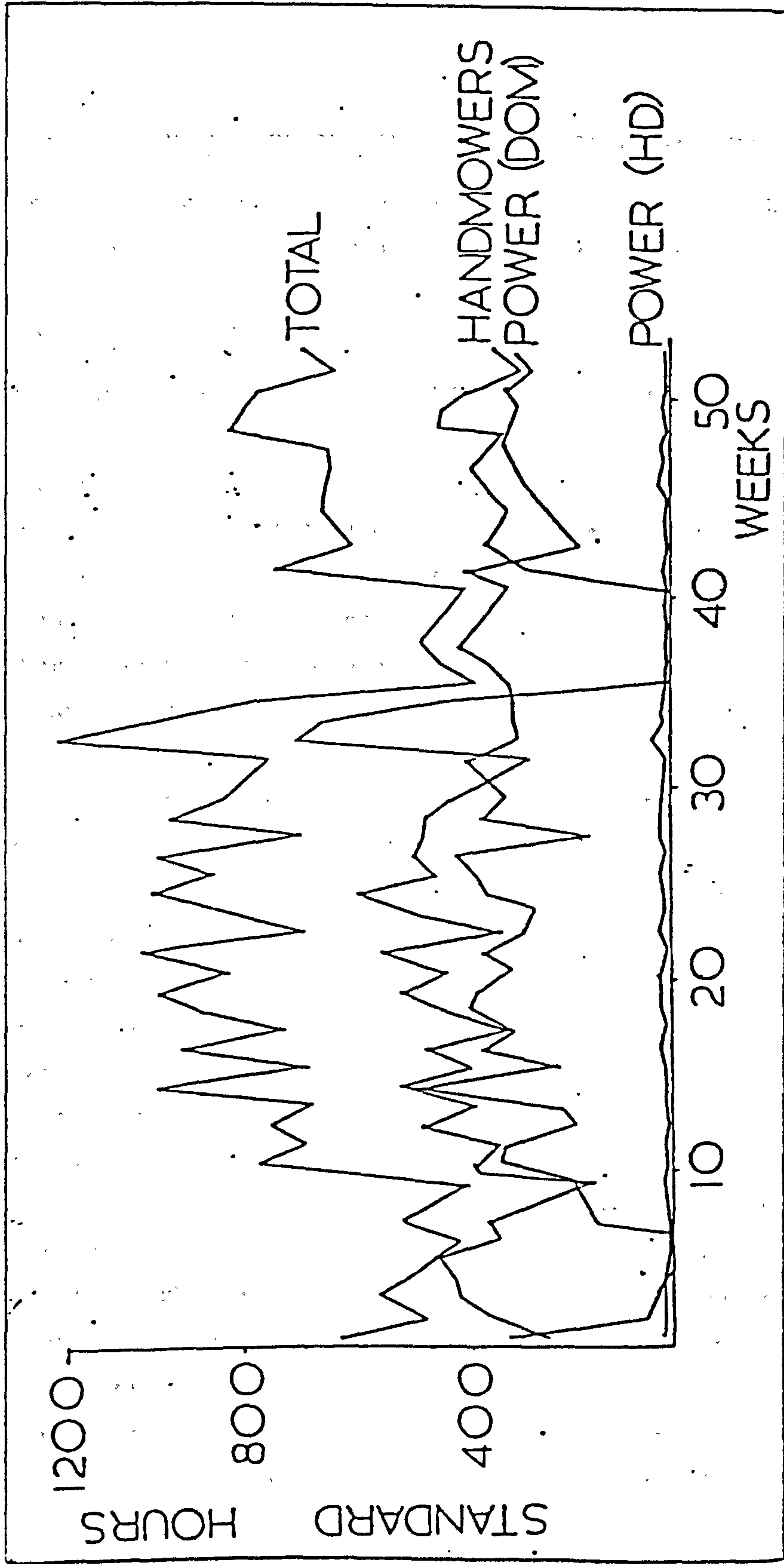
These downtimes include repair, preventive maintenance, tool changing and cleaning, etc.

#### Summary

The variations in product mix, process mix, routings, batch sizes, batch run lengths, annual quantities and therefore labour requirements require automation for productivity that is capable of handling such fluctuations in the manufacturing profile. The concepts behind FMS automation utilising computer control and flexible transfer will enable automation of the total cylinder assembly/machining system.



DIAG.5.18 CYLINDER PRODUCTION - 1980



DIAG. 5.19 STANDARD HOURS PRODUCED - 1980

### 5.3 TECHNOLOGY OF THE PRESENT CYLINDER MANUFACTURING SYSTEM

The technology to produce lawnmower cutting cylinders in the present system provides the base from which to automate the processes of system in the future.

#### 5.3.1 Assembly and Welding

The assembly of spider, spindle and blade components is carried out at the welding station by the operator prior to welding. There are two main methods of assembly:-

- i) For handmower cylinders and domestic power mower cylinders the spiders and blades are assembled and welded prior to insertion of the spindle for welding. Spacers are manually positioned between the spiders on a dummy mandrel for the blades to be inserted into the blade slots on the spiders. This method facilitates manual rotation of the spiders around the mandrel to align the slots to the blades whose form may not be consistent. When all blades are in position, the assembly is clamped under spring tension with chains screwed around the blades. This is then welded manually. Removal of the mandrel, spacers and chains followed by the insertion of the spindle with its welding completes the operation.
- ii) For cylinders longer than 20 inches, i.e. the heavy duty range, the reverse of the above method is required. The spiders need welding to the spindle to provide a frame in which to assemble the blades. The blade welding operation is performed in two halves. One side of blade is inserted and welded before the assembly is turned over for insertion of the remaining blades for weld completion.

Both types of assembly are necessary as, whilst the consistency of spindle and spider dimension can be guaranteed to within 0.003 inches, (their final processes are centreless grinding and pressing) the blades' last process is roll forming upon a material whose hardness may vary 10 degrees on the Rockwell-C Scale. The two methods eliminate any positional variation, a crucial factor in cylinder assembly.

Handmower cylinders require Manual Metal Arc (MMA) stick electrode welding, as 'low hydrogen carbon-manganese' rods must be used to prevent the high carbon blades from cracking (due to the air quench-hardening characteristics of the material, table 5.17). A Ferrod 3 rod, 12 SWG is used.



Type	Spindles	Spiders	Blades
Handmowers	0.25/0.07 - 0.15	0.15 max	0.70 - 0.85
Powermowers	0.25/0.07 - 0.15	0.15 max	0.30 - 0.35
Heavy duty	0.10 - 0.15/0.07 - 0.15	0.2 max/0.13 max	0.30 - 0.35

**Table 5.17 Percentage Carbon Content of Component Materials**

Power mower (domestic) and heavy duty cylinders are welded using the Metal Active Gas (MAG) method. This Metal Inert Gas (MIG) process uses carbon dioxide as the shielding gas with an 0.8 mm or 1.0 mm diameter mild steel wire electrode. This process is successful as the blades are much lower in carbon content.

The welding stations comprise of one booth per operator shielded from the remaining cylinder manufacturing system by an arc-glare safety curtain. Components are taken from stillages forming a buffer store to the work bench to create a smaller buffer store of materials. These are the fabricated and positioned behind the welder (an intermediate buffer store) or straight into an awaiting stillage, diagram 5.20. The work is arduous, monotonous and repetitive. Heavy leather protective clothing, gloves and heavy face/eye masks must be worn. Noise levels are high, irritant fumes are present and the operators are isolated from fellow colleagues. Such factors contributed to the high labour turnover for the year 1980. These turnovers ceased when the economic recession occurred, diagram 5.21. Originally 15 welders were employed. The top 4 cylinders required 46 per cent of the available labour for welding.

The welds are 15 mm run lengths on average for both blade to spider and spider to spindle operations, diagram 5.22, with component fitting clearances of 0.49 mm to 1.88 mm.

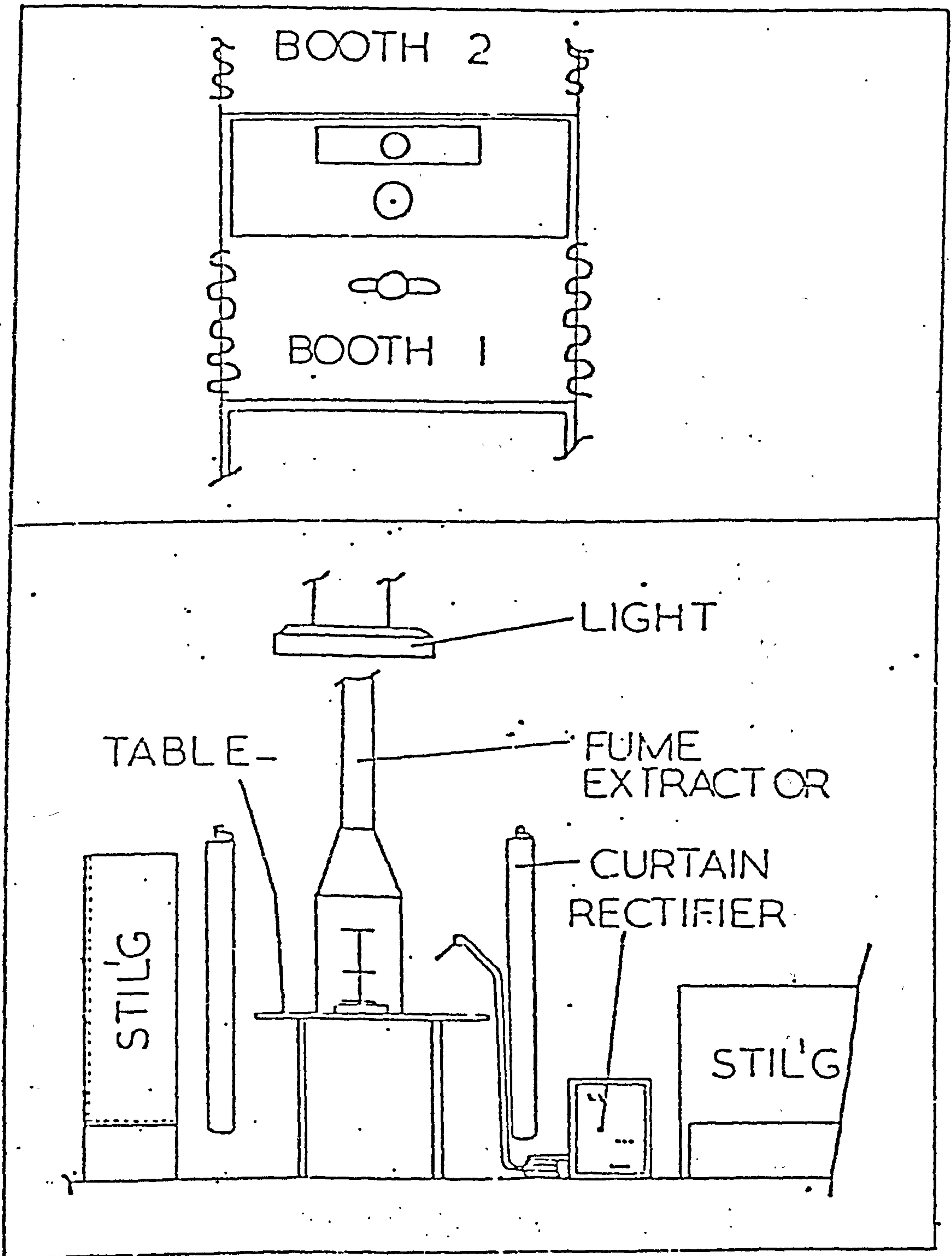
The welding settings for the MIG dip-transfer operation are

Wire feed rate	- 6 m/min
Current	- 120-125 Amps
Voltage	- 20-22 V
Feedrate	- 5 mm/sec

These may vary from one operator to another. Inspection is visual for every weld by the operator. As sustained concentration is required for monitoring a satisfactory level of quality in a non-ergonomically designed work station, the relaxation allowance on standard production times is 16 per cent and not 12½ per cent.

The main reasons for rejections are:-

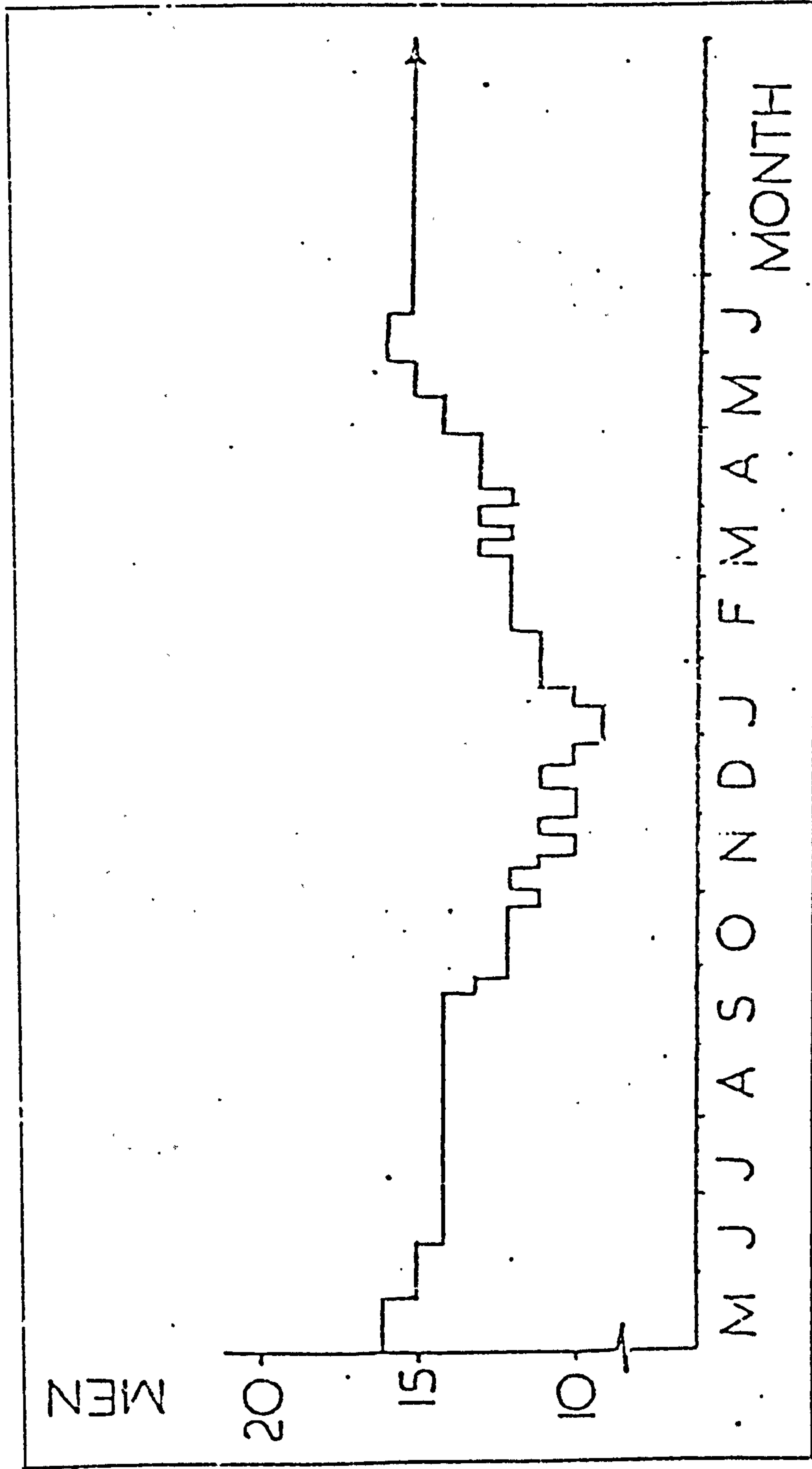
- i) Burnt blades - where a welder burns a hole through the blade with his electrode
- ii) Damaged - where the welder hits the end of the spindle to knock the slag off resulting in oversize or bent spindles

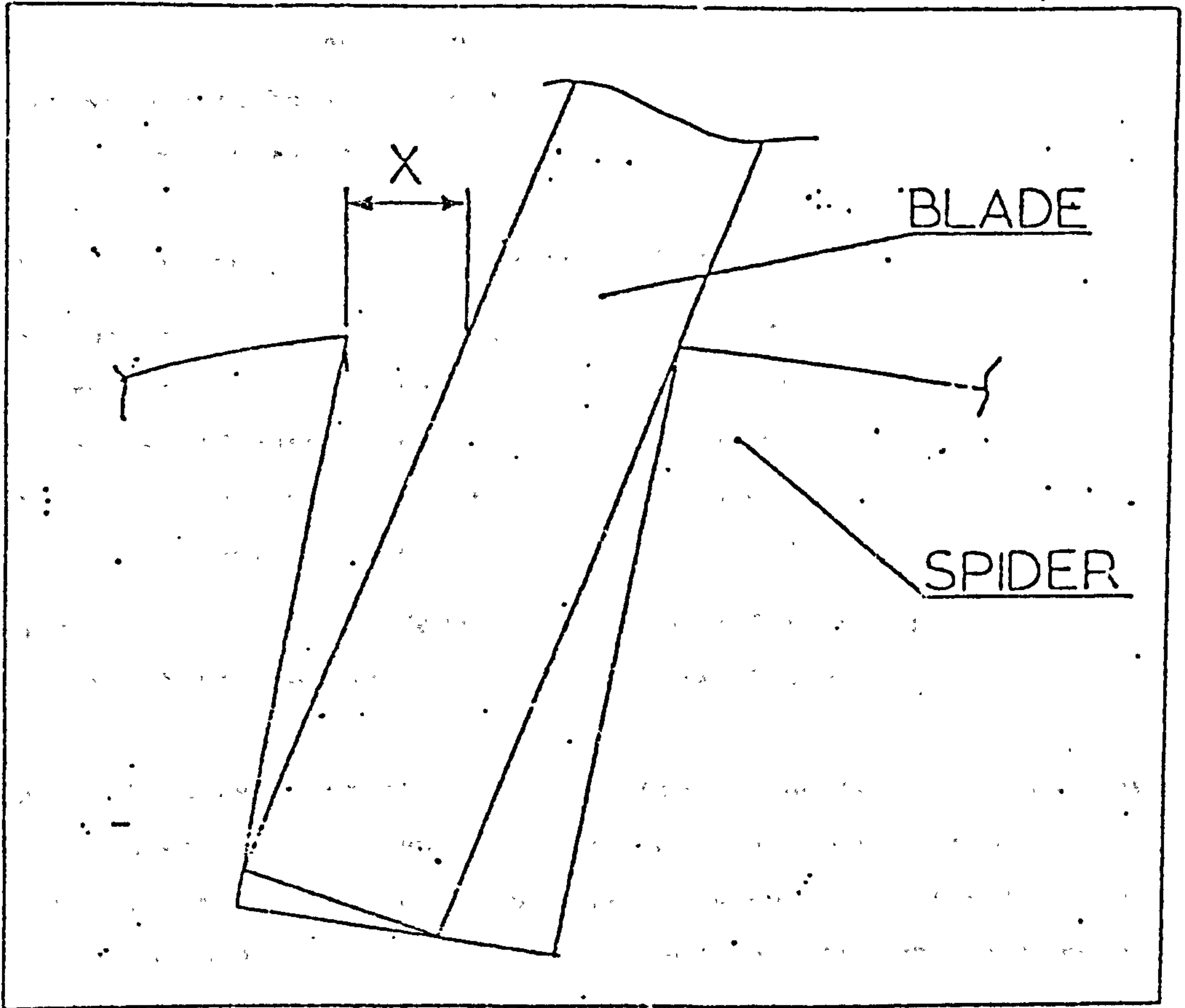


DIAG. 5.20

WELDING WORKSTATION (CURRENT MANUAL METHOD)

DIAG. 5.21 WELDING SECTION MANNING LEVELS (1979/1980)





DIMENSION X	MM
HANDMOWERS	1.29
DOMESTIC	1.88
HEAVY DUTY	1.44

DIAG. 5.22 CONFIGURATION OF WELD

- iii) Oversize spindles - where a spindle has not been ground but has still been welded into the assembly as the welder has not inspected it
- iv) Blades welded in back to front
- v) Spindle in wrong way round

The rejections for the period 9.12.79 to 17.5.80 are:-

Total number of rejections (cyls)	457
Total rejected for welding	285
Total number of assemblies	94,029
% of total rejected (all reasons)	0.488%
% of total rejected (welding)	0.304%

Thus, 62 per cent of all cylinders rejected were for welding reasons. Rejection levels are therefore negligible due to the flexibility of a manual system.

Assembly production was disrupted 11 times (1980) due to problems of cylinder supply to the assembly department. Four occasions were attributable to the manufacturing system - seven to the purchasing supply department. Thus, the manual system is highly flexible and effective although not very productive.

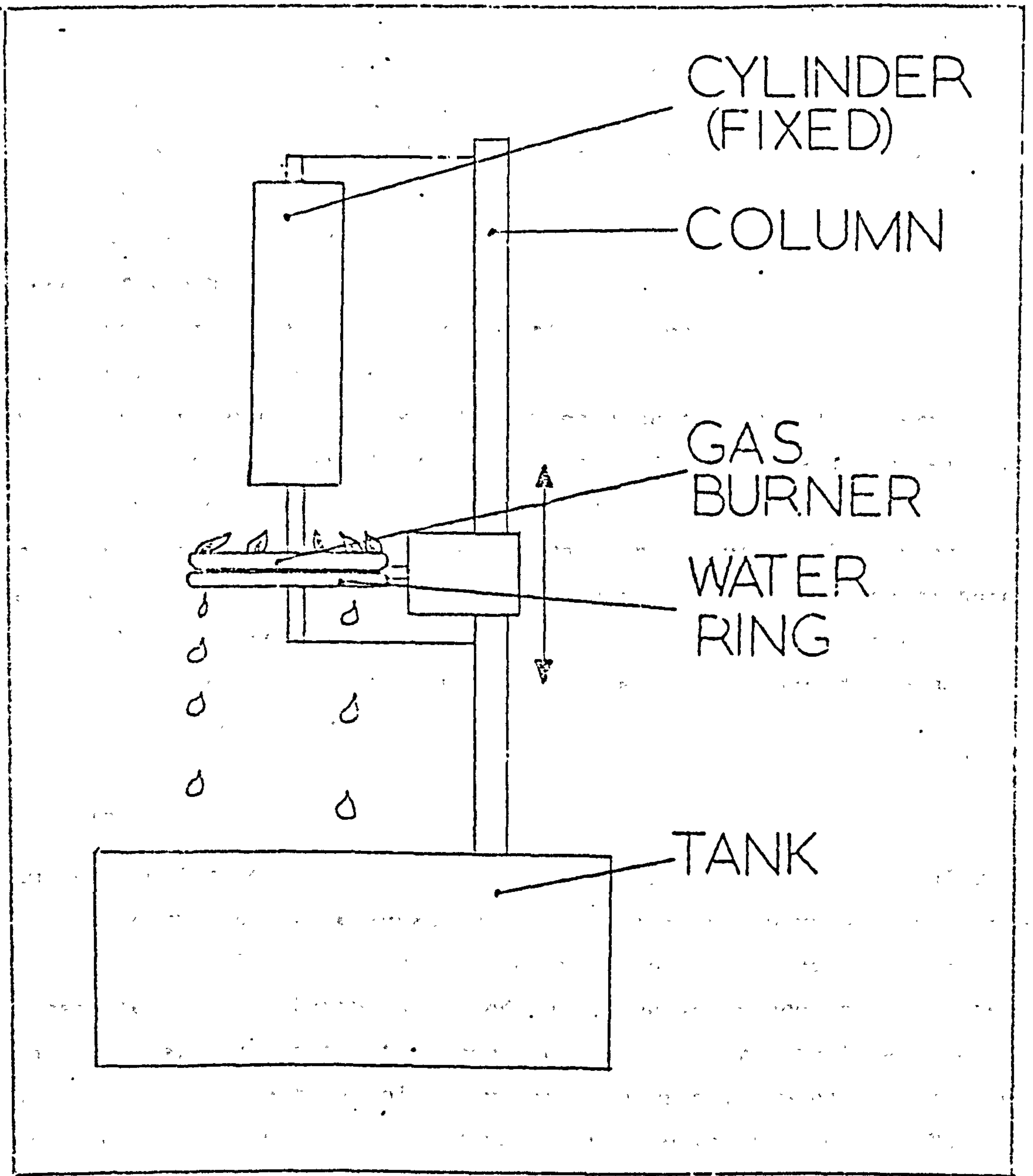
### 5.3.2 Hardening

Only the power mower (domestic) and heavy duty cylinder blades (EN 5C) are hardened. The tips are hardened to a depth of 6 mm to 23 - 28 Rockwell (C Scale) hardness (248-285 HB).

Cylinders are clamped vertically on their spindles between cups to position them within the flame and water rings which traverse along their length. A 'natural gas' (methane) and oxygen mix flame is used to provide the heat input. Cooled water is used for an immediate water quench to harden the blade tips. A mechanical finger maintains the blade tips in the flame as the burner ring advances along the cylinder. The concept of the process is shown in diagram 5.2 3.

The sequence is as follows:-

- i) the cylinder is loaded between cup centres
- ii) the cup centres are clamped to secure the cylinder
- iii) the burner gas is ignited from a pilot light (always on) with a solenoid permitting the high pressure gas through into the burner ring



DIAG. 5.23

FLAME - HARDENING CONCEPT

- iv) the burner ring advances to heat the first 3/8 inch of each blade to ensure adequate heat input
- v) the burner ring dwells at this position for 3 seconds on a timer circuit
- vi) the burner then traverses upwards at a controlled feed rate, continually heating and quenching the blade tips, on a D.C. variable reversible motor driving a lead screw
- vii) the burner is extinguished 3/8 inch from the top of the blades to prevent burning the blade away
- viii) the burner ring dwells a second time to ensure full quenching of the ends of the blades.
- ix) the burner ring returns to the start position
- x) the cylinder is unclamped

Present loading is manual to a two-station machine for cylinders less than 20 inches in length and a single station machine for cylinders greater than 20 inches. The sequences from iii) to ix) above are automatically controlled using relay/contact logic. All other operations are manual including transfer from a stillage of cylinders to be hardened to a stillage of hardened cylinders. Reject levels are again negligible as rework is carried out by the setter whilst setting the machine. Once set, the automatic sequence maintains the cylinders' hardness levels.

### 5.3.3 Grinding

The diameter and form of the cylinder is ground on a plain cylindrical grinding machine. An eight inch wide wheel (26 inches diameter) plunges two to four times, as required, along a cylinder's length to bring the cylinder into roughly parallel form. Having achieved this, the workpiece is oscillated along the wheel with a finer cut to machine the cylinder into tolerance. With the cylinder not being a solid component to grind, appreciable deformation is experienced whilst the wheelhead plunges in onto the cylinder. Therefore a slow workpiece rotation of 30-60 r.p.m. is required. At this speed, the cylinder is ground with the coolant flooding the area of cut. The intermittent cut creates a large burr that must be manually wiped off with a stone or knife after the plunge cuts are completed. For the finishing cut the workpiece speed is raised to 300 r.p.m. The wheel's peripheral speed remains constant at 30 metres per second. The cylinder is ground in the opposite direction to that with which it will cut in the lawnmower. This is due to the fact that the flexing distortion produces a rake angle on the blade as the blade (previously under stress from the grinding pressure) relaxes off the wheel. The resulting rake in fact assists a blade's cutting



action (diagram 5.24). The coolant is shut off at the higher work speed rotation as the 'paddlewheel' action of the cylinder would otherwise drench the operator. Thus, the present grinding cycle is:-

- i) manually load cylinder - manually locking tailstock into position
- ii) manually switch on workpiece rotation (30 r.p.m.) and coolant
- iii) manually feed wheel in (fast)
- iv) manually plunge wheel into cylinder
- v) manually retract wheel
- vi) traverse to next plunging position
- vii) repeat iii) to v)
- viii) traverse cylinder approximately 5 times to size cylinder
- ix) retract wheel head and stop traversing and work rotation
- x) scrape cylinder manually
- xi) shut off coolant
- xii) increase workpiece rotation to 300 r.p.m.
- xiii) (approx) 6 traverses for finish grind
- xiv) stop workpiece rotation
- xv) unload component (scrape if necessary)

The workpiece is driven from one of the blades. This is necessary as the cylinder is mounted into bearings on the cones assembled onto its spindle ends, and ensures parallelism to the bottom blade as assembled into the lawnmower.

The present wheel specification is:-

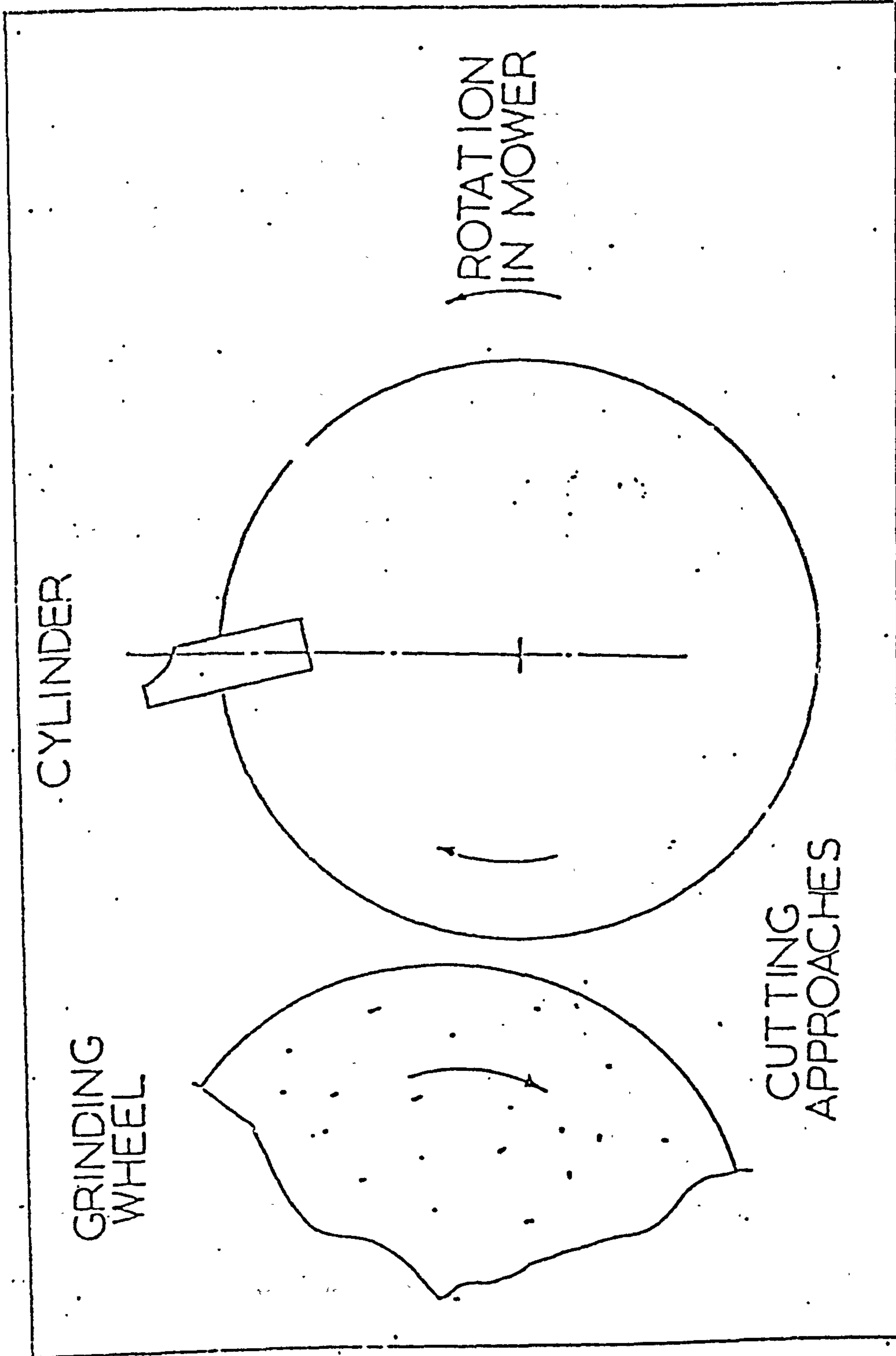
660 mm x 200 mm x 304.8 mm  
(26" x 8" x 12" )

Recessed both sides 20.64 mm deep x 355.6 mm diameter

A 46/60 PV.

These wheels require dressing every 27 grinding cycles at the start of their lives. This rate increases to every 15 cycles towards the end of their lives.

Inspection of the cylinders is on every tenth cylinder produced using a circular gauge. Approximately 3/32 inch on the diameter is required to be ground away in order to produce a satisfactory parallel cylinder. The round edge of the hot rolled blade must be removed as well as any variation in blade positioning resulting from the manual assembly/welding process. Table 5.18 lists the fabricated and ground dimensions of the cylinder mix. The actual fabricated variance on cylinder diameter may be as high as 3/64 inch although the average variation is 1/64 inch. Therefore, as much as



DIAG 5.24 THE METHOD OF GRINDING

Cylinder Type (KEY TABLE 5.8)	Grinding MIN	Dimensions MAX
1	5.000	5.059
2	5.000	5.059
3	5.000	5.059
4	5.718	5.781
5	5.718	5.781
6	5.297	5.327
7	5.265	5.235
8	5.86	5.89
9	5.86	5.89
10	5.750	5.812
11	5.750	5.812
12	5.359	5.390
13	5.359	5.390
14	5.359	5.390
15	5.370	5.380
16	5.359	5.390
17	5.365	5.385
18	5.370	5.380
19	5.365	5.385
20	5.365	5.385
21	6.120	6.130

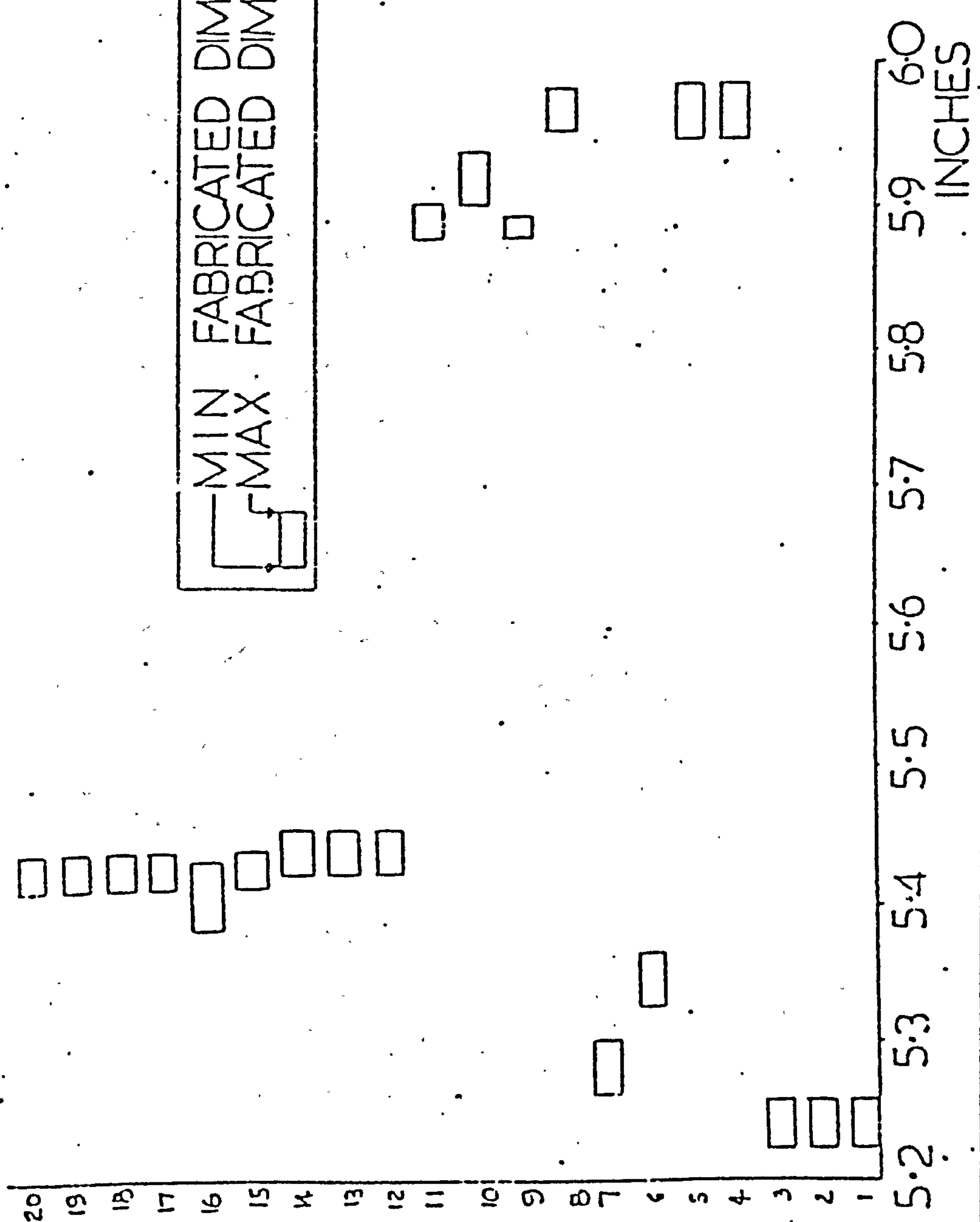
Table 5.18 Grinding Specifications

3/32 inch may have to be ground from the cylinder's diameter to produce a parallel form, diagram 5.25. The 1980 grinding requirements amounted to 15,733 standard hours (8.55 man years). This was accomplished on the day and night shifts of the department.

#### 5.3.4 Transfer

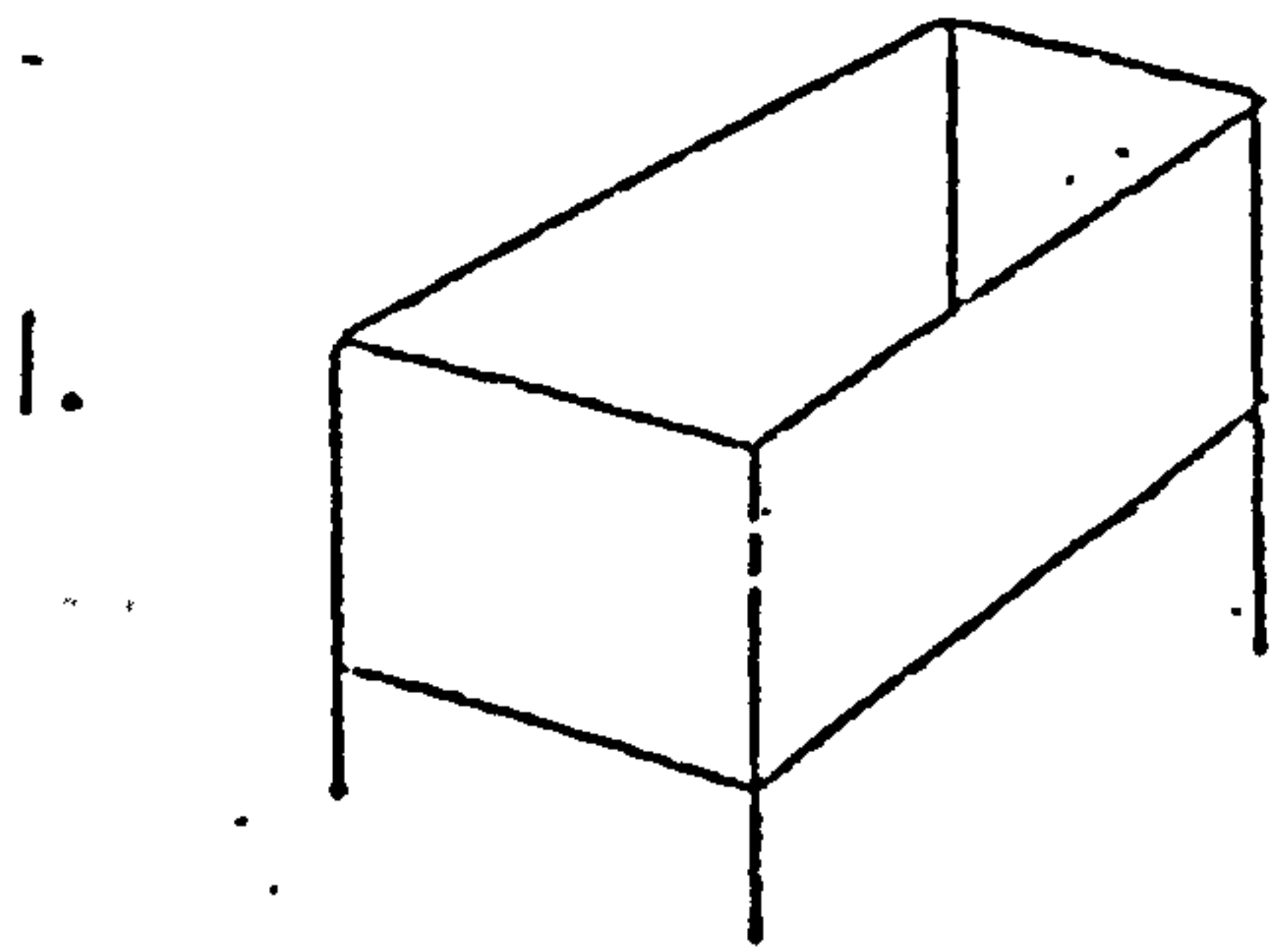
The transfer of all component materials is manual throughout the whole cylinder manufacturing system. Fork lift trucks supply and retrieve materials and cylinders to and from the system only. The major transfer operations are to the welding, hardening and grinding stations. Transfers onto machines from stillages is carried out manually. Pallet trucks are used to transfer the larger square cage stillages (diagram 5.26) around the system. Smaller loads of components are manually towed in tug boxes. Open faced stillages are used to transfer cylinders away from the welding stations. The various methods of transfer are fully detailed in table 5. Unit loads vary from 30 cylinders to 100 cylinders per stillage, depending upon the physical size of the cylinder. All cylinders, whether ground or not, are stacked upon each other except the more expensive heavy duty cylinders which are laid upon lengths of corrugated cardboard to protect the finely-ground blade edges.

CYLINDER TYPE (KEY TABLE 5.10.)

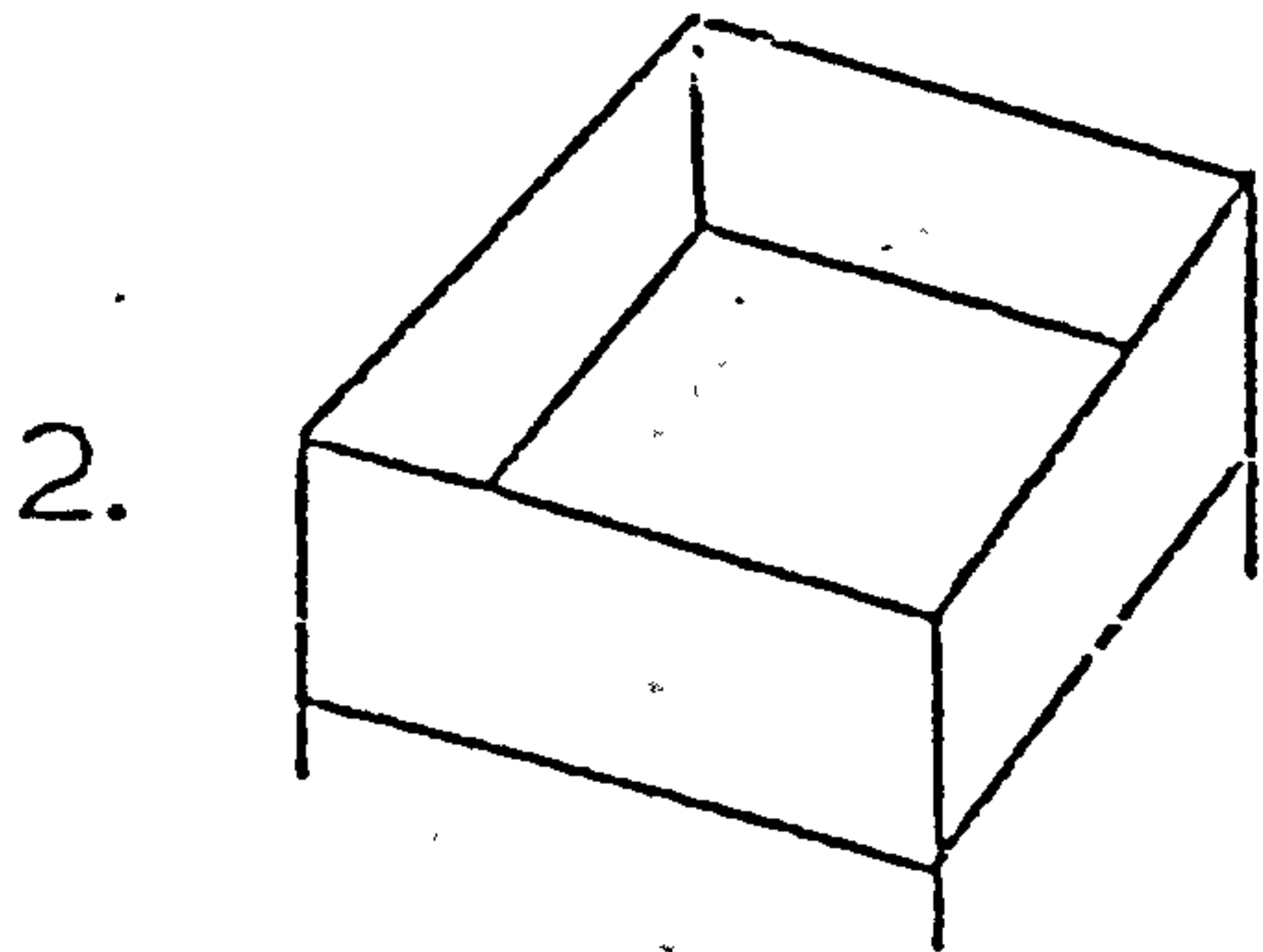


MIN FABRICATED DIMENSION  
 MAX FABRICATED DIMENSION

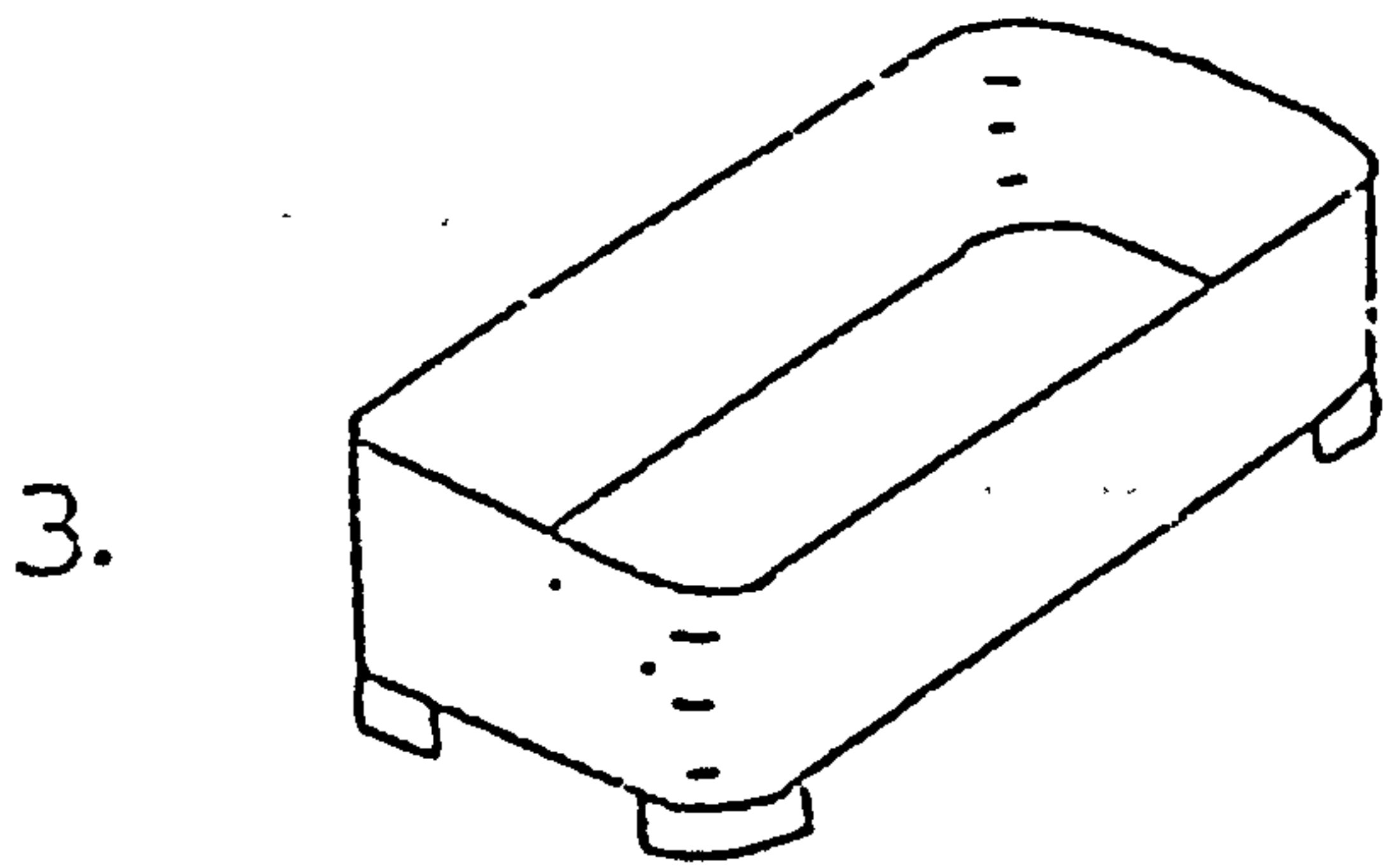
DIAG. 5.25 CYLINDER DIAMETERS FOR GRINDING



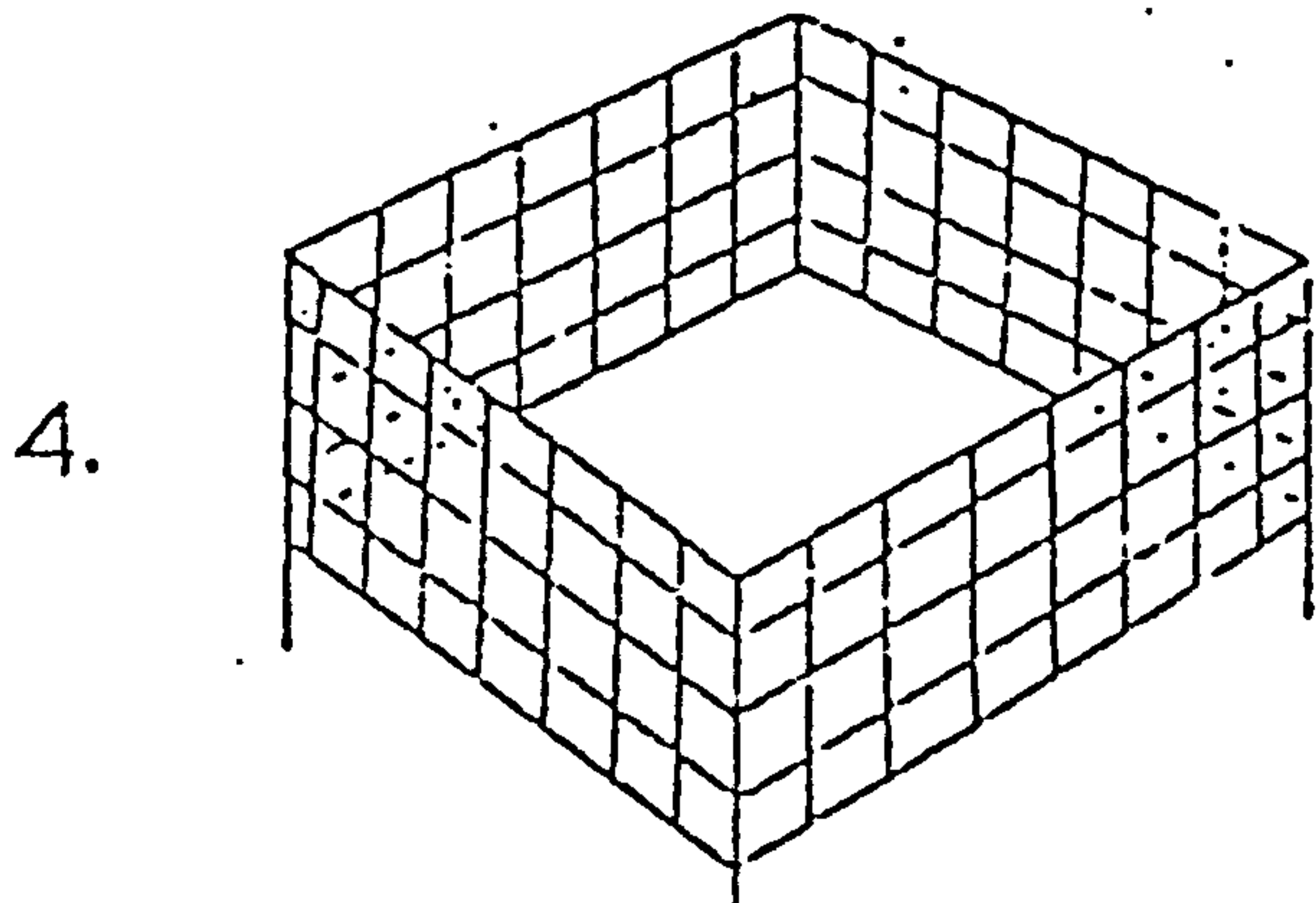
BLADES



SPINDLES



SPIDERS

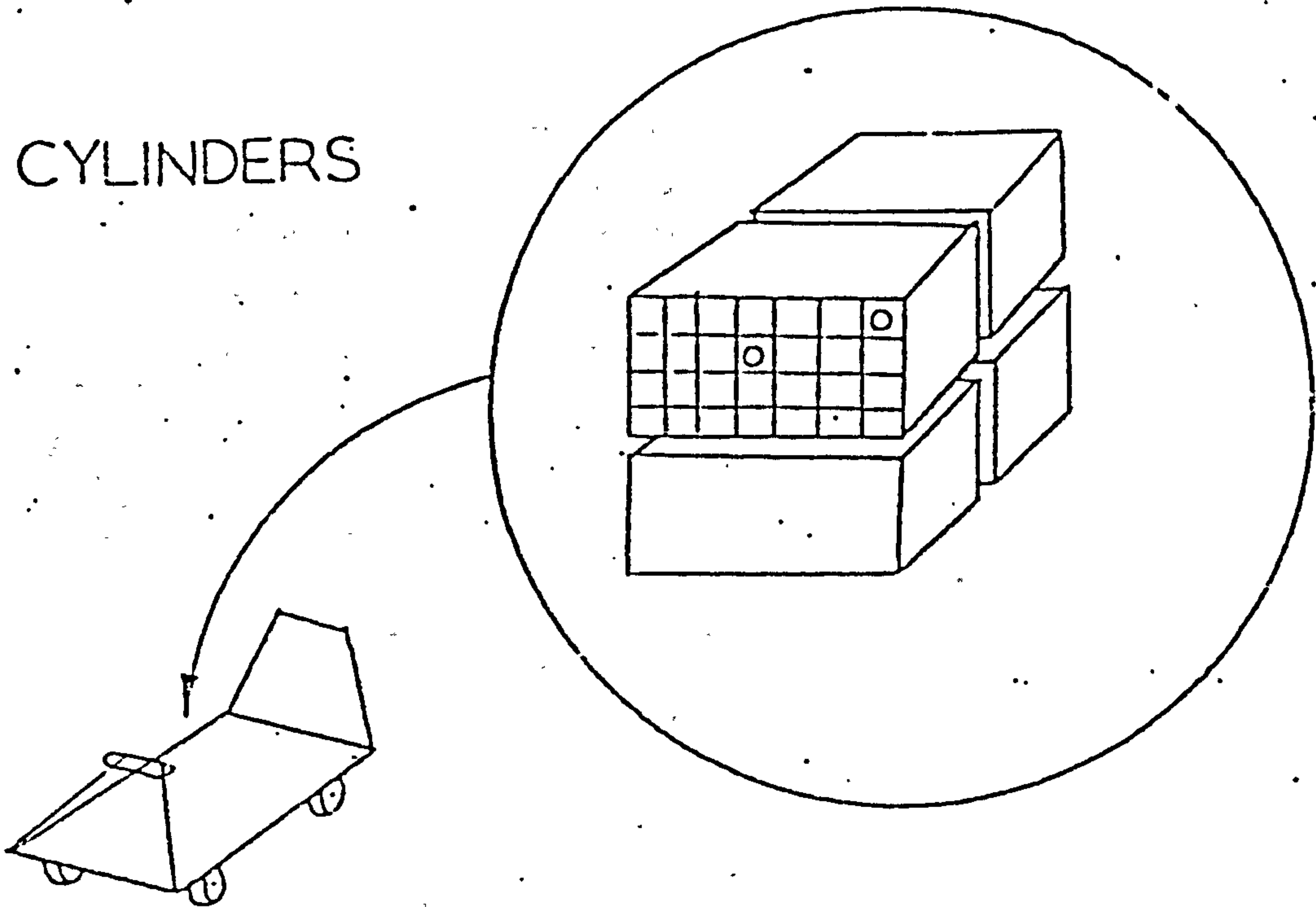


CYLINDERS

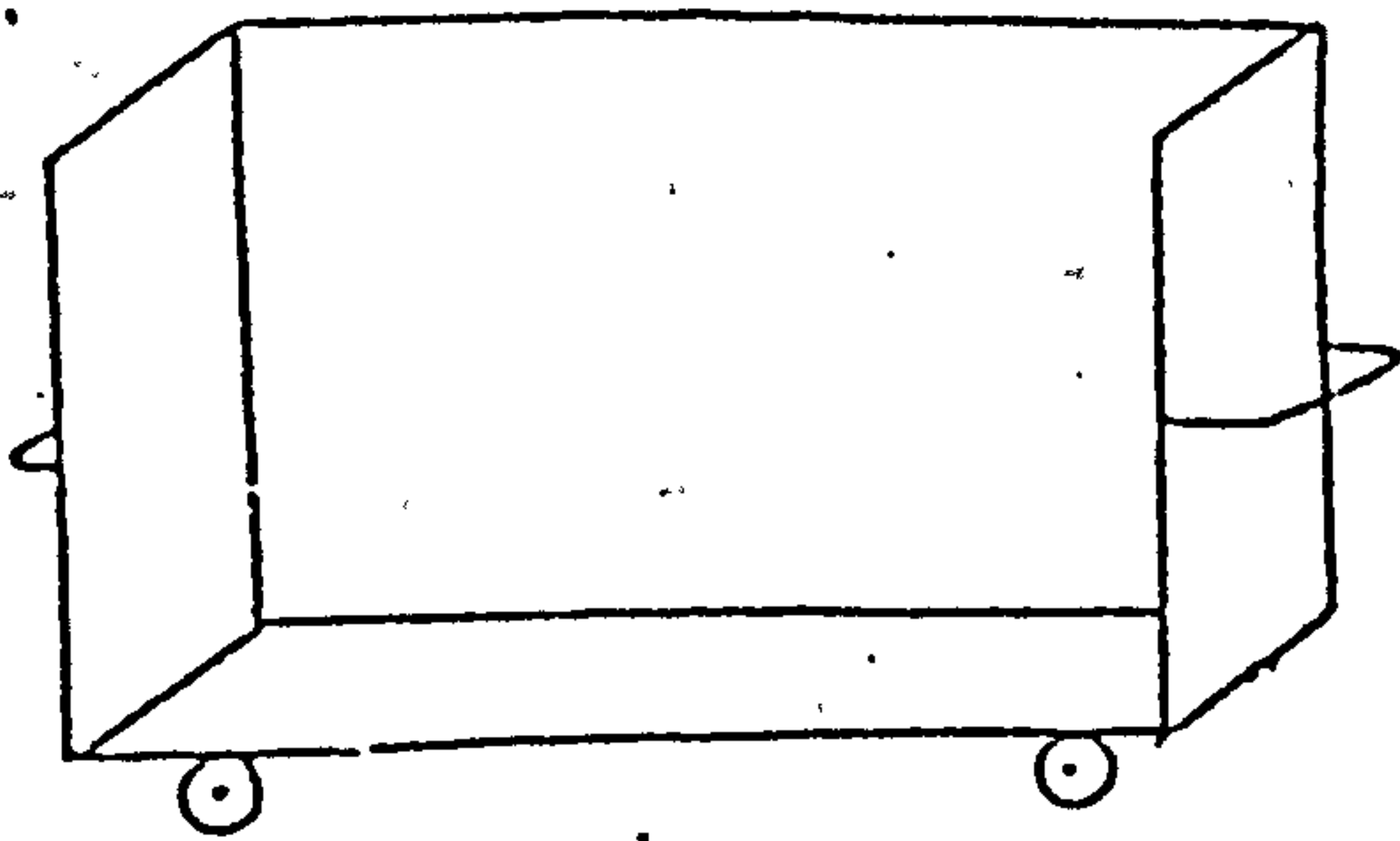
DIAG. 5.261 TRANSFER STILLAGES (DIMENSIONS - TABLE 5.15)

CYLINDERS

5.



6.



CYLINDERS

DIAG. 5.26ii TRANSFER STILLAGES

From	To	By	Sketch on Diagram 6.7	Size (ins)	Capacity
Press shop	Welding area	Square stillage	(3)	41 x 25 x 7	5000 spiders
Blade forming	Welding area	Narrow stillage	(1)	36 x 19 x 25	1000 blades
Spindle machines	Welding area	Tug box	(2)	24 x 24 x 13	400 spindles
Welding area	Welding bench	Manually	-	-	1 cylinder
Welding Bench	Buffer store	Manually	-	-	1 cylinder
Buffer store	Hardening station	Tall narrow stillage	(6)	20 x 55 x 50	100 cylinders
Hardening station	Grinding machines	Square cage stillage	(4)	48 x 34 x 29	75 cylinders
Grinding machines	Degrease	Multiple cages on stillage	(5)	4 x (20 x 46 x 29)	4 x 28 cylinders

Table 5.19 Methods of Current Manual Transfer



## SECTION 6

### TECHNICAL DEVELOPMENTS REQUIRED TO ACHIEVE FMS OBJECTIVES

The major processes of welding, hardening and grinding require certain developments to achieve the automation objectives in designing an FMS for SLM. Welding and grinding necessitated the major investigations.

#### 6.1 WELDING

The power mower cylinders are welded using the CO<sub>2</sub> MAG processes. This is readily adaptable for automation with a robot manipulating the torch. The handmower cylinders are welded using the MMA processes. This must be developed into the MIG or MAG welding method for automation. A problem arises from welding the high carbon blade material (0.70 per cent to 0.85 per cent carbon) to the mild steel spider material (0.15 per cent carbon). A carbon equivalent in the weld root run higher than that in the spider will result in a reduced resistance to cracking. In general, steels with a carbon equivalent greater than 0.5 per cent require a higher welding temperature to ensure that welding is carried out without serious risk of crack formation. Thus, the weldability of the blade material and not the choice of electrode is critical. The blade material must be pre-heated to and welded at the same temperature as required when welding the spider steel alone.

Manually welded handmower cylinders with a 100 per cent CO<sub>2</sub> gas shield produce cold-cracking behind the weld on the blade. Tests (Wadsworth (1982)) on a Cincinnati T3 hydraulic six-axis robot (one of the least positional accurate welding robots) were carried out to determine the suitability of an Argon/CO<sub>2</sub> gas shield MIG process. The success of the welding process depends upon the choice of wire, shielding gas and welding conditions.

The wire and gas combinations used in the initial tests are:-

- A : Present MMA method
- B : 1 mm Bostrand 20 Wire/Argoshield 20 (120A, 18V)
- C : 1.2 mm Corofil B55 Wire/Argoshield 20 (140A, 18V)
- D : 1 mm Bostrand MS Wire/CO<sub>2</sub> (120A, 21V)
- E : 1 mm Bostrand MS Wire/Argoshield 20 (120A, 18V)

Hardness tests were carried out on each fillet using a 10 kg load (HV). The results are tabulated in table 6.1. The hardest and softest combination were selected for microstructural examination (D and C respectively). Microscopic examination of the softest fillet (C) subsequent to etching in 2 per cent Nital, revealed a typical acicular ferrite-pro-eutectoid ferrite weld microstructure. The structure on the Heat Affected Zone (HAZ) was also typical ferrite-pearlite microstructure on both legs of the fillet. A similar examination on the hardest fillet revealed a martensitic/lower bainite transformation of the weld with the base of the leg of the fillet being fully martensitic in the heat affected region. The best results, i.e. those which produced the lowest values in the HAZ of the EN42 material (spiral blade) were those welds carried out with an Argon (20 per cent)/CO<sub>2</sub> (80 per cent) shielding gas mixture. They were from the larger fillet welds, welded with higher heat inputs giving slower rates of cooling. These tests were carried out by the Welding Laboratories of BOC Ltd, Walthamstow, London.

Further tests were carried out by the Derby Lonsdale College, Derby (UK), to determine the effects of pre-heating the weld to produce better results. The techniques employed are shown in table 6.2. Weld samples from each technique were micro-analysed to observe the grain structures, the extent of the HAZ, the hardness of the weld, the penetration and any defects.

From the six welded cylinders, two welds, one from the end of the cylinder and one from the centre, were sectioned for metallurgical examination. From cylinder QLM A1 both of the welds examined had rounded profiles with short weld lengths on both the high carbon blade and the mild steel disc. In each case, penetration into the mild steel was adequate with a clean weld. The heat affected zones in the EN42 steel are shallow in both welds. The hardness survey is shown in diagram 6.1.

The two welds examined in cylinder QLM B1 showed similar characteristics. The profiles were less rounded but were still convex. Both welds were sound with the inclusion content very low (diagram 6.2). The welds from ESAB/A had profiles which were slightly concave. Length in the weld-blade interface was satisfactory but, particularly in the case of the inner weld, the distribution of the weld-pool favoured the EN42 too strongly. Penetration in both materials was good with clean welds. The HAZ extended across the full section of the blade. Hardening was confined to a relatively narrow zone near the weld (diagram 6.3).

Test Cylinder	Position	1	2	3	4	5	6
A		135	162	322	309	782	325
B		137	151	345	383	405	283
C		142	159	264	274	387	302
D		133	158	409	437	894	319
E		131	165	251	245	405	283

Table 6.1 Hardness Test Results

Units = HV (Hardness Vickers)

TABLE 6.2 WELDING TEST RESULTS COMPARISON CHART

Cylinder Designation	H.A.Z.	Penetration (Blade)	Hardness VPH			Comments
			General	Blade Tip	Maximum	
QLM A1 End	Very little	None	295	281	420	Some inclusions, incorrect angle
Centre	$\frac{1}{2}$ across section	Little	258	290	642	Reasonable weld
QLM B1 End	$\frac{1}{2}$ across section	Little	200	272	800	Some inclusions, reasonable weld
Centre	$\frac{1}{2}$ across section	Little	300	285	620	Few inclusions lack of penetration
ESAB A End	Right across section	Full	299		753	Good clean weld
Centre	Right across section	Full		321	766	Good clean weld. Angle could be improved
WIRS 1 End	Right across section	Good but bridged	281	306	405	Good weld. Fine grains
Centre	$\frac{2}{3}$ across section	Good	270	290	580	Good weld. Fine grains
WIRS 5 End	$\frac{1}{2}$ across section	Fair but bridged	299	281	405	Lack of fusion and penetration.
Centre	$\frac{1}{2}$ across section	Fair but bridged	285		592	Lack of fusion and penetration.
GIUCE i End	Right across section	Good	336		772	Good clean weld. No inclusion.
Centre	Right across section	Good	336	790	800	Good clean weld. No inclusion.

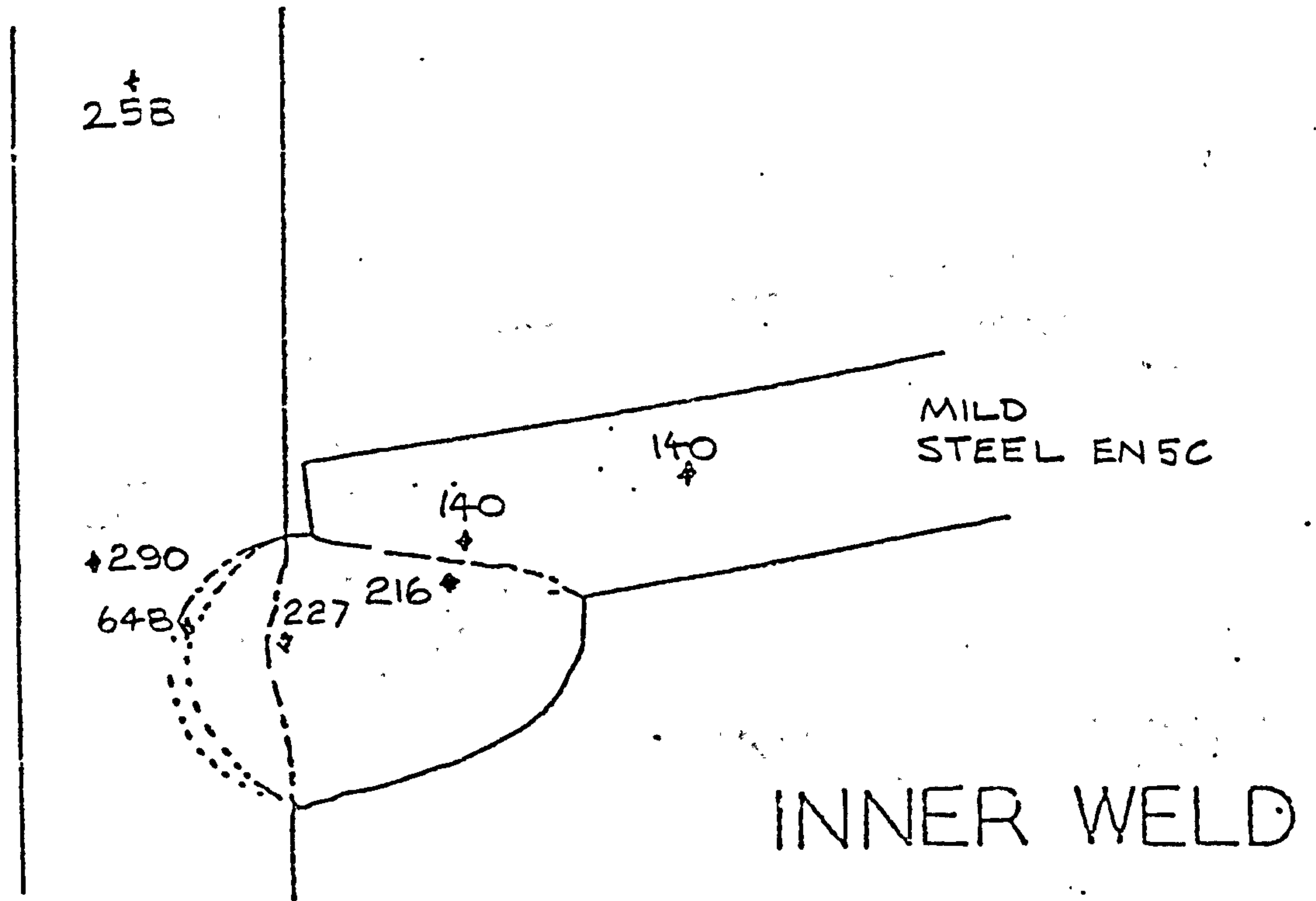
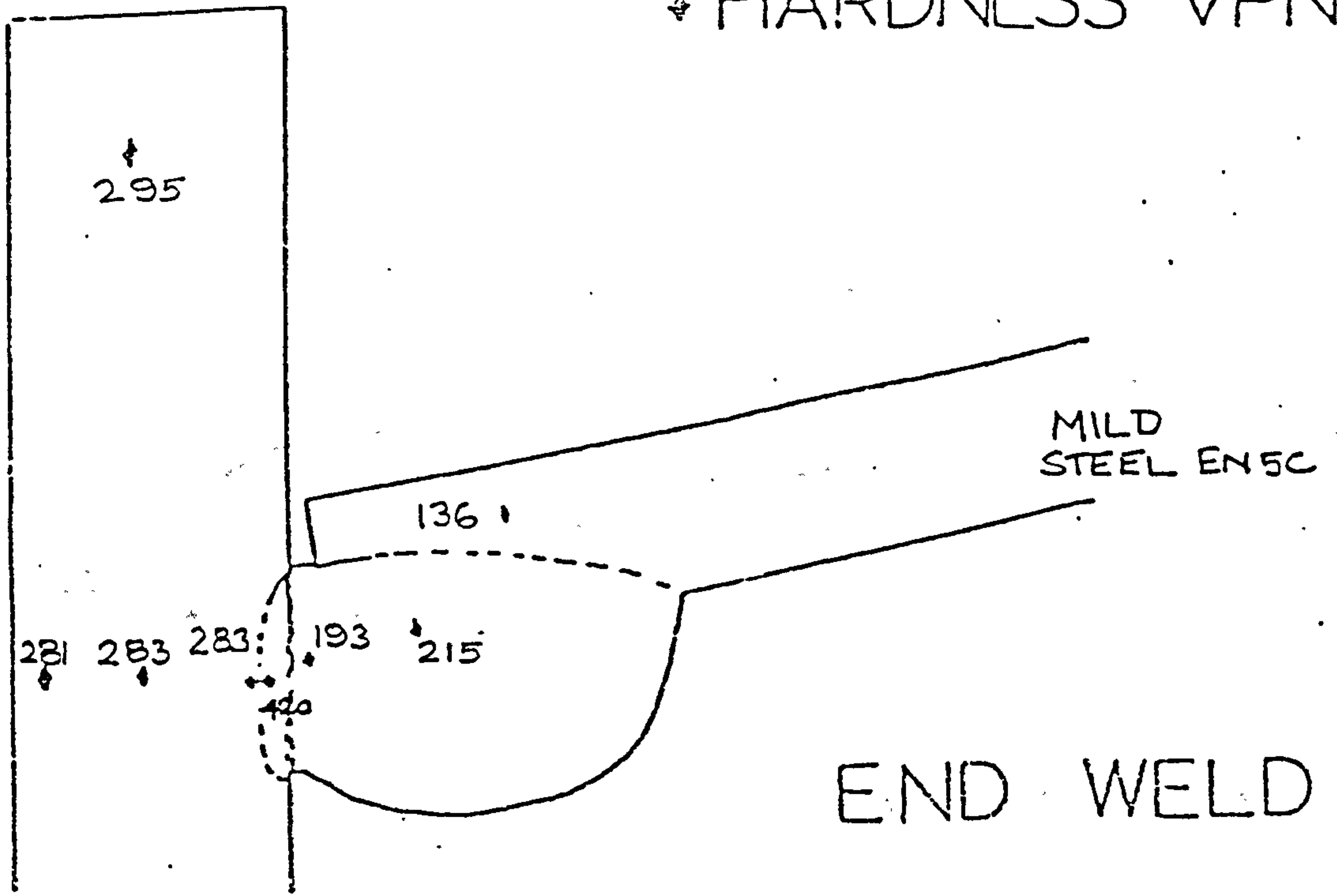
Designations	Manufacturer	Welding Method	Quantity
QLM A1 - 12	Qualcast	An initial preheat spot then full CO <sub>2</sub> weld.	12
QLM E1 - 6	Qualcast	Straight CO <sub>2</sub> weld	6
BF 1 - 4	British Federal	Straight Argonshield 80/20	4
ESAB - D	E.S.A.B.	Straight Argonshield weld but pre ignition	4
WIRS 1	WIRS	½ sec. preheat spot then argonshield 95/5	1
WIRS 2	WIRS	Preheat to 100°C Then argonshield weld 95/5	1
WIRS 3 - 5	WIRS	No preheat. Delay start/sec argonshield weld 95/5	3
			31

TABLE 6.2ii WELD TEST METHODS

Output Power	Continuous to BS 1799 Intermittent	30kw 33kw	45kw 50kw	60kw 66kw
Output Frequency		300-500KHz		
Power Supply		Standard voltages 380-440, 3 phase, 50Hz, 3 wire		
Power Consumption Full Load		48Kva	70Kva	94Kva
Power Factor Full Load		0.9		
Oscillator Valve		1:EEBW1176J2	1:EEBW1176J2	1:EEBW1184J2
Rectification		Full wave - Solid state		
H.T. Control		Thyristor Control as standard		
Circuit Breaker		Fitted as standard		
COOLING WATER	Pressure (nominal)	60 p.s.i. (4.1 kg/cm <sup>2</sup> )		
Closed Circuit Recommended	Consumption (approx)	8 G.P.M. (36 litres/min)	9 G.P.M. 41. (litres/min)	10.5 G.P.M. (48 litres/min)
*Approximate Shipping Details	Nett weight Gross weight Cube capacity	3216 lb (1459 kg) 4654 lb (2112 kg) 288 ft <sup>3</sup> (8.37 m <sup>3</sup> )	3284 lb (1481 kg) 4716 lb (2139 kg) 303 ft <sup>3</sup> (8.57 m <sup>3</sup> )	3384 lb (1527 kg) 4816 lb (2185 kg) 327 ft <sup>3</sup> (8.97 m <sup>3</sup> )
* Including H.T. transformer and oscillator valve packed separately				

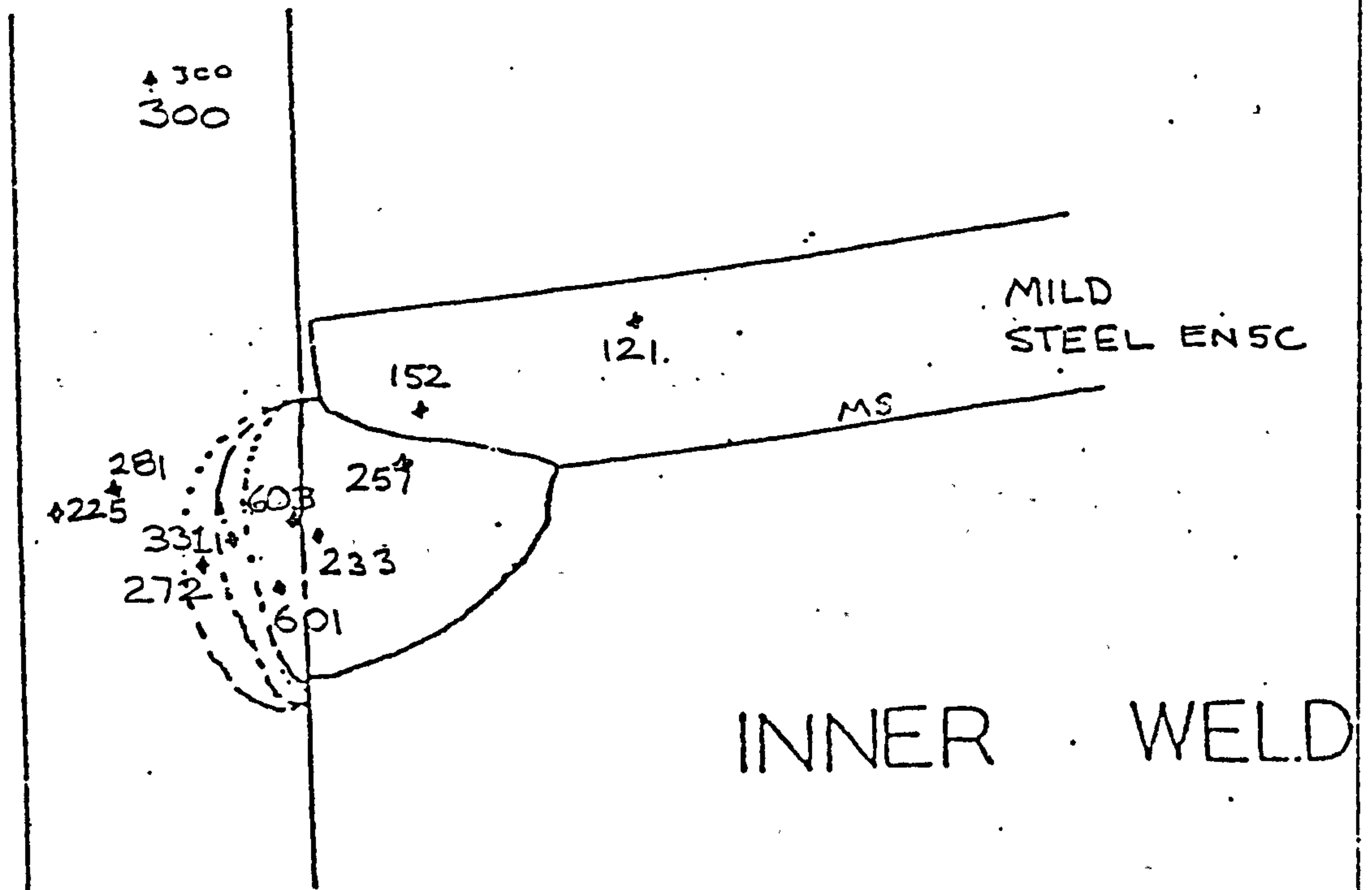
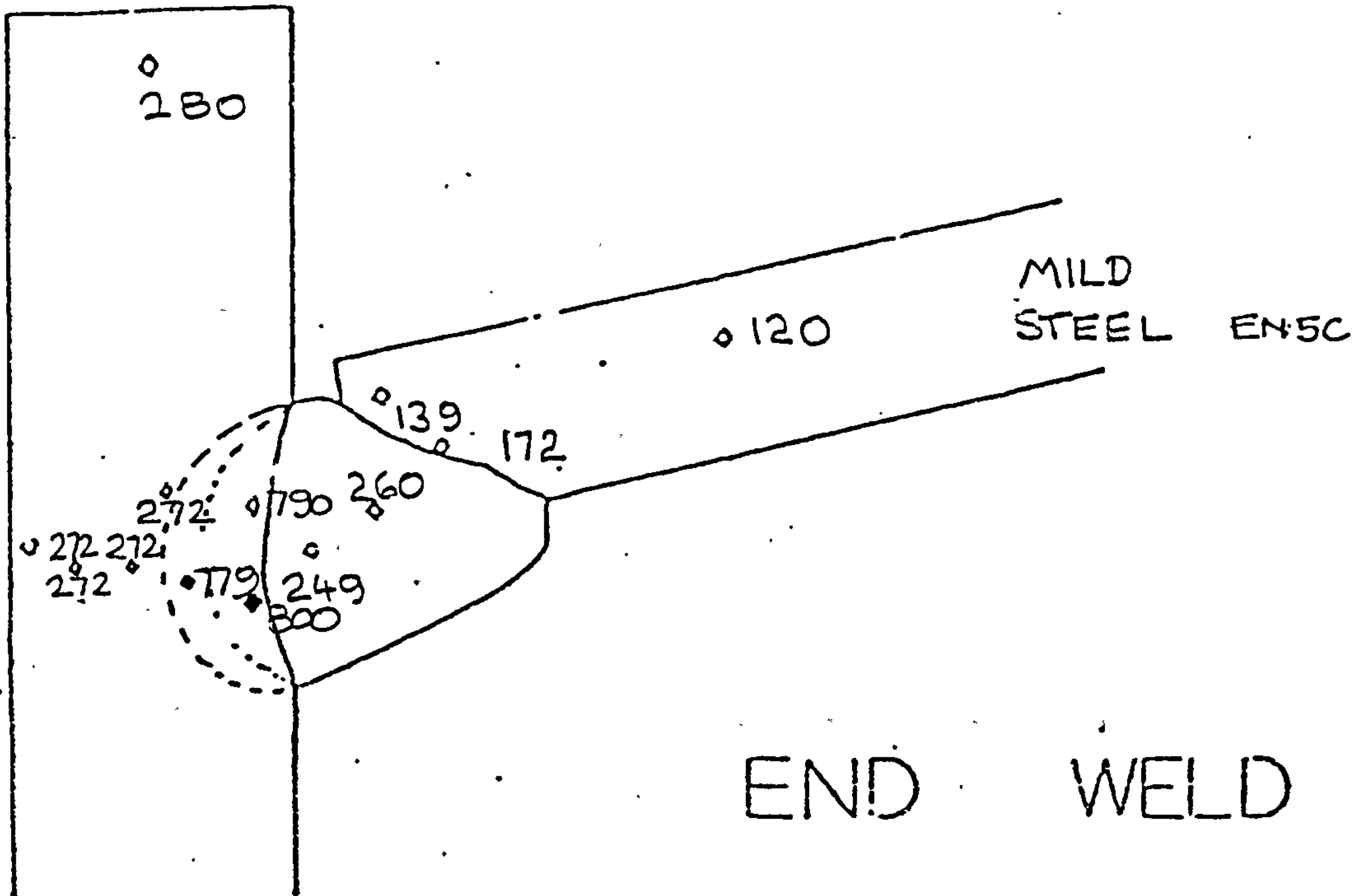
TABLE 6.3 INDUCTION HARDENING MACHINE SPECIFICATION

HARDNESS VPN

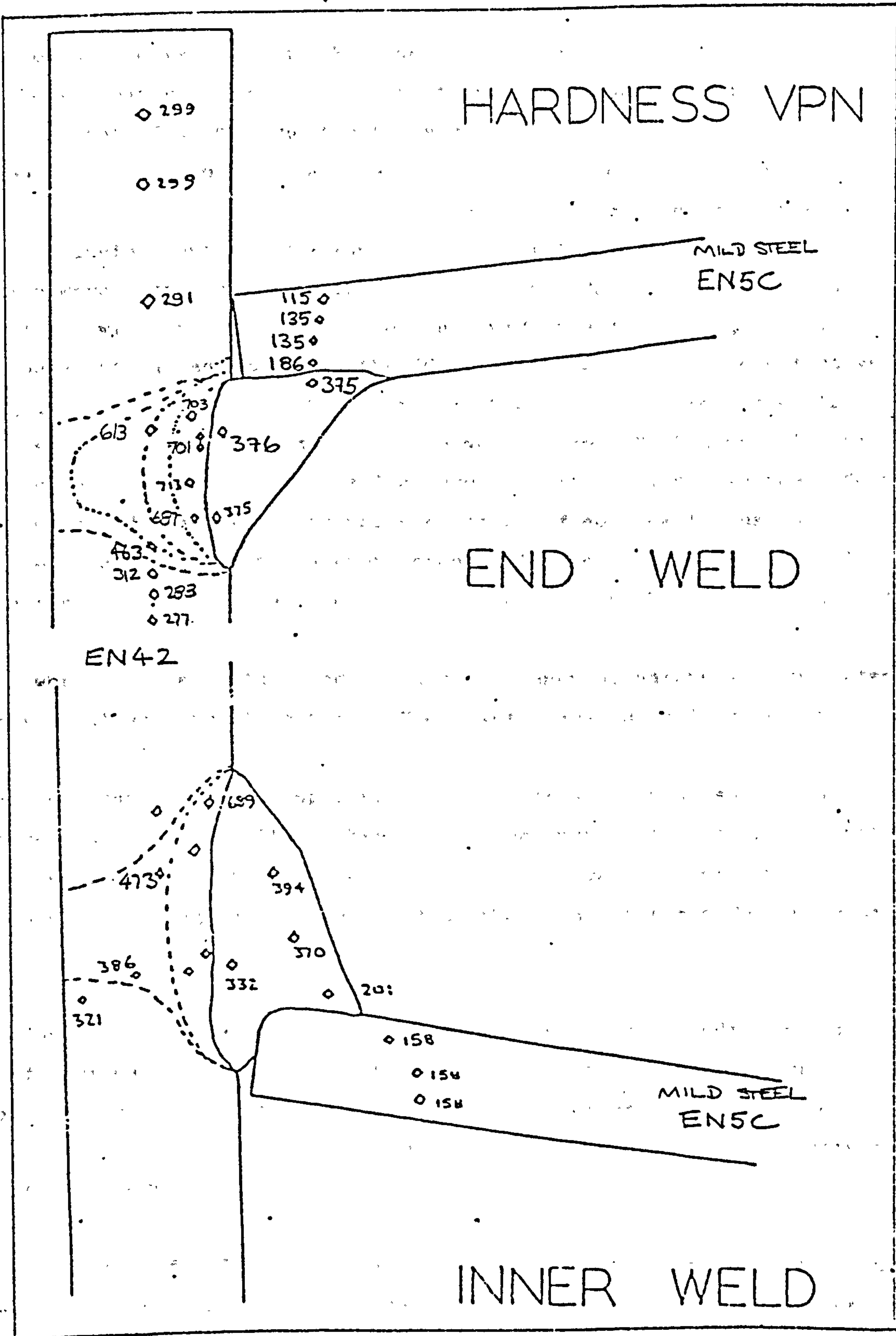


DIAG. 6.1 CYLINDER OLN -- A1 WEST

◊ HARDNESS VPN



DIAG. 6.2 CYLINDER QLM - B1 TEST



DIAG. 6.3 CYLINDER ESAB/A TEST



The profiles of the welds from WIRS 1 were slightly concave with distribution between the two materials even. Penetration was adequate. There was a full section heat affected zone for the end weld but for the inner weld the larger heat-sink had limited the effect to half the section thickness. Metallurgically these welds were of good quality having fine grain structure and a low inclusion content (diagram 6.4). Profiles for the two welds from WIRS 5 were very similar to the two from the WIRS 1 cylinder. Penetration was lower with only 80 per cent of the weld interface being sound. Although penetration was better in the EN42, bridging reduced the effective weld length to 60 per cent. The general lack of fusion is reflected in the hardness pattern in diagram 6.5. The welds from GINGER 1 were larger with a good weld distribution and a flat profile with a dimple in the middle. Penetration was adequate with the welds clean and free from inclusions. The high heat input and/or the higher hardenability of the blade material has given rise to hardening of the full thickness of the blade (diagram 6.6).

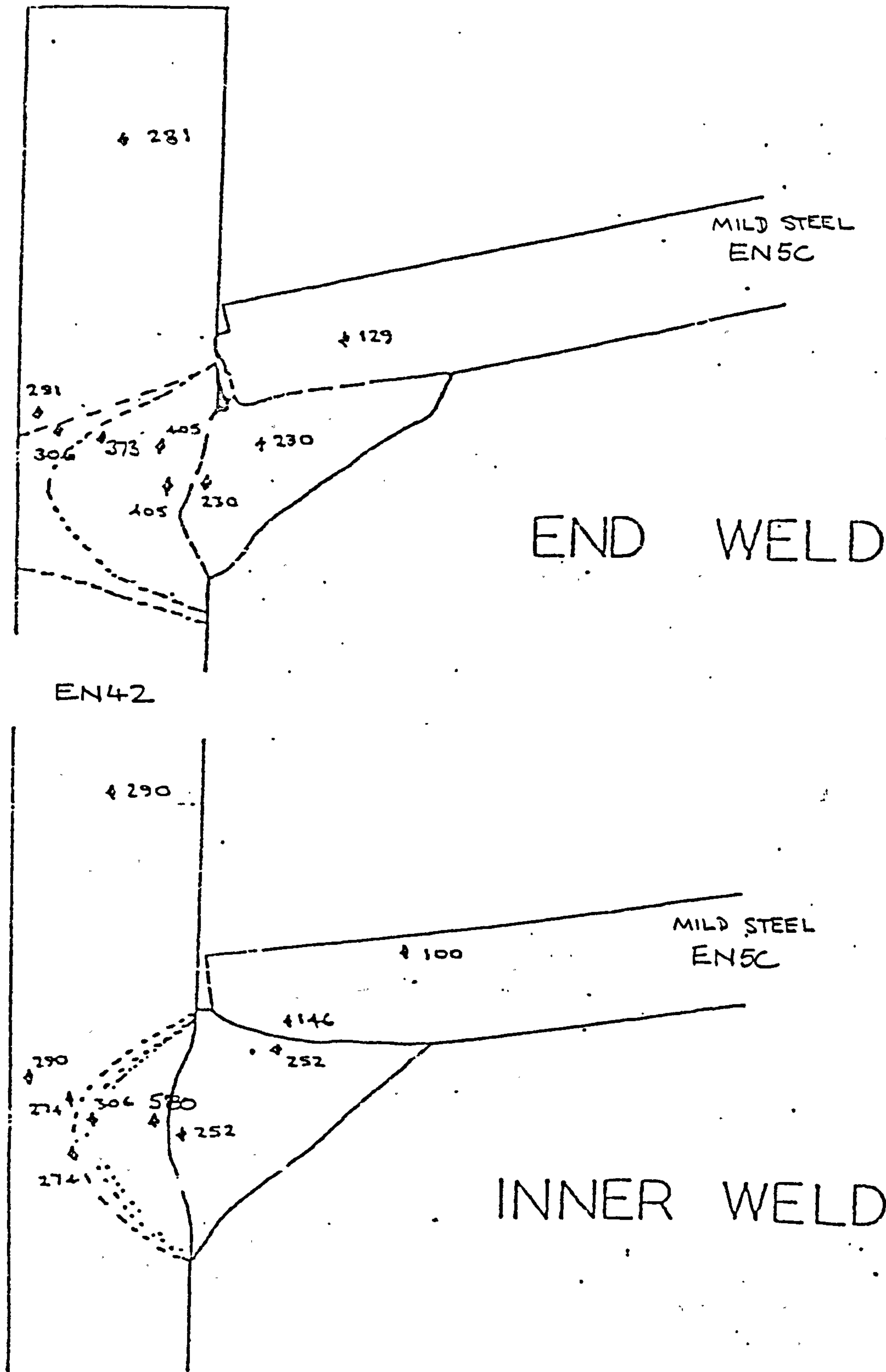
No cracks were observed with an adequate consistency of hardness value between the parent metal and the blade tip. The results are summarised in table 6.2.

Although the techniques of using a pre-ignition or a pre-heat spot of weld were not conclusively justified, there was a tendency to give slightly better welds. The importance of the correct angle of the welding torch with the correct welding settings are established as the major criteria for successful welding.

The crack and defect free Argon/CO<sub>2</sub> gas mix welding results indicate that failure of fabricated cylinders is unlikely. This has been proven by grinding fifty such cylinders and examining the after-grind welds. No cracks or failures occurred. The strength of the whole fabricated cylinder was seen to be increased.

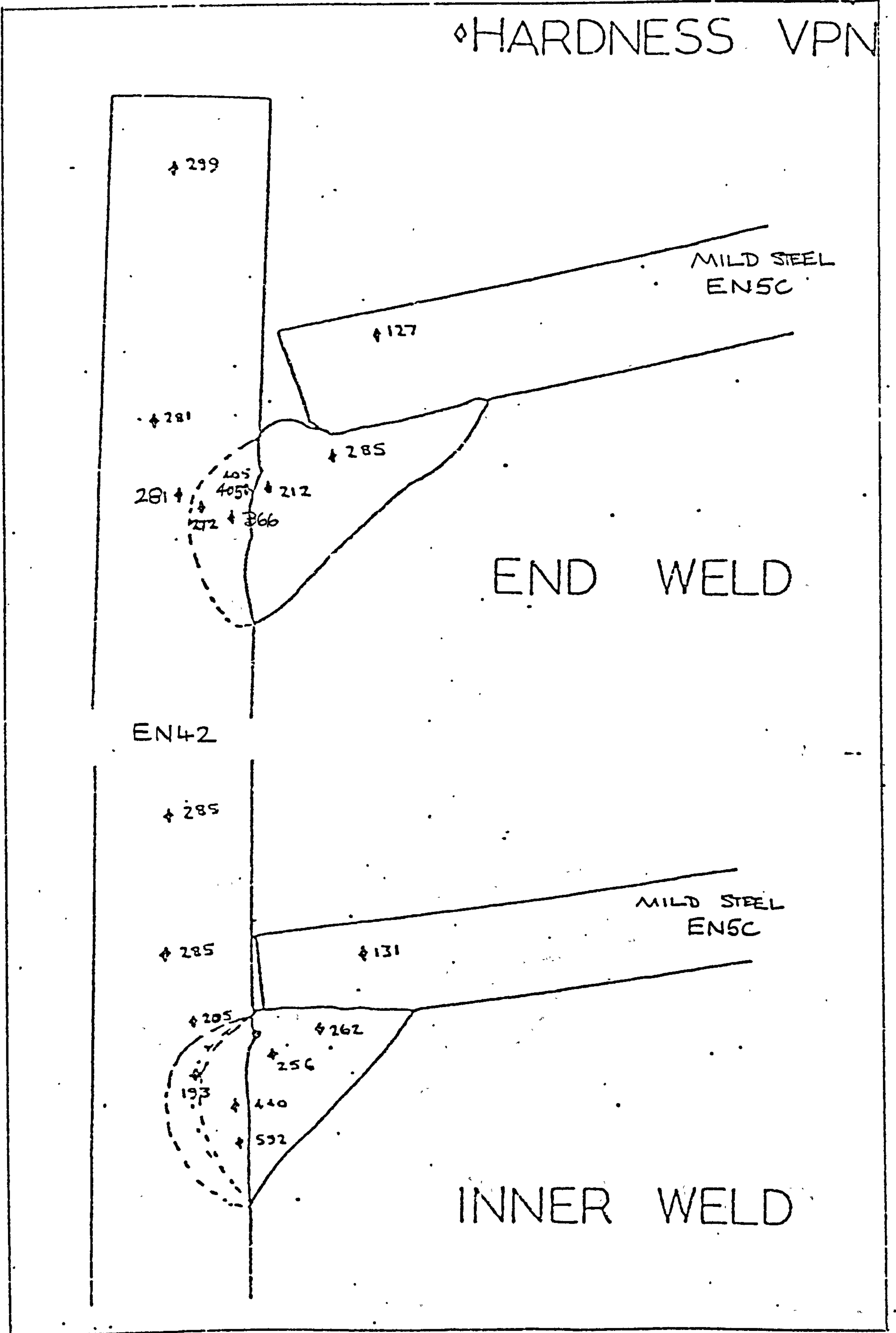
The present method of MAG welding the blades (with high-hardenability and air hardening characteristics) with "low hydrogen carbon manganese" electrodes is improved with the use of a double-deoxidised copper coated mild steel wire when used with the Argon/CO<sub>2</sub> shielding gas. Such a wire is Phillips PZ6000 which produces less than 4 ml of hydrogen per 100 g of weld metal. A thin copper coating ensures good electrical contact and will reduce friction during the required high-speed feeding and minimise corrosion of the wire. The wire specification is:-

◊ HARDNESS VPN.



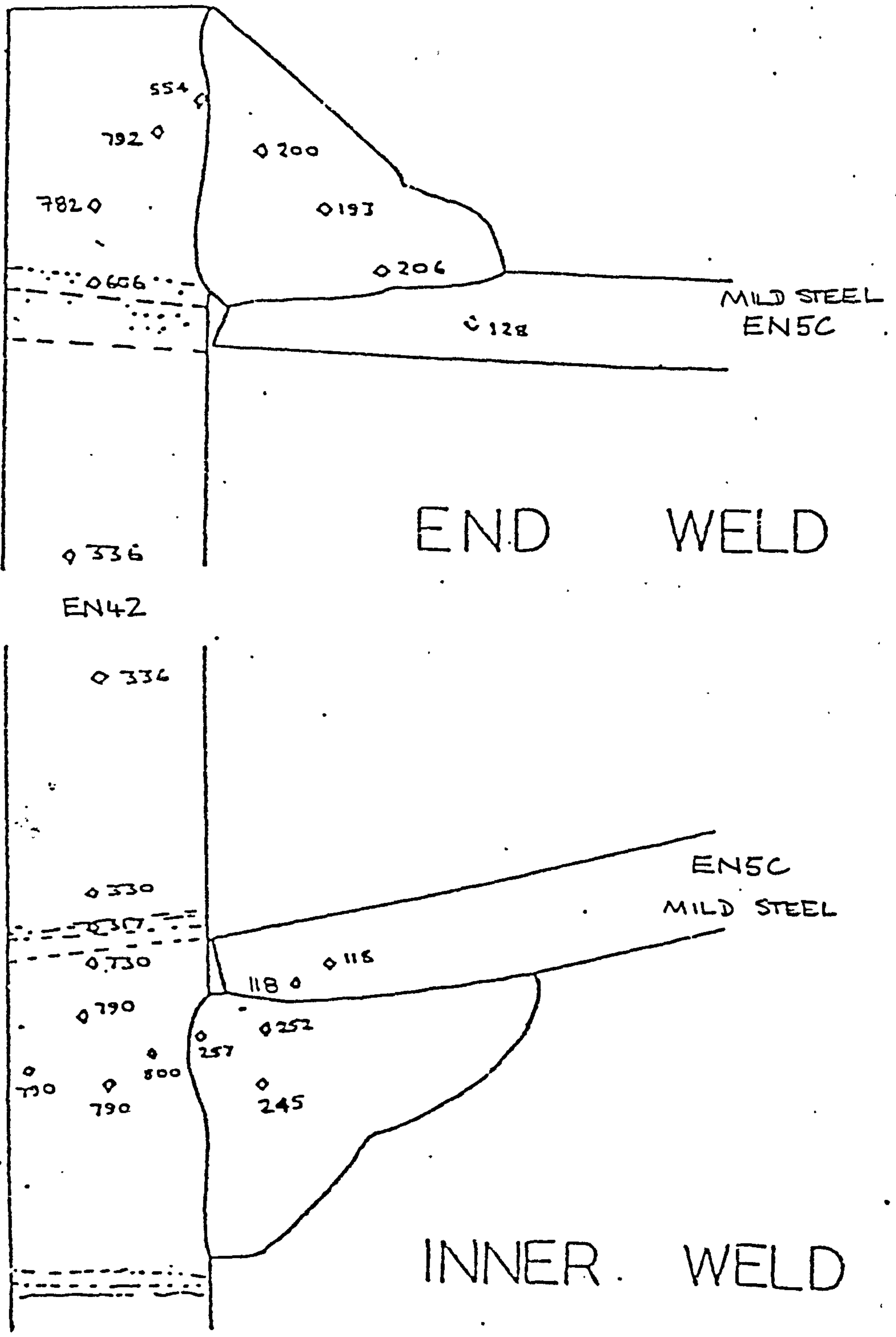
DIAG. 6.4 CYLINDER WELDS/1 TEST

◇ HARDNESS VPN

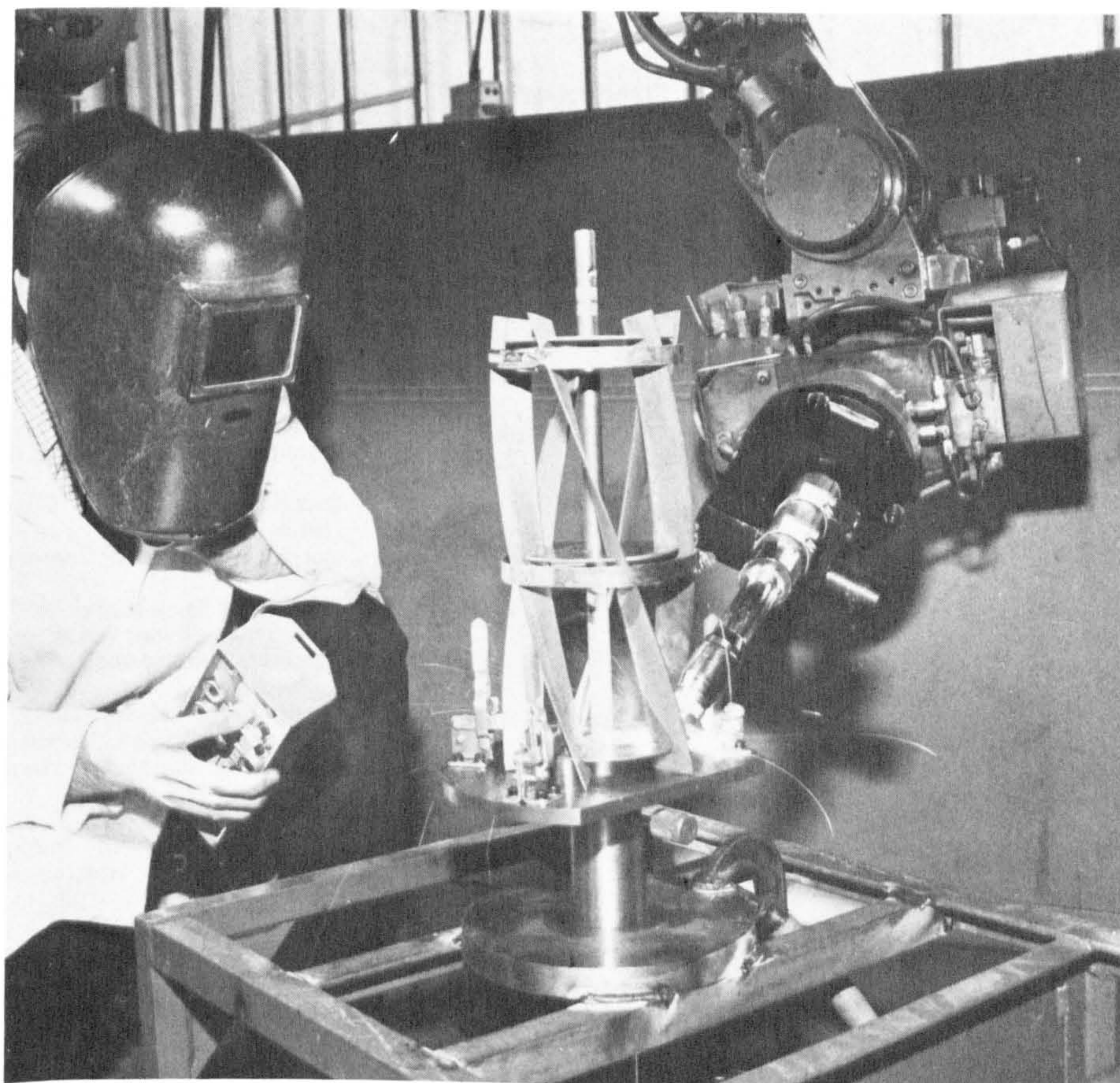


DIAG. 6.5 - CYLINDER WIRS/5 TEST

◇ HARDNESS VPN



DIAG. 6.6 CYLINDER GINGER/1 TEST



DIAG. 6.7 ROBOTIC WELDING AT LOUGHBOROUGH UNIVERSITY

C	:	0.07% - 0.12%
S	:	0.025% max
Si	:	0.70% - 1.00%
P	:	0.25% max
Mn	:	1.30% - 1.60%
Cu	:	0.40% max
YS	:	400 N/mm <sup>2</sup> min
UTS	:	510 - 570 N/mm <sup>2</sup>
Elongation	:	26% min
Impact Value	:	Charpy V-Notch at
		+ 20°C : 100 J min
		- 20°C : 70 J min
		- 30°C : 47 J min

## 6.2 HARDENING

The present process of flame hardening has been analytically compared to induction hardening to ascertain if a process change would facilitate automation. The major consideration with the automation of this process is the total exclusion of the operator from the machine and therefore the prohibition of the present manual visual inspection on every blade to ensure that blade cracking and distortion does not occur.

When a temperature gradient occurs in the blade, i.e. one part is hotter than the next, thermal expansion causes the hotter part to expand more creating a thermal stress. Similarly if one part of the blade grows relative to the adjacent part, due to a structural change (e.g. austenite, the high temperature phase in steel, transforming to martensite, the hard phase formed at low temperatures during quenching) a transformation stress is developed. Thus, the choice and method of quenching the chosen heat-input method is critical.

### 6.2.1 High Frequency Induction Hardening

The HF induction hardening process was examined and found acceptable in the degree and depth of hardness of blade tips obtained. A 60 kW generator is required with provision for circulation and cooling of the quench medium around the coil element. Thus, a free standing quench collection tank, filter, circulating pump, pressure valves and motor starter are required. X

The machine to harden cylinders up to 36 inches in length consists of a vertically traversing carriage powered by a D.C. driven lead screw with a fixed nut mounted to the carriage. The complete carriage is mounted within a dry section of the unit and traversed on twin guide bars. An extension of the carriage is carried through to the quench section with blinds to shroud the dry section. The carriage carries the component through the coil element and quenching ring. A machined base plate is mounted to the carriage extension to form the mounting face for the top and bottom centres for component location. The top centre is spring loaded and fixed. The lower centre can be adjusted along the base plate according to cylinder length. An air motor attached to the bottom centre provides variable rotation of the component.

The specification of this machine is included in table 6.3. In principle, the process is very similar to the existing flame hardening method. The heat-input is by the high frequency electromagnetic field of the coil electrode rather than by an oxygen-fuel gas mixture. The calculated cycle times for the process were:-

Load/unload	15 seconds
Dead traverse	10 seconds
Heat/dwell	5 seconds
Heat traverse	45 seconds
Quench dwell	5 seconds
	—
Total	80 seconds
	—

The process was rejected as the running and capital costs are higher than those of the flame hardening process. The induction hardening machine requires 105 units of electricity per hour to provide the energy to heat the cylinder blades. At 1982 prices of £0.04857 per Kilo Watt hour of electricity, this equates to an hourly energy cost of £5.09 compared to £2.08 for the equivalent gas costs per hour. Electrode coils compared to gas ring burners cost £931 versus £1031 each, respectively. At 1982 prices, the induction hardening machine costs £55,000 compared to £30,000 for the flame hardening machine. Additionally, soft spots appear in the

blades in the region of blade/spider welds where the mass of the spider material affects the magnetic field and prevents blade-tip hardening. Thus, induction hardening of cylinder blades is not acceptable technically or in terms of comparative cost.

### 6.2.2 Flame Hardening

The flame hardening process, having been accepted as the hardening method, had to be proven and developed to maintain a consistent crack-free hardened blade tip as automation excludes an operator from carrying out the 100 per cent visual inspection as is present practice. "Progressive-scan" (progressive heat and quench) is the hardening method employed where the cylinder blades are heated by the cylinder being passed axially through the burner ring, followed by the quench ring. It is necessary that the quench ring provides adequate flow to lower the blade temperature sufficiently to not only ensure complete transformation to martensite, but to also prevent self-tempering of the blade. In certain circumstances, the blades may not be cooled completely to room temperature. The severity of quench and rapidity of quench application can be varied by altering the distance between the flame burner and the point of quench impingement, as well as pressure, flow volume and temperature of the quenchant. These parameters are discussed by Novorsky (1981).

The rate of heat input can be controlled by the flame intensity, feed rate, burner-blade distance and oxygen-fuel gas mixture (methane) and flow/pressure in particular. Thus, the critical parameter to control is the quenching rate. The quenching mediums tested were water, oil and synthetic polymer quenchants.

Oil is the normal choice for materials requiring a very mild quench whether spray or immersion.

The following problems necessitate careful choice of quenchant medium:-



a) Soft Spots

Soft spots commonly occur when water has been used as the quenchant. These spots are usually self-tempered martensite caused by an interrupted or incomplete quench. The water may boil off the surface leaving a steam pocket that is not removed by further spraying. This usually occurs at actual quench impingement points and is more likely to occur with low hardenability steels. Poor quench ring or part design may impede the free exit of steam, also causing soft spots. With progressive hardening, an erratic or misdirected stream of quenchant will "pre-quench" a limited area leaving soft spots. Another form of soft spot can occur immediately below a collar although this does not occur with cylinder blades.

b) Quench Cracks

Cracks can arise from four major sources: the quenchant chosen is too severe for the application, resulting in an extremely rapid removal of heat from the quenched surface; non-uniformity of quenching can establish excessive residual stresses by varying rates of phase transformation; the cylinder blade being hardened may contain abrupt change in contour with insufficient transitional area; surface roughness, e.g. tool marks, can cause cracking or become stress raisers reducing the service life of the cylinder.

c) Part Distortion

This problem is commonly caused by the relief of prior stresses, uneven heating, non-uniform quenching, geometry and surface roughness. Cracks occur in the cylinder blades as distortion is impeded by their fabricated construction onto the rigid spiders/spindle assembly.

Crack free hardening cannot be reliably guaranteed with water quenching for all cylinder types. One cylinder in twenty has been found to be cracked in the longer cylinder range (24 inches to 34 inches). A 100 per cent oil quench is impracticable due to the fumes, cost, fire risk and difficulties in cooling and circulating the medium. Therefore, tests have been carried out using polymer quenchants (a synthetic medium). Polymer quenchants are organic chemicals of high molecular weight, known as polyalkylene glycols, which dissolve in water at room temperature

to form a true solution. As the solution is heated, the polymer becomes insoluble at temperatures above 77°C. When the solution is cooled again, the polymer goes back into solution and is fully miscible. This property is known as 'inverse solubility' and imparts a distinct cooling mechanism to polymer quenchant solutions. When a hot blade is quenched in such a solution, cooling occurs in the three distinct stages similar to the three stages in oil quenching.

Stage 1 When the blade is quenched, the solution in immediate contact with the metal is heated to above 77°C (the inverse solubility temperature). The polymer becomes insoluble in the water and a thin polymer layer deposits on the surface of the blade. This is a period of 'slow' cooling analogous to the vapour blanket stage in oil quenching.

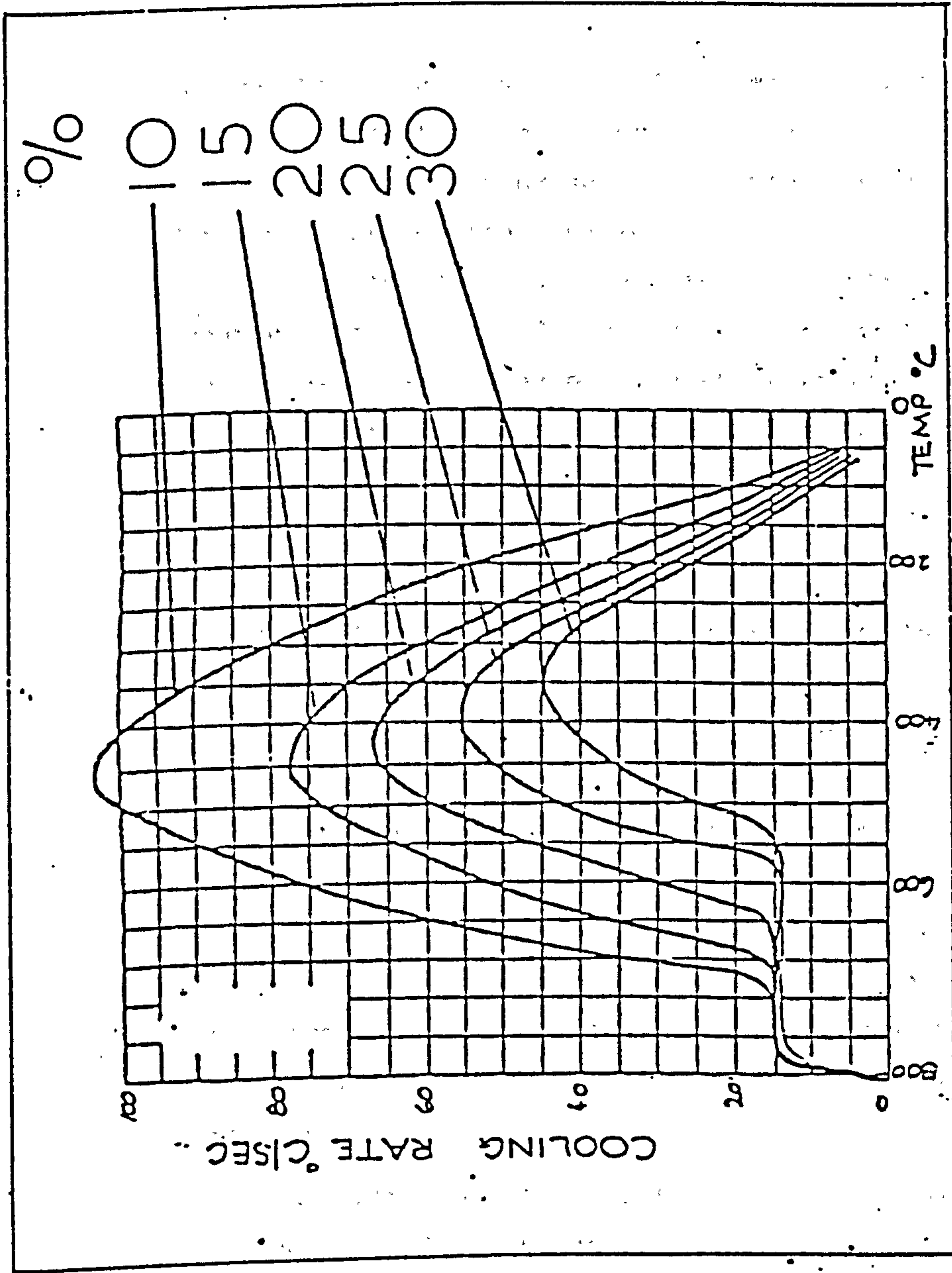
Stage 2 After a period of time, this layer becomes active and the cooling rate increases, equivalent to the boiling stage in oil quenching.

Stage 3 When local temperatures fall below the inversion temperature of the polymer, the layer re-dissolves and heat is taken away by the liquid phase (analogous to liquid cooling).

Polymer solutions are resistant to micro-organisms and behave neutrally to metals of different electrolytic potential. They contain corrosion inhibitors, do not leave residues on the blade material, are nitrite-free, are biodegradable and physiologically harmless.

The cooling rate of the polymer quenchant can be varied to suit individual requirements by changing the concentration of the solution. This influences the thickness of the polymer film which is deposited on the surface of the component during quenching and also the extent of the active period. The effects of the concentration upon the quenching speed is shown in diagram 6B, for two commercially available polymer quenchants. Solutions of 3 to 4 per cent improve the wettability of the quenchant on the blade surface and can replace brine or nitrate solutions by imparting a more uniform water quench, so preventing soft spots.

Solutions of 12 to 15 per cent achieve quenching rates better than those obtainable with fast quenching oils and are therefore suitable for low



DIAG. 6.8 THE EFFECTS OF POLYMER QUENCHANT CONCENTRATION  
ON QUENCHING SPEED

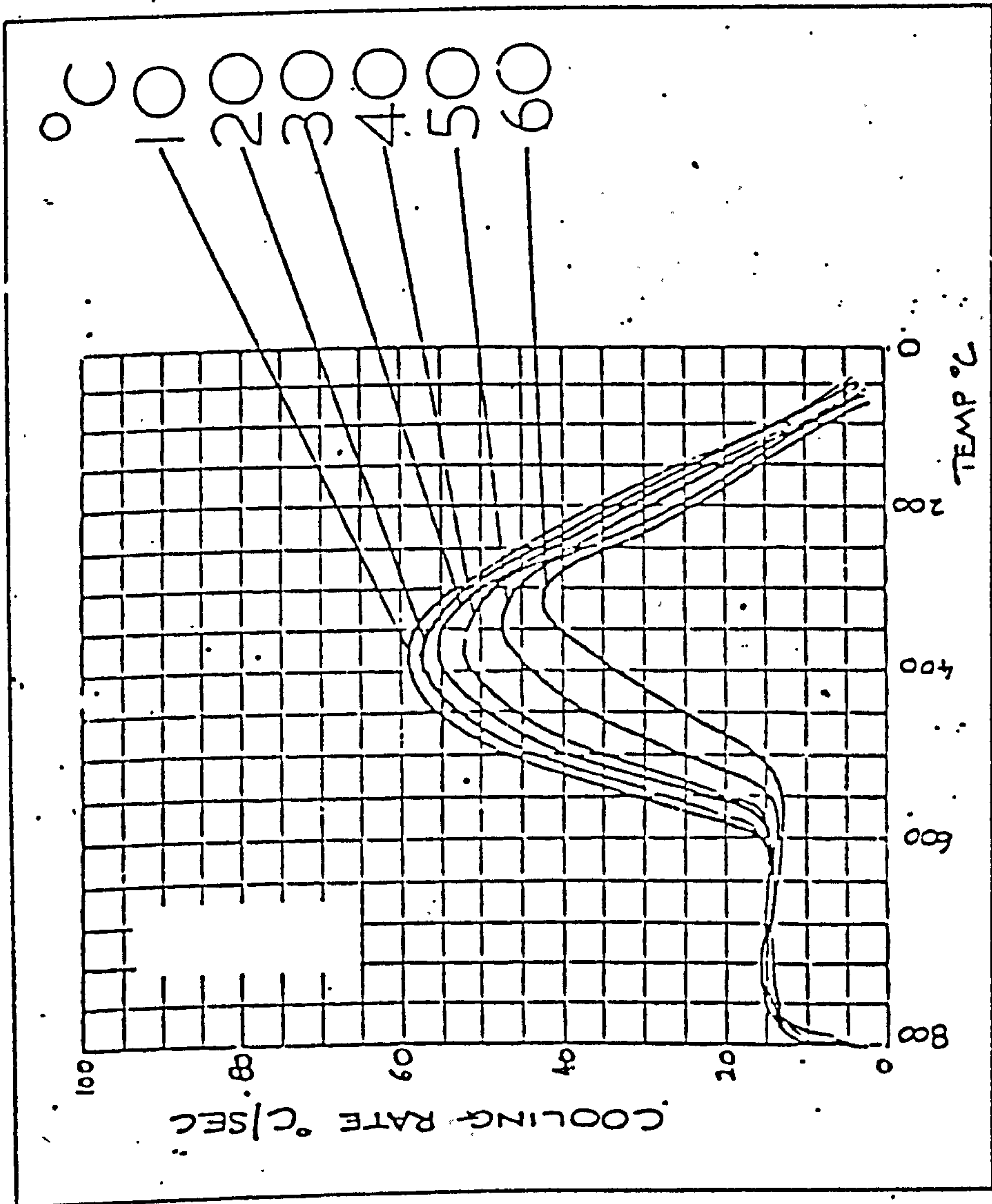
hardenability applications where maximum mechanical properties are required.

Solutions of 15 to 30 per cent provide cooling rates to suit a wide range of through hardening and case hardening steels.

The quenching speed is also influenced by the temperature of the solution. Recommended working temperatures are 35°C to 50°C (diagram 6.9). The flexibility of quenching speed obtainable by varying the concentration of the polymer solution enables the selection of the most appropriate cooling rate for specific blade sections, thereby developing the mechanical properties of the blades. Large amounts of water contamination can be tolerated before quenching speed is influenced significantly. This eliminates the soft spot, distortion and cracking problems associated with trace water contamination in mineral oils, and the cracking problems experienced with water quenching.

The results of extensive quenching tests carried out on an identical machine to be used for automation (see Section 7 for machine specification) are shown in diagram 6.10. For a hardness of 41 - 45 Rockwell C-Scale to a depth of 4 to 6 mm, a 35 per cent mixture of polymer quenchant with water was proven to be most suitable for crack-free hardened blades. Pure water or a three per cent mixture gave extremely high hardness values but with cracked blade surfaces. The addition of the quenchant decreased the speed of heat removal thereby retaining the hardness of material without cracks. The optimum oxygen fuel gas and quench pressures and flow were arrived at empirically. The final values for the hardening parameters are:

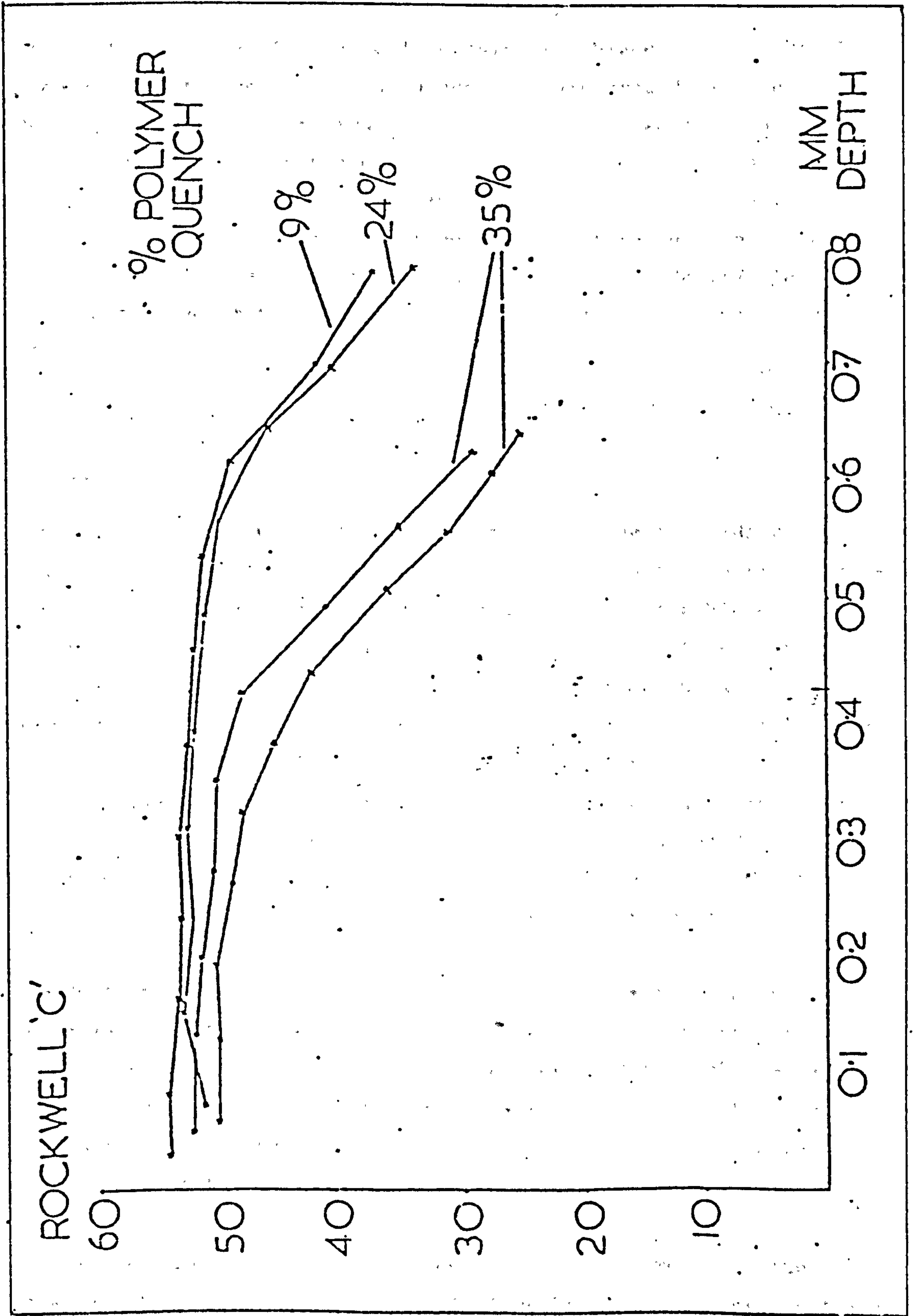
Temperature of heat input	840°C
Fuel gas flow (methane)	3 cu.m. per hour
Fuel gas pressure	0.58 bar
Oxygen flow	8 cu.m. per hour
Polymer quenchant	35 per cent
Feed rate	250 mm/min
Initial heating time	4 seconds
Final quenching time	15 seconds
Cycle time	177 seconds (34")



DIAG 6.9 THE EFFECTS OF POLYMER QUENCHANT TEMPERATURE

ON QUENCHING SPEED

DIAG. 6.10 HARDENING TEST RESULTS



The tests resulted in a blade-tip hardness in the range of 50.5 to 54.5 Rockwell C-Scale in order to achieve the required 40 to 45 Rockwell C-Scale hardness up to 6 mm within the blade. This is a desirable factor as at 55 Rockwell C-Scale, the blade tips are still not too brittle for use. As the blade tips are ground away, after hardening, the effective maximum hardness is 53 Rockwell C-Scale. The tests proved that the present tolerance of hardness set at 40 to 45 Rockwell C-Scale was too narrow and too low to be technically achievable on EN5C at the above parameters. Future development at SLM will bring the average hardness level down to the desired level by increasing the feed rate and thereby reducing the cycle time (a fringe benefit).

### 6.3 GRINDING

#### 6.3.1 Blade edge burr

The present grinding method using an 8 inch wide wheel builds up a hardened edge on the ground blade tip resulting in a thin burr approximately 2 to 3 mm wide remaining along the length of the blades on a cylinder. In the past this has been desirable as the thin sliver of metal is easily filed off by the grinding operator during a grinding cycle. If the burr were smaller but more strongly welded to the blade, then it would not be easily removed and therefore an undesirable by-product of the grinding process. For the purposes of automation, where no operator may be permitted into the production area, the cylinder must be ground without any burr whatsoever. To this objective the present grinding process had to be developed.

The production of the burr is a result of the intermittent grinding action created by the blades being pushed onto the eight inch wide grinding wheel. As the blade passes the wheel and the cylinder and blade relax from the cutting pressure, the metal torn from the blade builds up on the cutting edge. This is highly detrimental to the cutting action of the cylinder in the final mower assembly.

Either an increase in the cutting speed and/or an increase in the wheel width (to increase the length of blade being cut at any one time) is required to counteract the present inherent intermittency. A wider cutting wheel surface may also result in a perfect cylindrical

surface being ground without any rake angles being produced thus enabling the reversing of wheel rotation on the workholder so that, if there were to be a burr produced, it would not be on the cutting edge and therefore be inconsequential.

### 6.3.2 Increasing wheel speeds

Tests were carried out on machines with a constant grinding wheel peripheral speed of 60 metres per second (12,000 s.f.p.m.). The grinding options are:

- i) to grind with a narrow wheel (2-6 inches wide) and "stitch-grind" for as many plunges as required to cover the cylinder's length.
- ii) to grind with a narrow wheel (2-6 inches wide) and constantly traverse the cylinder before the wheel thereby "wiping" the cylinder to size.
- iii) to grind with as wide a wheel as possible at 60 metres per second to plunge grind as few times as possible.
- iv) to plunge with a wider wheel and "wipe" across the cylinder.

The machine used in the tests was an Erfurt/SMW Model SA 6 x 630 Heavy Duty Cylindrical Grinding Machine. At such a high wheel speed, extra safety guarding is legally required. The maximum width of wheel was limited to 6 inches. Thus, even on the smallest 12 inch long cylinder the 10 inch helix of spiral was not covered. Therefore, all tests were carried out under intermittent grinding conditions. The specification of the machine was:

Centre distance	3000 mm max.
Centre height over table	180 mm
Swing	355 mm
Max. weight of work	500 kg
Work table speed	5 m/min max
Work head r.p.m.	355 max
Grinding wheel bore	305 mm
Grinding wheel speed	60 m/s (12,000 sfpm)

On all four options it was found that a very hard 0.5 mm built-up edge on the cutting edge of the blades was unavoidably the result of high speed grinding. It was not possible to wipe this burr off with a file and therefore high speed narrow wheel grinding was considered as unacceptable for the automation of grinding.



### 6.3.3 Increasing wheel width

By increasing the wheel width of the grinding wheel the intermittent cut is eliminated on the second blade, due to its helix angle, and is being ground on the wheel prior to the blade before it has passed off the wheel. Therefore, with at least one blade continually on the wheel there is no relaxation of the cutting pressure which creates the intermittent cut. In order to achieve a wide cutting face there are two options:

- i) wide abrasive belt grinding
- ii) wide wheel grinding at 43 metres per second.

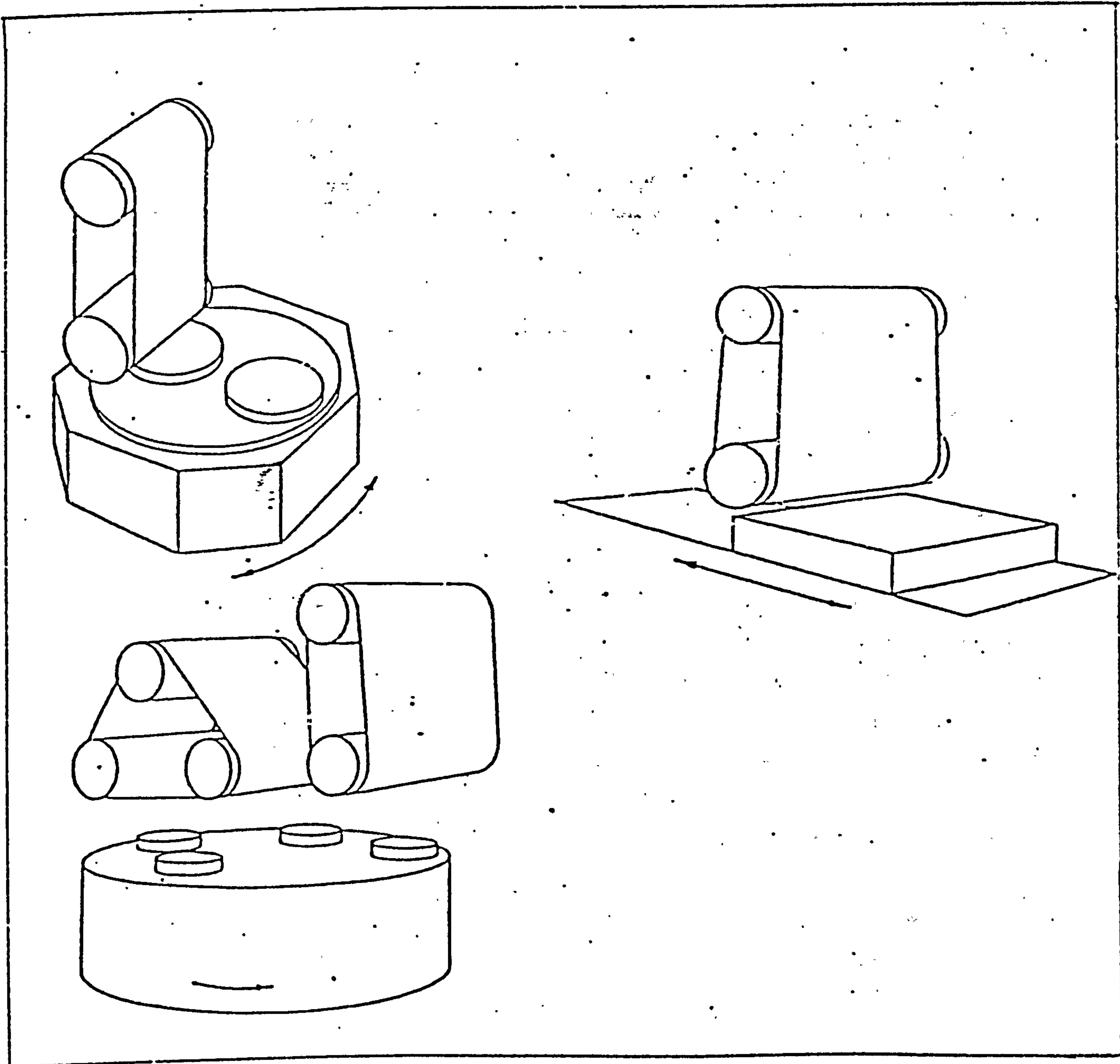
### 6.3.4 Belt grinding

Belt grinding enables high metal removal rates (up to 30 cu.in. per min.) with the benefits of fast changeover times at the end of a belt life and considerable increases in safety over a wheel should a belt break. The belt simply folds up into a containment chamber. Belt grinding enables the maintenance of low workpiece temperatures so that the surface hardness of the workpiece is not affected. The swarf is not reclaimable as it is contaminated with abrasive grit. Although higher powered motors are required to keep the belt (which does not have the inertia and momentum of a wheel) at the required speed, the total power consumption can be reduced if the cycle times are effectively reduced. Components can be ground in a wet or dry cutting environment.

A belt is a combination of backing, the bond that adheres the grains to the backing, the abrasive grains and the size coating or additional bond layer that seals the grain to the bond and provides the finish to the belt.

A typical belt grinding machine consists of an idler-tension roll (wheel) and a contact roll (wheel) on which to run the belt. Additionally, if the contact wheel is not driven a further drive roll (wheel) can be utilised. A fixture (often powered) is required to force the component being ground against the belt over the contact wheel or platen. Variations of configuring these units (diagram 6.11) enable flat surface grinding or cylindrical grinding operations to be carried out.

DIAG. 6.11 BELT - GRINDING MACHINE CONFIGURATIONS



Using various grit sizes, tests were carried out to establish the feasibility of belt grinding cylinders where the belt covered the whole length of the cylinder. Twelve and fourteen inch power and handmower cylinders were used. The 50 grit belt gave the average of the composite 40 and 60 mixed grit that is presently used in the 8 inch wide grinding wheels. The results are tabulated in table 6.4. The cylinders were mounted in standard 5 inch 3-jawed lathe chucks and consequently the poor results with the "out of round" and "taper" were to be expected. The present tolerances are:

Out of round	0.002 inches T.I.R.
Taper	0.0006 inches T.I.R.

Not one cylinder ground using a wide belt came within this tolerance specification. With the higher pressures required to obtain metal removal, flexing of the cylinder assembly creates an adverse cutting condition in which it is difficult to produce a truly cylindrical form.

The surface finish presently achieved using a grinding wheel is:

50 micro inches (CLA) minimum
60 micro inches (CLA) maximum

In order to achieve the stock removal rates desirable for automation in relation to acceptable belt lives, the minimum surface roughness that can be best achieved is 100 micro inches (CLA). The results ranged from 194 micro inches (CLA) to 277 micro inches (CLA). Such rough surfaces are unacceptable and will tear rather than cut grass. Also a fine burr was also produced on all test cylinders.

The solution to the surface finish problem is to grind the cylinders to size on a rough belt machine and to finish them on a second finer grit belt machine. This is technically feasible but doubles the number of machines and power consumption required, without grinding the cylinders without a burr.

The specification and design of the machine to belt grind cylinders was therefore rejected as, whilst fast cycle times were achievable, it was at the expense of the cylinders' design tolerances.

Test	Cylinder	Surface finish (CLA) inches	Out of round inches	Taper inches
1	12" Punch	260	0.019	0.025
2	12" Punch	254	0.024	0.025
3	12" Metric	194	0.007	0.018
4	12" Metric	218	0.026	0.018
5	14" Punch	277	0.003	0.010
6	14" Punch	273	0.005	0.010
7	14" Punch	-	0.025	0.100
8	14" Punch	-	0.051	0.004

Tests 1 - 6 = 5 50 grit @ 30 thou in 18 seconds

7 = 80 grit @ 70 thou in 30 seconds

8 = 40/60 grit @ 70 thou in 30 seconds

Table 6.4 Belt Grinding Test Results

Test	Method	Result
1	80 thou. for 20 seconds with dwell	Very small burr
2	60 thou. for 10 seconds, 20 thou. for 10 seconds	Very small burr
3	80 thou. for 10 seconds, 10 thou. for 10 seconds	Burrless
4	80 thou. for 10 seconds, 10 thou. for 10 seconds with dwell	Slightly larger burrs
5	70 thou. for 1 second, then 10 thou. for 10 seconds, 20 thou. for 10 seconds.	Small burrs
6	70 thou. for 15 seconds, 15 thou. for 20 seconds	Very small burr

Table 6.5 Wide face wheel Test Results

### 6.3.5 Wide wheel grinding

A Keighly/Newall universal cylindrical grinder type KG300 with a 26 inch diameter, 14.5 inch wide face, grinding wheel was used in a series of tests to establish the feasibility of grinding the cylinders free from burr on a wide face stone wheel. The specification of the machine is:

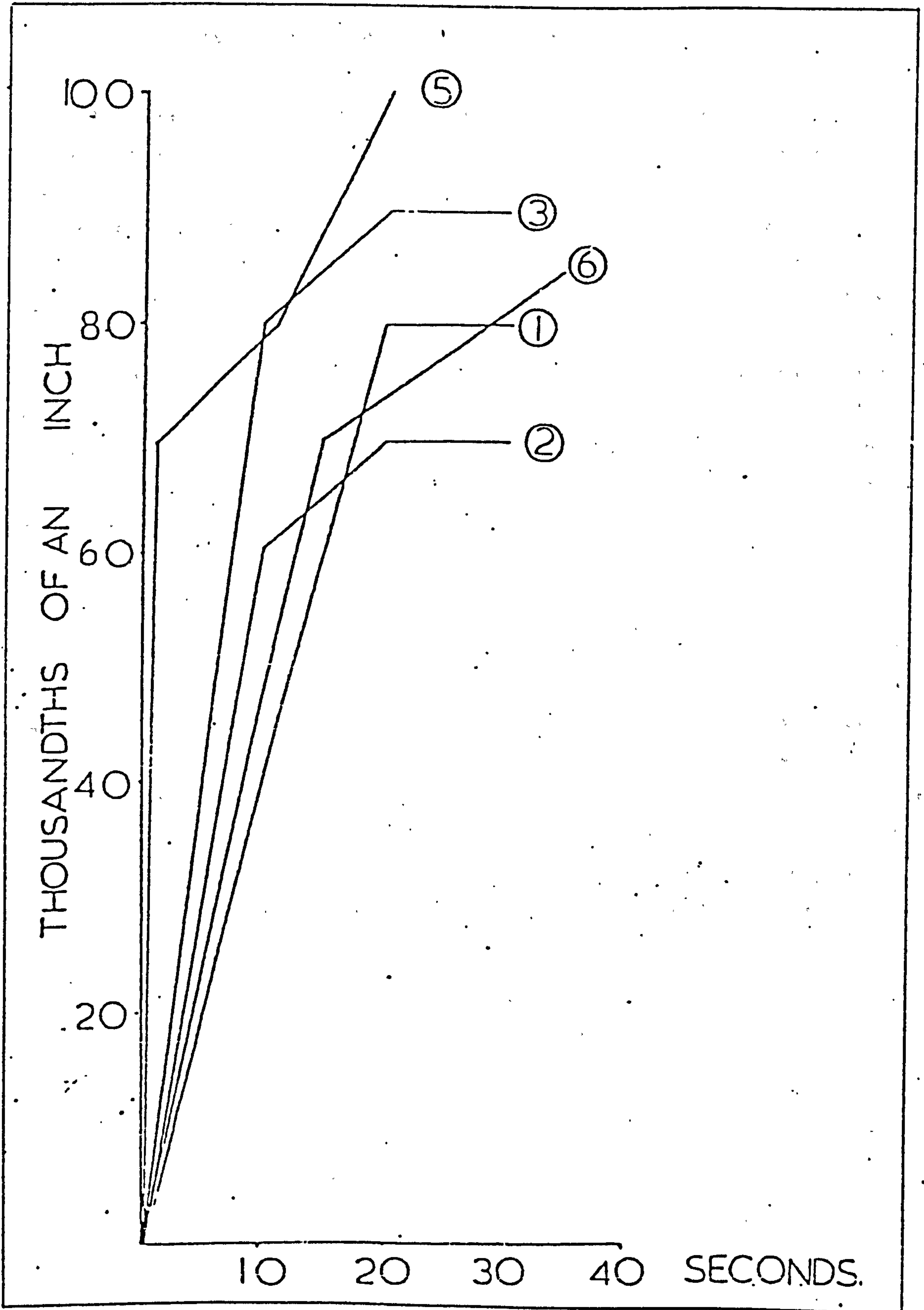
Maximum diameter ground	400 mm
Capacity between centres	1000 mm max.
Maximum wheel diameter	750 mm
Height of centres	216 mm max.
Wheel speed	43 metres per second
Wheel head motor	25 h.p.
Work head motor	2 h.p.
Electrical supply	415V $\pm$ 6% 3 ph. 50 Hz.
Coolant	"Drumas" - B Soluble oil.

The feed rates of the wheel in-feed and the dwell periods at the end of the in-feed were varied to obtain the optimum cutting conditions. It was found that an initial feed of 60 to 70 thousandths of an inch for 10 to 20 seconds immediately followed by a shallower feed of 10 to 20 thousandths of an inch in 10 to 20 seconds produced the best results. Any dwell at the end of the cycle adversely affected the finish of the blade by building a small very hard burr. The most favourable cutting condition was:

<u>Cycle</u>	<u>Feed rate</u>	<u>Duration</u>	<u>Feed</u>
1	0.008 inch/second	10 seconds	0.080 inches
2	0.001 inch/second	10 seconds	0.010 inches

With no dwell between the feed rate change and the end of cycle 2 when the wheel retracts, the cylinders ground were found to have no burr on the blade edges. The surface finish and dimensional tolerances were within the SLM specification. The results are shown in diagram 6.12 and table 6.5. Total cycle times (for these results) are 20 to 30 seconds machining time.

Commercially available machines with the capability for this grinding operation are the Keighly LA12, the Newall Mac and Newall SA grinding machines.



DIAG. 6.12 GRINDING TEST IN - FEEDS

## SECTION 7

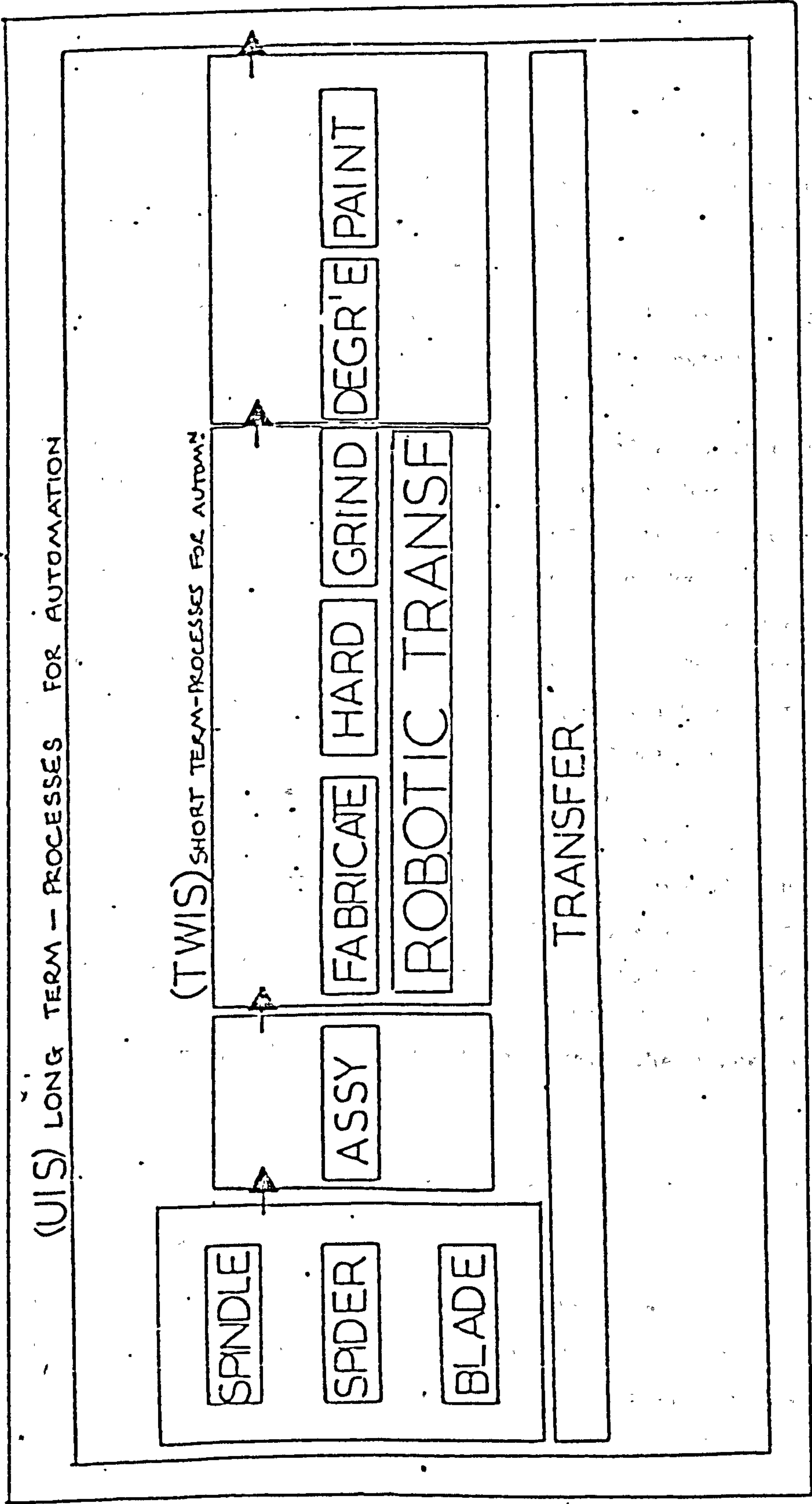
### FMS DESIGN FOR CYLINDER AUTOMATION

The Flexible Manufacturing System developed for cylinder production is designed following a stepwise implementation criteria. To automate all cylinders in one step is not practicably feasible. Nadler (1967, 1970) has devised a systems design concept which facilitates the required stepwise implementation. The design of an "ultimate ideal" system provides the objective for future automation, from which one may develop a "technological workable ideal" system. This practicable level of system design could technologically be implemented should there be no time or cost constraints. Nadler recognises the financial, marketing and managerial constraints and proposes that the "recommended" system, whilst not limited by these constraints, should include as much of the "technological workable ideal" system as possible. Nadler's work systems design concept is used for the development of the FMS at SLM.

#### 7.1 STEPWISE SYSTEM IMPLEMENTATION

The feasible "ultimate ideal" system boundaries are established as the (long term) potential automation of production for all cylinder types for all their processes from component production, assembly, fabrication, machining and painting (diagram 7.1). This defines the long range objectives which can not be practicably installed in one step as several technological developments require design and proving. The technology required is not available "off-the-shelf". This ultimate system provides the plans and guidelines for the future of cylinder production. The major sub-systems requiring further development are:

- i) automation of component manufacturing processes including
  - a) spindle production (turning, drilling, broaching, grinding)
  - b) spider production (press work)
  - c) blade production (roll forming, cropping, twisting)
- ii) integration of processes above to form automatic production cells to manufacture spindles, blades and spiders
- iii) integration of above production cells with cylinder assembly and machining production cells
- iv) automation of assembly of components
- v) integration of the finishing processes (degreasing and painting) to create a totally automated cylinder manufacturing system.



DIAG. 7.1 LONGTERM AUTOMATION OBJECTIVES (ULTIMATE IDEAL SYSTEM)



Practical restrictions such as man-power availability, research facilities, money and time, necessitate concentration upon the design and development of the final stages of cylinder manufacture. A step down from the "ultimate ideal" system is Nadler's "technologically workable ideal" system which more easily utilises available knowledge, equipment and components. Such a system, shown in diagram 7.2, would automate the fabrication, hardening and grinding for all the cylinder designs. The concepts of FMS, the application of robotic welding and transfer and the micro-control of machine tools technologically enable the automation of this manufacturing system. Financial, market, human and managerial limitations impose lesser constraints on this level of system so that it becomes the very important guide with which to develop the "recommended" system, with the near-future objective of subsequently achieving the "technologically workable" system.

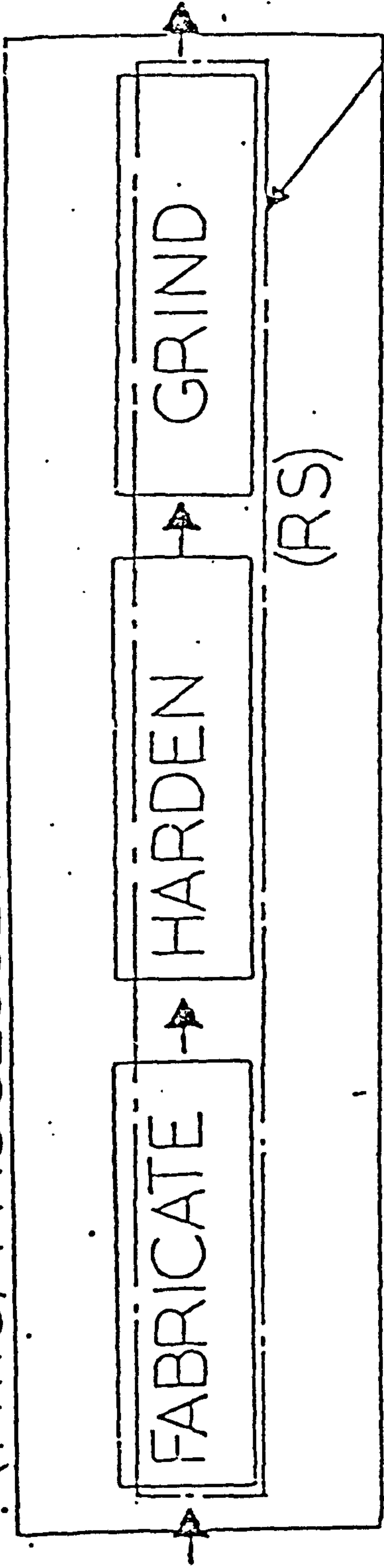
This concept of incrementing the introduction of automated systems enables the long-term automated system to be conceived in phases. The first phase to practicably automate the cylinder production system concentrates upon the eight major cylinder designs for the welding, hardening and grinding processes. This will establish the basic FMS for automated cylinder production (Phase I - the "recommended" system). Duplicating the welding, grinding and hardening capacities of this system achieves the "technological workable ideal" system's objectives for the automation of the same processes for all 21 cylinder types (Phase II). This second phase can be duplicated (diagram 7.3) should the capacity of the system require enlarging. Phase I constitutes a complementary FMS (Section 2). Phase II expands this to an interchangeable FMS. Expansion of the system, were it technologically possible, to the level of the "ultimate ideal" system would also be in two subsequent construction phases. Phase III would integrate the degreasing and painting processes and Phase IV would integrate the blade forming processes and assembly.

#### 7.1.1 Total Cylinder Production Automation - the "Ultimate Ideal" System

##### (i) Cell modules

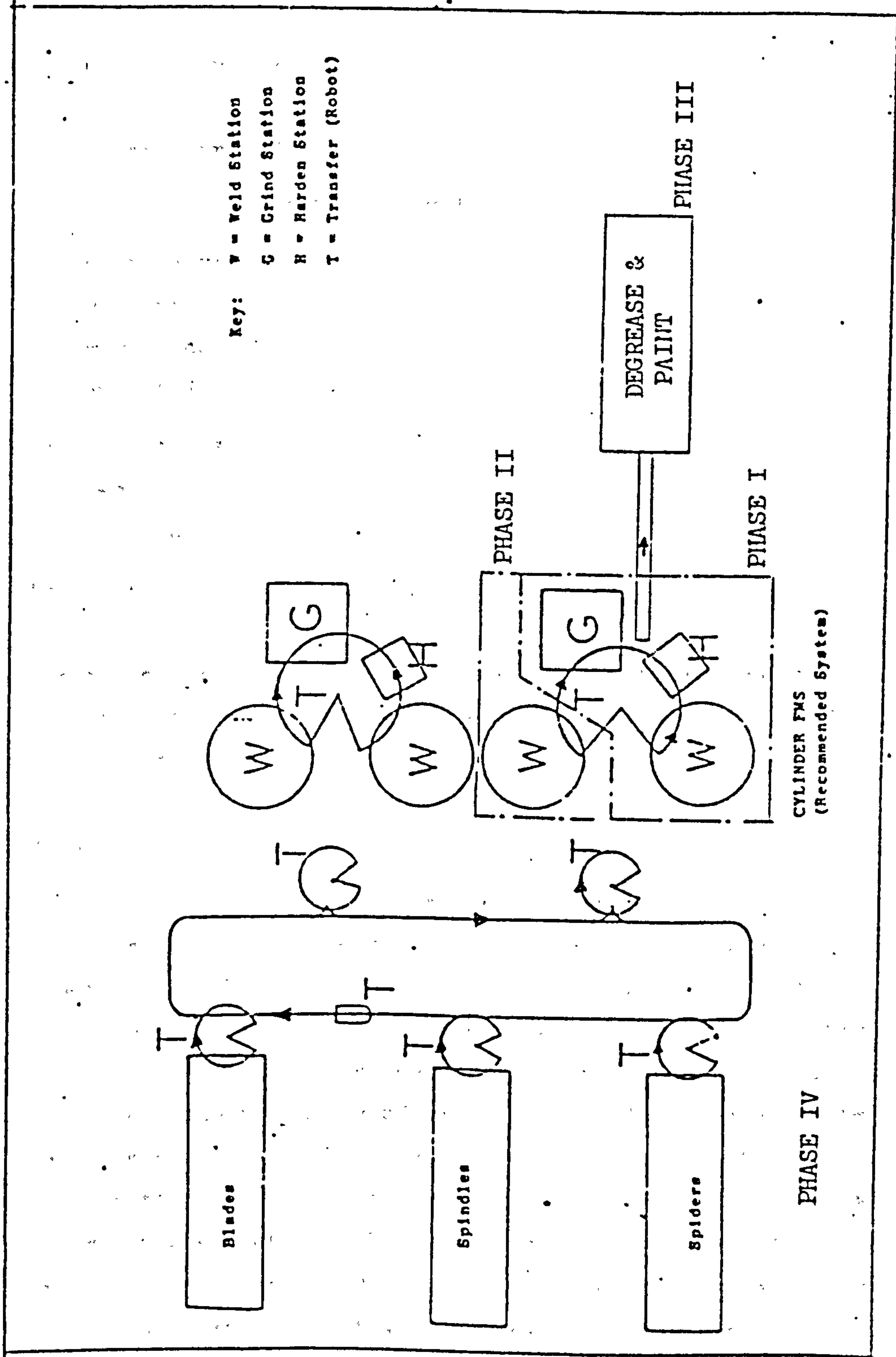
Diagram 7.3 illustrates one system configuration for total automation. It is configured around a materials handling method between processes utilising robotic carts (automated wire guided vehicles). This enables total future flexibility for handling of unit loads between the various production cells depending upon the relevant cylinder routings. The cellular modules that construct the system are:

(TWIS) PROCESSES FOR AUTOMATION



RECOMMENDED  
SYSTEM (66%  
OF TWIS THRO'PUT  
CAPABILITY)

DIAG. 7.2 SHORT TERM AUTOMATION OBJECTIVES (TECHNOLOGICAL WORKABLE  
IDEAL SYSTEM)



DIAG. 7.3 PHASES OF FMS IMPLEMENTATION

- i) Blade forming
  - a) raw material (blades) store
  - b) rolling machine
  - c) cropping press
  - d) twisting rolls
  - e) robotic transfer
- ii) Manual and/or automatic assembly
- iii) Cylinder fabrication-machining
  - a) welding
  - b) hardening
  - c) grinding
- iv) Cylinder finishing
  - a) degrease
  - b) painting
- v) Transfer

The number and magnitude of individual cells for future construction will depend upon future production requirements. This system provides the ideal objectives to aim for.

(ii) Transfer

A feasible transfer vehicle route between cells (diagram 7.3) would be determined by a wire loop laid into a groove 10 mm wide cut into the floor. The channel is then filled in flush with the floor surface. A frequency generator supplies current to the loop creating a magnetic field which is sensed by the robot cart. When a vehicle is correctly on course, the intensity of the magnetic field sensed by two coils will be the same. If a difference at corners is detected a suitable signal is sent to the steering motor which will turn the cart to maintain the desired travel route. With complex systems like the FMS, with several branches, loops and spurs, several frequencies can be generated in each section such that a cart will follow the correct routing giving flexible material flow within the system. The car can drive in four directions (forward, reverse and 90 degrees to either side) and is fitted with additional guidance detectors. It can be programmed to stop adjacent to a machining station requiring a delivery of components. All four wheels (in diamond configuration) can turn through 90 degrees, as guidance is programmed, to transfer to a short guide path section at right angles to the main gangway. The machine would then move at

slow speed to a cell loading position. The machine would be fitted with a short chain conveyor on the loading platform to transfer unit loads. Special pallets of 1000 mm x 1000 mm to carry a weight of 600 kg are required. The cart would have its own 'on-board' micro-processor and a full set of system programmes for automatic collection and discharge of loads on to cantilevered supports.

The system parameters are:

- i) 30 pallets maximum in the system
- ii) 80 to 160 minutes per pallet transfer cycle time
- iii) 40-50 components per pallet
- iv) four process routings
- v) one transfer cart (robotic) in the system

The transfer system is interfaceable with other systems being automated in the factory. Such a transfer system would cost £80,000.

#### (iii) Component automation

The cells to form blade components require a major commitment of resources to develop process automation. Robotic transfer is required between raw material, roll, crop and twist operations. These operations require NC/programmable capabilities for flexible operation. The concept to automate assembly of components is feasible. Manually assembling components must be the practicable compromise until this technologically difficult operation is developed. Assembly onto special fixtures for cylinder welding is required. These will circulate between the assembly and welding stations.

#### (iv) Finishing

To degrease the cylinders prior to painting, a 3-stage industrial wash plant is required comprising of wash, rinse and blow-off sections. Vestibule sections are needed at the entrance and discharge ends of each compartment and spray retaining curtains to prevent overspray. Components are carried through the machine on a conveyor, the speed of which is variable to meet varying production rates. Shed plates are fitted beneath the conveyor to direct used wash liquid through a mesh filter on the wash stage back to the tank on the rinse stage. On leaving the rinse stage, components would pass through a heated blow-off section to remove excess moisture. The wash and rinse tanks are both heated by natural gas burner units. This type of plant ensures the degreasing process is interfaceable into the system as it is continuous in nature.

The specification of plant required is:

Length	8000 mm
Width	1500 mm
Height	2450 mm
Conveyor load height	1000 mm
Conveyor width	450 mm
Wash tunnel height	450 mm
Wash tank capacity	300 gallons
Rinse tank capacity	300 gallons
Washing media	Aqueous alkali
Working temperature	70-80 degrees C
Electrical supply	440V/3ph/50Hz

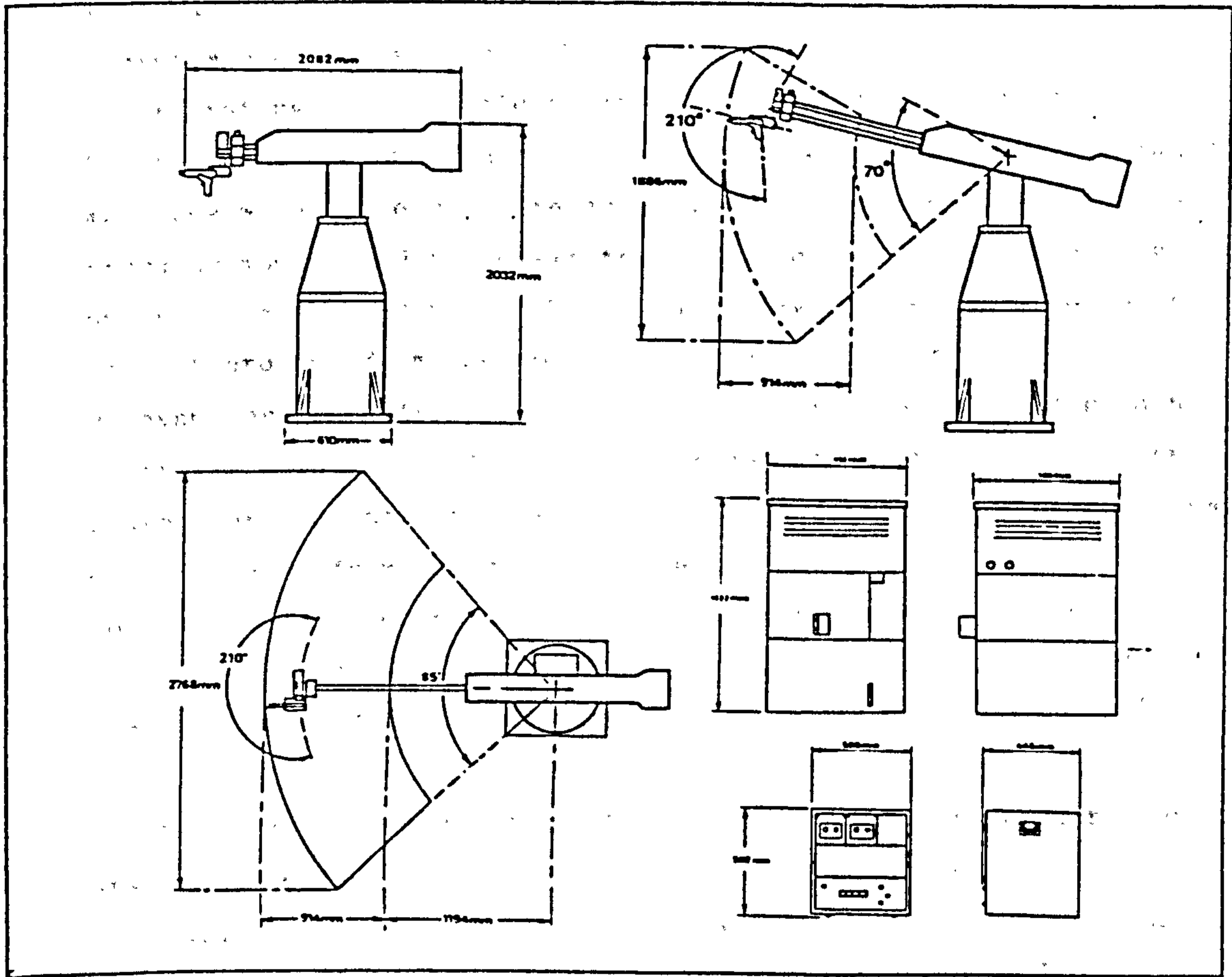
This continuous process can be integrated on the same conveyor transfer mechanism to the painting process. To maintain flexibility a programmable spray paint manipulator (robot) is required. For high paint economy, with medium to high outputs of complex workpieces such as cylinders, a spray painting robot is required. Within the continuous conveyor spray booth, the robot may coat-all-over or touch-in the cylinder. Automatic component sensing, colour changing and component size and shape sensing is required. A robot (shown in diagram 7.4) for the following system specification is suitable:

Paint medium	Air assisted electrostatic or wet paint		
Reciprocator	Ramp 4088 Electronic Robot		
Material control equipment	Paint/solvent valve		
Generator	90kV		
Spray booth type	No pump waterwash		
Air flow (inlet)	9400 cfm		
Air flow (extract)	9900 cfm		
Spray booth dimensions	Height	Width	Depth
internal	13	12	15
external	14	13	17

The coating of the cylinders may be more readily accomplished by their rotation throughout the spray cycle.

(v) Control

The control of the system can be developed to full DNC capability. Programmable machine control units can hierarchically interface to



DIAG. 7.4 PAIN T SPRAYING ROBOT

module master control units which in turn are interfaced to the system control unit. This hierarchical structure enables modular expansion of the system.

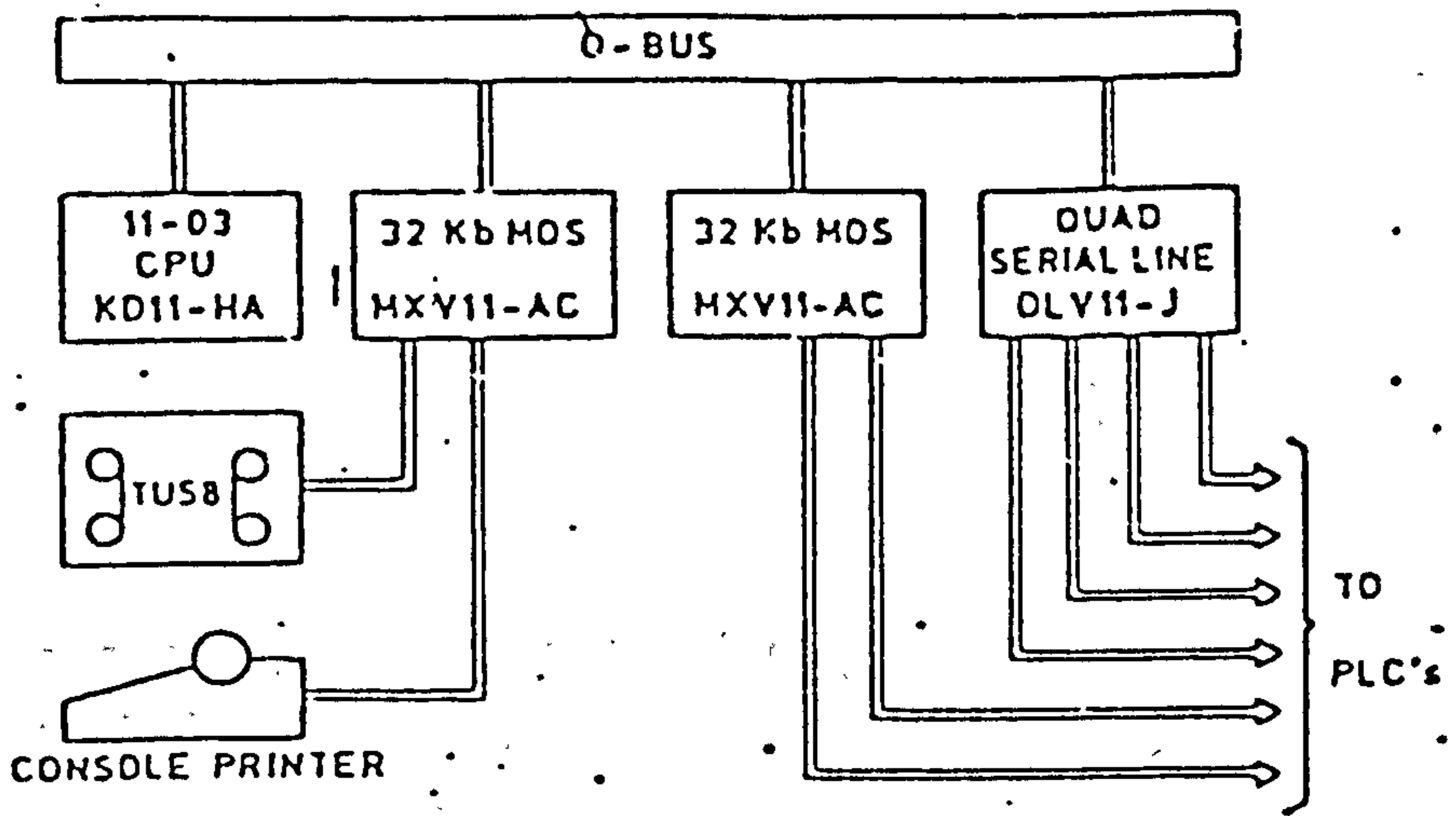
Two control system configurations are economically feasible. The first option covers a multistage implementation of the control system (diagram 7.5). Initially one cell would be controlled by a single microcomputer controller. The diagram illustrates a microcontroller incorporating a 16 bit microcomputer (e.g. PDP 11/03 supplied by Digital Equipment Company). All programmes necessary for running the machines within the cell are held on tape cassette (TU58). The operator would load the cassette into the tape unit (TU58) for the system to be booted up. The operator may then select the desired product program from the console. The controller will select the relevant programs from the cassette and downline-load the machine controllers in the cell. Any alarm conditions may be logged on the console printer and/or stored on a second cassette. For the expansion of the system from one cell to several cells, this whole control module can be repeated with each cell being totally independent of all the other cells. Should any fault occur in this configuration, it is strictly limited to the affected cell.

In the event of several cells being in use with a management reporting system, then each cell controller could be connected to a PDP 11/24 type minicomputer or similar unibus machine. All software would be held on discs interfaced to the minicomputer. The cell controllers then act as data concentrators and permit emergency operation of the cells in the event of the minicomputer malfunctioning.

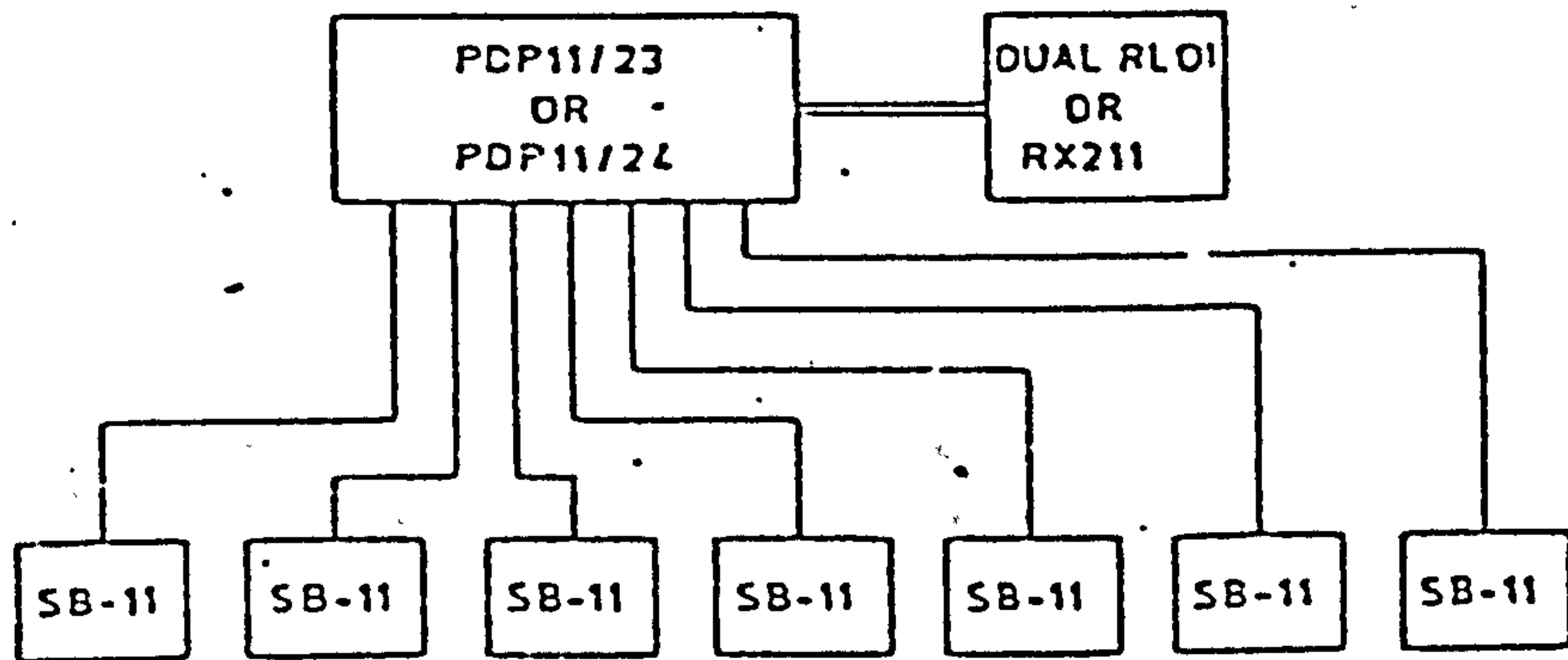
The second control option utilises a minicomputer to directly control the machine tool cells. This centralises control rather than decentralises control as in option one. The system, illustrated in diagram 7.6, allows for the introduction of additional manufacturing cells at a later date and is sufficiently powerful to include additional management reporting/data processing should this be required.

The proposed software facilities are as follows:





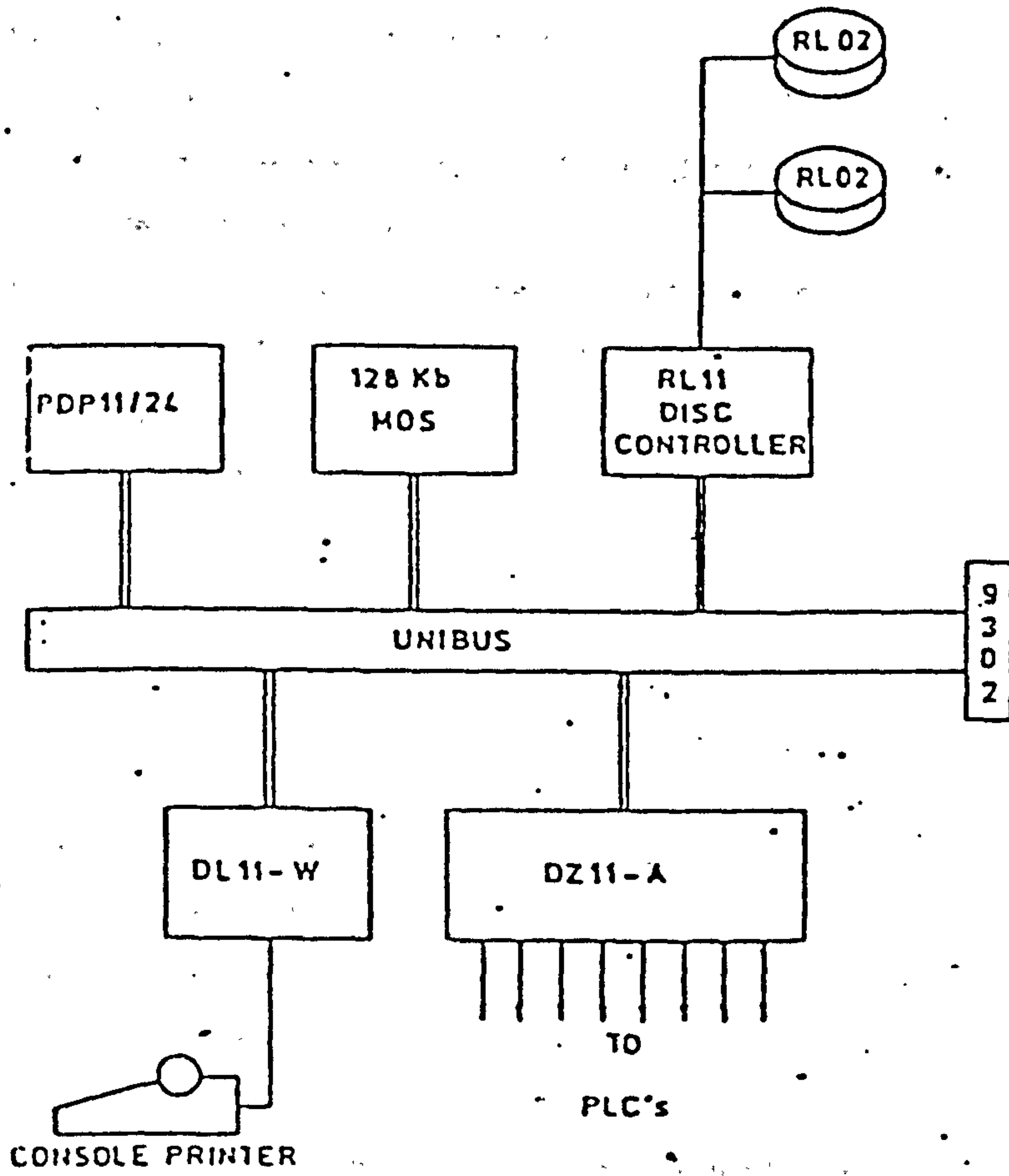
INITIAL SYSTEM  
BASED UPON SINGLE CELL



ULTIMATE SYSTEM  
EXPANDABLE UP TO AT LEAST 32 CELLS

OPTION 1

DIAG. 7.5 DNC CONFIGURATION



OPTION 2

DIAG. 7.6 DNC CONFIGURATION

- a) having switched the machine on the central processor instructs the operating system to request the date and time before a program menu can be loaded
- b) level 1 of the menu would offer the operator a choice of (say) 10 different cylinders
- c) level 2 of the menu system would be invoked on product selection (entry of 1-10) and would offer the operator the choice of (say) 3 cells, viz:
  - 1. cell 1 - welder
  - 2 cell 1 - hardener
  - 3 cell 1 - grinder
  - 4 cell 1 - robot
  - ,
  - ,
  - ,
  - 9 cell 3 - welder
  - 10 cell 3 - hardener
  - 11 cell 3 - grinder
  - 12 cell 3 - robot

Selection from level 2 will activate a small programme name (relevant to i) a cylinder name and ii) a machine within the cell) to the main transmission programme, which on loading, selects the relevant program and transmits the contents to the relevant machine controller (a PLC). The PLC can be monitored for its reaction to each instruction being transmitted, thereby detecting and reporting faulty transmissions. A program to monitor and store the entry of raw material or amended PLC programs will be required. This would be loaded at the start of the day and brought into action by an interrupt from the programming terminal of the PLC.

With this option, a large part of the system's control is lost, thereby shutting down the system, should the minicomputer controller go down. Therefore, the option 1 approach is to be selected.

#### 7.1.2 Cylinder Machining Automation - the "Technologically Workable Ideal" System

The "technologically workable ideal" system can be constructed in two phases, each with the capability to fabricate, harden and grind cylinders. A transfer system using carts is integrated around the system for optimum transfer of cylinders to and from the system. Alternative layouts are feasible.

However, either they

- a) do not integrate the transfer system so easily, or
- b) do not expand modularly enough to warrant construction, or
- c) their construction involves more costly hardware and software, (diagram 7.7).

The feasible system is a production unit of four or five process machines configured around a transfer robot to form a rotational production FMS.

The advantages of this approach are that having proceeded most of the way along the system's implementation learning-curve, extending the capacity of the system necessitates duplication of the system design only (diagram 7.3).

To obtain this level of system design, all alternatives of transfer and machine tool control must be considered in order to implement the most suitable hardware and software. The choice of robots and control will enforce constraints upon the design of the FMS.

### 7.1.3 Robot and Control Capabilities

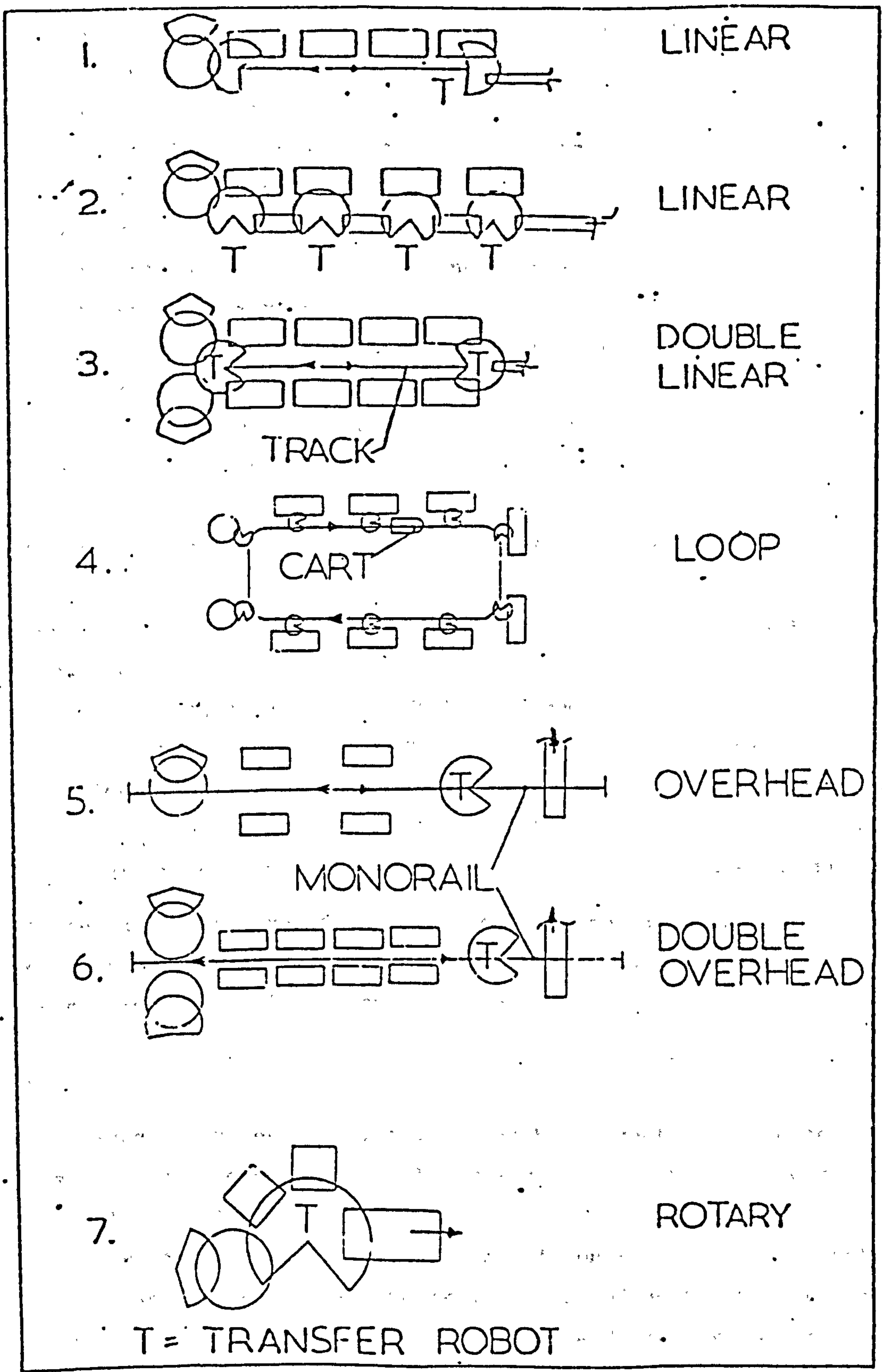
#### (i) Robotic Welding and Transfer

The requirements of a robot for the control of a workstation, be it for the welding or transfer, are:

- a) five or six axes of manipulation
- b) fast teachability
- c) local and library memory
- d) random program selection by external stimuli
- e) accurate positioning repeatability
- f) high reliability
- g) compatible computer interfaces

To achieve the flexibility required for the "technologically workable ideal" system, these parameters preclude many of the commercially available robots such as pick and place units.

A technically suitable short list of robots can be assembled for the two robotic requirements required in the FMS. The polar configuration (tank-turret) of manipulator is ideally suitable for the transfer function within the cell. Both polar or "arms and elbow" configurations or robotic manipulator are suitable for the welding function. A



DIAG. 7.7 ALTERNATIVE LAYOUTS

technically suitable shortlist is shown in table 7.1. The robots shown are chosen from the total population with regard to their

- a) velocity and acceleration
- b) load handling capacity
- c) static and dynamic stiffness of structure
- d) working space
- e) reliability
- f) ease of operation including programming
- g) ease of maintenance
- h) ease of fault detection and diagnostic capabilities
- i) resistance to heat and chemicals
- j) operational life span
- k) safety features

The following considerations are also taken into account:

<u>Function</u>	<u>Arc welding</u>	<u>Transfer</u>
Parameter		
1. Positioning accuracy	± 0.2 - 1.0 mm	± 0.2 - 1.0 mm
2. Velocity variation	STEPLESS	single or multistep
3. Velocity	up to 1000 mm/s	High > 1000 mm/s
4. Form of motion	defined path	point to point
5. Programme sequence	continuous	discontinuous

These parameters provide a selection of acceptable robot choices for which the important criterion of cost is the only remaining factor upon which the choice of robot is made.

### Control

As discussed in Section 4, the hierarchical control is to be decentralised. The choice of control hardware and software is determined by the following factors:

- a) Physical structure - the size of controller units, construction, basic essential sub-units and range of additional sub-units.
- b) Functional structure - functions performed by controllers comprising basic essential sub-units only and functional extension achieved by use of additional optional sub-units.
- c) Unit capabilities - type and scope of capabilities of the unit itself for plant interfacing, sequence control, loop control, alarm monitoring, data logging, supervisory control, operator

	Asea Irb6	Cincinnati T3	GKN Lincman	Hall Merlin	Hitachi	Unimation Puma	Hall Little Giant	Unimation 2000/2001
Load Capacity	6 kg	45 kg	10 kg	14 kg	10 kg	5 kg	30 kg	70 kg
Position acc.	± 0.2 mm	± 1.27 mm	± 0.3 mm	± 1.0 mm	± 0.2 mm	± 0.1 mm	± 1 mm	± 1.25 mm
Configuration	arm/elbow	arm/elbow	arm/elbow	polar	arm/elbow	arm/elbow	polar	polar
Axes	5 or 6	6	5	5	5	5 or 6	4	2 - 6
Type of control*	PTP/CP	CP	PTP/CP	CP	CP	PTP/CP	PTP	PTP/CP
Drive	electric	electro/hyd.	electric	electro/hyd.	electric	electric	electro/hyd.	electro/hyd
Power	2kVA	22kVA	4kVA	5kVA	3kVA	2kVA	5kVA	11kVA
Memory	semiconductor	semiconductor	wire	semiconductor	core	semiconductor	core	wire
Measuring system	resolver	resolver	encoder	potentiometer	encoder	encoder	potentiometer	encoder
External functions	16 in/14 out	52 in/44 out	16 in/15 out	12 in/12 out	13 in/15 out	8 in/8 out	12 in/12 out	12 in/12 out
PROCESS	WELDING				HANDLING			

\* PTP = Point to Point/CP = Continuous path

Table 7.1 Alternative Robots for the FMS (cylinder automation)

- interfacing, and any other monitoring and control tasks.
- d) System capabilities - type and scope of capabilities with other system units.
  - e) Analogue signal interfaces - type and scope of standard and non-standard analogue interfaces provided with identification of the optional sub-units and statement of any capacity restrictions.
  - f) Other signal interfaces - type and scope of interfaces for status signals (switches, relays, etc.) for pulse trains (counters, frequency, etc.) with statements of any capacity restrictions.
  - g) Digital data interfaces - type and scope of standard and non-standard parallel or serial data links with statement of any capacity restrictions.
  - h) Communications - scope of standard and non-standard serial communications capabilities (including scope of the protocol used).
  - i) Operator facilities - physical form, functional operation and ergonomics of operator displays and controls.
  - j) Configuration and programming facilities - scope for unit configuration and programming in terms of the range of monitoring and control schemes that can be implemented, method of programming including the physical devices used and the languages used, programming aids including the facilities for program preparation, checking and correction.
  - k) Performance - capacity in terms of size of monitoring and control scheme that can be implemented, efficiency of software, hardware utilisation, speed of operation (or operation cycle time) and interactions with size of monitoring and control scheme, accuracy of signal conversion and resolution of data handling.
  - l) Environmental requirements - permissible range of temperature, humidity, vibration, air-borne radio frequency interference, mains-borne electrical interference and other environmental constraints.
  - m) Power supply requirements - power consumption and permissible power supply transients, fluctuations and interruption durations.
  - n) Integrity and security - inbuilt self-checking and diagnostic features, modes of failures or progressive degradation, inbuilt features for checking connected items and units, power failure detection and automatic recovery features.



- o) Safety - any codes of practice or standards to which the system must comply or is certified relating to safety afforded to personnel or the environment.
- p) Maintenance - maintenance skills and tools required, fault diagnosis and correction methods, requirements of routing maintenance.
- q) Support - location and scope of manufacturers, suppliers or agents support services for training, technical support in applications engineering and maintenance.

These factors enable the technical assessment of the wide range of commercially available programmable control equipment, based upon microprocessor technology, that has the capability to control the machine tools in the cylinder FMS. Such an assessment is hindered by the diversity of equipment, lack of standards and the non-uniformity of method and terminology in manufacturers' technical literature and specifications.

Alternative control systems suitable for the control of the SLM-FMS (which are capable of the minimum requirements of:

- a) the capability of performing both closed loop and sequence control,
- b) the provision of a control orientated programming language with pre-programmed algorithms for PID (proportional, integral and derivative) loop control,
- c) self-containment - with the communication facilities enabling the use in larger systems forming distributed control networks),

are commercially available. Their chief characteristics which make them suitable for decentralised control are:

- a) arithmetic operations
- b) operator communication
- c) data transfer
- d) analogue control
- e) distributed control
- f) data manipulation

The only other factor affecting final control hardware choice is the eventual cost of the system. From the alternatives, the choice of control system which encompasses all the selection factors is the GEC GEM/80 system.

(iii) The Machine Tools

The selection of hardening and grinding machine tools is entirely constrained to machine tools capable of the hardening and grinding parameters established in Section 5. The choice of control system interfaces their sequencing into the FMS operation.

7.2 THE RECOMMENDED SYSTEM

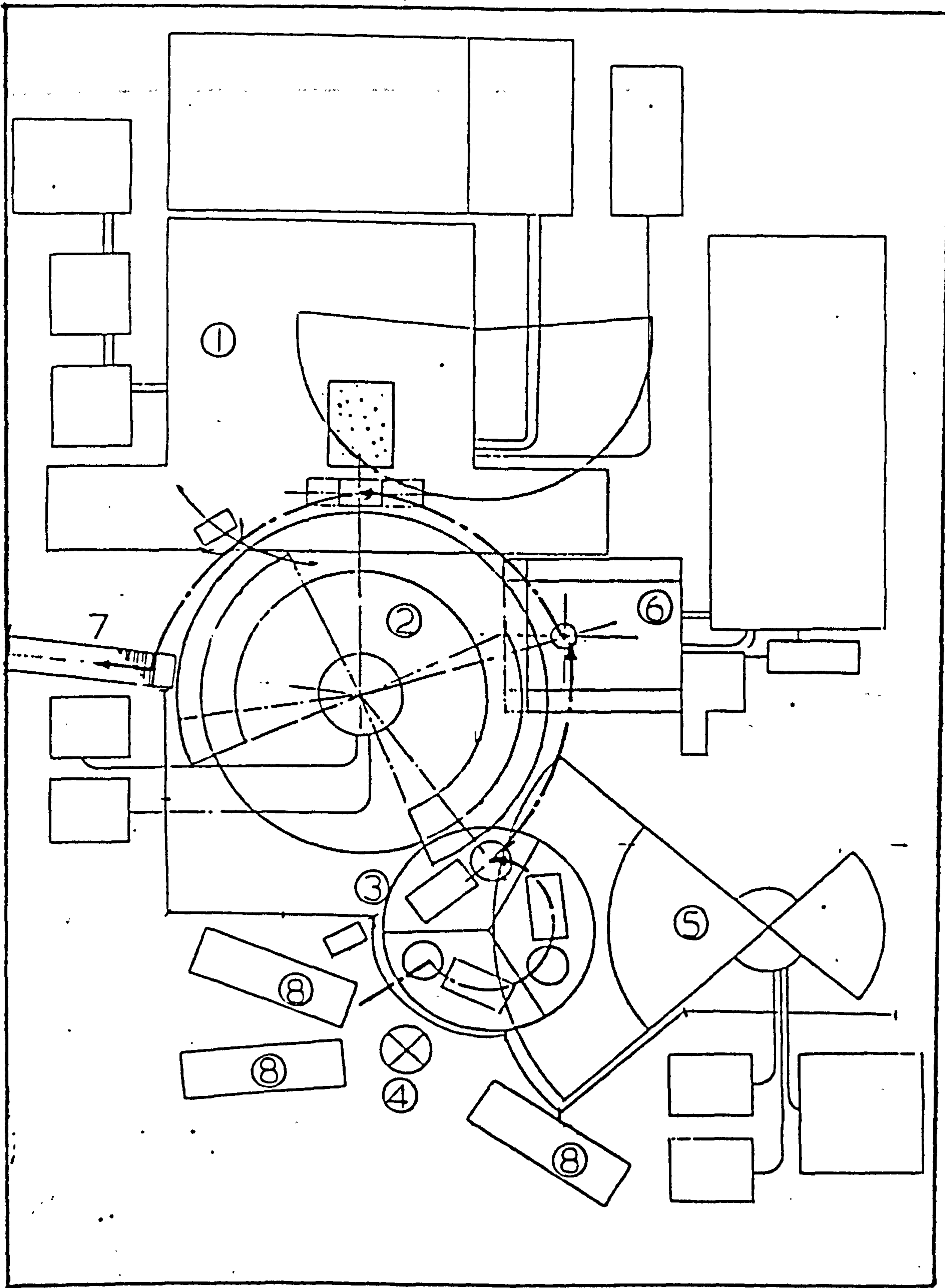
7.2.1 Phase I: The Recommended System

The physical configuration for the first phase of construction of the FMS is illustrated in diagram 7.8. The welding robot, turntable, hardening machine and grinding machine are configured around a transfer robot which manipulates the cylinders through the processes automatically. The system's functional specification (table 7.2) summarises the detailed specifications which are expanded in the following sections. The system has the capability of eight different cylinders for their fabrication, hardening and grinding processes. Although the system can process cylinders up to 17 inches in length, 6 inches in diameter, the cell can process any cylinder, be it solid or fabricated, to a maximum size of 10 inches diameter and 36 inches in length. The maximum capability is constrained by:

- a) grinding swing and distance between head and tail stock on grinding machine
- b) distance between centres on hardening machine and available burner size design.

The process sequence through the cell is:

- 1 Component parts assembled manually into operation No.1 fixture
- 2 Rotate on turntable to welding station
- 3 Weld operation No. 1 by robot
- 4 Rotate on turntable to assembly station
- 5 Transfer operation No. 1 into operation No. 2 fixture
- 6 Blades assembled manually into operation No. 2 fixture (automatic clamping)
- 7 Rotate on turntable to welding station
- 8 Weld operation No. 2 by robot
- 9 Turntable rotation to unload station
- 10 Automatic unclamping of operation No. 2 fixture
- 11 Robotic unloading of operation No. 2 fixture



KEY

- 1 GRINDING MACHINE
- 2 TRANSFER ROBOT
- 3 TOOLING TURNTABLE
- 4 OPERATOR/LOADER
- 5 WELDING ROBOT
- 6 HARDENING MACHINE
- 7 CONVEYOR
- 8 COMPONENTS

DIAG. 7.8

FMS LAYOUT  
(PHASE ONE  
CONFIGURATION)

PRODUCT MIX : Phase I. Robot Pilot Cell Processes.

<u>Part No:</u>	<u>Description:</u>	<u>Mover Type:</u>	<u>Components Spiders: Blades:</u>	<u>Weld Programme No:</u>	<u>Hardening Programme:</u>	<u>Grinding dimension:</u>	<u>Grinding Programme:</u>
L.21605	PANTHER 30	Hand	3 5	1	-	5"	-
L.21607	PANTHER 35	Hand	3 5	2	-	5"	1
L.21614	PANTHER 40	Hand	4 5	3	-	5"	1
L.07014	S. CLIPPER 35	Hand	4 5	4	-	5.3/4"	2
L.07015	S. CLIPPER 40	Hand	4 5	5	-	5.3/4"	2
L.08449	PUNCH 30	Power	3 5	6	1	5.1/8"	2
L.08725	PUNCH 35	Power	4 6	7	2	5.1/8"	3
L.21035	PUNCH 43	Power	4 6	8	3	5.1/8"	4
L.09359	ATCO DOM. 35	Power	3 6	9	1	5.3/8"	4
L.09369	ATCO DOM. 43	Power	4 6	10	3	5.3/8"	4

TABLE 7.2i FMS CAPABILITY SPECIFICATION

FUNCTION:	<ul style="list-style-type: none"> <li>i) To fabricate manually assembled cylinders by M.I.G. welding blades to spiders and spiders to spindles.</li> <li>ii) To harden blade tips of power mower cylinders to a depth of 6 mm at 42 Rockwell 'C' scale.</li> <li>iii) To grind the cylinder outer diameters to a parallel form without the production of any burrs on the blade tips.</li> <li>iv) To automate transfer of cylinders throughout the system.</li> <li>v) To automate the control of the operations (i) to (iv) above.</li> </ul>																		
PROCESS MIX: (EQUIPMENT)	<ul style="list-style-type: none"> <li>welding - 1 off - Hall Automation 5-axes electro-hydraulic continuous path robot.</li> <li>tooling - 1 off - 360 degree rotary turntable of 3 stations (load/weld/unload) each containing a first and a second assembly fixture.</li> <li>transfer - 1 off - Hall Automation 4-axes electro-hydraulic point to point robot with double gripper mechanism.</li> <li>hardening - 1 off - Peddinghaus single burner (ring) progressive flame hardening machine with polymer quenchant (35% concentration).</li> <li>grinding - 1 off - Newall SA 17½ inch wide wheel plunge cylindrical grinder.</li> <li>control - 1 off - G.E.C. GEM.80 control system consisting of 1 off - 246 micro controller (host) computer, 1 off - 130 micro controller (hardening) and 1 off - 100 programmable controller (grinding), plus serial interfacing and keyboard/video peripheral equipment.</li> </ul>																		
PRODUCT MIX:	<table border="1"> <thead> <tr> <th data-bbox="641 1992 782 2023"><u>Part No:</u></th> <th data-bbox="1116 1992 1322 2023"><u>Description:</u></th> </tr> </thead> <tbody> <tr> <td data-bbox="641 2054 782 2085">L.21605</td> <td data-bbox="923 2054 1447 2085">12" Metric hand mower cylinder</td> </tr> <tr> <td data-bbox="641 2085 782 2116">L.21607</td> <td data-bbox="923 2085 1447 2116">14" Metric hand mower cylinder</td> </tr> <tr> <td data-bbox="641 2116 782 2147">L.21614</td> <td data-bbox="923 2116 1447 2147">16" Metric hand mower cylinder</td> </tr> <tr> <td data-bbox="641 2147 782 2178">L.07014</td> <td data-bbox="923 2147 1487 2178">14" 'H'-type hand mower cylinder</td> </tr> <tr> <td data-bbox="641 2178 782 2209">L.07015</td> <td data-bbox="923 2178 1487 2209">16" 'H'-type hand mower cylinder</td> </tr> <tr> <td data-bbox="641 2209 782 2240">L.08469</td> <td data-bbox="923 2209 1608 2240">12" Punch domestic power mower cylinder</td> </tr> <tr> <td data-bbox="641 2240 782 2271">L.08725</td> <td data-bbox="923 2240 1608 2271">14" Punch domestic power mower cylinder</td> </tr> <tr> <td data-bbox="641 2271 782 2303">L.21935</td> <td data-bbox="923 2271 1608 2303">17" Punch domestic power mower cylinder</td> </tr> </tbody> </table>	<u>Part No:</u>	<u>Description:</u>	L.21605	12" Metric hand mower cylinder	L.21607	14" Metric hand mower cylinder	L.21614	16" Metric hand mower cylinder	L.07014	14" 'H'-type hand mower cylinder	L.07015	16" 'H'-type hand mower cylinder	L.08469	12" Punch domestic power mower cylinder	L.08725	14" Punch domestic power mower cylinder	L.21935	17" Punch domestic power mower cylinder
<u>Part No:</u>	<u>Description:</u>																		
L.21605	12" Metric hand mower cylinder																		
L.21607	14" Metric hand mower cylinder																		
L.21614	16" Metric hand mower cylinder																		
L.07014	14" 'H'-type hand mower cylinder																		
L.07015	16" 'H'-type hand mower cylinder																		
L.08469	12" Punch domestic power mower cylinder																		
L.08725	14" Punch domestic power mower cylinder																		
L.21935	17" Punch domestic power mower cylinder																		
LAYOUT	(See diagram 7.8)																		

TABLE 7.2ii FMS FUNCTIONAL SPECIFICATION ( SUMMARISED DESCRIPTION )

- 12 Robotic loading of hardening station
- 13 Flame hardening of blade tips
- 14 Robotic unloading of hardening station
- 15 Robotic loading of grinding station
- 16 Grinding of cylinder diameter
- 17 Robotic unloading of grinding station
- 18 Robotic loading to take-out conveyor

Two major routings are required for a) handmower cylinders and b) power mower cylinders. They are, respectively:

- a) Assemble - Weld - Grind
- b) Assemble - Weld - Harden - Grind

To achieve this for the eight cylinders, eight operation No. 1 welding programmes, eight operation No. 2 welding programmes, eight transfer, three grinding and three hardening programmes are required to obtain the eight unique combinations of production programme sequences for each cylinder type.

#### (1) Machine (Hardware) Specifications

The three types of machines required to achieve production are

- i) a MIG welding set with a programmable manipulator of the welding torch,
- ii) a flame hardening machine under programmable control,
- iii) a cylindrical grinder under programmable control.

##### a) The Robotic Welding Equipment and Tooling

The Hal programmable welding robot with two rotational and one translational arm movement for regional motions and two rotational wrist movements for local motions, has the capability to weld the cylinders. The 5-axis robot with continuous path (linear interpolation) torch manipulation provides an accuracy at the welding gun of  $\pm 1$  mm. A welding cycle time of 1.11 to 1.75 minutes is possible. The welding robot can be taught by two different methods. With the 'manual teach' method, the operator takes hold of the welding torch which is mounted at the front of the robot and guides the machine through a normal welding sequence. The taught programme is recorded by the control system as the operator manipulates the robot. More common is the 'power teach' method in the linear interpolation mode. This is beneficial where a higher accuracy is required. A small hand held control box is used to position the robot (using variable potentiometers for each axis) to the start and end of each weld. These two points are recorded by

operating a pushbutton switch on the control box. The control system automatically plots the path between the points. The physical specification of the robot is shown in diagram 7.9. Other specifications are:

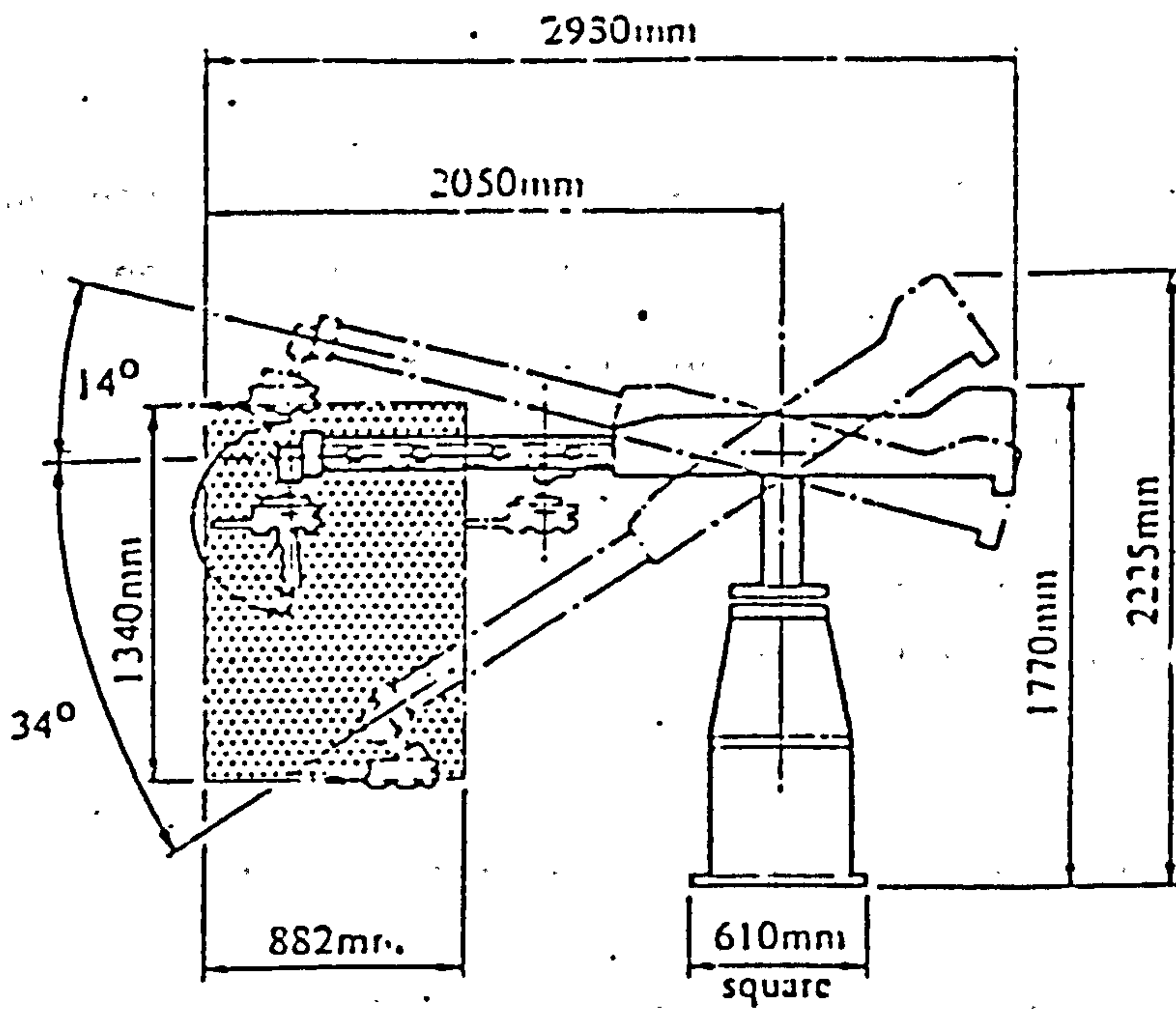
Load capacity	13.6 Kg (30 lbs)
Degress of Freedom (axes)	5 (polar)
Accuracy within	± 1.0 mm of the arc
Max. rotational speed	Swing 30°/sec, Tilt 30°/sec, Wrist 90°/sec
Max. extension speed	9 m/min
Max. welding speed	3 m/min
Weight	560 Kg
Type of drive	electrohydraulic 5kVA
Programming method	teaching
Type of memory	semiconductor
Memory capacity	20 min
Measuring system	potentiometer
External functions	12 inputs/12 outputs

The control system, known as "HAL System 90", is a solid state microprocessor based control with edit, copy, self-diagnosis and test facilities. It provides job number selection, continuous indications of memory capacity usage, over-teach and audible malfunction alarms.

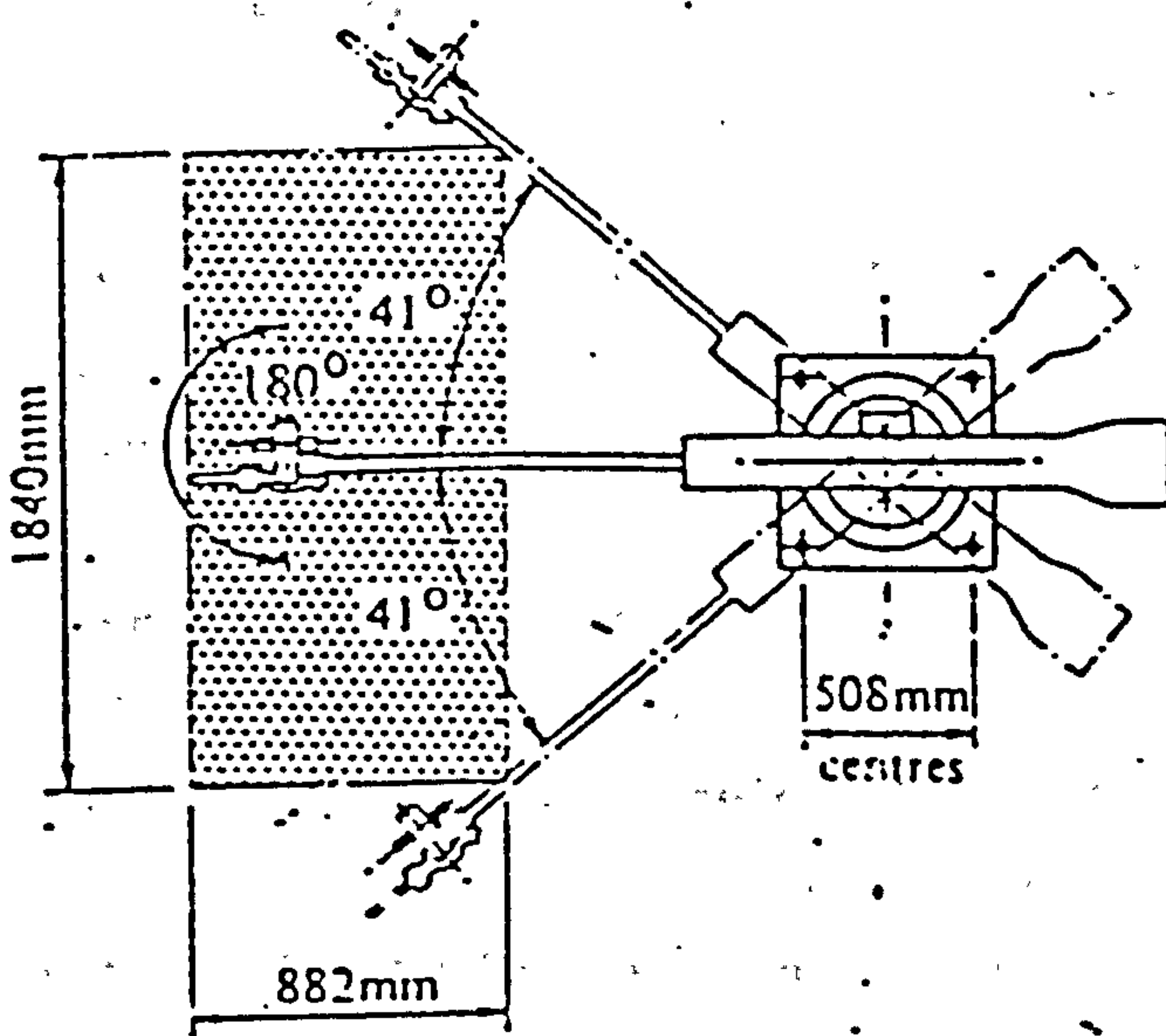
Programme storage is in plug-in memory modules (non-volatile) so that different welding programmes, for different cylinders, can be initiated. The printed circuit cards plug into a standard card frame with interconnections by means of a printed circuit back plane. All connections to external functions pass through filter networks to guard against externally generated electrical noise. The general controller specification is:

Electrical supply	100 to 240 V single phase 50-60 Hz 600VA
Number of addressable modules	15 max.
Number of programs per module	63 max.
Program capacity per module	10 minutes
Dimensions (H x W x D)	1425 x 510 x 450 mm
Weight	40 Kg

The work envelope obtainable is 1840 mm x 882 mm (1.622 cubic metres) and is sufficient to weld the two operations required.



SIDE VIEW COVERAGE



PLAN VIEW OF COVERAGE

DIAG. 7.9 GEC/HALL AUTOMATION WELDING ROBOT



The welding equipment required is the LAH 500 optimatic system as supplied by ESAB - UK Ltd. This consists of:

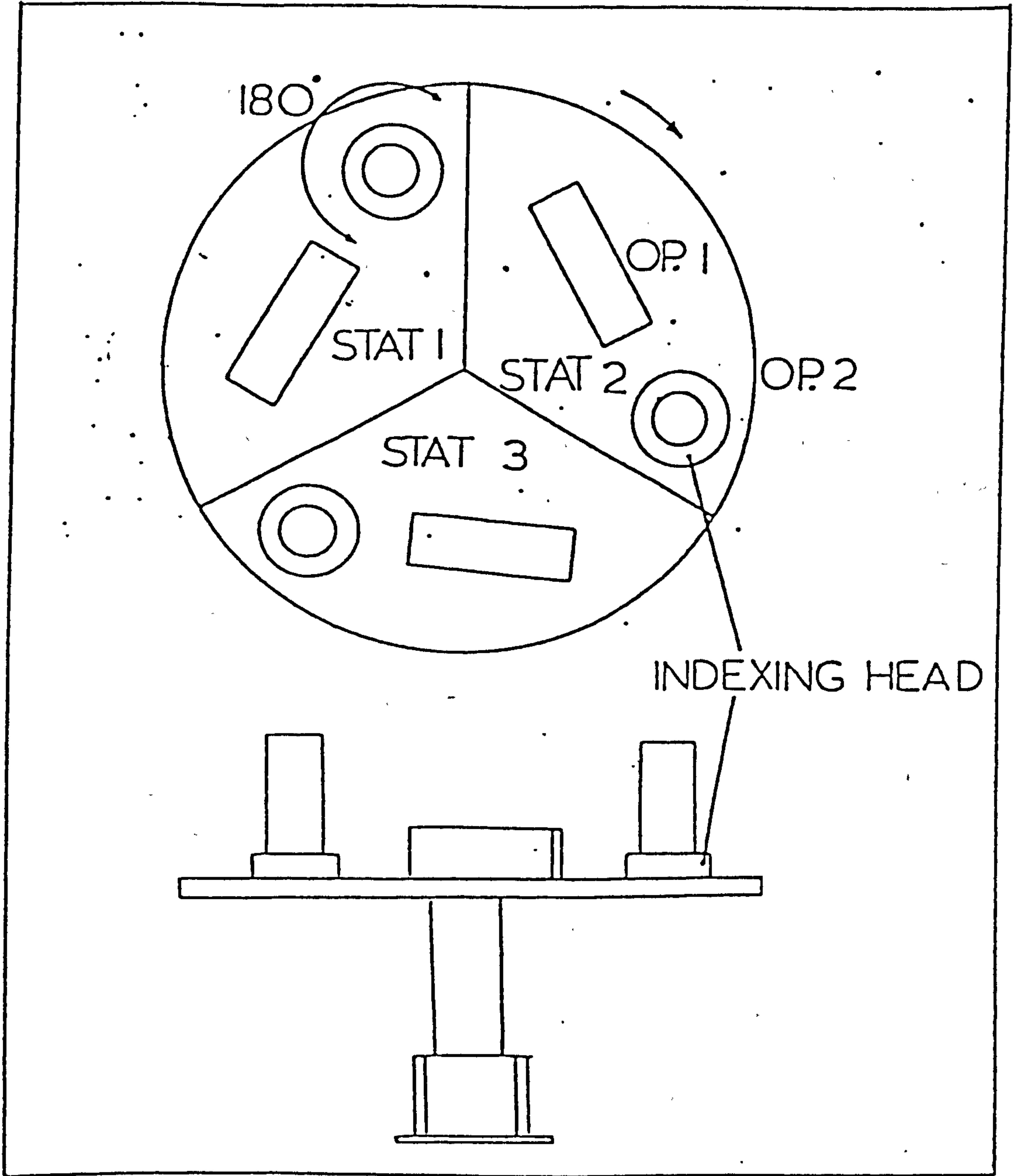
- 1 LAH 500 thyristor controlled rectifier with mains voltage compensation, continuously variable welding voltage and solid state electronic control
- 1 MEC 44 optimatic wire feed unit with two thyristor controlled wire feed motors and geared tandem feed rolls for solid wires
- 1 PSD 250M swan neck air cooled torch (250 amps at 60 per cent duty cycle)
- 1 PAG 16 interfacing and programming unit for weld parameter selection by the robot
- 1 Programmable air blast equipment for releasing welding spatter from the torch nozzle

The welding parameters vary according to cylinder type and material conditions. The parameters are:

Voltage	18 - 21 V
Current	160 - 180 A
Welding speed	19 - 24 inches per minute
Wire feed rate	22 - 25 feet per minute

The production welding conditions are affected by the welding torch position, voltage, current, filler wire feed rate and the torch traverse speed parameters. The optimum conditions must be obtained empirically.

The tooling consists of three stations equally spaced on a 48 inch diameter 360 degree rotary table. Each station consists of one operation No. 1 fixture and one operation No. 2 fixture (diagram 7.10). The fixture for operation No. 1 locates the spiders and spindle horizontally to avoid overhead welding. Clamping is manually carried out using toggle clamps. Clearance is required for access of the welding torch. The fixture for operation No. 2 locates the welded assembly from the first operation vertically for the positioning of the blades. This also avoids overhead welding. Clamping is actuated automatically on the operator's signal. This fixture rotates 180 degrees to provide access of the rear welds for the robot. Unclamping is automatic for robotic extraction of the welded cylinder from the fixture. One of each of these fixtures are positioned in each of the three stations on the turntable. The three station design of the turntable is to present



DIAG. 7.10 ASSEMBLY-WELD TURNTABLE

the three pairs of fixtures to:

- i) the load/assembly station (operator)
- ii) the welding station (robot)
- iii) the unload station (robot)

Therefore, 360 degrees rotation is required in one direction only.

The control signals required are for clamping and indexing initiation.

The safety signals required from the tooling hardware are:

- i) if a cylinder is present in a fixture for welding
- ii) if the turntable has successfully rotated
- iii) if the second fixture has successfully unclamped
- iv) that the second fixture has successfully rotated
- v) that turntable rotation initiates on operator request only.

Therefore, the operational sequence at the human interface to the system is:

Start up sequence -

- i) operator assembles spiders and spindle
- ii) turntable rotates to welding robot
- iii) robot welds operation one.
- iv) turntable rotates to load station

Operational sequence -

- v) manual transfer of welded assembly into second fixture
- vi) blades assembled into second fixture
- vii) as i)
- viii) as ii)
- ix) robot welds operation two and one whilst operator loads next station
- x) turntable rotates welded cylinder to unload station
- xi) automatic unclamping of second fixture
- xii) robotic unloading of second fixture
- xiii) turntable rotates to load station
- xiv) as v), etc.

This method ensures the welding, loading and unloading processes are productively carried out simultaneously.

#### b) The Hardening Machine

The machine to harden power mower blade tips is conceptually the same design as that used in the present manual system. However, a programmable controller is required for automatic control interfacing with

the total system. The vertical hardening machine is for use with 0.6 bar natural gas and 2 to 10 bar oxygen pressures. It has the capability to progressively harden 12 inch, 14 inch, 17 inch and 20 inch cylinders. The machine consists of a solid table frame with a built-in quenching medium tank. This has a mounted water collecting pan 36 inches high. The hardening station is mounted on a framed table plate and is equipped with a guide column. The guide column is equipped with an adjustable head and tail stocks with centres. The upper centre is provided with an air cylinder for automatic loading/unloading. A variable speed (DC) drive motor drives a ball leadscrew from the top of the column. The burner is mounted on a slide driven by a nut on the leadscrew. This slide progresses the burner along the cylinder's length. A cam race behind the column, with 12 cams, automatically sets the three parameters required for each of four different cylinder hardening processes. These parameters are:

- i) burner dwell on blade
- ii) burner gas extinguish and dwell
- iii) burner return

They are required for the following cycle to be fully automated:

- i) load hardening machine with a cylinder between centres
- ii) clamp centres
- iii) identify cylinder correctly positioned
- iv) start hardening sequence -
  - a) ignite burner gas from pilot light with solenoid permitting high pressure gas through
  - b) advance burner ring 3/8 inch
  - c) dwell - to preheat blades
  - d) progress burner up blade length
  - e) extinguish burner
  - f) dwell - to complete quenching
  - g) return burner to start position
- v) signal sequence finished
- vi) signal for unloading of cylinders
- vii) unclamp cup centres (on signal)

For safety reasons gas, oxygen and water flow and pressure must be continually monitored by the controller. The controller is also required to interface with the transfer robot to interlock the loading and unloading cycles with the necessary safety signals for successful

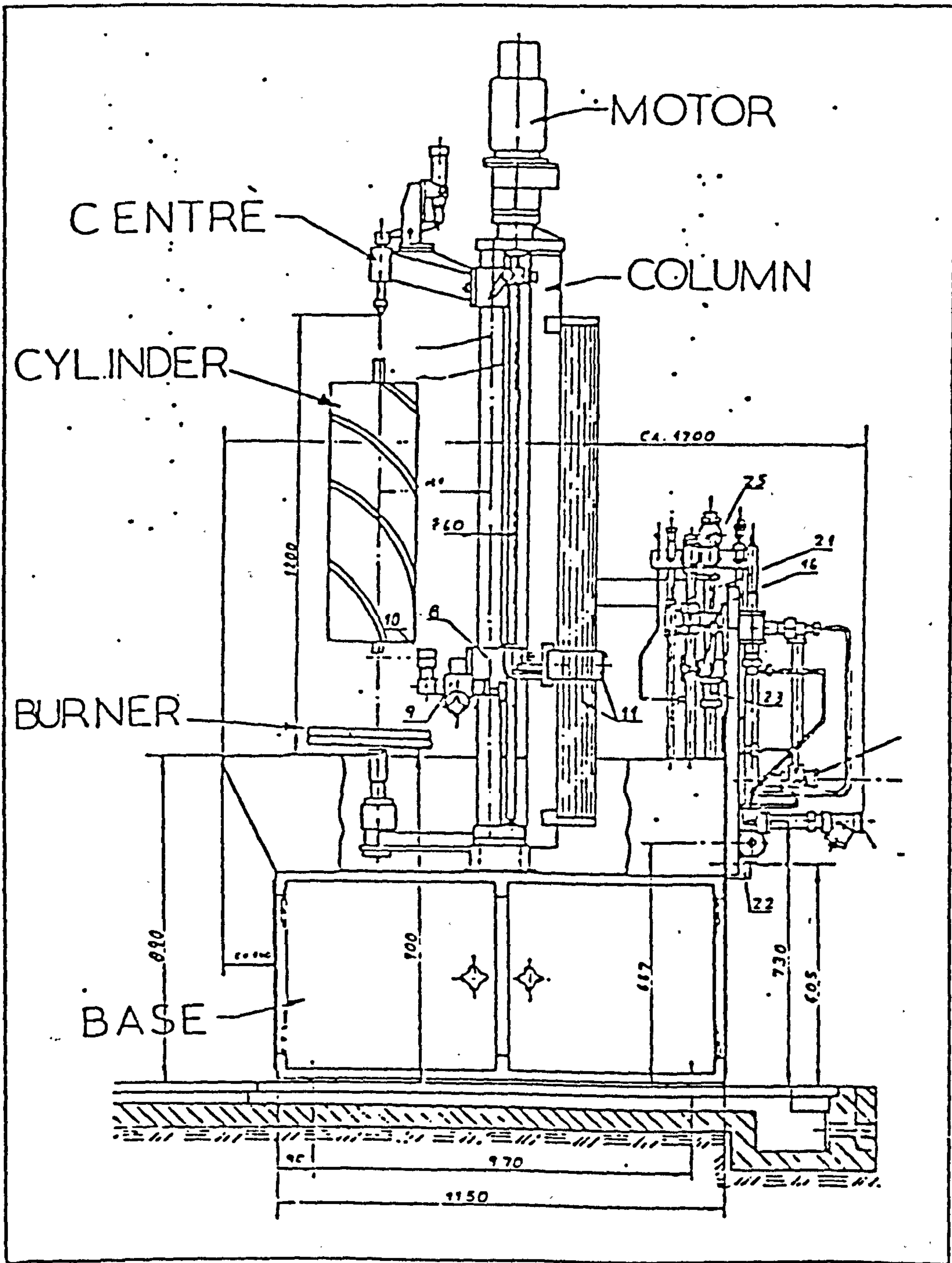
transfer of cylinders to and from the machine. Therefore, flow meter and double-pressure controls are required. Three burner designs are required for the 12 inch, 14 and 17 inch cylinders. The design of the machine is shown in diagram 7.11. A programmable controller with digital inputs and outputs for sequencing and analogue inputs and outputs for gas monitoring is required.

c) The Grinding Machine

A Newall S.A. cylindrical grinding machine with a microcontroller is to be commissioned for the grinding requirements of the cell. The machine carries a 26 inch diameter 17½ inch wide wheel to grind the cylinders without producing a burr. The workhead will rotate the cylinders up to 750 r.p.m. A 20 HP DC drive motor will rotate the wheel at a constant 43 metres per second. Work holding is by means of two collet chucks. A cylinder is placed in a cradle which is raised to align with the chucks. The tail stock operation pushes the component into the chuck and signals the initiation of the grinding sequence. The automatic grinding sequence is:

- i) load component onto cradle
- ii) close guard
- iii) cradle lift to position
- iv) tail stock forward
- v) chuck close
- vi) cradle lower
- vii) work rotate/coolant start
- viii) wheel plunge, rapid feed, slow feed, spark out
- ix) wheel retract/coolant off
- x) cradle raise
- xi) tail stock retract, guard open
- xii) robot secure cylinder
- xiii) table retract
- xiv) unload

In-process wheel balancing is required as well as automatic dressing. The main specification of the machine is:



DIAG. 7.11 FLAME HARDENING M/C

Max. diameter of component swing	305 mm
Max. distance of centres	915 mm
Max. grinding wheel diameter	915 mm
Worn wheel diameter	600 mm
Wheel bore diameter	304.8 mm
Wheel width	17½ inches
Max. plunge feed stroke	50 mm
Workhead speed range	25 - 750 r.p.m.
Work centre height from floor	41.5 inches

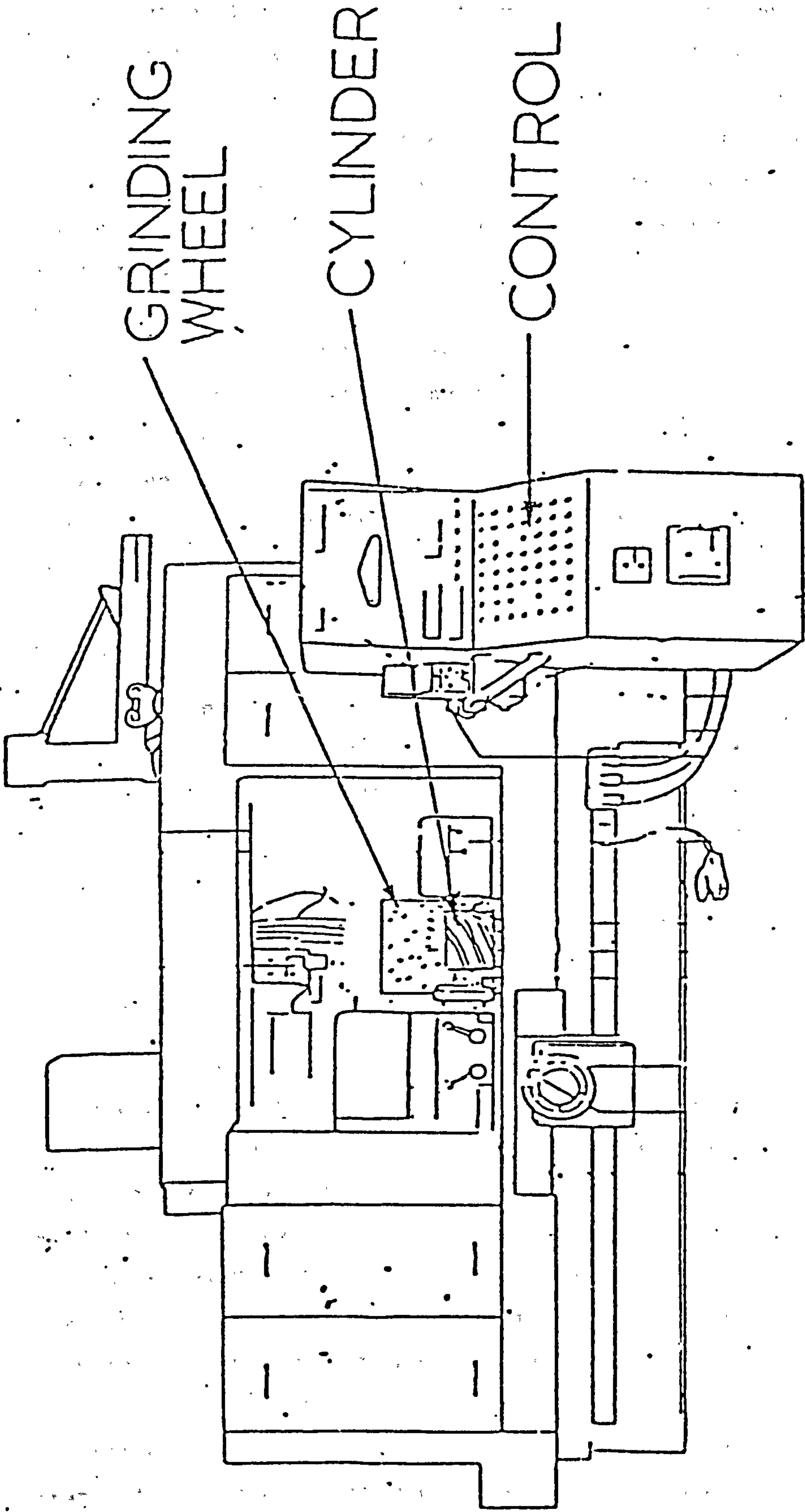
The grinding wheel is carried on a nitralloy precision ground wheel spindle with an autobalance unit. The spindle is mounted in ball and roller bearings. Accuracy of wheel form is maintained by the action of an automatic diamond dresser which dresses the wheel after a preset number of wheel revolutions during actual grinding operation. A layout of the machine is shown in diagram 7.12. Control of the machine is sequenced by a GEC GEM 80/100 programmable controller which also controls a Marposs E6 stepping motor microprocessor control for the in-feed of the grinding wheel. The Marposs system consists of:

- i) power supply and interface/monitoring unit
- ii) driver unit
- iii) wheel head in-feed rate control unit
- iv) dressing cycle and compensation unit

This system provides the control of the stepping motor position through an up-down counter and the control of the in-feed rates for both plunging and traversing. A closed loop (encoder) system ensures the correct stepping operation.

#### (ii) Workpiece Transfer

A transfer robot with a gripper provides the programmable flexibility required to handle the different diameter and length cylinders through the various processes. The cell configuration, diagram 7.8, is laid out such that the minimum of transference distances are achieved. This minimises transfer time and assists the cell's cycle time for the production of a cylinder. The processes begin immediately they have been loaded. The machine "requests" the robot for its unloading and recharging. This "service-request" procedure is monitored and sequenced by the host computer controller of the cell.



DIAG. 7.12 NEALL SA GRINDING MACHINE



a) The Transfer Robot

A Hall Automation 'Little Giant' general purpose transfer robot provides the capability for machine tool load/unload and parts transfer operations. The robot, shown in diagram 7.13, is controlled by the same type of microprocessor control as the welding robot. Additionally it has 12 input and 12 output channels to interlock the robot to the cell's sequencing. An editing function enables unrestricted alteration of a programme on a step by step basis. The controller has the facility for:

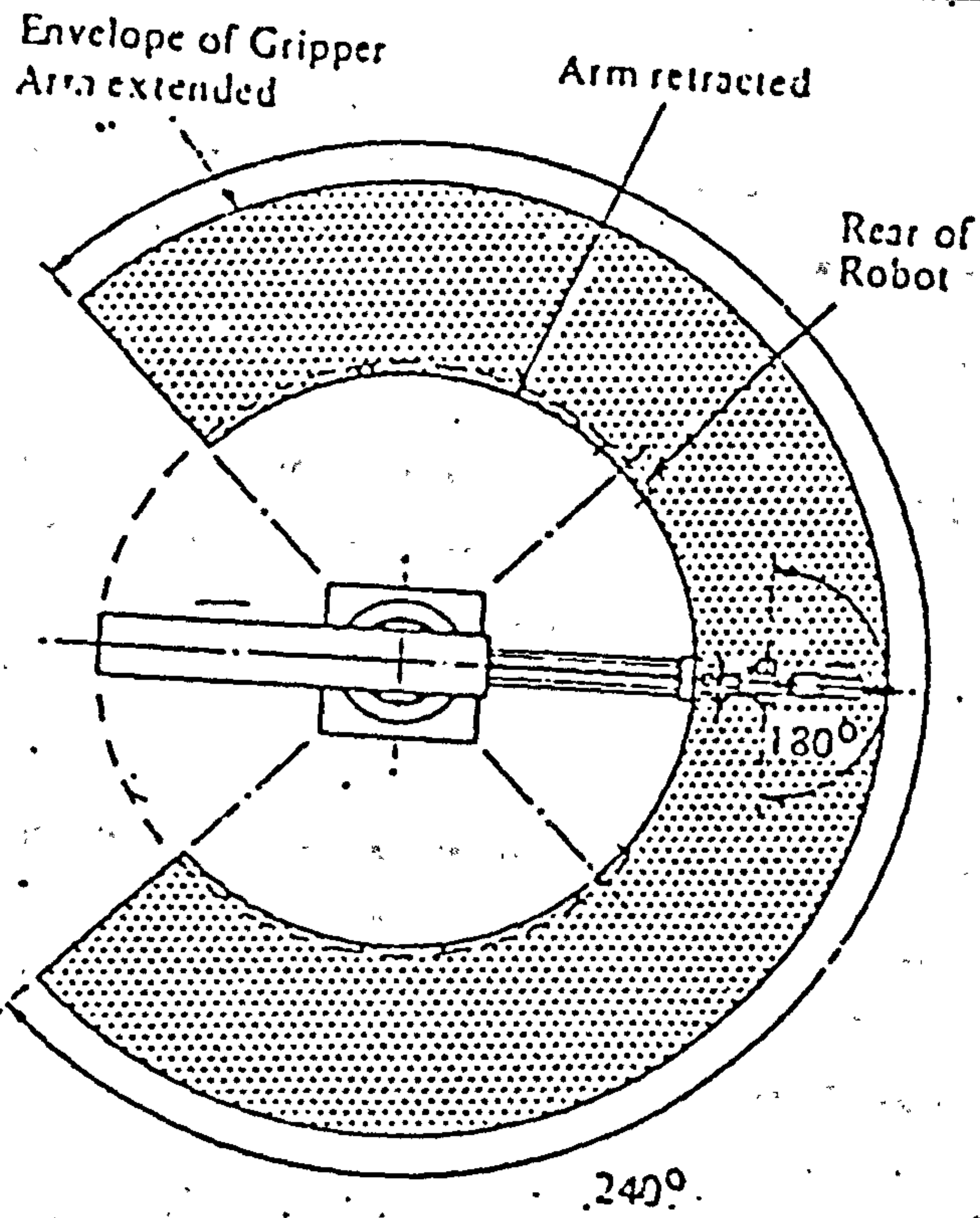
- i) job number identification
- ii) self test and fault diagnosis
- iii) short-cut facility
- iv) speed change
- v) acceleration/deceleration time selection
- vi) 100 - 200 point memory capacity

The general specification of the robot is:

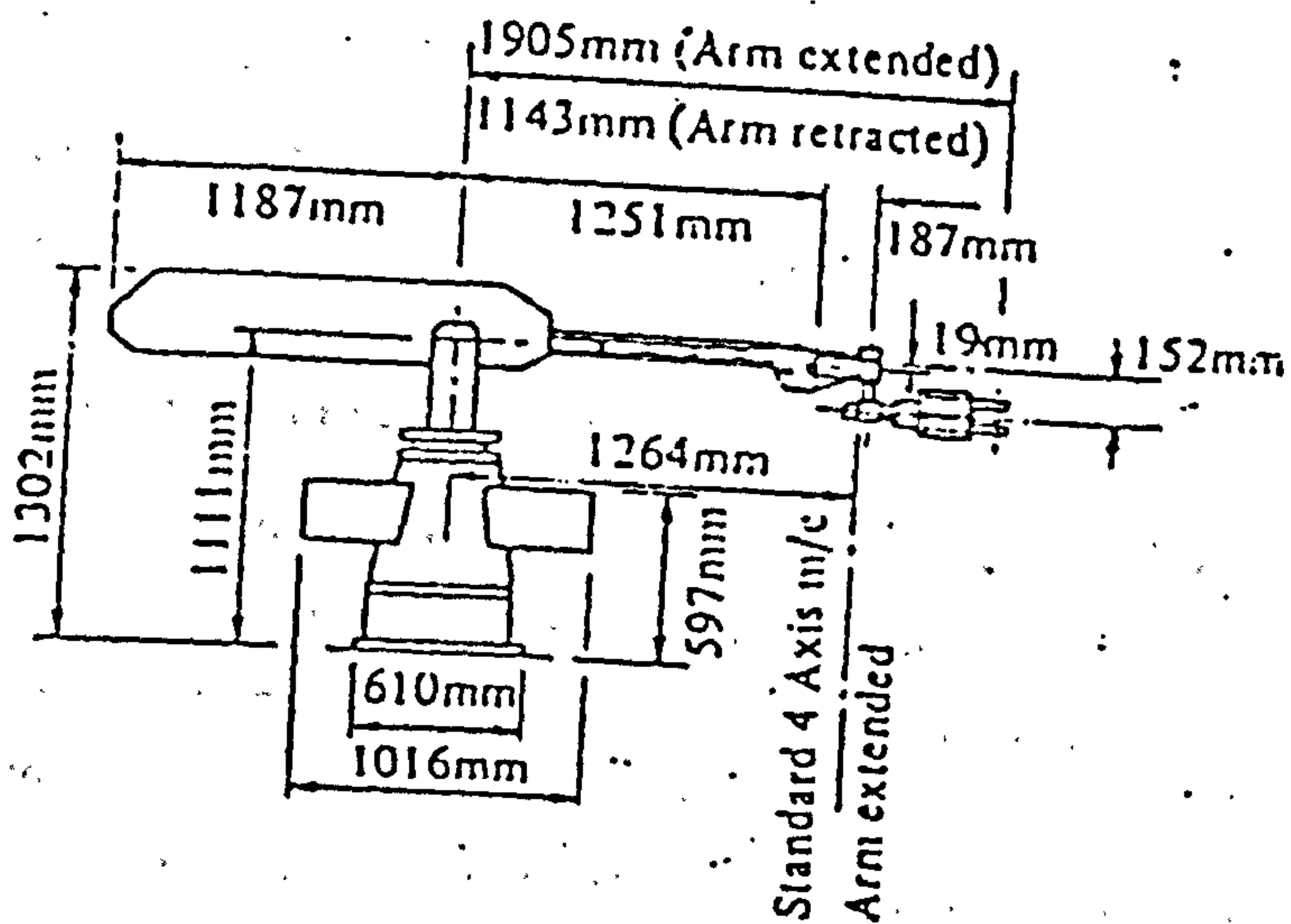
Load capacity	30 Kg
Main axes: rotate	270 degrees
horizontal	761 mm range
tilt	60 degree range
Accuracy	± 1.0 mm
Subsidiary axes: wrist tilt	180 degrees range

b) Mechanical Gripper

A clamping-tong gripper design is required to secure the cylinders on their diameter for parts transfer. To grip the cylinders externally enables one gripper design to handle all cylinder types. The transfer requires a vertical orientation of the cylinder from the welding fixture to a vertical orientation to the clamping centres on the hardening machine. From this machine the cylinders must be turned through 90 degrees to be clamped in the collet chucks on the grinding machine. They are maintained in this orientation for transference to the output conveyor. Each workpiece holding interface consists of a rotational degree of freedom. A gripper design allowing only one translational degree of freedom is therefore necessitated. The cylinder, having been assembled and welded does not lose its known orientation until after the grinding process. At this stage it does



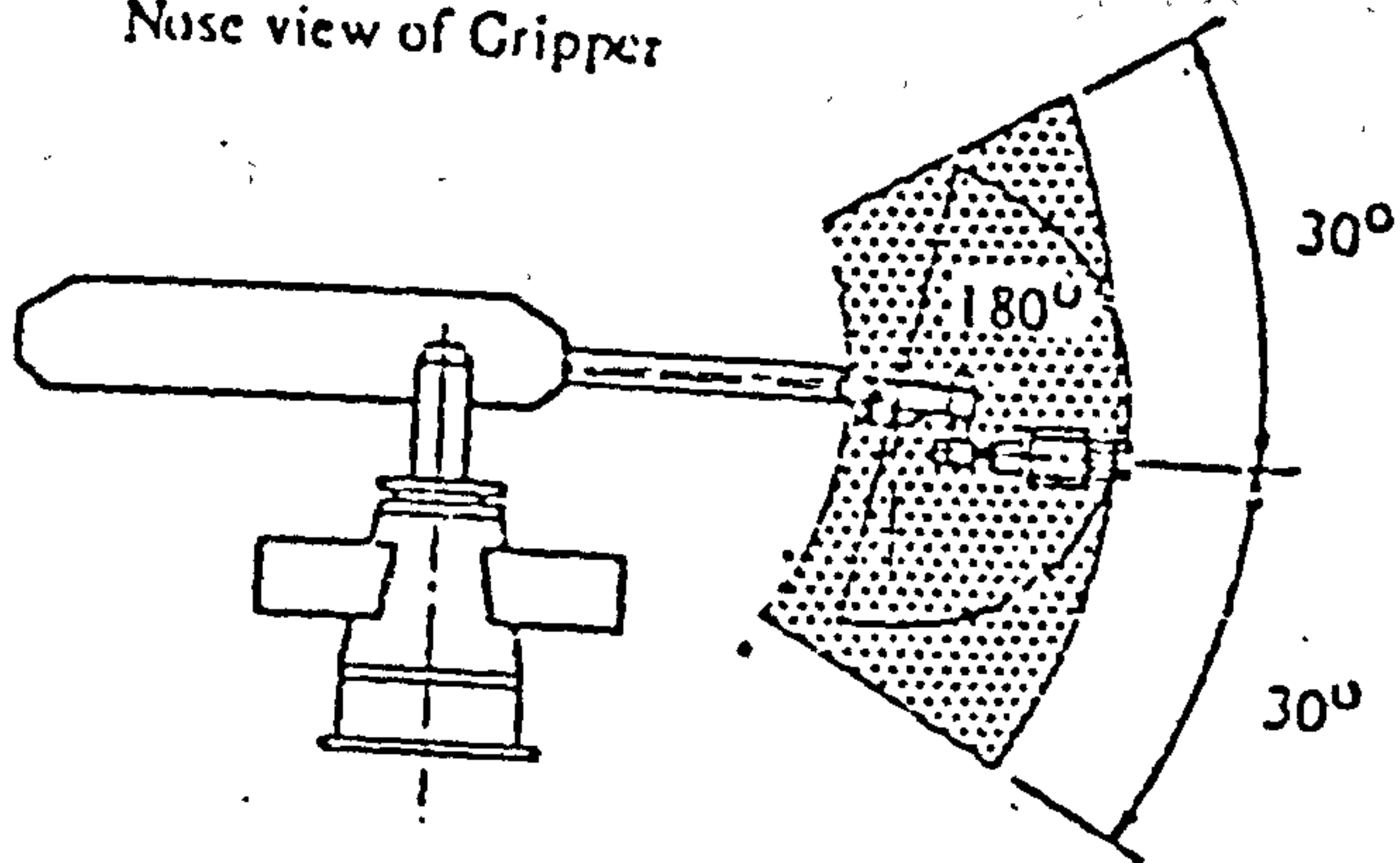
PLAN VIEW OF COVERAGE



SIDE VIEW ELEVATION



Nose view of Gripper



SIDE VIEW OF COVERAGE

DIAG. 7.13 GEC/HALL AUTOMATION TRANSFER ROBOT

not matter. Orientation must be kept to correctly position the cylinder into the hardening burner ring. This will be enabled as a cylinder is taken directly from the fixture for welding to the hardening fixture. The cycle for the cell is shown in diagram 7.14. One cylinder will be completely processed every 120 seconds. To provide the robot with the capability to transfer components to maintain this cycle time, a double gripper arrangement is required. The gripping sequence is shown in diagram 7.15.

A double gripper service-request transfer policy enables the two minute cycle time for all cylinder types up to 17 inches in length. The robot will be utilised for 36 per cent of the cell's cycle time. This enables future expansion of the cell for Phase II.

### (iii) Control (Functions)

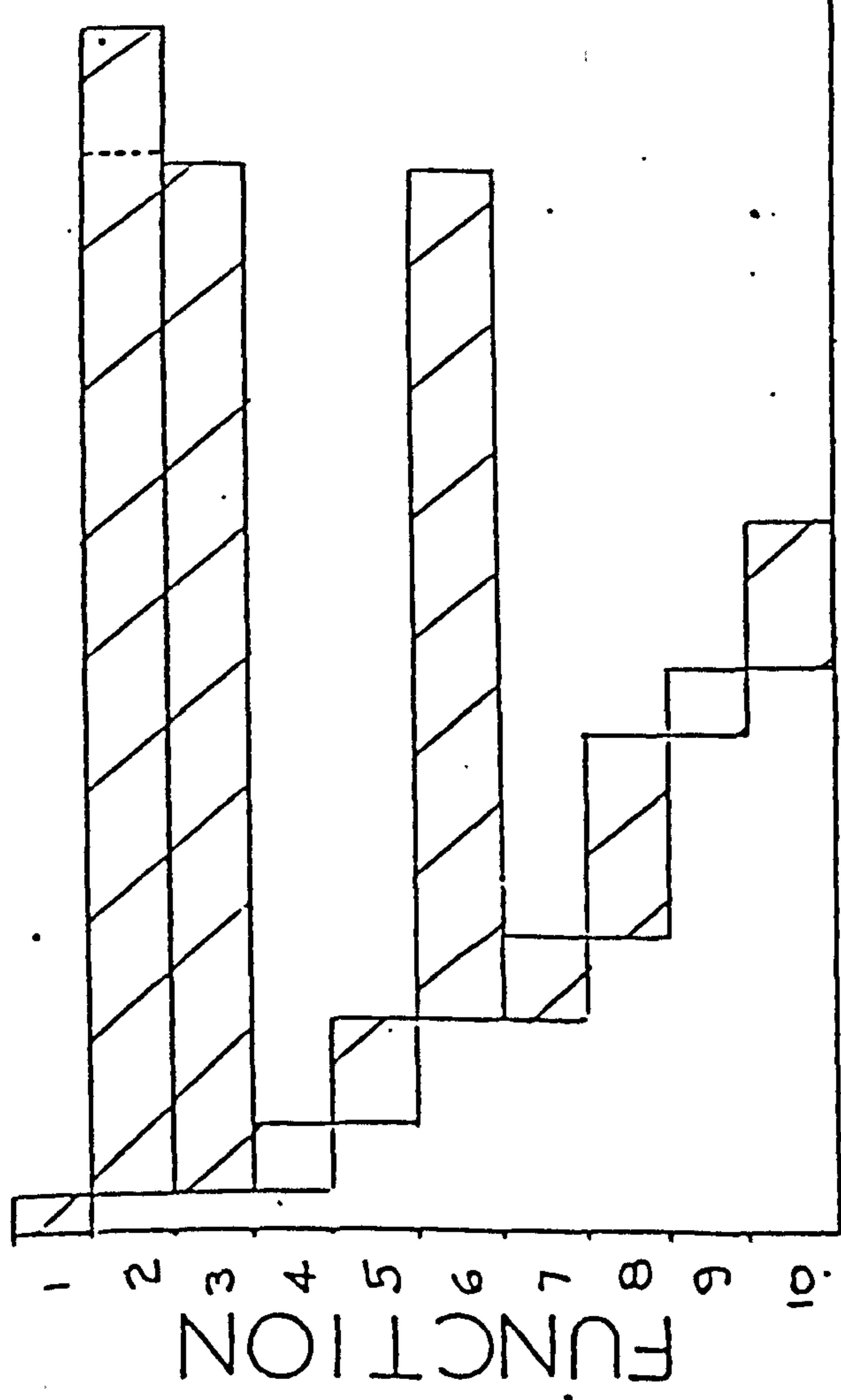
The scope of Phase I control is for the sequencing and control of the welding, hardening, grinding and transfer operations. The control hardware for Phase I has sufficient capacity for the expansion of Phase I control into Phase II (see below).

#### a) General Control Description

The production cycle of each cycle is defined to the control system in the form of a route through the process and the reference of one or more automatic operations to be performed at each workstation. For robot controlled operations the robots are taught by manually taking them through the required operations. Other operations such as hardening and grinding are defined in software. To prepare the cell to make a batch of cylinders of a type previously defined to the system, the operator enters the cylinder reference and batch size from a keyboard and sets up the relevant fixtures on the welding turntable. A central controller sends the required process program references to the process dedicated controllers. Thus, welding requires manual set up and initiation for the subsequent operations to be automatically sequenced by the central controller. The control configuration consists of 5 level-one controllers and a single central (host) controller at level two.

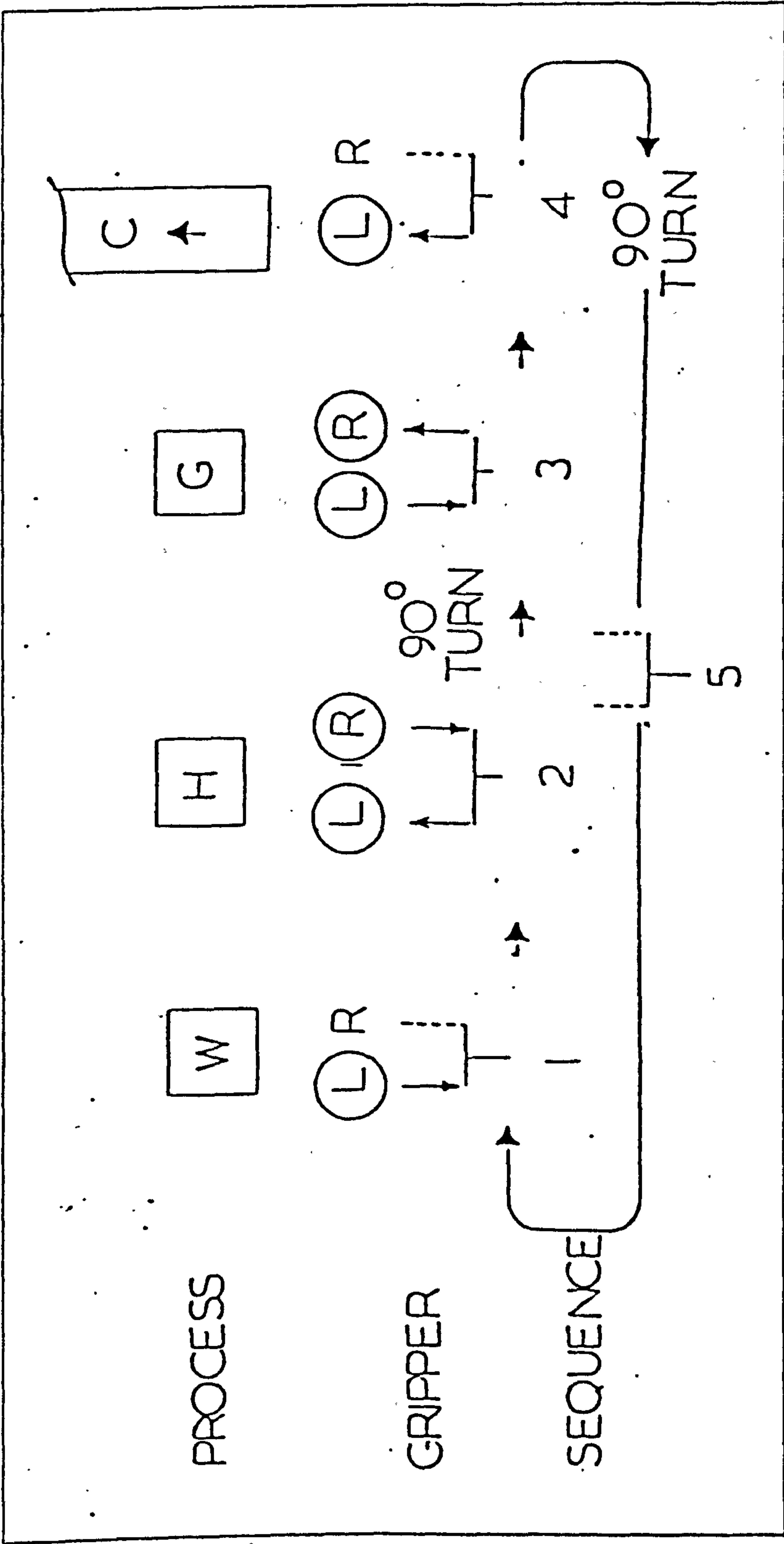
DESCRIPTION

- TABLE INDEX
- MANUAL LOAD
- WELD (ROBOT),
- } TRANSFER (ROBOT)
- } TO HARD. MIC
- HARDEN
- TRANSFER (ROBOT)
- GRIND
- } TRANSFER (ROBOT)
- } FROM GRIND



0 20 40 60 80 100 120  
DURATION SECONDS

DIAG. 7.14 EMS PRODUCTION CYCLE



DIAG. 7.15 DOUBLE GRIPPER SEQUENCE

b) Loading operator functions

At start up the operator sets up the welding table with the correct fixtures for the required cylinders. The horizontal and vertical fixtures have unique mechanical codes which are converted by sensors to electrical signals. The operator sets in the batch number, batch size and batch type via a keypad. The control then checks that the entered batch type checks with the welding fixtures. If they do not tally the system is inhibited from operation and a message appears on a video screen. After manual assembly of the spiders and spindle into the first operation fixture an "Op 1 fixture loaded" signal is generated which appears on the video screen. He then closes a safety gate. This action with the loaded signal together generate a "loading section turntable rotate permissive" signal which generates another signal on the screen. The turntable is now clear to rotate. After rotation the "permissive" signal goes off, preventing further rotation.

On completion of the operation No. 1 welding, the assembly arrives back at the loading section after 2 table rotations (120 degrees each station). The operator removes the assembly from the fixture, assembles the required number of blades and locates the assembly in the operation No. 2 fixture. The operator then retreats to a safe position and presses a "clamp" pushbutton which forces the blades into the spider assembly. After a satisfactory clamp the operator repeats the operation No. 1 loading and closes the gate for the "turntable rotate permissive" signal to be generated. This control sequence ensures the safety of the operator.

c) Welding station functions

The robot must be taught 2 programs for each cylinder type. This will be held on the robot controllers EAROM stores. When the jobs have been taught, the operator logs their program number and EAROM module numbers and then feeds this information into the central controller via a portable programming terminal. When all turntable rotate permissive signals are present, the turntable indexes and the welding robot is presented with one or two filled fixtures. The central controller supplies the welding robot with the correct program number and a start signal for the first

operation weld, if required, and then the program number and start signal for the second operation weld, if required. During the second operation, the vertical fixture must rotate. This is controlled via the central controller which waits for a "rotation complete" signal before letting the welding robot continue. If this signal does not appear, an alarm message is activated on the video screen. At the end of the second operation weld the central controller initiates the unclamping of the blades ready for the handling robot.

Until welding is complete, with the robot retracted, the "turntable rotate permissive" signal is not activated.

A "wire (welding) exhausted warning" signal and an "Argon/CO<sub>2</sub> gas levels low" warning signal prevent further welding cycles from starting but allow the current cycle to finish.

d) Transfer functions

For phase 1 the following hierarchy of handling sequences are required:

a) Weld - Harden - Grind - Conveyor (power mowers)

1 Go to weld position. Remove operation No. 2 welded cylinder from table in free gripper.

1a) Go to hardening machine from welder.

2 At hardening machine:

2a) If cylinder already in machine rotate gripper and remove hardened cylinder into free gripper.

Rotate gripper again. Then, or if no cylinder in hardening machine, insert cylinder into hardening machine.

3 At grinding machine:

3a) If cylinder already in grinding machine rotate gripper and remove ground cylinder into free gripper.

Rotate gripper again. Then, or if no cylinder in grinding machine, insert cylinder into grinding

machine. An interface, through the central controller is required to activate cradle and tail stock.

3b) Go to conveyor from grinder. Dispose of finished cylinder and go to welder.

b) Weld - Grind - Conveyor (Handmowers)

1 (as above) then

1a) Go to grinder from welder, then

3a) (as above) then

3b) (as above)

c) Weld - Grind - Harden - Grind (Heavy Duty)

1 (as above)

1a) (as above)

3a) (as above)

3b) (as above)

4 Go to hardening machine from grinding machine, then

2a) (as above)

2b) (as above)

3a) (as above)

3b) (as above)

The various sub-programs are sequenced from the central controller depending upon the main sequence required as defined by the cylinder type. Interlocking of the transfer robot is through the central controller. The transfer programs are held in the robot's controller EAROM store with the program identification numbers stored in the central controller.

e) Flame hardening functions

The flame hardening process requires a dedicated programmable controller for the machine which interfaces with the main controller. This allows the dwell times and travelling limits to be set automatically depending on the cylinder type. Local interlocking to the transfer robot is easily programmed and modified. Gas and quenching medium flow rates and pressures and flame ignition monitoring are facilitated for both successful hardening and safety reasons. The local controller therefore provides sequential, safety, and monitoring functions.

f) Grinding functions

The grinding process also requires a discrete dedicated programmable controller to allow automatic product change and easy program modification. The grinder control will hold the complete range of grinding programs. On change of cylinder type the central



controller will identify the next part to be made. For loading and unloading operations, the sequence is also controlled by the central controller which transmits signals to the grinding machine controller to operate the tail stock for gripping the cylinder. The grinding controller transmits "end of grinding cycle" and "grinder status" signals to the central controller to initiate the transfer of cylinders.

g) Conveyor function

Cylinders are automatically loaded to an extraction conveyor. This moves at a rate of 13 feet per hour thereby providing an hours buffer store of 30 cylinders before unloading manually into pallets is required. The conveyor also provides an interface with future expansion into subsequent cylinder processes. The conveyor is monitored by the central controller so that it is not overloaded.

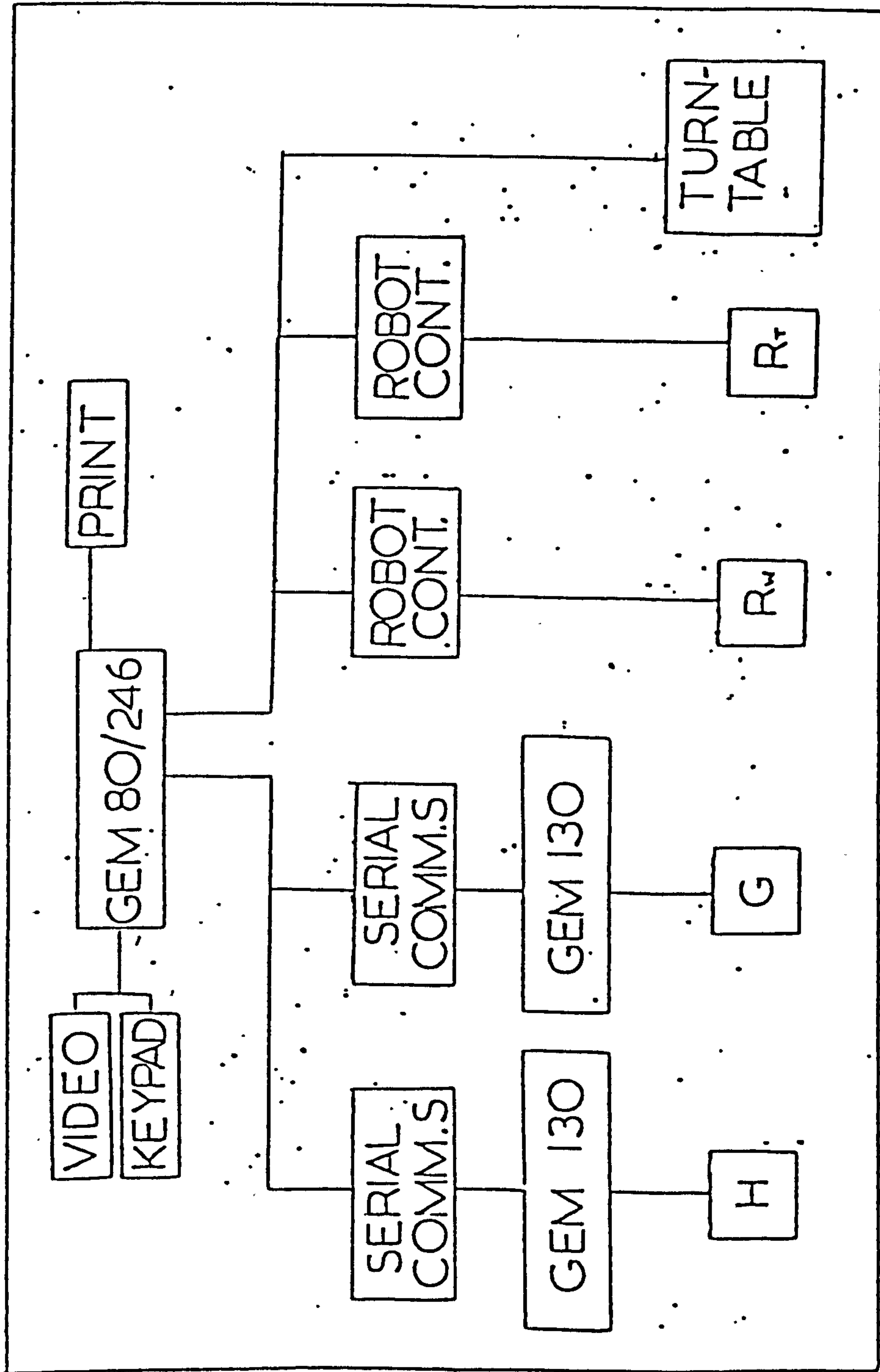
h) Reporting function

A local printer will produce batch reports and alarm messages. The status of individual items of plant will be indicated by a series of lamps at the operator's loading station. Data logging functions include:

- i) time started
- ii) present time
- iii) No. cylinders produced
- iv) No. cylinders rejected
- v) percentage rejection rate
- vi) current upper control limits
- vii) current lower control limits
- viii) out of control at time
- ix) batch size, type, number
- x) batch rate per minute
- xi) wheel dressing requirements
- xii) safety alarms

(iv) Control (hardware and configuration)

The control configuration (diagram 7.16) illustrates the hierarchy of the hardware. The equipment required is:



DIAG. 7.16 CONFIGURATION OF CONTROLLERS (PHASE I)

a) Central controller

1 off GEM 80/246 48k microcomputer (table 7.3)  
1 off Serial termination assembly  
5 off Logic I/O panels  
21 off Input blocks  
10 off Output blocks  
2 off Serial communications  
1 off Portable programmer  
1 off Trend printer  
1 off Monochrome monitor (20")  
1 off 8 x 8 keypad and overlay  
1 off Operators console

b) Flame hardening controller

1 off GEM 80/130 microcontroller (table 7.4)  
1 off Serial termination assembly  
1 off Logic I/O panels  
2 off Numeric I/O panels  
4 off Input blocks  
2 off Output blocks  
2 off Analogue input blocks  
1 off counter block

The central controller and the flame hardening controllers are housed in a suite of 3 sealed cubicles.

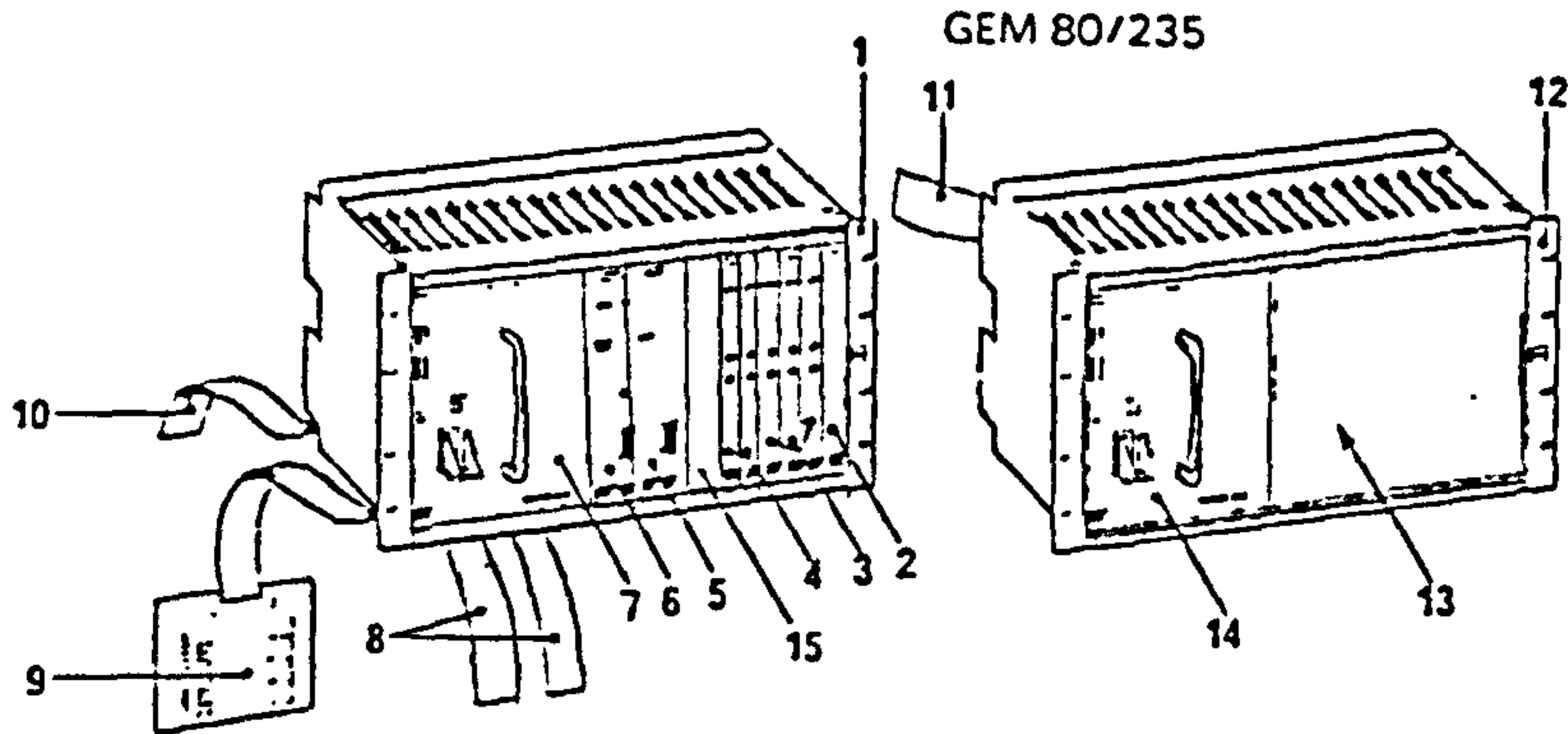
c) Grinding controller

1 off GEM 80/100 microcontroller  
1 off Serial termination assembly  
1 off Logic I/O panels  
2 off Numeric I/O panels  
4 off Input blocks  
2 off Output blocks  
1 off Counter block

The hardware and software enable control of the three processes for the production cycle time of 2 minutes per cylinder. The controllers enable programmable NC of previously hardwired special purpose machines (hardening and grinding) for interfacing with the cell's host controller.

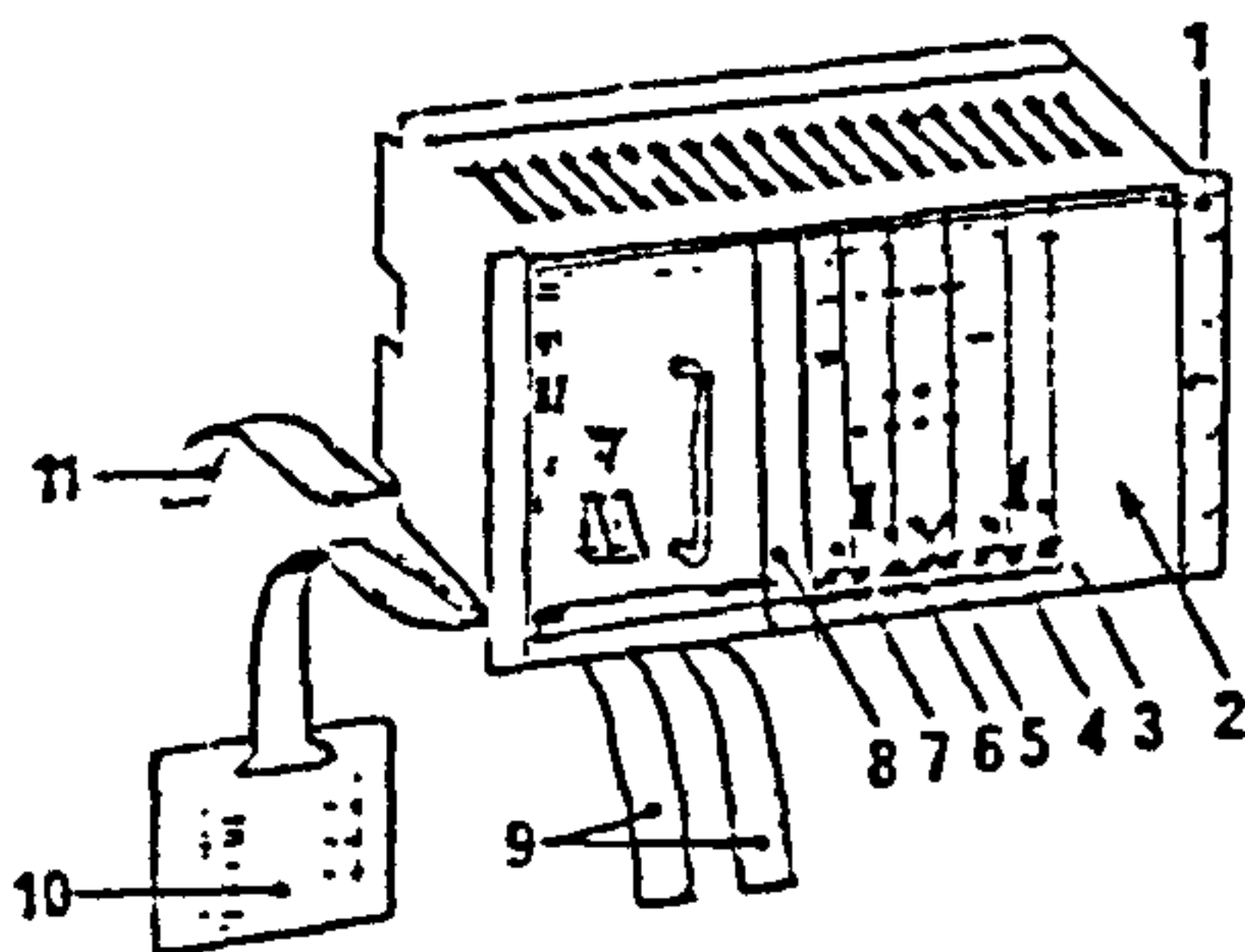
GEM 80/235/245

Micro-Controllers with Video Output



1. Central highway subrack (R0).
2. Fast I/O driver module.
3. Memory modules for control program.
4. Memory modules for video formats.
5. Video processor module.
6. Enhanced processor module.
7. Power module

8. Ribbon cables to I/O block termination panels.
9. Video termination panel.
10. Ribbon cable to serial link termination panel.
11. Fast I/O highway ribbon cable.
12. Fast I/O subrack (R1)
13. Space for up to 12 fast I/O modules.
14. Power module (optional)
15. Space for 4th memory module for control program or 2nd video processor



GEM 80/245

1. Subrack.
2. Space for up to 4 fast I/O modules
3. Fast I/O driver module.
4. Video processor module.
5. Memory modules for control program (options 1 or 2 modules).
6. Memory module for video formats.
7. Enhanced processor module.
8. Power module.
9. Ribbon cables to I/O block termination panels.
10. Video termination panel.
11. Ribbon cable to optional serial link termination panel.

DESCRIPTION

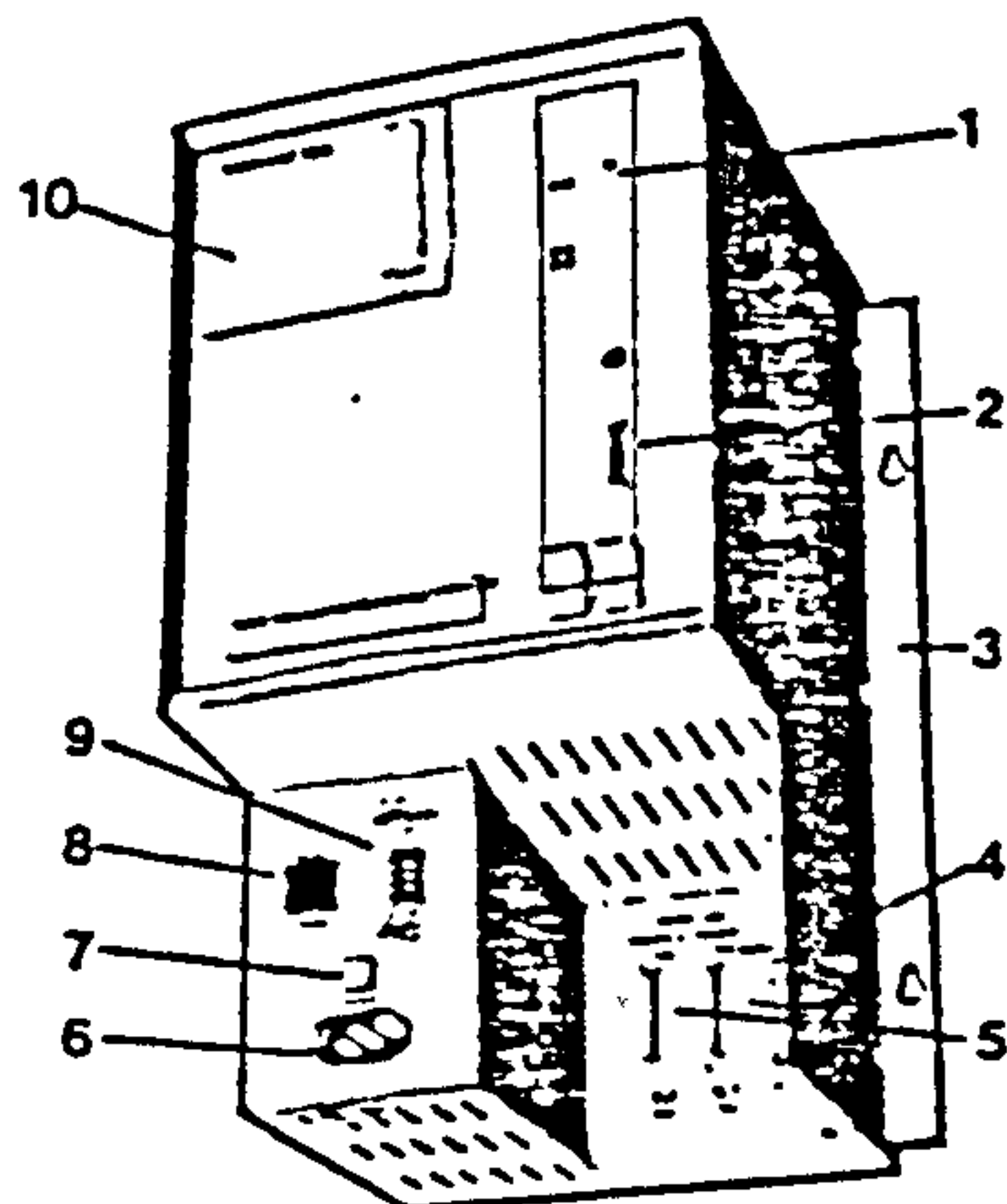
GEM 80/230 series and 240 series controllers perform logic, sequencing, closed loop control and logging functions, with the facility of video displays for plant operating personnel. The 240 series is a compact single subrack configuration offering the same facilities as the 230

series, but with smaller fast I/O and memory capacity.

Both the 235 and the 245 have an automatically flexible P-Table/Instructions boundary and configurable serial links.

TABLE 7.3 GEM 80/245 MICROCONTROLLER SPECIFICATION

## GEM80/130 Micro-Controller



1. Processor module (including memory)
2. Connector for programming and monitoring
3. Mounting flange
4. Connector for serial links to other controllers, or printer, or remote I/O
5. Connectors for basic I/O ribbon cables
6. Connector for mains power input
7. Mains indicator lamp
8. Mains fuse
9. Connector for watchdog interlock circuit
10. Identification label

### DESCRIPTION

GEM 80/130 controllers perform logic, sequencing, calculations, and closed loop control functions for industrial plants, with the facility for printout of text messages and numeric data.

All GEM 80 controllers are user programmable in the GEM 80 Control Language, and include comprehensive monitoring and diagnostic facilities. The 130 is fully compatible with the whole of the GEM 80 family.

A 130 controller consists of a central unit with integral power supplies and containing a single plug-in processor module.

To this basic configuration the user may add:-

- (a) Panels of I/O blocks for local I/O (digital and analogue).
- (b) Two serial links to other GEM 80 controllers; one link can be to remote I/O, the other can be to a printer.

A working system is completed by connecting up power supplies and watchdog interlock circuits and entering a user program in GEM 80 Control Language.

### FEATURES

- Compact, low cost.
- Easily understood ladder diagram Control Language.
- Straightforward relay logic with counting, timing, and sequencing functions.

- Straightforward numerical manipulation with functions for arithmetic, scaling and closed loop control.
- Local I/O up to 512 logic points or 32 analogue values or any mixture.
- I/O capacity expandable using serial link to remote I/O serialiser(s).
- Storage and printout of text messages; built in clock for time and date.
- Serial communications with other controllers.
- Built in automatic self test with duplicated watchdog for safety interlock.

### SPECIFICATION SUMMARY

User program capacity (bytes of CMOS RAM)	: 6K	12K
Control language instructions	: 1404	3000
Data table for user presets (including text for printer)	: 417	1568
Data tables for user variables (each table location = 16 bits)	: 323	1321
Local I/O capacity (bits)	: 512	512
Remote I/O capacity (bits)	: 1x512	4x512
Serial links (routes)	: 2(2)	2(5)
Power supply	: 110 or 220/240V, 50/60HZ	
Temperature	: 0 to 60°C operating (power derating above 50°C)	

Cont

TABLE 7.4 GEM 80/130 MICROCONTROLLER (PC) SPECIFICATION

### 7.2.2 Phase II

The second phase of implementation duplicates the machines around the same transfer robot to utilise its remaining reach capacity. The control hardware is not duplicated except for the I/O terminals and software. The capacity of the cell is doubled.

The control configuration is illustrated in diagram 7.17 for the physical layout of the FMS shown in diagram 7.18. A second transfer robot will provide the handling capability for the degreasing and painting process if required. The modular hierarchical design of the control in Phase I simplifies the addition of the Phase II capabilities. For the Phase II enhancements, the extra controllers required are:

- a) Central controller
  - 1 off video processor
  - 3 off logic I/O panels
  - 10 off input blocks
  - 10 off output blocks
  
- b) Hardening machine controller
  - 1 off logic I/O panel
  - 2 off numeric I/O panels
  - 4 off input blocks
  - 2 off analogue blocks

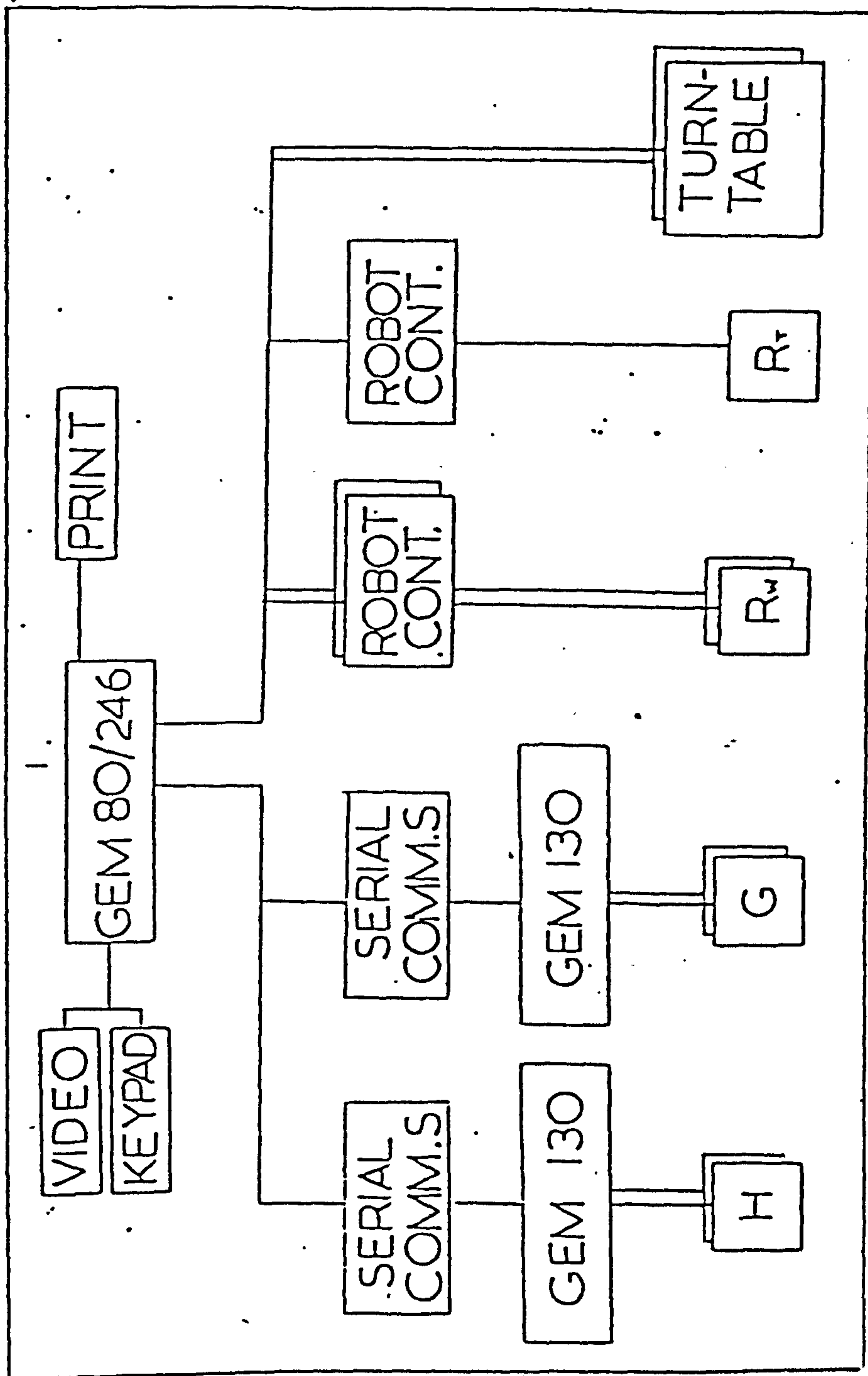
For Phase III, the following hardware is required:

- Degrease/paint controller
  - 1 off serial termination assembly
  - 2 off logic I/O panels
  - 8 off input blocks
  - 4 off output blocks
  - 1 off GEM 80/130 microcontroller

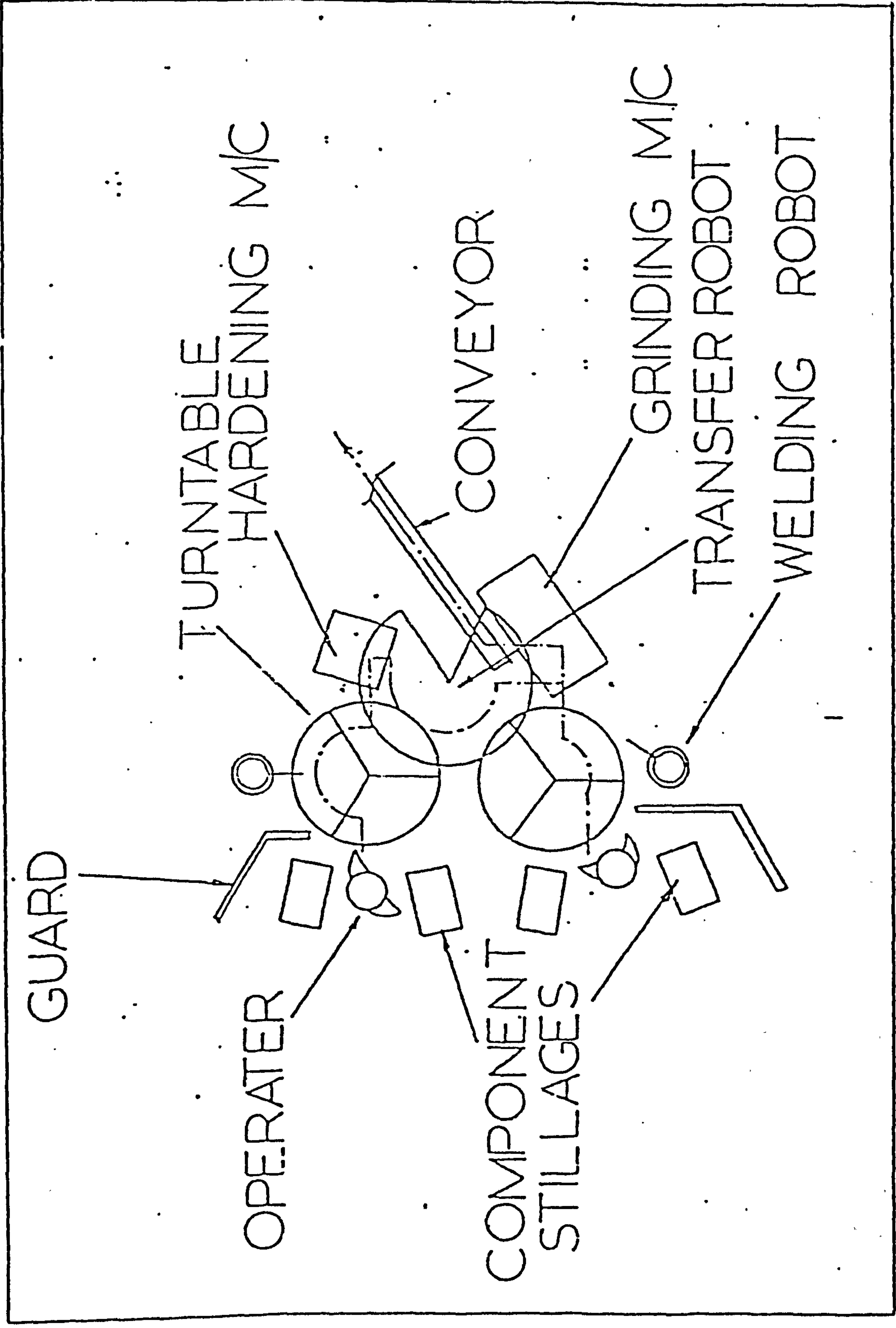
Transfer between the Phase II and III systems will require development.

The enhanced control enables the video output of process routings, machining times, costs and other production control requirements, from the data received from the machine and component logging functions, on an on-line basis.

As Phase I only is recommended for immediate implementation the costs and benefits are established for this system only.



DIAG. 7.17 CONFIGURATION OF CONTROLLERS (EXPANDED)



DIAG. 7.18 PHASE II LAYOUT



SECTION 8

EXPECTED BENEFITS AND OBSERVATIONS

8.1 CELL CAPABILITY AND CAPACITY (PHASE I)

The recommended system is planned to automate eight cylinder types for their welding, hardening and grinding processes. The cycle time for the cylinders will be two minutes compared with up to 15.5 minutes for a seventeen inch power mower cylinder's machine cycle time.

The cell has the flexible capability to process all cylinder types up to 17 inches in length. They are:

<u>Part No.</u>	<u>Length</u>	<u>Description</u>
L21605	12 inch	Handmower metric
L21607	14 inch	Handmower metric
L21614	16 inch	Handmower metric
L07014	14 inch	Handmower H-type
L07015	16 inch	Handmower H-type
L08469	12 inch	Powermower (Punch)
L08725	14 inch	Powermower (Punch)
L21935	17 inch	Powermower (Punch)
L09359	14 inch	Powermower (Atco)
L09360	17 inch	Powermower (Atco)

Cylinders of lengths over 17 inches require more than one plunge on the grinding machine and extend the hardening process cycle time. This will increase the cell's cycle time of two minutes per cylinder.

The cell has a capacity of 96,034 cylinders per annum if operated over two shifts per day. This allows for a 10 per cent non-available allowance for downtime, particularly maintenance downtime. The company operates a 37.5 hour week for 45 weeks of the year. The annual requirements for the cylinders within the cell's two minute cycle capability exceeds the cell's capacity by fiftyfour thousand cylinders. Therefore, for maximum benefits from the implementation of the cell, the cylinders loaded onto the cell throughout a production year must be selectively chosen to increase production cost savings. The programmed annual volumes for the first eight of the above cylinders are:

<u>Part No.</u>	<u>Annual Volume (1983)</u>
L21605	47,000
L21607	28,300
L21614	9,000
L07014	6,775
L07015	7,775
L08469	18,950
L08725	24,755
L21935	9,250
	<hr/>
	151,805 cylinders

Thus, these major eight cylinder designs exceed the annual capacity of the cell. A typical annual cell loading is:

<u>Part No.</u>	<u>Quantity per Annum</u>
L21607	19,529
L21614	9,000
L07014	6,775
L07015	7,775
L08469	18,950
L08725	24,755
L21935	9,250
	<hr/>
	96,034

## 8.2 LABOUR COST SAVINGS

The above cell loading provides a labour cost savings benefit.

The present process times upon which the labour costs for 1982 are based are:

<u>Part No.</u>	<u>Assy + Weld</u>	<u>Cone</u>	<u>Harden</u>	<u>Grind</u>	<u>Total</u>
L21605	8.33	0.66	-	4.35	13.34
L21607	8.33	0.66	-	4.76	14.25
L21614	10.51	0.66	-	5.43	16.60
L07014	10.66	0.66	-	3.98	15.30
L07015	10.66	0.66	-	4.48	15.80
L08469	9.28	-	3.28	5.36	17.92
L08725	12.16	-	3.80	5.90	21.86
L21935	12.16	-	4.81	7.50	24.47 units:mins.

This equates to the following labour costs per cylinder (marginal cost). The costs are based on the 1982 labour rates of £1.32 per hour with the inclusion of variable overheads at a rate of 150 per cent of the labour rate.

<u>Part No.</u>	<u>Present labour cost per cylinder (£)</u>
L21605	0.7337
L21607	0.7838
L21614	0.9130
L07014	0.8415
L07015	0.8690
L08469	0.9856
L08725	1.2023
L21935	1.3459

With the allowances included to compare the FMS labour cost for each cylinder (i.e. £0.1766) the total labour cost savings for the cell loading in one year can be established as follows:

<u>Part No.</u>	<u>Unit Cost Saving (£)</u>	<u>Total Annual Cost Saving (£)</u>
L21607	0.6072	11,858
L21614	0.7364	6,628
L07014	0.6649	4,505
L07015	0.6924	5,383
L08469	0.8090	15,330
L08725	1.0257	25,391
L21935	1.1693	10,816
		TOTAL
		£79,911

The present system's labour requirements for this annual quantity of cylinder throughput is 9.4 man years (table 8.1). A labour equivalent of 3.7 men per shift is saved.

### 8.3 FURTHER BENEFITS

The cell replaces 3 grinding machines, one hardening machine and 3 welding booths. The area for these machines approxiamtes 2080 square feet. The area for the cell requires 1225 square feet. A floor space saving of 855 square feet is obtained.

The cell will be flexible for fast batch change-overs. Only the tooling

Part No.	Quantity per annum (A)	Total Allowed Labour Time (mins) (B)	Total Standard process Cycle Time mins. (C = B ÷ 1.75)	Total Requirements (man yrs.)
L21607	19,529	14.25	8.14	1.48
L21614	9,000	16.16	9.48	0.80
L07014	6,775	15.3	8.75	0.55
L07015	7,775	15.8	9.02	0.65
L08469	18,950	17.92	10.24	1.82
L08725	24,755	21.86	12.49	2.89
L21935	9,250	24.47	13.98	1.21
	<u>96,034</u>			<u>9.40</u>

Proposed system manning level = 1 man per shift

Proposed labour savings =  $\frac{\text{Total man year requirements} - \text{Total proposed manning level}}{\text{Number shifts employed on}}$

$$= \frac{9.4 - 2}{2}$$

$$= 3.7 \text{ man years per shift}$$

Table 8.1 Current System Labour Requirements

fixtures for loading the system with components require setting-up for different cylinder batch runs. The hardening machine's gas-burner and grinding machine's grinding wheel have the capability for processing all seven cylinder types. The reduction in the throughput times to 2.0 minutes with fixture set-up times of 5 minutes (approx) enables low batch quantities to be produced, thereby reducing work-in-progress levels and manufacturing lead-times.

Material savings of £0.04 per handmower cylinder are obtainable by changing from the MMA welding process to the MIG welding process for handmower cylinders (table 8.2).

#### 8.4 THE COST OF THE FMS

The total capital equipment costs of the cell for Phase I approximates £304,500 as follows: (see table 8.3 for compilation)

Tooling	£53,790
Robot (weld)	£46,000
Robot (transfer)	£37,500
Controllers (inc. software)	£63,804
Hardening machine	£27,524
Grinding machine	£75,882
	<hr/>
TOTAL	£304,500
	<hr/>

(Source: Supplier Co. quotations)

The UK Government Department of Industry has agreed to fund 50 per cent of all the costs involved in developing the Phase I system. This financial aid has been arranged through the Production Engineering Committee (PEC) which has taken over the functions of the Automated Smallbatch Production (ASP) Committee. A two year development period is to be set up in which to make the FMS productive. The development and installation costs are also included in the Government's aid programme. Thus, the total FMS cost is:

Capital equipment costs	£304,500
Installation costs	£ 10,000
SLM R & D costs	£ 19,387
	<hr/>
PROJECT CAPITAL COST	£333,887
	<hr/>

Present cost per cylinder (Manual Metal Arc) <sup>1</sup>	= 6.55p
Proposed cost per cylinder (Metal Inert Gas) <sup>2</sup>	= 2.48p
	<hr/>
Cost saving per cylinder	= 4.07p
	<hr/>
Annual savings for 43,071 cylinders	= £1,753
	<hr/>
1) MMA welding rods	= £1.04/kg
Welds per rod	= 18
Rods per cylinder welded	= 1.5
Cost of rod per cylinder	= 6.55p
2) Cost of wire per cylinder	= 0.98p
Cost of gas per cylinder	= 1.50p

Table 8.2    Material Cost Savings

<u>Description</u>	£	£
<b>1 <u>Ancillary Plant and Tooling</u></b>		
Supplier: Oakwood Design		
1 off 3 position turntable	24,750	
1 off 3 sets Op.1 and Op.2 fixtures	3,630	
7 off 3 sets Op.1 and Op.2 fixtures	25,410	53,790
<b>2 <u>Robot (Weld)</u></b>		
Supplier: GEC (Hall Automation)		
1 off Robot	38,500	
1 set Welding equipment	3,500	
Installation and commissioning	4,000	46,000
<b>3 <u>Robot (Transfer)</u></b>		
Supplier: GEC (Hall Automation)		
1 off Robot	30,500	
Gripper (double)	2,000	
Installation and commissioning	5,000	37,500
<b>4 <u>Control (inc. Hardware and Software)</u></b>		
Supplier: GEC Fast Div.		
Cell control	49,500	
Hardening control	9,578	
	<hr/>	
	59,078	
8% increase	63,804	63,804
<b>5 <u>Hardening Machine</u></b>		
Supplier: Peddinghams GmbH		
1 off Vertical hardening machine	26,905	
Programming unit (loan)	619	27,524
<b>6 <u>Grinding Machine</u></b>		
Supplier: MSM Ltd		
1 off 17½" wide wheel cylindrical grinding machine (15,000 already paid).	60,882	
	15,000	75,882
		<hr/>
<b>TOTAL CAPITAL EQUIPMENT COST</b>		<b>304,500</b>
		<hr/>

Table 8.3 Compilation of Capital Equipment Costs

Additionally, an allowance from revenue funds of £10,000 per annum must be allocated for the maintenance, training and running costs involved.

The cash flow of the costs over the two year period is shown in diagram 8.1. Initial payments are required to prepare the site and order the hardware and software. Most of the costs are paid during the development period as machine capabilities are established with the commissioning of the equipment. The software must be developed subsequent to machine commissioning and therefore progress payments for the control of the FMS must be included (table 8.4).

## 8.5 FINANCIAL RETURNS FROM THE FMS

### (i) Accounting Rate of Return

The ARR equates the total savings divided by the total project cost. The potential annual materials saving of £1,753 (table 8.2) are added to the annual labour cost savings for the total cost savings that the company have used to establish the payback period.

Total Cost Savings = £79,911 (labour) +
£ 1,753 (materials)
<u>                  </u>
£81,664
<u>                  </u>

The return is:-

ARR	= 81,664 ÷ 333,887
	= 24.4 per cent

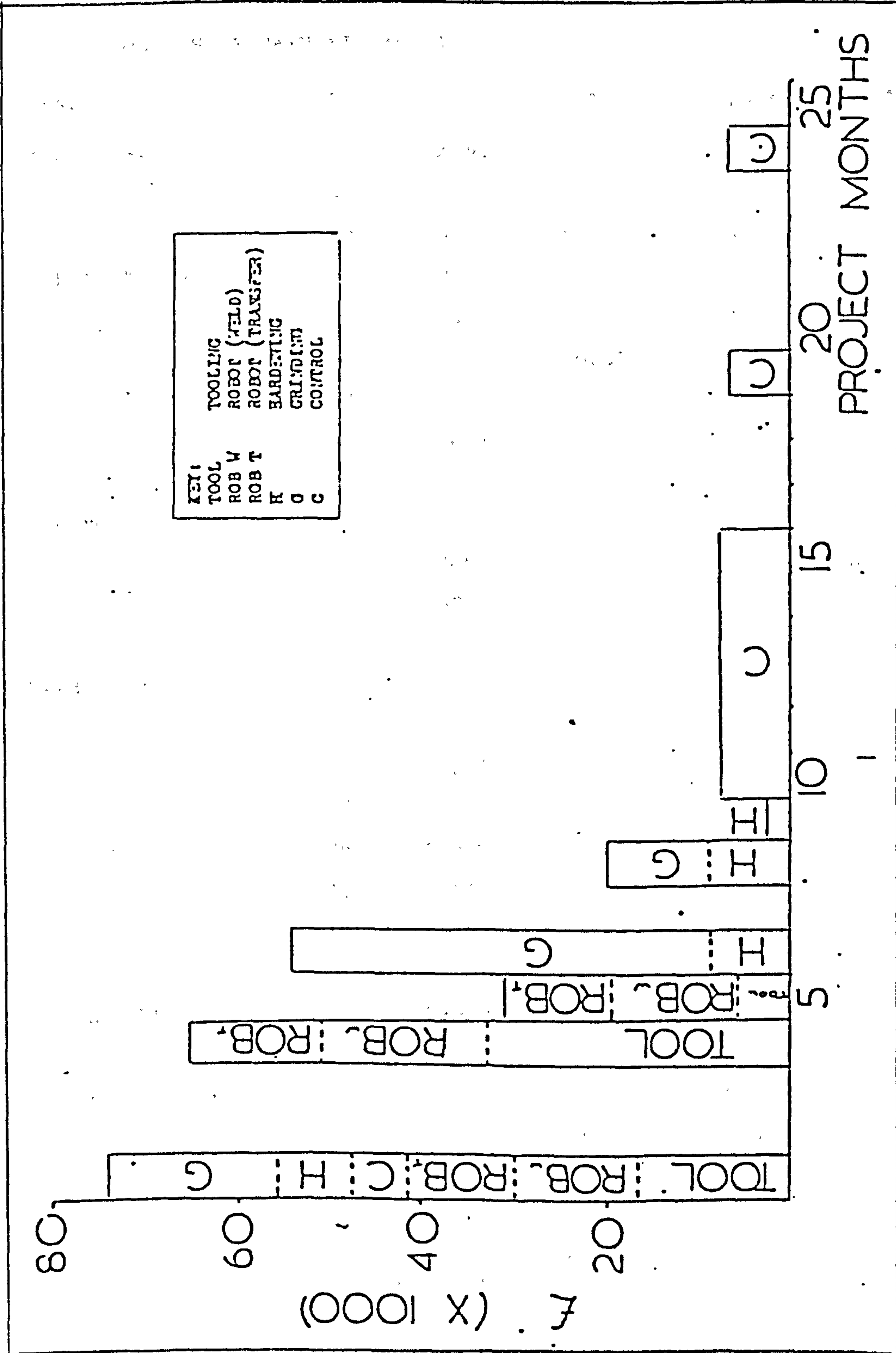
This is a reasonable return with a 4 year payback period on the project's cost but ignores the future cost savings obtained over the ten year life period of the project. With grant aid, the return is 50% with a 2 year payback period.

### (ii) Discounted Cash Flow (DCF) Analysis

The DCF financial returns on the project are evaluated in table 8.5. The discounted cash flow analysis includes the grants and capital allowances over the cell's ten year life and balances the annual savings by deducting the tax payable on the savings. The DCF returns are:-

- a) WITH GRANT AID           - Payback = 2 years 4 months (IRR = 45%)
- b) WITHOUT GRANT AID       - Payback = 4 years 5 months (IRR = 30%)





DIAG 8.1 PROJECT COSTS VS. TIME

Table 8.4 PROGRESSIVE PAYMENTS ANALYSIS

Item	Description	%	£	£ TOTAL	Month
1	Ancilliary Plant	30	16137		1
		60	32274		4
		10	5379	53790	5
2	Robot (Weld)	30	13800		1
		40	18400		4
		30	13800	46000	5
3	Robot (Transfer)	30	11250		1
		40	15000		4
		30	11250	37500	5
4	Control	10	6380		1
		70	44662		10 - 15 (inc)
		10	6380		19
		10	6382	63804	24
5	Hardening	30	8257		1
		30	8257		6
		30	8257		8
		10	2753		9
6	Grinding	25	18970		1
		60	45529		6
		15	11383	<u>75882</u>	8
			304500		
7	INSTALLATION	100	10000	<u>10000</u>	1 - 4
			£314500		
8	R & D (revenue)	25	50000		1 - 4 inc
		75	14387	19387	4 -16 inc
TOT COST OF PROJECT				<u>£333887</u>	

Year	Capital Expenditure less disposal proceeds	Grant	Capital Allowance	Tax Saving at 52%	Associated Revenue Expenditure	Tax on Revenue Expenditure @ 52%	Profit before depreciation, interest & revenue expenditure	Tax on Profit	Sub Total	Accumulated Sub Total to Zero	Net Cash Flow	Present Value DCF @ 26%
1	(299)	150	-	-	(10)	(5)	13	-	(141)	(141)	(141)	(141)
2	(35)	17	149	77	(10)	(5)	83	(7)	130	(11)	130	103
3	-	-	18	9	(10)	(5)	72	(43)	33	22	33	21
4	-	-	-	-	(10)	(5)	77	(37)	35	-	35	17
5	-	-	-	-	(10)	(5)	83	(40)	38	-	38	15
6	-	-	-	-	(10)	(5)	90	(43)	42	-	42	13
7	-	-	-	-	(10)	(5)	97	(46)	47	-	47	12
8	-	-	-	-	(10)	(5)	104	(50)	49	-	49	10
9	-	-	-	-	(10)	(5)	112	(54)	53	-	53	7
10	-	-	-	-	(10)	(5)	120	(58)	58	-	58	6
11	5	-	(5)	(3)	(10)	(5)	139	(62)	72	-	72	6
TOTALS	(329)	167	162	83	(110)	(55)	990	(440)	416	-	416	69

Table 8.5 Financial Payback Analysis

Condensed from BIRMID QUALCAST  
Justification Proposal Form BQ-526 (units: £'000's).

As no savings would be obtained in the first year of development the "payback" period of the project is 2 years and 4 months. With an inflation allowance of  $7\frac{1}{2}$  per cent per annum for the life of the project, the Internal Rate of Return equates to 45 per cent. This is a very reasonable return. The analysis included in table 8.6 shows the discounted cash flows, without the grant aid, for comparison. Even though the capital allowances are higher the Internal Rate of Return is decreased to 30 per cent with the project taking 4 years and 5 months to recover the costs. In both analyses the allowance for maintenance and repairs of £10,000 per annum has been made for the ten year life of the FMS. The funds will be allocated from revenue.

Year	Capital Expenditure less disposal proceeds	Grant	Capital Allowance	Tax Saving @ 52%	Associated Revenue Expenditure	Tax on Revenue Expenditure @ 52%	Profit before Depreciation, Interest & Revenue Expenditure	Tax on Profit	Sub Total	Accumulated Sub Total to Zero	Net Cash Flow	Present Value DCF @ 26%
1	(299)	-	-	-	(10)	(5)	13	-	(291)	(291)	(291)	(291)
2	(35)	-	299	155	(10)	(5)	83	(7)	191	(100)	191	151
3	-	-	35	18	(10)	(5)	72	(43)	42	(58)	42	26
4	-	-	-	-	(10)	(5)	77	(37)	35	(23)	35	18
5	-	-	-	-	(10)	(5)	83	(40)	38	15	38	15
6	-	-	-	-	(10)	(5)	90	(43)	42	-	42	17
7	-	-	-	-	(10)	(5)	97	(46)	46	-	46	14
8	-	-	-	-	(10)	(5)	104	(50)	49	-	49	12
9	-	-	-	-	(10)	(5)	112	(54)	53	-	53	11
10	-	-	-	-	(10)	(5)	120	(58)	57	-	57	9
11	5	-	(5)	-	(10)	(5)	139	(62)	74	-	74	9
TOTALS	(329)	-	329	-	(110)	(55)	990	(440)	336	-	336	(9)

Table 8.6 Financial Payback Analysis

Condensed from BIRMID QUALCAST

justification proposal form BQ-526 (units: £'000's).

## SECTION 9

### DISCUSSION

Whilst the cost of microprocessor based controllers has decreased over the years, the cost of making use of the controllers is not cheap. Effective use of this equipment is achieved with their application in the FMS design. The interfacing of programmable controllers with the grinding and hardening machines creates flexible machine units from previously special purpose designs. The controllers also provide the interface to the "host" controller of the system. The financial benefits that can be obtained by the automation of batch production, with the variable product and process mixes, will enable the cost of the automation to be recovered with cost savings over a 10 year life of the FMS. The cost/benefit analysis is the best indicator of the strength of installing the FMS. Expected advantages of savings in energy, materials and downtime, improved reliability, easier maintenance, low capital and operating costs, improved accuracy and quality can be established more reliably after the implementation of the system.

#### 9.1 IMPLEMENTATION

##### 9.1.1 Turn-key development

With the introduction of the new technology into SLM it is prudent to implement the project in small steps proving the technology step by step. This includes the implementation of Phase I. The control hardware and software technology is to be bought-in because it is commercially available. It is both necessary and desirable to sub-contract the control development as the company does not have the required NC expertise. This raises several important factors in the control supplier/user relationship:

- i) The time spent on user site should be effectively used
- ii) An identifiable and responsible person on both sides is required
- iii) The understanding of user needs by the supplier is crucial
- iv) Involvement throughout the project from design, through commissioning to full scale operation is required of the two parties
- v) Good after-sales support is necessary
- vi) Good documentation is necessary

The new technology also raises further requirements of the user (SLM) company. Apart from a broad understanding of the technology SLM must also realise the requirements for new skills and training, attitudes, work patterns and

industrial relations.

A valuable technology transfer will take place as the company learns how to apply the technology effectively. The FMS provides considerable benefits but the cost of disruption to the remaining production systems may be high if the implementation is not competently planned. The implication for management strategy is to introduce the technology gradually but to aim towards the high level of systems integration in the longer term.

The stepwise implementation (below) is detailed in diagram 9.1. It is preferable to develop the FMS at SLM in order for the company to obtain in-house experience with the technology. To achieve this the cell will be constructed at SLM under the site commissioning of the supplier of the control hard and software. SLM will free-issue the robots, hardening and grinding equipment with their control hardware ready for the development of the software.

#### 9.1.2 Implementation programme

The implementation programme will follow these steps:

- i) Prove the MIG/MAG welding processes (1)
- ii) Develop the tooling for welding operations (2)
- iii) Develop the welding programmes on robot for 12 inch handmower cylinder (3)
- iv) Develop the grinding (wheel plunge) techniques for 12 inch handmower cylinder (4)
- v) Integrate the robotic transfer of 12 inch handmower cylinders for the welding and grinding processes under the control of the "host" computer (5)

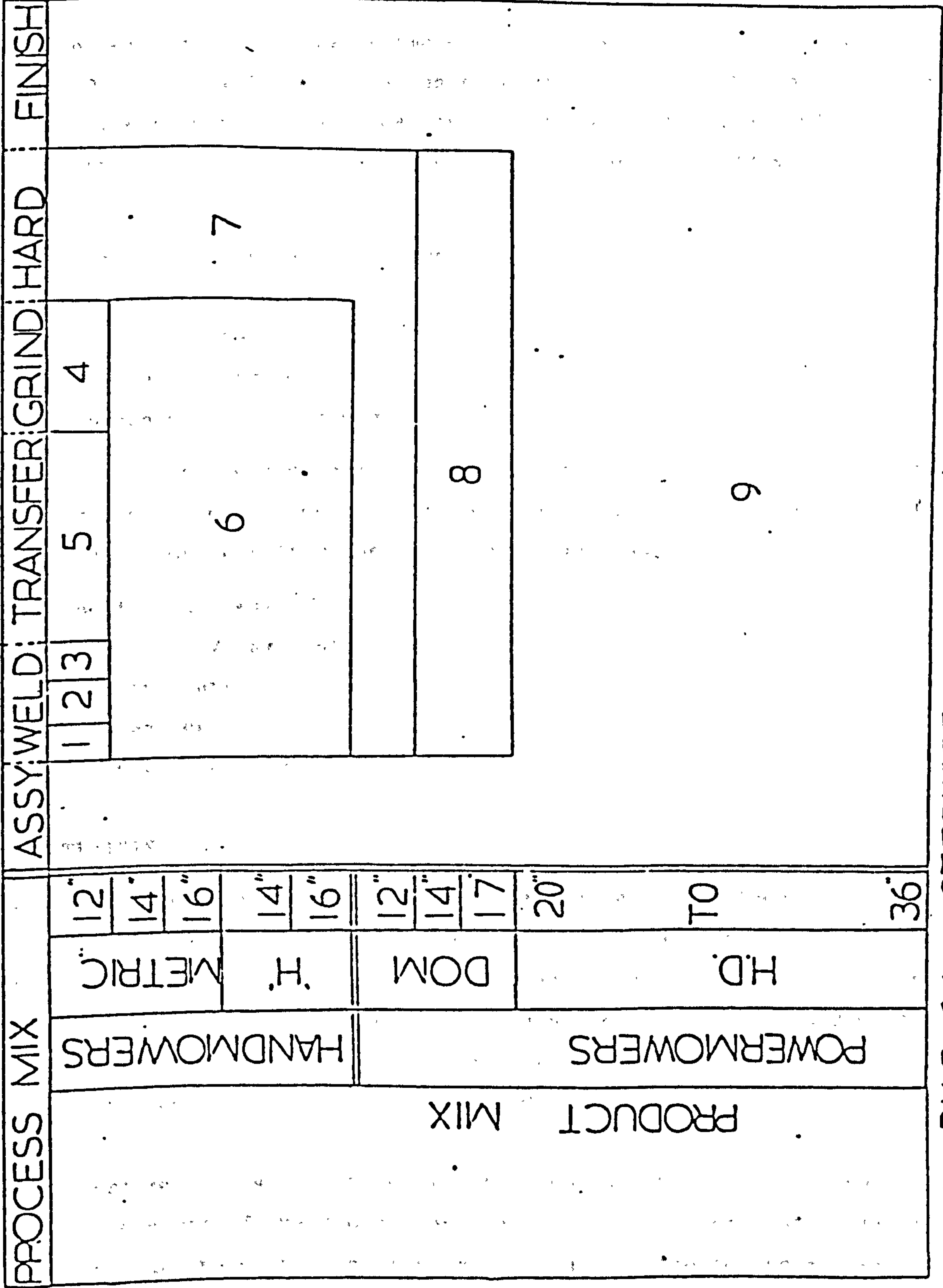
At this stage the FMS will have achieved the capability of producing the 12 inch handmower cylinder and will begin to accrue the cost savings.

- vi) Expand the above system capability to encompass all handmower cylinders by development of the extra tooling, robotic welding/transfer programmes and the grinding programmes required (6)

The system will now have the capability to process all handmower cylinders.

- vii) Develop the hardening process for 12 inch power mower cylinders and integrate this into the system for the manufacture (welding, hardening, grinding and transfer) of powermower cylinders (7)

PHASE I  
 CONSISTS OF  
 STEPS 1 TO  
 8.



DIAG. 9.1 STEPWISE IMPLEMENTATION MAP



The system will now have the capability for all handmower and the 12 inch powermower cylinders.

- viii) Develop the tooling and integration of the welding, (8)  
hardening and grinding processes of the remaining  
powermower cylinders to expand the capability of the  
system to all cylinders up to 17 inches in length

## 9.2 DEVELOPMENT TEAM

The time periods for the major implementation activities are shown in diagram 9.2. It will take two years for the system to be totally integrated into the company. To successfully accomplish this, a qualified development team must be established. The team will consist of (diagram 9.3):

- i) a project co-ordinator/controller
- ii) a system operator
- iii) a system setter
- iv) a system supervisor
- v) a process/production engineer

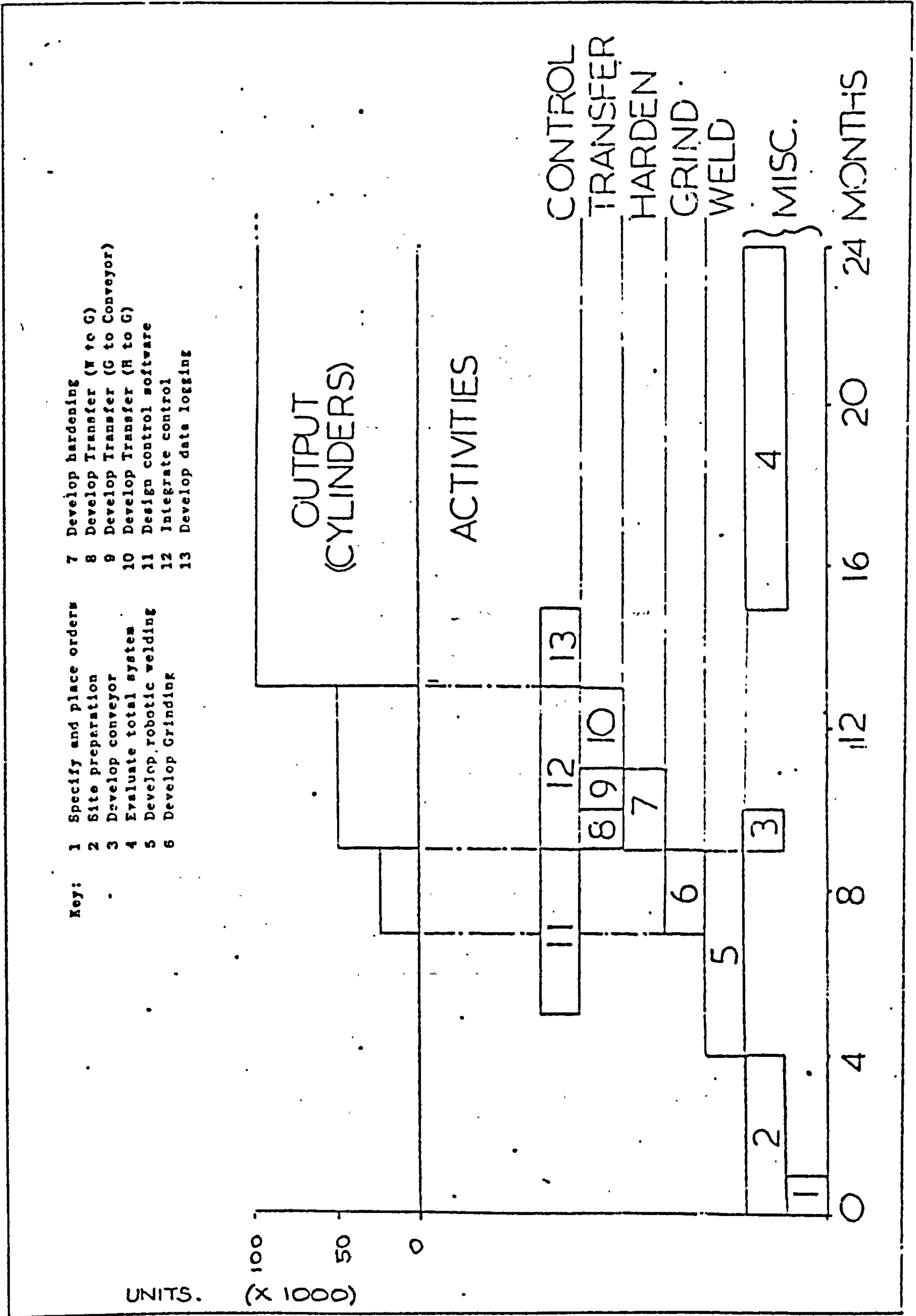
This team will be responsible for ensuring the technology of the FMS successfully produces the cylinders. It must report to a production liaison team consisting of members from the following functions:

- i) Tooling and Design
- ii) Production Management
- iii) Quality Control
- iv) Maintenance
- v) Production Control

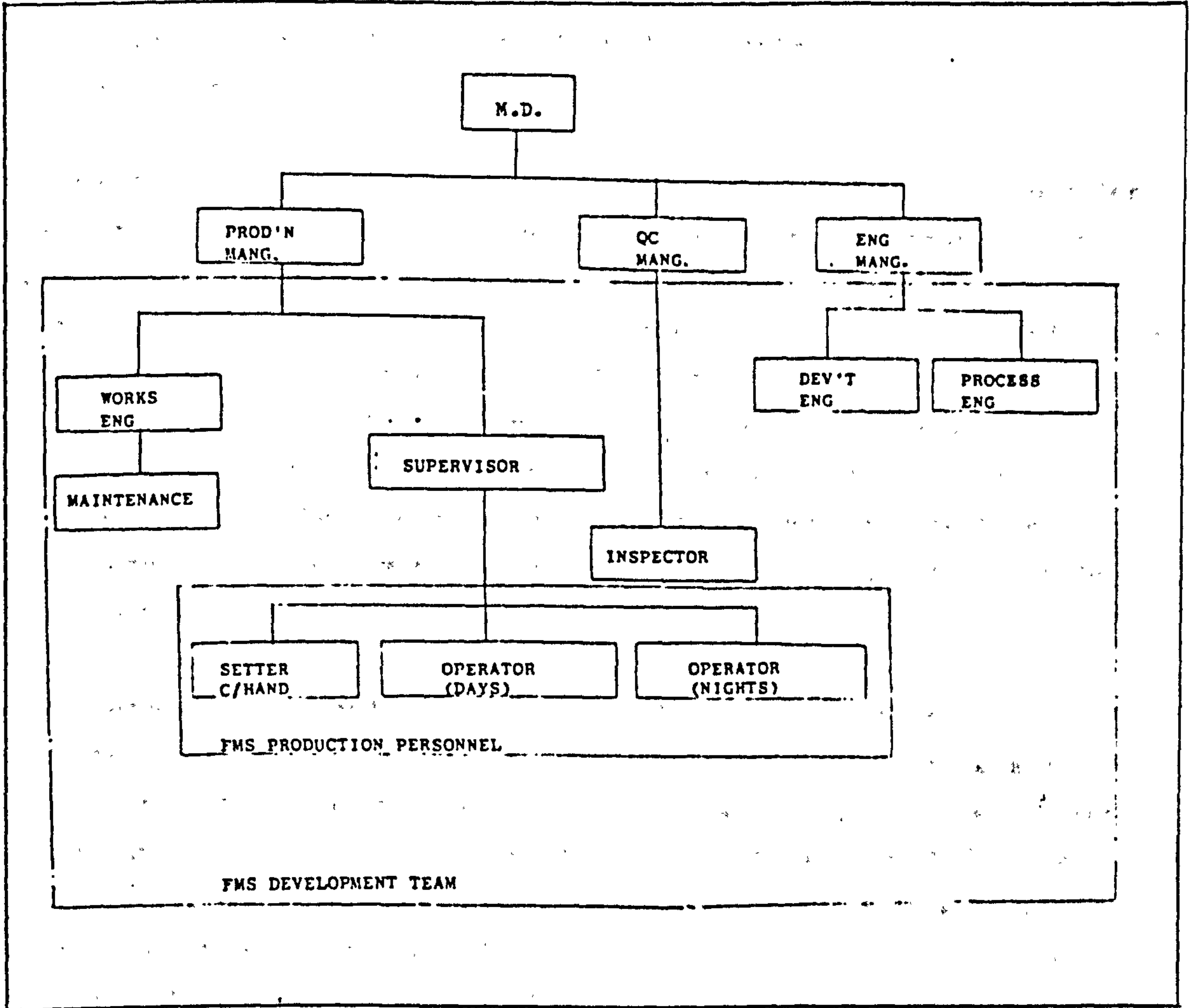
## 9.3 TRAINING

New or modified skills are required for almost all the labour groups of the company. Operators will be faced with the new procedures and equipment and will need competent training. The maintenance staff will have to cope with sophisticated electronics and self-diagnostics. The management of the above functions has the responsibility for overseeing the change and ensuring a smooth introduction of the FMS.

Rather than rely on sub-contract maintenance, which can relinquish a certain amount of control of the production facilities, it is prudent to train the company's maintenance personnel thereby obtaining the necessary skills in-house. There are big advantages to be gained with the familiarity that the



DIAG. 9.2 DEVELOPMENT PROGRAMME



DIAG. 9.3

FMS PERSONNEL

maintenance staff will have with the equipment. Once trained they can be useful quickly with the company retaining control by having the skills in-house. This approach offers the opportunity of retraining staff displaced from other functions which helps to develop a flexible, high quality workforce, thus cushioning the impact of the FMS's introduction. This is discussed by Parrish (1981).

The attitude to change and resistance to the new technology must be considered from the start. Fears of job loss must be allowed for. For many people, the new technology has appeared long after their original training and they have to make major changes to adapt to it. The provision of clear and freely available information may counter this. The implementation of the project must be carried out with participation of the unions in the company. Due to the 1980-82 recession with the subsequent redundancies in the UK, the prevailing attitude of the unions is that of encouraging investment in capital equipment as a commitment to future jobs. However, this attitude must not be assumed.

Changes in responsibility and in the power/influence structure also need to be anticipated. The introduction of on-line production monitoring may well change the character of supervisory jobs as information will now be instantly available to anyone via visual display instead of through the traditional written/verbal system. For the project to be a success, it is essential to provide clear information, open discussion and involvement of all concerned. Careful monitoring of commissioning and implementation with a quick response to problems will expedite the success of the project.

To assist the technology transfer the company has rebuilt a special purpose machine (totally divorced from the FMS) with a programmable controller sequencing the operations. This will provide early experience for the company personnel.

## SECTION 10

### CONCLUSIONS AND RECOMMENDATIONS

#### 10.1 GENERAL CONCLUSIONS

The concepts of Flexible Manufacturing Systems are appropriate in the design of an automated production system at Suffolk Lawnmowers Ltd. Flexibility is required for the present systems variable product process and batch size mixes. Alternative degrees of automation have been recognised as appropriate for short and long term development. Particular attention has been directed at the design of a robotic Flexible Manufacturing System which constitutes the initial phase for total automation. This Phase I automates the eight following cylinder designs encompassing the stages of welding, hardening, grinding and transfer.

<u>Part No</u>	<u>Cylinder description</u>
L21605	12 inch Handmower (metric)
L21607	14 inch Handmower (metric)
L21614	16 inch Handmower (metric)
L07014	14 inch Handmower (H-type)
L07015	16 inch Handmower (H-type)
L08649	12 inch Powermower (Domestic)
L08725	14 inch Powermower (Domestic)
L21935	17 inch Powermower (Domestic)

The company (Suffolk Lawnmowers Ltd) has accepted the conclusions of the research and the recommended design of the FMS for Phase I (see below). The timing of the Phase I implementation is currently under review with the intention of commencing construction during the 1982/83 financial year. The DoI has agreed to fund 50 per cent of the capital and development costs with a cash grant.

The FMS has the potential for expansion. A second phase of automation duplicates the capacity and capability of the Phase I system to all 21 cylinder designs. Further long term phases will encompass the degreasing, painting, component manufacture and assembly processes.

#### 10.2 MAJOR CONCLUSIONS

(i) The most appropriate form of system design (Phase I) is shown in table/

diagram 10.1. The welding, hardening and grinding stations are configured around the transfer robot for automatic processing of cylinders of up to 17 inches in length and 6 inches in diameter. (Section 7.2). A fifteen month development period is necessary with a nine month nursing-in period.

(ii) Experimental work (Section 6.2) has indicated that the critical stages of welding, grinding and hardening can successfully be automated providing:-

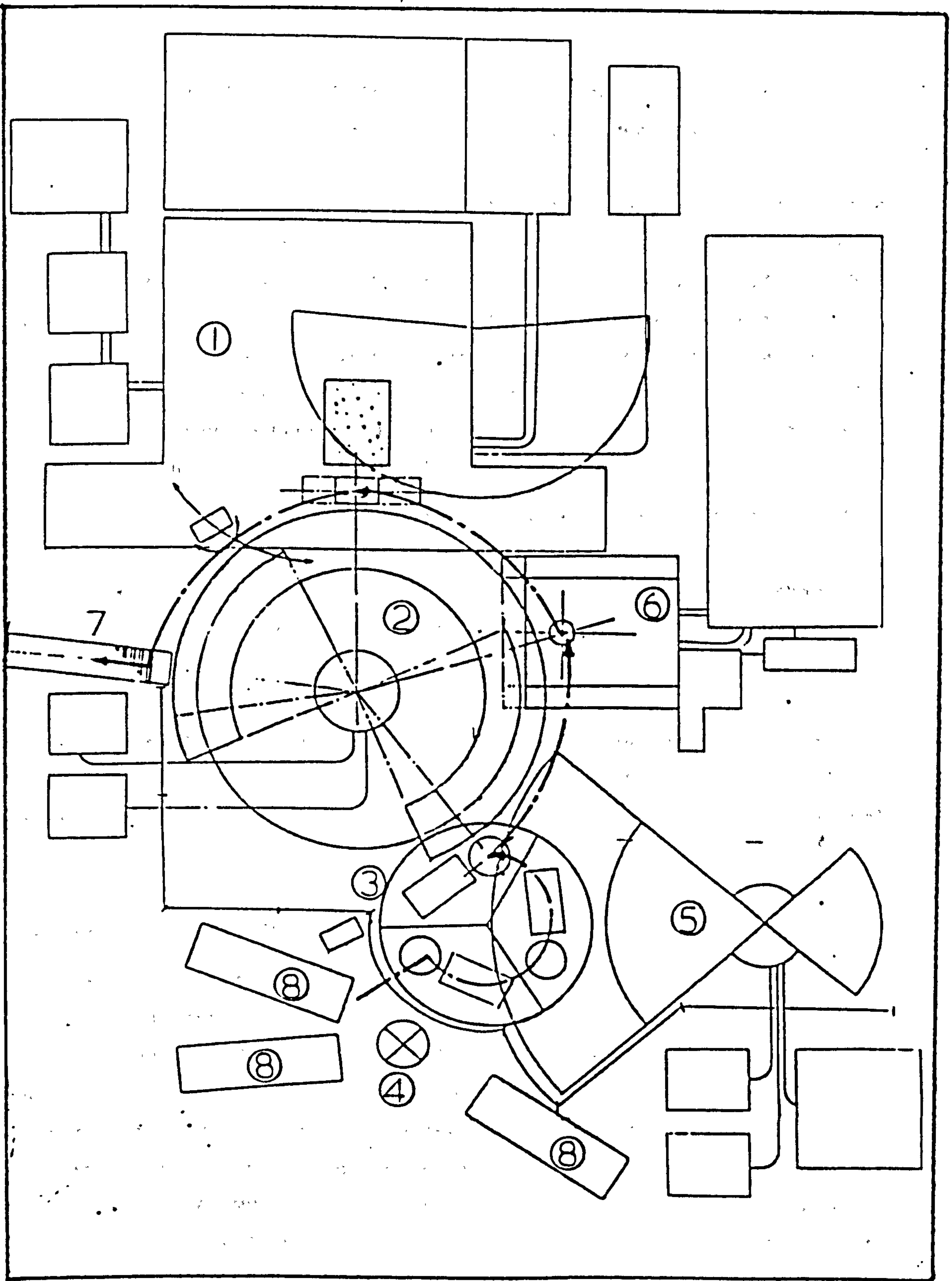
- a) The Argon Arc (Metal Inert Gas) welding process, using an 80 per cent CO<sub>2</sub> and 20 per cent Argon mixture, is used for power and particularly handmower cylinders.
- b) A computer controlled, continuous-path, 5 axes robotic manipulator is used for the manipulation of the welding gun for cylinder fabrication. This will raise the welding quality of lawnmower cylinders. The robot recommended is the GEC-Hall Automation "Merlin" welding robot.
- c) Progressive (natural gas) flame hardening with a 35 per cent polymer quenchant mix is required to harden power-mower cylinder blade tips. This will raise the quality over the present process. The machine recommended is the Peddinghaus flame-hardening machine.
- d) Wide-face plunge cylindrical grinding is recommended for the sizing of all cylinder diameters. The feed required is 0.080 inches over 10 seconds - no dwell - 0.010 inches in 10 seconds - dwell - return. This will maintain grinding quality and reduce the process cycle time. The machine recommended is the Newall SA cylindrical grinding machine.

(iii) A computer controlled, point-to-point, 5 axes robotic manipulator is required for the flexible transfer of cylinders between the process machines. A double gripper is necessary to achieve an output of 30 cylinders per hour (Section 4.2 and 7.2). The robot selected is the GEC-Hall Automation "Little Giant" transfer robot.

(iv) Decentralised hierarchical computer control creating a DNC cell, is required to sequence the FMS processes. A micro-controller is required for the control of the overall system sequencing. Programmable logic controllers (microprocessor based) are required for the individual control of the grinding and hardening machines.

FUNCTION:	<ul style="list-style-type: none"> <li>i) To fabricate manually assembled cylinders by M.I.G. welding blades to spiders and spiders to spindles.</li> <li>ii) To harden blade tips of power mower cylinders to a depth of 6 mm at 42 Rockwell 'C' scale.</li> <li>iii) To grind the cylinder outer diameters to a parallel form without the production of any burrs on the blade tips.</li> <li>iv) To automate transfer of cylinders throughout the system.</li> <li>v) To automate the control of the operations (i) to (iv) above.</li> </ul>																		
PROCESS MIX: (EQUIPMENT)	<ul style="list-style-type: none"> <li>welding - 1 off - Hall Automation 5-axes electro-hydraulic continuous path robot.</li> <li>tooling - 1 off - 360 degree rotary turntable of 3 stations (load/weld/unload) each containing a first and a second assembly fixture.</li> <li>transfer - 1 off - Hall Automation 4-axes electro-hydraulic point to point robot with double gripper mechanism.</li> <li>hardening - 1 off - Peddinghaus single burner (ring) progressive flame hardening machine with polymer quenchant (35% concentration).</li> <li>grinding - 1 off - Newall SA 17½ inch wide wheel plunge cylindrical grinder.</li> <li>control - 1 off - G.E.C. GEN.80 control system consisting of 1 off - 246 micro controller (host) computer, 1 off - 130 micro controller (hardening) and 1 off - 100 programmable controller (grinding), plus serial interfacing and keyboard/video peripheral equipment.</li> </ul>																		
PRODUCT MIX:	<table border="0" style="width: 100%;"> <thead> <tr> <th style="text-align: left;"><u>Part No:</u></th> <th style="text-align: left;"><u>Description:</u></th> </tr> </thead> <tbody> <tr> <td>L.21605</td> <td>12" Metric hand mower cylinder</td> </tr> <tr> <td>L.21607</td> <td>14" Metric hand mower cylinder</td> </tr> <tr> <td>L.21614</td> <td>16" Metric hand mower cylinder</td> </tr> <tr> <td>L.07014</td> <td>14" 'H'-type hand mower cylinder</td> </tr> <tr> <td>L.07015</td> <td>16" 'H'-type hand mower cylinder</td> </tr> <tr> <td>L.08469</td> <td>12" Punch domestic power mower cylinder</td> </tr> <tr> <td>L.08725</td> <td>14" Punch domestic power mower cylinder</td> </tr> <tr> <td>L.21935</td> <td>17" Punch domestic power mower cylinder</td> </tr> </tbody> </table>	<u>Part No:</u>	<u>Description:</u>	L.21605	12" Metric hand mower cylinder	L.21607	14" Metric hand mower cylinder	L.21614	16" Metric hand mower cylinder	L.07014	14" 'H'-type hand mower cylinder	L.07015	16" 'H'-type hand mower cylinder	L.08469	12" Punch domestic power mower cylinder	L.08725	14" Punch domestic power mower cylinder	L.21935	17" Punch domestic power mower cylinder
<u>Part No:</u>	<u>Description:</u>																		
L.21605	12" Metric hand mower cylinder																		
L.21607	14" Metric hand mower cylinder																		
L.21614	16" Metric hand mower cylinder																		
L.07014	14" 'H'-type hand mower cylinder																		
L.07015	16" 'H'-type hand mower cylinder																		
L.08469	12" Punch domestic power mower cylinder																		
L.08725	14" Punch domestic power mower cylinder																		
L.21935	17" Punch domestic power mower cylinder																		
LAYOUT	(See diagram 7.8).																		

TABLE 10.1 FMS FUNCTIONAL SPECIFICATION (SUMMARY)



KEY

- 1 GRINDING MACHINE
- 2 TRANSFER ROBOT
- 3 TOOLING TURNTABLE
- 4 OPERATOR/LOADER
- 5 WELDING ROBOT
- 6 HARDENING MACHINE
- 7 CONVEYOR
- 8 COMPONENTS

DIAG. 10.1

FMS LAYOUT  
(PHASE ONE  
CONFIGURATION)



(Section 4.4 and 7.2). GEC's GEM/80 programmable control system is recommended for both hardware and software requirements.

(v) The cost of the capital equipment, installation and development of the FMS investment is estimated at £333,000. Training and maintenance costs are estimated at £10,000 per annum for the ten year life of the system. A successful case has been made for external support of the capital costs. The Department of Industry has confirmed that 50 per cent of this cost will be grant aided. Thus the net cost of the investment to the company (163,000) can be recovered in 2 years and 4 months against labour and material savings (Section 8).

a) The ARR is 24% with a 4.0 year payback period without grant aid, or 50% with a 2.0 year payback period with grant aid.

b) The DCF Internal Rate of Return is 30% with a 4.4 year payback period without grant aid or 45% with a 2.3 year payback period with grant aid.

(iv) The system will be capable of producing 96 thousand cylinders per annum on a 2 shift basis at a level of 80 per cent utilisation. Higher output can be obtained by developing and increasing the system's efficiency.

### 10.3 FURTHER RECOMMENDATIONS

(1) The construction of the first phase of the FMS will require evaluation of the operational performance of the equipment. The estimated cycle times of the cylinders should consistently be achieved. Company policy should be to initiate an investigation into the equipment and system's reliability with the objectives of implementing preventive maintenance and determining the achievable cycle times. The specification of the programmable controllers enables automatic recording of management and operational information. Therefore the efficiency of the system should be measured, particularly

- increases in quality obtained
- increases in quality consistency
- reductions in rejection levels
- increases in machine utilisation
- increases in output per shift
- increases in material savings

(ii) Training and education in the technology of the in-house workforce if imperative particularly

- the operators and setters of the system
- maintenance personnel
- staff, supervision, production planning

(iii) A post-audit analysis should be carried out to determine the economics of the system and to ensure that the anticipated payback is achieved.

## SECTION 11

### SUGGESTIONS FOR FURTHER WORK

The potential to expand the automation objectives to other production processes is possible.

Further detailed investigations are required to integrate the designs of the subsequent phases of automation into the recommended phase design in order to achieve the long term automation objectives. These will include evaluation of the commercially available paint spraying robots, degreasing equipment and automatic wire-guided vehicle systems.

Automation of the production of the components which are assembled into a cylinder require an in-depth investigation for the most suitable production methods (Section 7.1). The automation of component processes include:

- i) Development of the automation of turning, drilling, broaching and grinding processes of spindle production
- ii) Development of the automation of roll forming, cropping and twisting processes of blade production
- iii) Development of the automation of presswork for spider production
- iv) These processes should be organised into production cells with automatic transfer from these cells to the Phase I and II systems.

To enable this level of automation, automatic assembly of the components is required.

These programmes of automation require careful economic analyses to ensure satisfactory financial returns on the cost of the capital equipment and the large development costs that will be incurred.

## APPENDICES

### 1. REVIEW OF EXISTING FLEXIBLE MANUFACTURING SYSTEMS

#### 1.1 EVOLUTION OF FMS

##### 1.1.1 Academic Development of the FMS

Most FMS have evolved as a result of commercial interests although many universities and institutes have cooperated with some relevant research and development programmes. Weck (1979) has found that FMS for rotational workpieces are relatively rare compared with those for prismatic pieces.

The concept of automatic machining with automatic material transfer was first developed in the UK by Molins Ltd (Stephenson (1969)) in 1967 with the Molins System 24. This consisted of three special purpose three axis milling machines with high speed spindles for the machining of light alloys. The flexibility arose from the capability of being able to machine different components from a common block of raw material (aluminium). Only one total system of this innovative concept was sold and is still working in the USA. Work transfer was by pallets on conveyor feeding pendulum loading stations (Williamson (1968)).

About the same time in the USA, the Cincinnati Milacron Variable Mission System of machining centres, with pallet and roller conveyor transfer, was designed. The system also included multi-spindle NC machines with spindle head changing capability. The system is now commercially available with programmable cart transfer for the pallets (Perry (1969)).

The Sundstrand Corporation of the USA also developed an NC line with a pallet and roller conveyor system. It has been built on order from 1967 using Omnimill 5 axis machining centres. It operates on magnesium alloy components for speed control mechanisms in aircraft over a 24 hour period per day. Their maximum component capacity is 400 mm x 400 mm (Brosher (1967)).

These systems were initially of the tape numerical control type. By 1968 CNC and DNC systems were sufficiently developed for use with FMS (Feinberg (1968)).

In 1971 the East German firm VEB "7 October" built the Rota-F-125-NC FMS which consisted of independent CNC machines under DNC control. Unlike the three prismatic systems above, this system was for rotational components up to 125 mm in diameter. The system includes four lathes, two milling machines, one cylindrical grinder and a storage facility. The system was first introduced at the Leipzig Spring Fair (Berthold (1975)). At the same fair in 1972 the same company introduced the Rota-FZ-200 rotary FMS for gear production for the whole of the German Democratic Republic. With optimising control, i.e. control decisions being made off-line and then implemented on the system, it takes gear blanks from (60-200 mm diameter) from a three tier pallet by a stacker crane which loads the buffer stores or machine loading stations. Transfer onto the machines is by simple robot of the gripper, arm and slides type. The system comprises of all standard machine tools so that the modularity of the system has enabled successful exportation to the USSR and Poland. The exported systems are of greater capacity producing one million gears per annum using 52 stations, 5 stacker cranes and roller conveyors, whereas the East German system produces 150,000 gears per annum on a 15 shift per week basis.

Also in 1972, the East German company VEB Auerbach implemented its DNC system for prismatic parts up to 400 mm. The USSR also developed a rotational (AUIRota) and prismatic (System Prisma) at the Enims and Orgstankinprom Companies respectively (Willhelm (1976)). They are fully operational.

Japan had developed at this time several prismatic and rotational DNC systems which were unveiled at the 6th International Machine Tool show in Tokyo, (Pfeifer (1973)). Of the prismatic systems were included the Toyota "Tripos" system, the systems of the Makino Milling Machine Company, the Nigata Engineering Company and a system used at the Toshiba Company. The rotational systems included Fuji's "Elmer-10" system, the Ikegai System, Wasions "Fk" system and the Okuma Company's "Parts Centre 1" system which also included heat treating, grinding and inspection functions (Barash (1976)).

In the same year Sundstrand built a large prismatic system for Ingersoll Rand at Roanoke, USA (Osborn (1972); Cook (1975)) and an even larger system

for the Caterpillar Company, Illinois, USA (Williams (1974)). The first system machines iron casting and steel forgings of a 915 mm cube capacity. It consists of two five-axis OM3 Omnimill machining centres, two four-axis OM3 machining centres and two four-axis OD3 Omnimill drills. All machines have an automatic tool changing facility. The system can transfer 2250 Kgf unit loads and upto 16 different parts at one time. The controller is an IBM 360/30 computer which controls the pallet transfer system and a conveyor loop, using Motorola magnetic identification cards. The second system uses four OM3 omnimills, three OD3 Omnidrills, two vertical turret lathes, and one digital inspection machine. The system is controlled by a PDP 11/20 computer. The shuttle car workpiece transfer system consists of two automatically controlled Conco tractor type transporters with cross-travelling shuttle mechanisms. The transporters are on two rails between two machine rows therefore a buffer store is created on the transporter itself. A Sunstrand Omnicontrol computer controls the whole FMS.

In 1973 Kearny and Trecker of the USA built an FMS for the Rockwell Company (Sandford (1973)) and the Allis Chalmers company at Milwaukee. The first system machines truck axles using six K and T 3630 Modu-line 3 axis machining centres, one vertical turret lathe and a digital inspection machine. An Interdata 700 computer controls the system with another Interdata controlling the workpiece handling. The system has a pooled buffer stock with workpieces being moved into localised queues. The second system machines tractor components using a milling machine, five Milwaukee Matic Machining Centres and four Duplex multi spindle head index units. Two control computers are used. One for the machine tools (DNC) and one for the materials handling. Eight components can be machined using 24 three-wheel (tow) trolleys on an under-floor chain mechanism.

These American FMS have been developed with considerable cooperation of their universities (Milwaukee-Wisconsin and Purdue).

The "Prisma-2" FMS built in East Germany in 1973, has been described as the most technological sophisticated system (Hutchinson (1979)). It is situated in a 180 x 50 x 30 metre controlled environment room being of 100 x 25 metre size itself. It machines castings of 1 x 1 x 1-6 metres

maximum for the Fritz Heckert Company's machine tool range. The pallets for the workpieces sit on air cushions and are driven by linear induction motors. There are two inspection stations. Part programmes can be updated on-line to compensate for casting dimensions and tool wear allowances. The parts can also be washed to clear chips.

The "PC-3" system constructed at Erfurt in East Germany has a 57 metre straight track with one cart servicing 14 locations including five large Svoda machine tools. As a typical work cycle time of 100 hours is common, infrequent workpiece movements (weighing 24 tons) over 7 metres can be handled. One hundred and twenty parts can be processed at a rate of two and a half per day.

In 1975 at the first EMO exhibition in Paris the Mauserschaere company demonstrated a turret type robot servicing a vertical NC lathe and an NC machining centre. This was the initial indication that the FMS concept need not apply to very large systems only. Liebherr GmbH also demonstrated a robot serving four of their machine tools at the show.

#### 1.1.2 Academic Development of the FMS

Since 1975, with these major innovations, other countries have taken up and are developing the FMS approach to batch production. Rathmill (1980) has highlighted the major research area as follows. In East Germany since 1978 at the Research Centre for machine tools, Karl Marx Stadt, work is being carried out on the development of fully automated machine cells in which support functions such as tool-flow are fully automated to achieve an FMS.

Also at the Technical University of Dresden, in East Germany, and the Machine Tool and Manufacturing Technical Institute, work on computer based machinability data optimisation models is being carried out in conjunction with the development of two linked DNC cells to create an FMS.

The Czechoslovakian VUOSO Machine Tool Research Institute has a 5 year programme to build six different prototype FMS, to cover a full range of workpiece types. In Hungary the Computer and Automation Institute in Budapest is building an FMS with robots for prismatic parts. This is in cooperation with the CZEPEL machine tool company.

The Bulgarian state Machine Tool Research Institute in Sofia has handed over, to ZMM industries, two tested FMS (one is rotational the other for prismatic parts). Both systems work side by side under one controller.

The KTH Royal Institute of Technology in Sweden and its industrial counterpart the IVF Institute of Production Engineering Research in Stockholm is investigating CAD/CAM production with limited manpower and the subsequent social implications of automation. Also in Sweden the ASEA-AC motor plant has a minicomputer-robot integrated manufacturing cell to produce motor shafts and end plates in large batch sizes. It works on a day and night shift with minimal manual supervision.

The UK has been very slow to develop any FMS. The 600 Group has undertaken a rotational parts FMS using essentially existing machine tool hardware. Additionally the Ingersoll Rand UK plant has installed expensive machining centres and is intending to develop it into an FMS progressively. Recently in 1981, Kearney Trecker Marwin, at Normalair-Garret's plant, has set up a two-machining centre FMS. However other companies like GEC and BOC have dropped out due to the cost. Sims (1982) provides a good description of the present and future work on FMS in the UK.

The number of FMS in the world has been counted by Collins (1980) at twenty six in Japan, ten in the USA eight in West Germany, four in East Germany, three in Czechoslovakia, two in Sweden and one in Norway. There are four prismatic FMS to every one rotational system. These numbers are increasing every year. The largest is the Sundstrand Rockford System which has seventy machines. On average 250 components can be processed with up to 20 components in circulation at any one time. Prismatic parts can be up to the size of a two metre cube weighing 1600 kg. On average 4000 parts per month on a three-shift basis can be maintained. Up to 90 per cent efficiency has been claimed with eight machines for batches of 50 or less. The existing older systems have lasted up to 17 years work (on a single shift equivalent) and the cost can be up to 4 to 7 million US dollars spread roughly 50:50 on the machines and the control. Collins believes a second generation of smaller systems is possible.



Willhelm (1976) has accurately classified the world's FMS according to country, type of workpiece spectrum, type and number of operations available, stage of development and workpiece transfer system. He finds the USA is predominantly prismatic in its FMS developments whilst Japan has mainly rotational FMS.

Hutchinson (1979) describes the East German systems as the most technical, with the Japanese as being the most ambitious with their announcement of the methodology for Unmanned Manufacture (MUM) programme. The original objectives were the design and development of a factory manned not by 600 people but by only 20. This programme has since been modified to more realisable objectives. He believes that as West Germany is the leader in machine tool exports it could easily be the future leader in FMS technology. However it is the USA who is the leader in economic production from FMS.

The size of application in physical layout, number of machines and total cost of FMS is continually reducing to levels where smaller companies can afford such systems. The difference is pointed out by Hartley (1982) when describing the Yamazaki FMS in Japan, which cost £9 million, compared to the Murata FMS, again in Japan, which cost less than half a million pounds sterling.

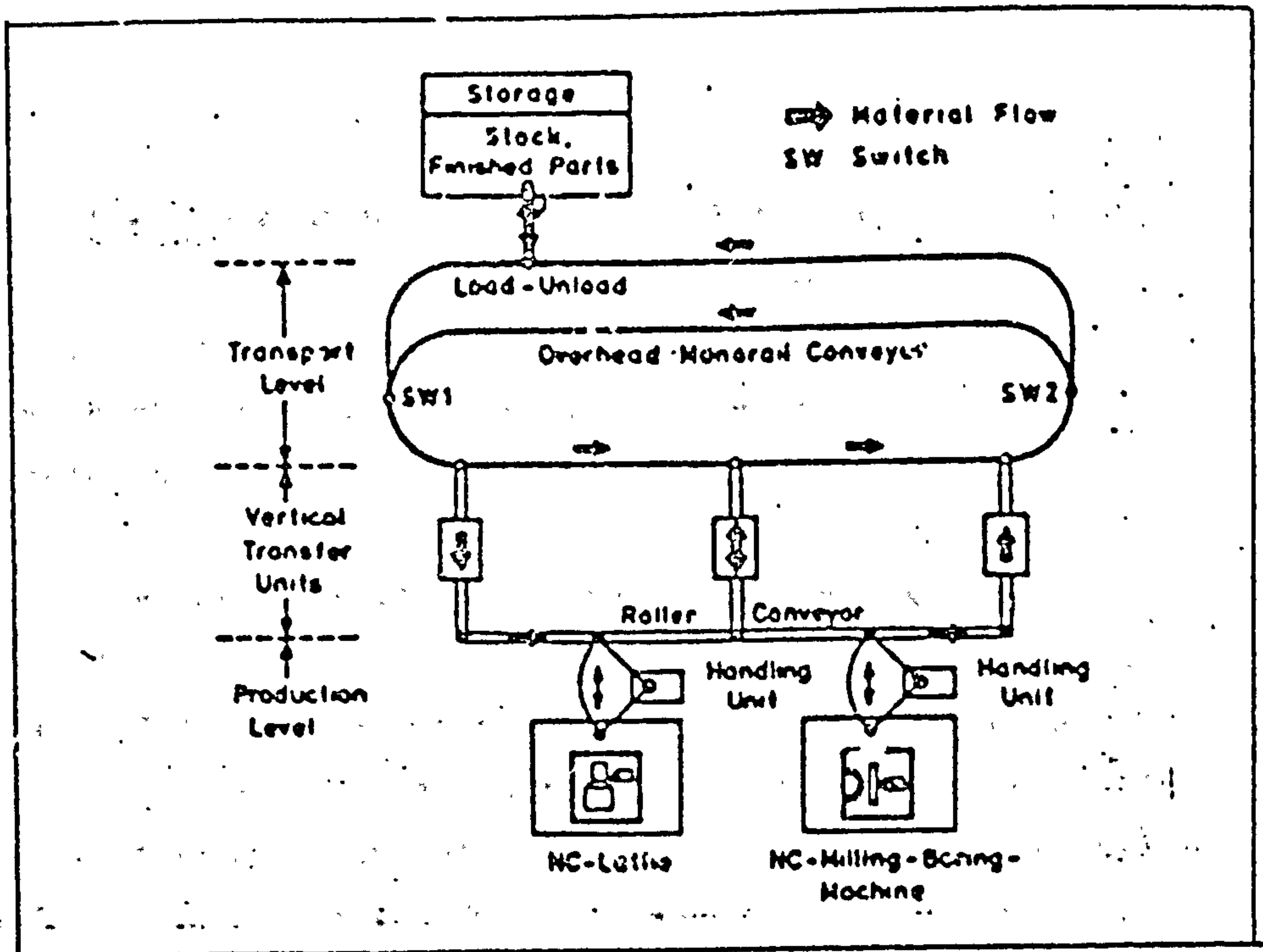
## 1.2 POTENTIAL FORMS OF FLEXIBLE MANUFACTURING SYSTEMS RELEVANT TO SLM LTD

### 1.2.1 West German Developments

Flexible manufacturing systems have been developed in West Germany both in industry and the technical universities.

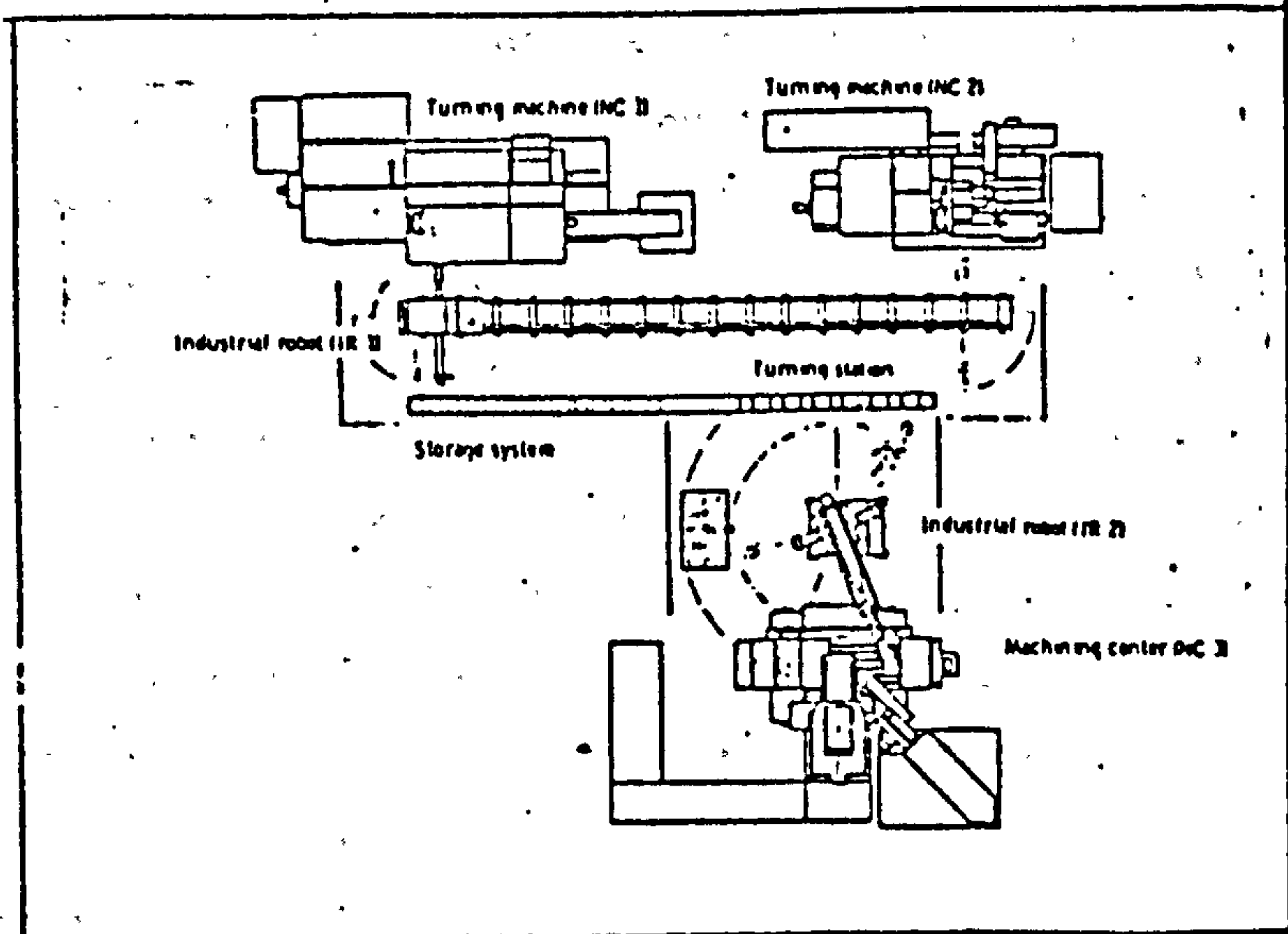
#### i) Berlin University (diagram A.1)

Professor Spur (1977) has developed a rotational FMS at the laboratories of Berlin University from standard machine tools and handling systems. The system consists of a universal NC turning machine, a coordinate turret drilling/milling/boring machine (NC), two work handling systems, a power driven roller conveyor and the control system. The two transport systems of different designs are the main components of the material flow system. The work pieces are carried on standardised pallets. The pallet transfer is arranged on two levels. Near the



DIAG. A.1

THE BERLIN UNIVERSITY FMS



DIAG. A.2

THE AACHEN UNIVERSITY FMS

machine tool area they move at working height (1st level) on the power-driven roller conveyor. A second level above the previous one is provided by the overhead monorail conveyor, which connects the machining area with the loading and unloading stations. The two levels are connected by three vertical transfer units.

The monorail conveyor consists of a main track and an auxiliary loop containing the loading and unloading stations. There are two track switching points to feed the main and auxiliary track. Vehicles fitted with electric drive utilise the rail to transport pallets. The FMS is laid out for the machining of rotational parts. Usually the workpieces are first turned on the NC lathe and then transferred to the milling machine. The handling systems are robots. One, a VFW Fokker Transferautomat-E is controlled by a programmable controller with a plug board containing 62 steps and 10 command potentiometers per axis. The other, a Hawker Siddely Versatran 500P, has a flexible controller for programme and sequence interlocks with a Guildemeister CNC control and 30 discrete positions by command potentiometers.

A vertically armed handling unit with double gripper for blank and finished parts handling of workpieces has been integrated with an NC lathe for the development of a rotational Flexible Manufacturing cell. Components are transferred to/from the chuck and the pallets. The whole system is numerically controlled. The grippers are actuated by hydraulic drives and are programmable for different gripping diameters. The machining system is equipped with an automatic jaw changing unit. A jaw magazine is axially and rotationally moveable around the chuck. Three jaws of a set can be radially positioned in the T-slots of the chuck according to the required clamping diameter. Systems for quality control and tool-break detection for integration are being developed so the requirements for a high level of automation and flexibility can be achieved. Components from 40 to 300 millimetres can be automatically machined without setting, loading and tool exchange interruption for a shift. The systems are described by Merchant (1975) and Spur (1979).

ii) Aachen University (diagram A.2)

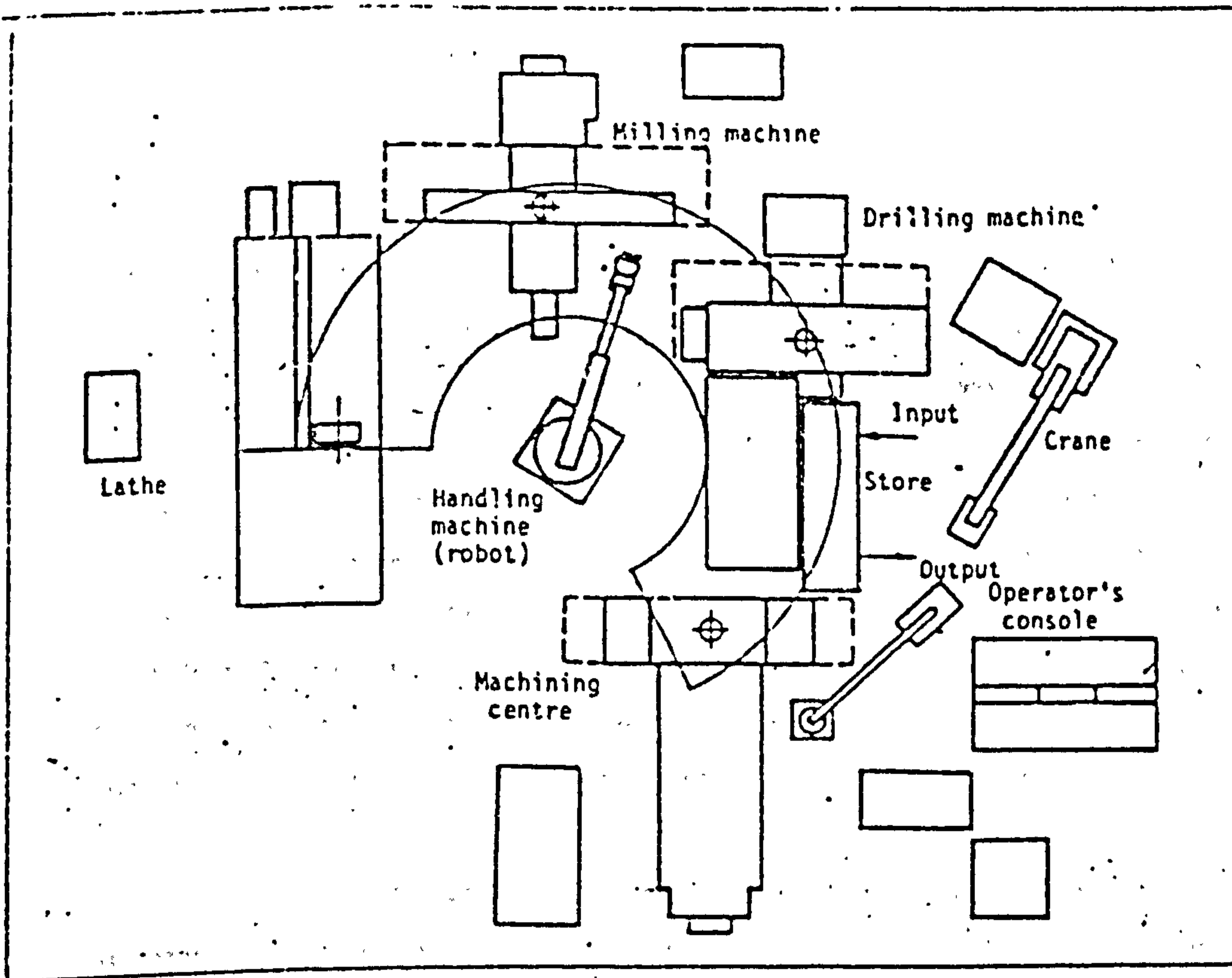
A rotational FMS has been developed at the Machine Tool Laboratory, Aachen University. The NC turning machines and an NC machining centre are interconnected with respect to the material flow by means of two handling devices. Loading and unloading of both machine tools is done by a 5-axis linear industrial robot that has access to raw and semi-finished parts in a central storage system. The machining centre is also supplied with parts from the central storage by a folding-arm robot. Rotational parts that require further machining may be handed over to the machining centre at particular places in the central storage unit that are laid out as turning stations. The whole system is under the control of a central manufacturing computer. A CAMAC-DNC peripheral system is used for data transmission. Additional synchronisation signals required by the handling devices when loading or unloading as well as extended NC functions are processed in hardwired CAMAC modules. Unlike pallets in other FMS workpieces are not mounted on coded carriers. Weck (1979) describes the workpiece tracking as being carried out by software which identifies the workpiece numbers. In order to achieve a high degree of security elaborate software functions have been essential for checking the status of machines as well as that of the handling devices and storage stations. Five rotational workpieces are machined in the system, three are completely finished on the two lathes while two require operations on the machining centre.

1.2.2 Norwegian Developments

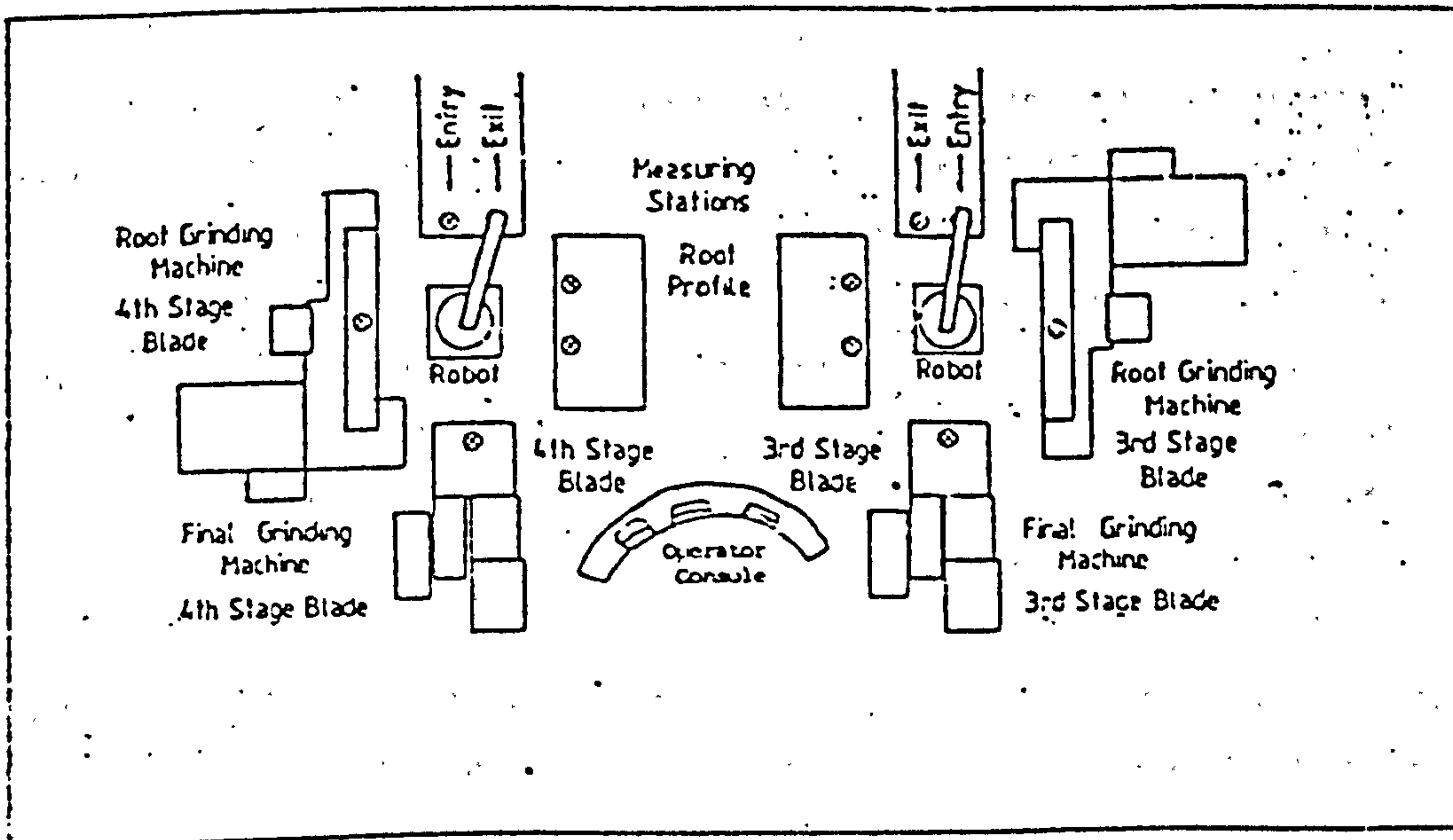
i) Trondheim FMS (diagram A.3)

In Norway where a manned nightshift is illegal the incentive for an unmanned FMS has assisted technological development.

Professor Oyvind BJORKE at the NTH SINTEF, University of Trondheim is developing a robotic cell for unmanned working. He believes man should be in the manufacturing environment only when and where he finds such duties acceptable. The Trondheim FMS comprises a manufacturing cell which as a whole employs some ten people. Their duties include setting up the "cell-core" and during the night it is this core only that continues working. A typical cell core incorporates



DIAG. A.3 THE TRONDHEIM ROBOTIC FMS



DIAG. A.4 THE RAMIGO ROBOTIC FMS

a heavy-duty robot, around which are grouped several CNC machine tools of different types including a machining centre and a stock and palletising station. Previously prepared work is taken by the robot from this station during night-time unmanned operation for transfer to the machines, and completed items are returned to it. Only normally commercially available plant is used in the cell as a whole and in the core. The way the existing technology is put together is innovatory. In a production area at Trondheim University a 4 machine cell core has been working since 1979 on a variety of workpieces submitted by Norwegian Industry for trial purposes.

The machine tools have their own NC or CNC controllers but are supervised by a central minicomputer on the next higher level. A workshop terminal (data display) is connected to this allowing the operators to interact with the system checking parts and allowing retrieval progress, machine loading and cell status reports.

Professor Bjorke (1977, 1978, 1979) describes the cell loading system. It is interfaced through the terminals. From time to time part requirements for a couple of periods are loaded in the system. At the beginning of a period the loading system is executed giving a set of lots as output. These lots will cover approximately one period. If the capacity requirements is a little less than one period the loading system will be executed with the next period's requirements a little too early. If the capacity needed exceeds that of the period remaining parts are added to the next period's requirement and the loading system operated. The cell loading system will thus normally be executed once every period. However if necessary a new loading can be executed at any time.

Since each lot contains a certain product mix in order to ensure high utilisation of the cell a certain proportion between the number of each product type present in the cell must exist. If not the optimal load profile may not be achieved. The operator loading parts needs a tool giving him information about how many of each part he should load, eventually within which limits he can select the number.

ii) Kongsberg: RAMIGO cell (diagram A.4)

The Kongsberg company is investigating methods of automating small batch high value components with robotic supervision of creep feeding grinding operations. In the Robotics and Automated Measuring in Grinding Operations (RAMIGO) two cells are being developed dedicated to the creep feed grinding of aircraft turbine blades. The machining cells are to be sited near two small furnaces where the blades are cast into shuttles. The moulds are constructed so that only the blade surfaces to be machined protrude from the shuttle. After casting and cooling the shuttles are transported by automatic conveyor to one of the two grinding cells, which consist of two Elb grinding machines a measuring machine and a servicing robot all under DNC. Two types of grinding machine are used, one for plane grinding and one for profile. These are loaded and unloaded by the robot sited in the centre of the cells. This will also carry out in-process measuring at a station sited between the two grinding machines in each cell and this supervises the profile and dimensions of each workpiece - automatically rejecting deviant parts. The grinders, robots and conveyors are off-the-shelf products. The development of the cell and measuring machine has been carried out with the cooperation of Oslo University.

Three shift operation is possible. The same company is beginning research into a prismatic FMS for commercial sales. It will be prismatic using fibre optics for control communication with machining centres and lathes.

1.2.2 Summary

Throughout the world prismatic systems exceed rotational systems in application. The larger number of these systems are for machining large box-like castings. The American Machinist Report (1981) has found that the largest sector is the machine-tool industry producing machine tool structures,

The economic evidence in support of FMS is sparse and much more needs to be made of the intangible benefits such as the greater response to market demands.

There is a distinct trend towards unmanned night-shift systems where men prepare buffers of work on the day shift for unattended machines to continue overnight. This is more suitable to systems requiring little transfer due to large machining cycle times.

Sim (1981) believes the secret of success lies in assembling the total package from modules with care taken to ensure cost-effective solutions being implemented. The American Machinist's report (1981) has found that hierarchical control of systems, with micro- and mini- computers is increasing. This raises the total reliability of complex systems such as FMS.

From the late 1960's the growth of the FMS population has steadily expanded. This is illustrated in diagram A.5. Although the concept was born in the UK the Japanese, USA and West Germans have seen the potential for the last 20 years and implemented most of the world's systems.

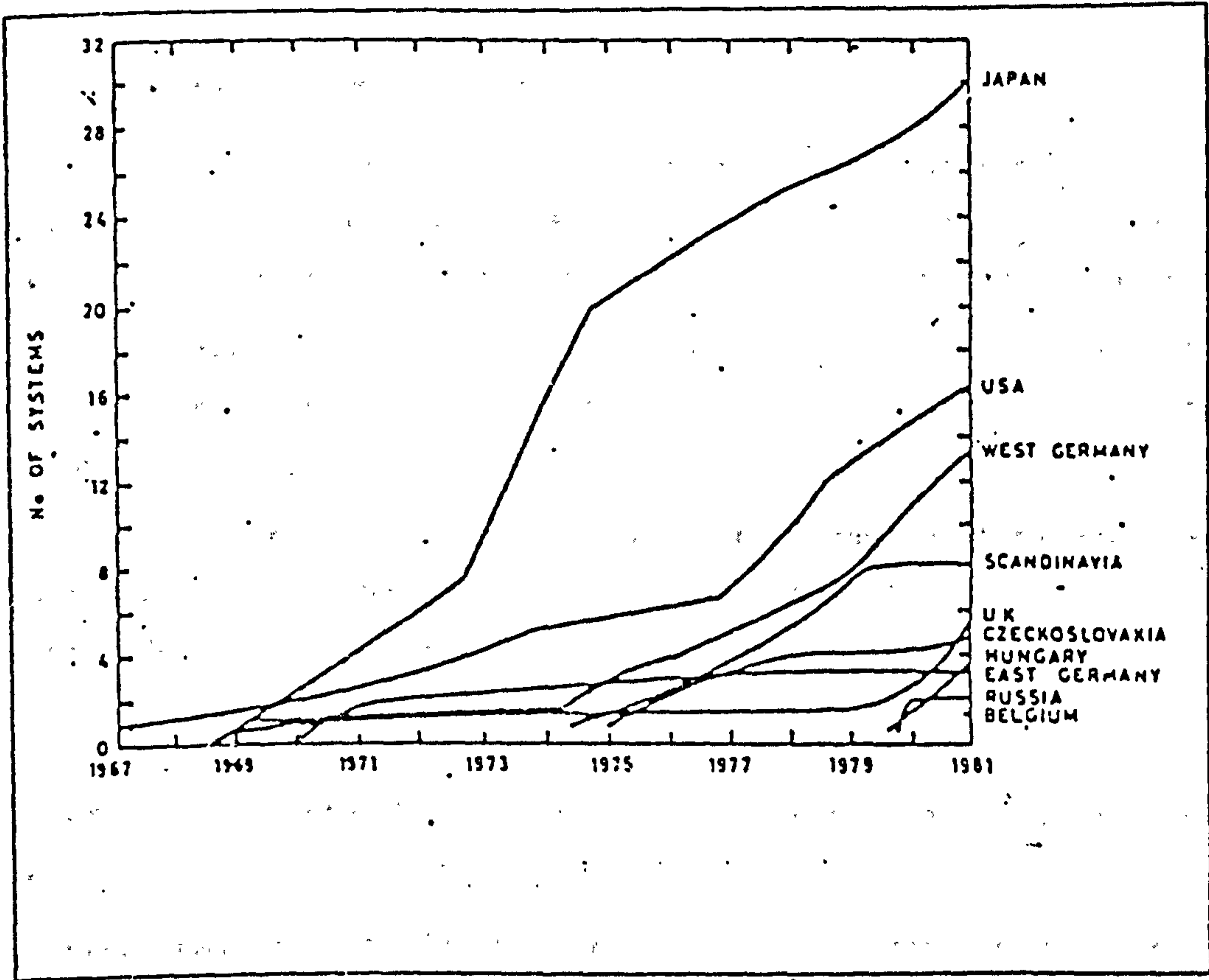
Lower cost (than the multimillion pound systems that exist today) FMS developments are virtually certain to increase in number. With the concepts having been demonstrated and proven by the larger, more sophisticated 'pioneering' systems smaller less ambitious systems will emerge. Standalone CNC concepts in ten to twenty years will be as dated, in comparison with FMS, as manual machines are seen now in comparison with their contemporary CNC counterparts. The smaller size FMS, as already developed in Norway, is technologically feasible for application in industry.

The introduction of robots into FMS has opened a new phase in FMS development. Robots either serve a machine at its loading station or serve a group of machines.

Rather than large mainframe computers, smaller, cheaper, microcontrollers and programmable logic controllers (PLC's) will be used for system control in future. With the ever increasing use of robots for cheap transfer the development and implementation of FMS into smaller companies like SLM Ltd is a feasible proposition.

The FMS design of a robot servicing several machines is examined in more detail (Section 3).





DIAG. A.5 GROWTH OF FMS WORLDWIDE - SOURCE WOOD (1982)

## 2. ROBOTIC APPLICATIONS FOR FLEXIBLE MANUFACTURING SYSTEMS

For over 20 years industrial robots have been developing with wide applications of the "first generation" robots already installed. The implementation of standalone robots provides a wealth of experience with which to incorporate robots, under DNC, into an FMS.

### 2.1 INDUSTRIAL ROBOT DEFINITIONS

There is no standard interpretation or precise definition of an "industrial robot" and opinions vary as to exactly which machines are or are not robots. According to the British Robot Association (1981) an industrial robot is:

"a reprogrammable device designed to both manipulate and transport parts, tools or specialised manufacturing implements through variable programmed motions for the performance of specific manufacturing tasks".

This definition precludes most of the simpler manipulating equipment such as an automatic loading/unloading arm and pick and place devices. Such devices are provided only with very limited programming facilities and their motion, as a rule, follows simple fixed sequences.

The definition adopted by the Robot Institute of America (RIA) describes a robot as:

"a reprogrammable multi-function manipulator designed to move material parts, tools or specialised devices through variable programmed motions for the performance of a variety of tasks". (Rathmill (1981); Koekebakker (1980)).

Engleberger (1977) explains that a robot is a highly sophisticated automation component combining computer-like electronics and hardware with advanced electromechanical servos to make a free standing piece of equipment with great application flexibility. The abiding design philosophy is that a great deal of flexibility can be built into a single piece of automation.

An industrial robot is basically, therefore, a CNC machine tool of specialist design.

It has become customary to view industrial robot technology as developing in three major conceptual stages, and to refer to robots belonging to these stages as respectively robots of the first, second and third generations.

The present first generation robots available commercially have neither 'senses' or 'brain', i.e. they lack sensors allowing them to receive information about changes in their surroundings as well as sufficient computing power to allow them to process and interpret this information.

The second generation robots are provided with sensing capabilities and are, at present, largely at the experimental stage. Research is being carried on worldwide particularly in the USA, Japan, the USSR and East and West Europe according to the Ingersoll Report (1980). Such robots are also provided with a fairly high level of computing power, allowing them to process any data received and to respond to changes taking place in their environment.

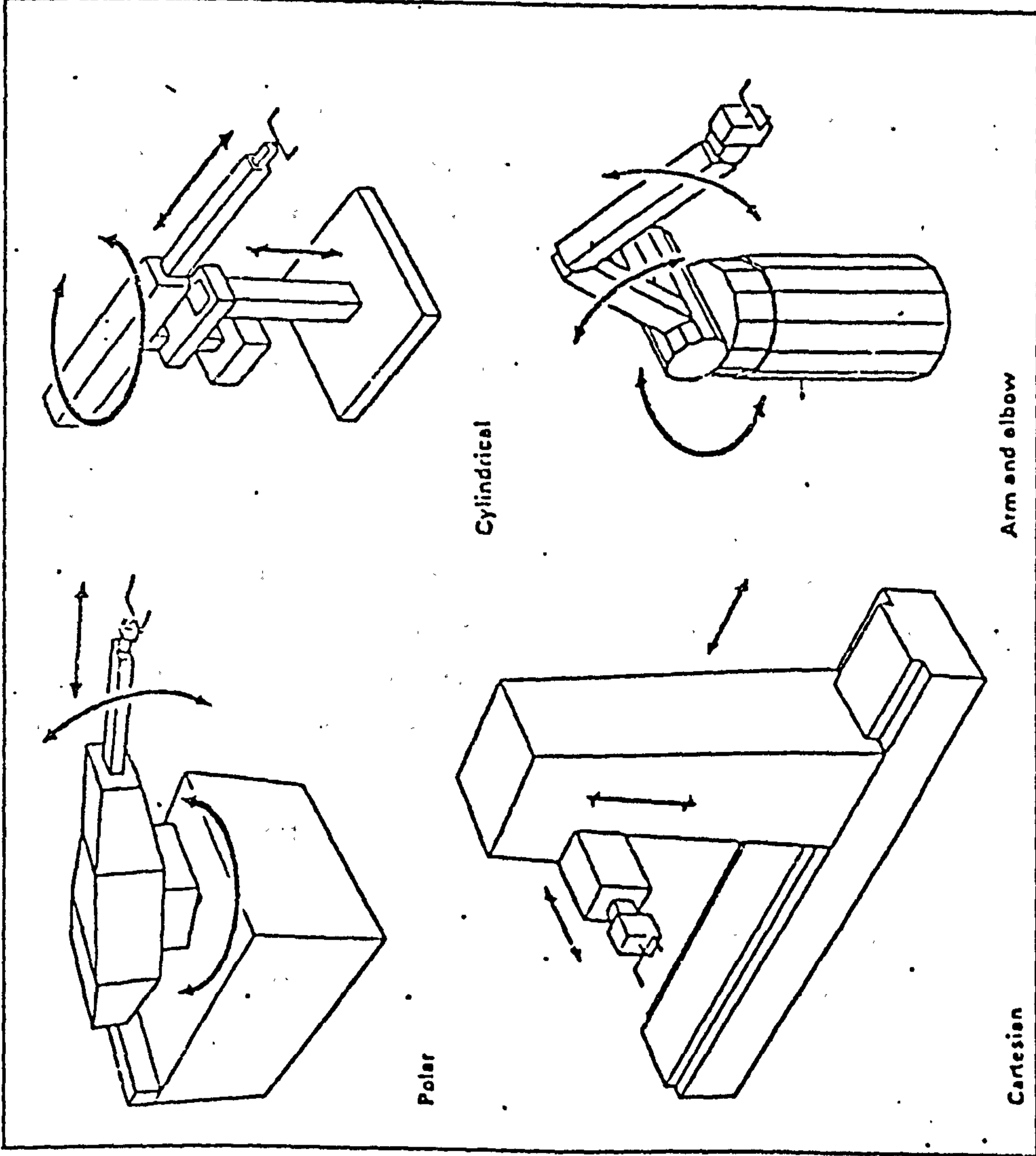
The third generation of robots are not yet in existence. They are characterised mainly by their ability to 'think', i.e. make decisions, plan and execute tasks, and interpret information received via sensors and by other means.

A robot can be broken down into subsystems (of a complex technical system) which each serve as a definite functional purpose. These subsystems are:

- i) physical and kinematic configuration
- ii) control system
- iii) drive system
- iv) measuring system
- v) sensors
- vi) end effectors

The physical and kinematic configuration of a robot is provided by its general structure and by the arrangement and type, i.e. whether translational or rotational of its axes of movement. Most of today's robots belong to one of the four basic configurations, (diagram B.1). They are either of the polar (tank-turret configuration) cylindrical, cartesian or arm and elbow types. Various extensions and modifications of these basic configurations are possible.

The purpose of the control system is basically two fold. It must direct the machine through its movements and sequences of operations in the normal



DIAG. B.1 ROBOT CONFIGURATIONS

automatic mode and it must provide means for an operator to program the robot. Control systems span a wide complexity range. At its very simplest (on the borderline between pick and place devices) a robot may be controlled by a series of adjustable stops or limit switches. At the other extreme, there are computer type, sophisticated control systems with expensive programmable memories and powerful information processing capabilities. With the advent and continued development of microprocessors, the computer type control system has become more prevalent.

There are two types of motion control, either point-to-point (PTP) or continuous path (CP) control. In point-to-point control the robot retraces the points recorded on instructions from the operator during the programming phase. Between these points, the path of motion is not specified by the control. Continuous path control is implemented by two different methods. In one, the robot retraces a sequence of points, previously recorded automatically, continuously or at regular time intervals (10-100 per second). In the other method the path between the points programmed by the operator is determined by computer generated interpolation. Such interpolation is usually straight line but can be circular arc or any suitable curve that can be generated mathematically. Dependent on the degree of sophistication of the control system, different modes of programming are possible. The simplest control systems are programmed by physical set-up, i.e. by setting stops, potentiometers, etc. The more advanced systems permit programming by teaching, i.e. the robot is either 'driven' or 'led' through its required sequence of operations with the relevant information stored in memory. In addition to teaching, advanced control systems permit programming via programming languages. In such cases, alphanumeric data is entered into memory via a keyboard as explained by Heginbotham (1981).

Hydraulic, pneumatic and electric actuators (or combinations) are the basic constituents of the drive systems. Hydraulic power is used to attain large forces and high accuracy, whilst pneumatic power is suitable for light duty and rapid action work and is also cheaper. Electric motor drives lend themselves readily to accurate position and velocity control and are generally cleaner than hydraulic drives, presenting no contamination problems. According to Engleberger (1980) 50 per cent of all

industrial robots have hydraulic actuating power, with pneumatics and electric motors accounting for 30 per cent and 20 per cent respectively.

A measuring system provides internal feedback about the position and velocity of robot axes. Position measuring systems are based on encoders, resolvers and potentiometers. Velocity is measured directly by means of a tachogenerator or obtained from displacement measurements by differentiation.

To enable the robot to carry out its set tasks, end effectors, i.e. grippers, tools, welding guns, etc., are attached to the robot's tool point. Research into robotics has been carried out by Tanner (1977, 1980), Heginbotham (1980), Roth (1980) and Warnecke (1980).

In addition to the above characteristics, Warnecke (1979) has detailed other parameters that define a robot's capability and performance profile. The main parameters are positioning accuracy, load handling capacity, velocity and acceleration, static and dynamic stiffness of the structure, working space, reliability, ease of maintenance, diagnostic capabilities and safety features.

## 2.2 EXAMPLES OF ROBOTIC PRODUCTION SYSTEMS

One of the earliest applications envisaged for the robot was that of loading and unloading one, two or more machine tools. Complex integrated systems (e.g. FMS) apart, the task of simply loading and unloading machine tools is one which robots have been capable of carrying out very effectively for a number of years now. For welding processes, in low volume jobbing shop environments, manually operated Metal Inert Gas (MIG) welding sets have offered a great deal of flexibility. However, where batch sizes and work variety exist, a robot welder becomes a major contributor to increased output. Practical research and user experience indicates that arc time is around 80 per cent of the cycle time with robot, compared with 40 per cent for human operators (Parrish (1980)). Robots are also used for paint spraying, spot welding, fettling, hot handling and assembly tasks.

### 2.2.1 Robotic Arc Welding

Welding processes are flexibly automated with welding robots. According to Lepsenyi (1980) special purpose welding machines do not provide universality of function and are therefore unsuitable for FMS. The industrial robot first proved its arc welding capabilities with the MIG process, having already been proven in the spot welding processes as described by Spynu (1976) and Page (1976).

One of the first applications with arc welding was in Japan where Kawasaki produced a continuous path version of the Unimate. The advantages of using a general purpose industrial robot for torch manipulation are that, because of their multi-axes positioning capability and their reprogrammability, they can be used for a variety of shapes of workpieces. Hunter (1978) explains the advantages are achieved with the additional benefits of consistent improved quality, higher utilisation, reductions of health problems and reduced rejection rates. The major requirements of a robot for arc welding are positional accuracy and smooth continuous path motion. Accuracy of torch positioning relative to the weld joint is necessary to ensure full fusion together with satisfactory weld bead shape. Smooth motion is necessary too, to obtain a good bead shape. Jerky movements of a welding gun will result in changes in arc length which may in turn lead to weld defects. Weston (1979) states that continuous path motion is required for seam following, especially in a number of separate planes on the workpiece.

In spite of their mechanical flexibility and dexterity, current commercial arc welding robots have at best only very limited abilities to sense workpiece position and joint configuration. This means that any tolerance to uncontrolled variations in workpiece geometry or position must be accommodated within the tolerance of the welding process itself. This is important particularly when workpiece holders, providing at least two more axes of positioning, allow the workpiece to be orientated in 6 to 8 axes. Although a man is flexible in his approach to this problem and can make adjustments to a wide range of fabrication situations, his output productivity is low, and the quality of his work will vary with his ability

and motivation. In addition to these limitations, the welding industry is experiencing increasing difficulty due to rising labour costs, shortage of skilled personnel and environmental regulations. These factors, together with developments in electronic and robotic systems make the trend towards robot arc welding almost inevitable.

There are various international examples of systems which prove robot arc welding capabilities. The Ingersoll Report (1980) details such examples and the development work being carried out in the world to improve the application. Generally, it has found that with good parts fit-up and manual loading, a productive welding system is achievable using robots. A few of the better examples follow showing the benefits. For instance, a robot installation can assist the smoothing of manning levels.

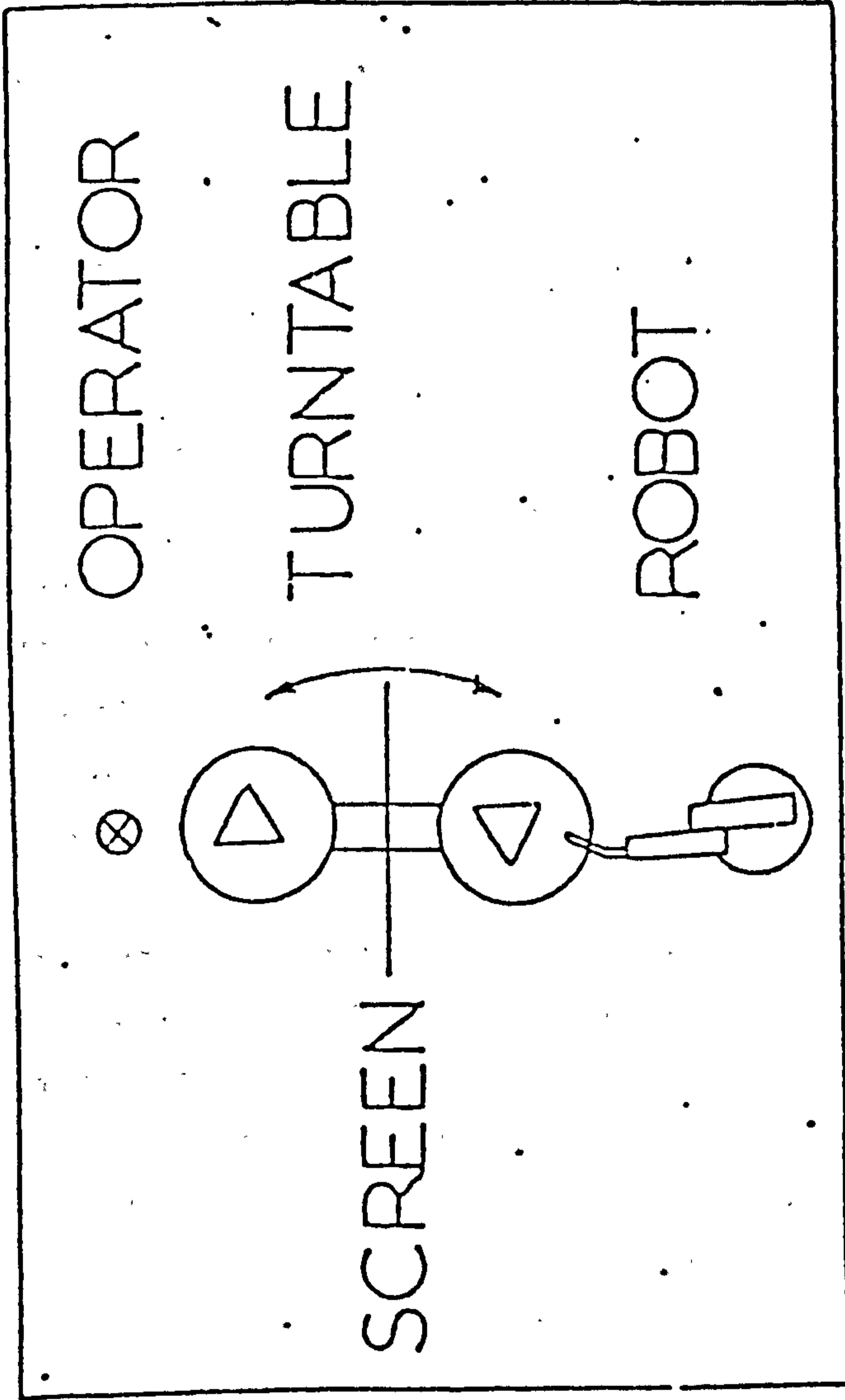
An ESAB ASEA Irb6 robot has been installed to weld aluminium beer kegs of as many as 20 different designs during a production run at Grundys Ltd in the UK. The automatic plant was found to do a satisfactory job in one third of the time in comparison with the manual set-up. However, it has been found that the major benefit of this application was that it helped to solve the difficult manning problems arising from large fluctuations in work flow through the plant, as described by Hebbert (1980) and Page (1977).

The use of an indexing work holder permits manual assembly, thereby maintaining flexibility, with automatic welding. The objectives attained by the application of another ASEA Irb6 robot to arc weld blanked and formed sheet metal components were:

- i) improved and consistent quality of welds requiring no subsequent dressing operations and
- ii) removal of a human operator from a tedious, unpleasant and potentially dangerous task

The plant incorporating the robot, diagram B.2, consists of a rotary table with a loading and welding station. At the loading station, the operator mounts the components to be welded (part of a car seat)





DIAG. B.2 ROBOTIC WELDING CELL

into a jig. The table is then rotated through  $180^{\circ}$  with the welding operations subsequently carried out by the robot at a welding speed of 5 m/min with the entire cycle taking 90 seconds. The welding and loading stations are separated from one another by a screen protecting the operator from the heat, light and fumes of the process.

Several welding operations can be divided amongst various robots to achieve a low cycle time, without going into the inflexibilities and expense of a robot transfer line. Spur (1980) describes the German Volkswagen plant where a multiple turntable is used. A four station turntable is utilised with two robots to weld engine mountings for six cylinder and four cylinder engines by the German company, George Kuikka. Components are loaded at station one manually before being welded automatically at stations two and three by the two robots positioned at right angles to one another. A handling device automatically unloads station four onto a conveyor for extraction of the welded assembly away from the system. It was necessary to equip the system with two robots to achieve the station unit time required. Robot number 1 would weld the first half of the assembly requiring a second robot to finish the welding to maintain a sufficient cycle time of 58 seconds per part. However, flexibility is achieved as both robots can weld both operations, (Muller (1977)).

Two robot welders are used at Unarco Industries in the USA to weld shopping trolley carts, (frame subassemblies). The robots make 14 welds on each cart frame on tubular steel sections. One welds a single frame size non-stop for two shifts daily. The second robot runs the second frame size for a week or two then switches over to frames of a third size. Each of the robots operates with a two position indexer having two identical sets of fixtures separated by 180 degrees. The robot welds a frame on one fixture while an operator unloads at the other. When a robot completes the 14 welds it activates the indexing switch to bring the next frame into welding position. It also releases the completed frame for removal by the operator.

Weston (1981) describes a system where the combined functions of welding and transfer by robot have been successfully demonstrated

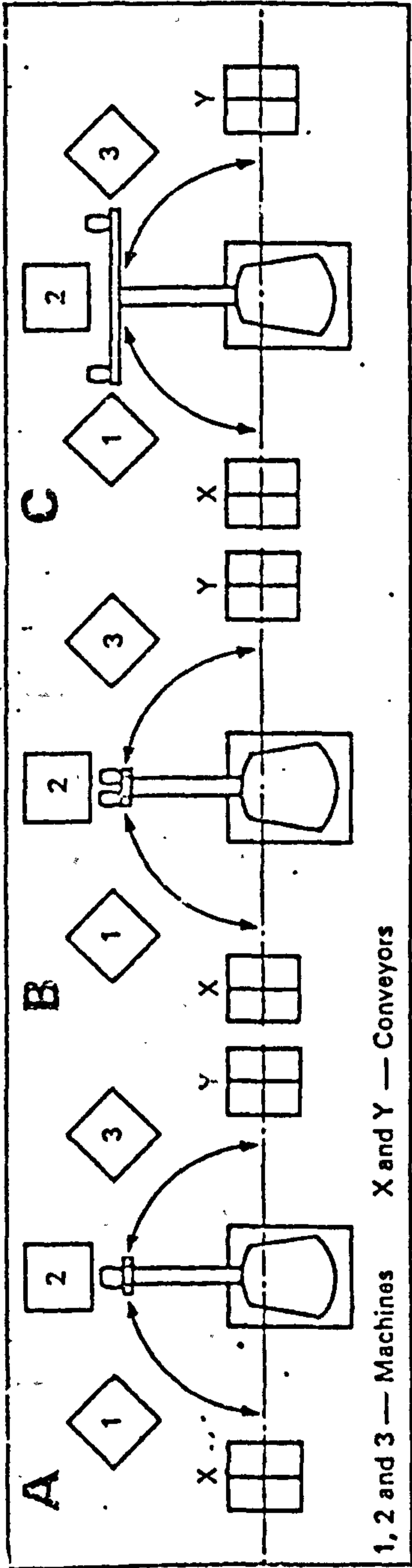
(at the Welding Institute at Cambridge in the UK). The first robot loads a plate into the first of two jigs. Whilst a second robot welds the plate, the first robot loads a second jig. It then holds a third plate vertical at the second jig for the second robot to commence welding inside the fillet to make an 'L' shaped bracket. The transfer robot then collects the first plate and holds it across the 'L' plate whilst the welding robot tack welds it into position. It then fillet welds the plate at the top and bottom joints before the first robot unloads the finished component, fully welded. This demonstrates the welding/transfer feasibility of a welding system in which minimal jiggling is required.

### 2.2.2 Robots for Transfer

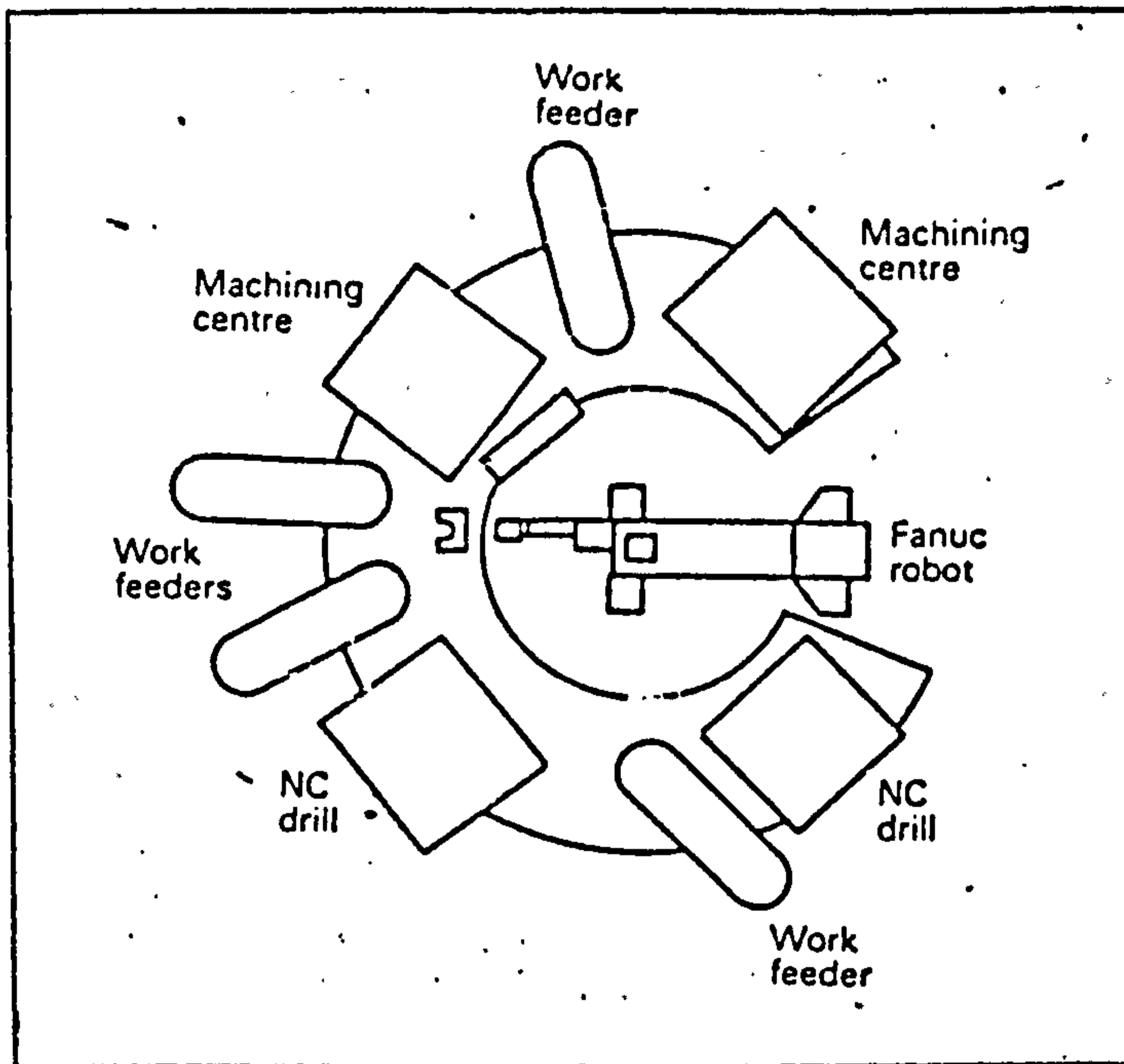
A process layout favouring the most efficient use of robots in batch manufacturing would be based on a group technology cell, according to PERA (1977), rather than long continuous assembly lines. The robots can be arranged to operate at centralised work stations. A review of the role of robots in group technology manufacturing systems has been made by Morishita (1973) to evaluate various layouts.

The three layouts shown in diagram B.3 were analysed. The first consisted of a single handed robot serving three machines with input conveyor X and output conveyor Y. The second system included a double handed gripper robot with the third system consisting of a widely spaced double gripper which served two machines at one time. It was concluded that the double gripper robot arrangement shown in the second system was the most efficient. The machines were utilised to a level of 80 per cent to 90 per cent with the robot varying between 50 per cent and 80 per cent efficiency. It was found that for circular transfer operations, the maximum number of machines serviceable is about five, due to space limitations. Machine operations should be between 0.5 and 2.0 minutes for high efficiency and the ratio of machine utilisation to loading time should be in the range 10 to 20, in order to obtain the best use of the cell.

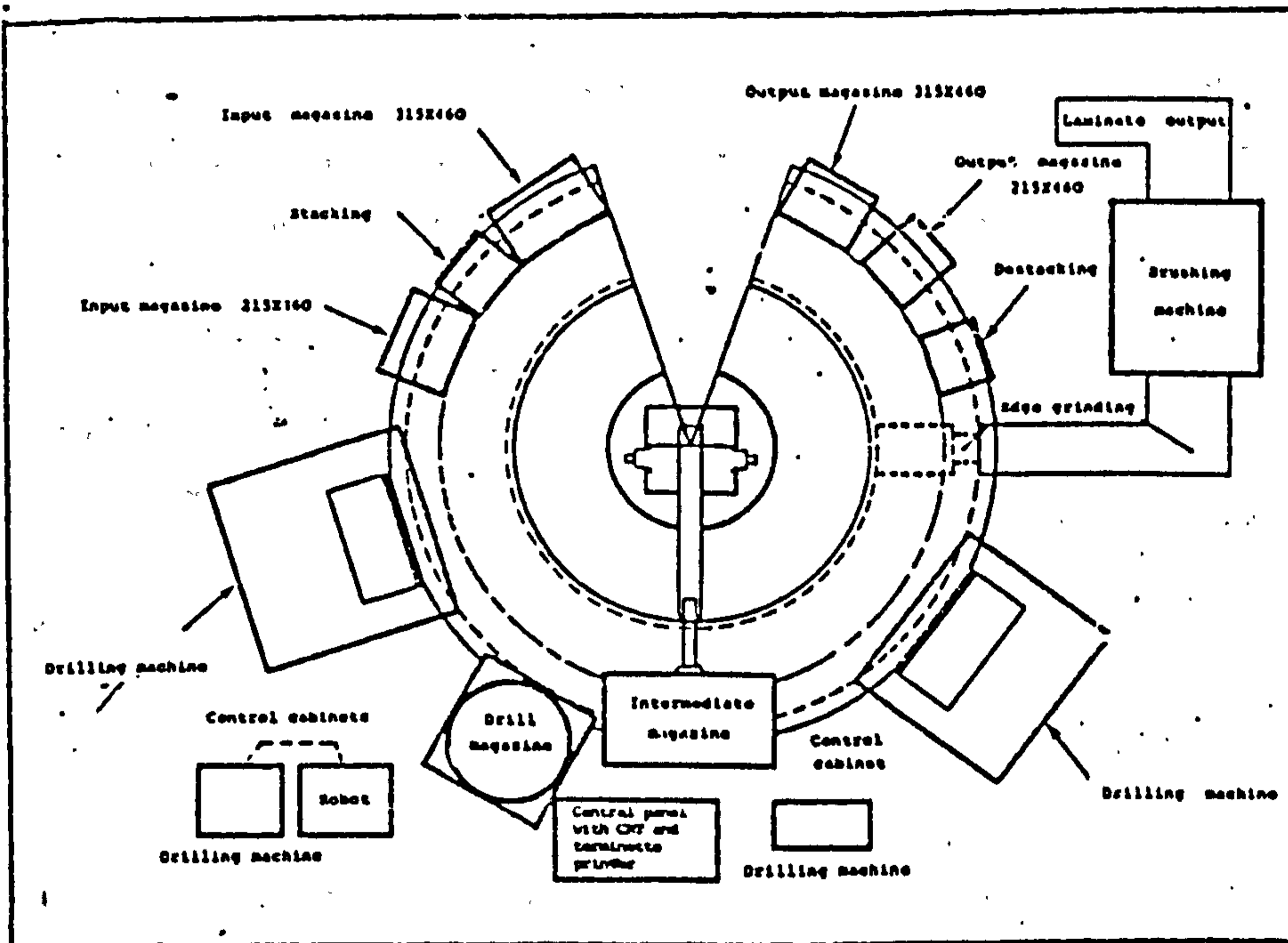
Unattended machining is enabled when the transfer robot is under computer control. The arrangement of several NC machine tools and a Fanuc model 2 robot, shown in diagram B.4, constitutes a system capable of unattended operation. The robot is fitted with a double gripper for loading and unloading the machines making round-the-clock operation of the capital intensive plant possible. The deviation of



DIAG. B.3 EXPERIMENTAL CELLS



DIAG. B.4 ROBOTIC MACHINING SYSTEM



DIAG. B.5 ROBOTIC DRILLING SYSTEM

the work cycle in comparison with the traditional method has been reduced by half, thereby enabling a threefold increase in productivity.

An excellent example of the successful integration of robots into a manufacturing system can be seen in Sweden. A later system developed at Asea, Vasteras, integrates a robot with a machine cell. Asea have equipped their robot in the cell with extended memory, some adaptivity and computer linking. The result is a system linked by a central computer which processes customer orders, gives out necessary information to production cells and makes it possible to produce to specific orders, (diagram B.5).

The computer acts as a library for the robot, composes a selection of preprogrammed operations and orders the robot to carry them out. The system is used to drill printed circuit boards and consists of a "MODCOMP" supervisory computer, two Excellon XL3 drilling machines, and an Asea IRb-60 robot. Around 1500 printed circuit boards are produced with an average batch size of 20 per order. Although only two sizes of laminate board are involved, the robot programmes can be complex. Drills can be loaded with stacks including an entry board and a back up laminate. The robot puts the different stacks together and places them in an intermediate magazine. The robot also loads and unloads the drilling machines and transfers the laminates to other parts of the cell for edge grinding and brushing. It can also change drills in the event of a breakage.

Another example of the successful use of robots for small batch manufacturing automation is demonstrated by the DoALL company of Illinois, one of the world's largest suppliers of machine cutting tools. Robots are integrated into a system using existing NC equipment.

The overall system has the programming ease of CNC machinery along with a simplified approach to parts classification. The concept bridges the gap between present inefficient methods and the more sophisticated approach of Group Technology using CAD/CAM techniques. The difference between this latter technique and the simpler approach using robots is mainly in the system used for parts classification. While Group Technology systems classify a family of parts in terms of its relationships to machines, the system using robots classifies the parts in relation to the machine operations required. This permits a selection of machines according to the shape and size of parts involved in present operations and these can be tooled accordingly. Once it has been

determined which parts are to be produced and the machines needed to process them, the robot can be introduced to automatically load them. The robot readily handles such families of parts through a series of machine tools. When paired with general purpose machine tools a robot integrates them into a single-purpose family-dedicated system for a range of various parts. The sequencing programme used can be called upon wherever required for various batch runs. In such systems, the machine tools retain their standalone flexibility yet an overall system is produced. These systems are described by Dallas (1979).

## REFERENCES

- Abbot, A. (1979) Choosing a programmable controller  
Meas. Cont. (GB) v. 12, n. 9, Sept.  
pp 356 - 362
- Allen, C. (1974) The formation and operation of a cell  
system. Proc. 14th Internat. Mach. Tool  
Design Res. Conf. pp 145 - 153.  
Publ. by MacMillan, London, GB.
- American Machinist, (1981) Special Report 740. CAM: an international  
comparison. Amer. Mach. (USA). Nov.  
pp 207 - 226.
- Anon (1982) Work starts on Andersons FMS giant.  
Metalworking Production, January, p 88.
- Arndt, G. (1976) Forecasting and Production Technology.  
An outlook on manufacturing systems.  
Proc. Am.Eng.Conf., I.E., Australia,  
Townsville, May, pp 63 - 67.
- Arndt, G. (1977) Integrated flexible manufacturing systems  
towards automation in batch production.  
New Zealand Engineering, V. 32, n. 7.,  
July, pp 150 - 155.
- ASP Report, (1977) Automated small batch production study  
and programmes. Available from ASP Com-  
mittee, Nat. Eng. Lab., East Kilbride,  
Glasgow, Scotland.
- Bailey, S.J. & Pluhar, K. (1979) Flexible manufacturing systems, digital  
controls and the automatic factory.  
Cont. Eng. September, pp. 59 - 64.
- Barash, M.M. (1976) Group Technology considerations in planning  
manufacturing systems. SME Tech. Pap.  
Ser. MS. CAD/CAM, 4th Conf. Dallas, Texas,  
Nov. 15 - 18, Pap. MS76 - 728, p 14.
- Barash, M.M. (1979) Computerised systems in the scheme of  
things. Fall Ind. Eng. Conf. AIIE Proc.  
Houston, Texas, Nov. 13 - 16. Publ. by  
AIIE (AIIE - P. 359) Norcross, Gal.,  
pp 239 - 246.
- Barash, M.M. (1982) Computerised manufacturing systems for  
discrete products. The handbook of Ind.  
Eng. edited by G. Salvendy. Publ. by  
J. Wiley and Sons, New York.
- Bergant, J.M. (1982) Achieving a successful first robot  
installation. Robotics Today, February,  
pp 63 - 66.
- Bernard, J.W. & Howard, G.M. (1970) Organising multilevel process control  
systems. Automation, March, pp 78 - 80.



- Berthold, H. (1975) Programme controlled machine tools. (Programgesteuerte Werkzeugmaschinen), VEB Verlag Technik, Berlin.
- Björke, O. & Rolstadas, A. (1977) The structure of control systems for manufacturing cells. Pap. 9th Int. Sem. on Manufacturing Systems, Cranfield, U.K. Available from Cranfield I.T., U.K.
- Björke, O. (1978) The use of robots within manufacturing cells. 2nd Int. Conf. on Computer Aided Manufacture. Available from NEL, East Kilbride, Glasgow, Scotland.
- Björke, O. (1979) The robot as a building block in manufacturing cells. AME Int. Spring Sem. New Orleans, La., April 10 - 12. Publ. by CAM. Int. Inc., 1107 Arlington, Texas.
- Branch, R.H. & Hoag, J.W. (1971) In process control think small. Modern Data, June, pp 31 - 34.
- Bredin, H. (1982) Unmanned manufacturing. Mech. Eng., February, pp 20 - 25.
- British Robot Association, (1981) British Industry accepts robots. BRA. Press Release, 10th February, Kempston, Beds., U.K.
- Brock, T. (1980) British Industry and robots. Robot Facts, Dec. Available from BRA, Kempston, Beds., U.K.
- Brasher, B.C. (1967) The NC plant goes to work. Amer. Mach., v. 111, n. 22, pp 138 - 144.
- Burbidge, J.L. (1975) The introduction of Group Technology. Halstead Press - John Wiley and Sons, New York.
- Burgdorf, E. (1979) Eigenschaften und einsatzgebiete synthetischer abschrecklösungen. SWF Sonderausdruck 74., v. 9, Carl Hanser Verlag, Munich 86.
- Buzzacott, J.A. et. al. (1980) Models for understanding FMS. AIIE. Trans. v. 12, n. 4, Dec. pp 339 - 350.
- Cauldwell, F.W. (1973) The improvement of manufacturing controls in a medium heavy manufacturing company. Proc. 14th MTDR Conf., UMIST, Manchester, U.K.
- Chiantella, N.A. (1976) Implementing the systems approach to manufacturing. Manufacturing Eng., March, v. 11, n. 3, pp 12 - 17.
- Charnley, C.J. (1977) Numerical control : present status and future. Eng. Digest, Aug. v. 38, n. 8, pp 21 - 27.

- Charnley, C.J. (1978) Numerical control : present status and future potential. Eng. Digest, May, v. 39, n. 9, pp 13 - 21.
- Coburn, J.D. & Emrich, K.B. (1982) Controlling robots with PCs. Mach. Design, February, pp 56 - 60.
- Collins, J. (1980) Integrated manufacture - the state of the art. Production Eng. (UK), June, pp 41 - 44.
- Cook, N.H. (1975) Computer managed parts manufacturing. Scientific American, February, n. 2, pp 21 - 29.
- Dallas, D.B. (1979) The robot enters the system. Manuf. Eng., February, pp 70 - 73.
- Dronesk, M. (1979) Technische und wirtschaftliche probleme der fertigung in flugzeugbau produktions-technisches Kolloquium, Berlin, pp 107 - 115.
- Engleberger, J.F. (1977) Designing robots for industrial environments. Mechanism and Machine Theory, v. 12, pp 403 - 412. Publ. by Pergamon Press (UK).
- Engleberger, J.F. (1979) Standalone versus distributed robotics. Symp. on computer vision and sensor based robots, Warren, M.I., September, pp 263 - 273. Available from G.M. Res. Lab., Warren, M.I.
- Engleberger, J.F. (1980) Robotics in practice. Publ. by Kogan Page, London.
- Everscheim, W. & Weck, M. (1975) Planung, entwicklung und aufbau flexibler fertigungssysteme. Industrie Anzeiger 97, v. 28, n. 26, pp 3 - 7.
- Feinberg, B. (1968) Goodbye to tape. Tool and Manuf. Eng. v. 60, n. 5, pp 18 - 21.
- Fox, P. (1980) Which programmable controller should you choose and why. Control and Instrum. (GB) v. 12, n. 9, September, pp 62 - 63.
- Fukuda, Y. & Kanda, Y. (1982) Japan's FMS and its problems. Metalworking Eng. and Marketing, September, pp 136 - 142.
- Garrett, L.T. (1979) Planning for integrated distributed control. Intech., (USA), v. 26, n. 10, October, pp 41 - 44.
- Gault, R.W. (1980) Programmable logic improves pigments. Elect. Rev., October, pp 29 - 32.
- Golden, L.D. (1980) Experience with programmable logic controllers in heat treating. Metal Progress (USA), v. 117, n. 5, April, pp 116 - 121.

- Grayson, T.J. (1973) An international assessment of group technology.  
Conf. pap., University of Aston, Birmingham, U.K.
- Grierson, D.K. (1982) The automated factory.  
Instrum. Contr. Sys. March, pp 36 - 41
- Groover, M.P. (1980) Industrial robots, a primer on the present technology.  
Ind. Eng. (USA) v. 12, n. 11, November, pp 54 - 61.
- Hartley, J. (1982) The little and large ways to flexibility.  
The Engineer, 15th April, pp 49 - 50.
- Hebbert, R.A. (1980) Handmade by robots.  
Metals Materials, Dec., pp 46 - 51.
- Heginbotham, W.B. (1980) Robots and automatic factories.  
Eng. Digest, Dec., v. 41, n. 12, pp 19 - 23.
- Heginbotham, W.B. (1981) Introduction to robotics.  
Practical Electronics, Oct., v. 17, n. 10, pp 30 - 33.
- Hegland, D.E. (1981) Flexible manufacturing.  
Prod. Eng., May, pp 38 - 43.
- Hellmuth, G. & Manfred, W. (1981) Flexible integrated machining system for the complete machining of different workpieces. Ind. Prod. Eng., February, pp 32 - 36.
- Hickey, J. (1980) PCs - reasons why they are used.  
Instrum. Cont. Sys., April, pp 59 - 61.
- Hitomi, K. (1979) Automated and computer integrated manufacturing systems. Publ. by Taylor and Francis Ltd., Macklin St., London, U.K.
- Holmes, J.G. (1982) The robot in the development of flexible manufacturing systems.  
Canadian Mach. Metalworking, February, pp 20 - 22.
- Hughes, J.J. et.al. (1975) Flexible manufacturing systems for improved mid-volume productivity.  
Sys. Eng. Conf. Proc., Las Vegas, Nevada, Nov. 19 - 21, pp 277 - 282.  
Publ. by AIIE (AIIE-P-75-3) Norcross, Galveston.
- Hughes, J.J. (1976) Multi-machine handling systems.  
2nd Ann. Mat. Handling Tech. Sem. (April) Purdue University, USA. Available from PERA, Melton Mowbray, Leics., U.K.
- Hunter, J.J. (1978) Automation of arc welding.  
The Ind. Robot, March, pp 27 - 31.

- Hutchinson, G.K. et al (1973) A flexible manufacturing system.  
Ind. Eng. (USA) Dec., pp 10 - 17.
- Hutchinson, G.K. (1976) Production capacity: CAM vs transferline.  
Ind. Eng. (USA), Sept., pp 30 - 35.
- Hutchinson, G.K. (1979) Advanced batch machining systems.  
Num. Cont. Soc. Proc. Ann. Meet. Conf.  
16th, Los Angeles, California, March 25 - 28,  
pp 118 - 146. Publ. by Num. Cont. Soc.,  
Glenview, Ill.
- Hutton, I. (1982) Kims plus logic cuts NC tape tangles.  
Metalworking Production, March, pp 173 - 181.
- Inaba, S. (1976) A flexible production system.  
Paper presented at CIRP/GAMI Conf.  
Recent Advances CAD/CAM., Paris, France.  
Sept. 6 - 7. Available from PERA, Melton  
Mowbray, Leics., U.K.
- Infotech (1980) Factory automation: the state of the art.  
Series 8, number 6, Vol. 1 - Analysis,  
Vol. 2 - Invited papers. Publ. by  
Infotech Ltd., Maidenhead, Berks, U.K.
- Ingersoll (1980) Industrial robots.  
Ingersoll Eng. Ltd., DoI and NEL report,  
Vol. 1 - Industrial appreciation, Vol 2 -  
Applications. Issued by NEL, East Kilbride,  
Glasgow, Scotland.
- Irwin, R. (1980) The engineers romance with programmable  
controllers.  
Prod. Eng. (USA), v. 27, n. 6, June,  
pp 40 - 46.
- Jabolonowski, J. (1980) Aiming for flexibility in manufacturing  
systems.  
Amer. Mach. v. 124, n. 3, March, pp 67 - 182.
- Jannotta, K.L. (1980) What is programmable control.  
Instrum. Cont. Sys. (USA) v. 53,  
n. 2, February, pp 21 - 25.
- Kobayashi, K. & Inaba, H. (1981) Practical approach for unmanned operation  
of FMS.  
Proc. 11th Int. Symp. Ind. Robots, Oct. 7 - 9,  
Tokyo, Japan. Publ. by IFS Ltd., Kempston,  
Beds, U.K.
- Koekebakker, J. (1980) Survey of industrial robots.  
Canadian Mach. Metalworking, Jan., pp 20 - 23.
- Kumontis, S.D. (1980) PC features.  
Instrum. Cont. Sys. (USA), March, pp 25 - 31.
- Lacy, K. (1982) Factory where man is a mere observer.  
Mach. Prod. Eng., 3rd March, pp 27 - 30.

- Lawrence, J.M.W. et.al.(1982) The interrelationship between components in an FMS.  
Eng. Digest, February, v. 43, n. 2, pp 9 - 11.
- Lepsenyi, I. (1980) Industrial robots in flexible manufacturing systems.  
10th Int. Symp. Ind. Robots, 5th Ind. Conf. Ind. Robot. Tech. Proc., Milan, Italy. March. Publ. by IFS Ltd., Kempston, Beds, U.K.
- Leslie, W.H.P. (1980) The factory of the future.  
Infotech Factory Autom. report. Ser. 6, n. 6. Publ. by Infotech Ltd., Maidenhead, Berks. U.K. pp. 129 - 135.
- Lipp, W. (1979) A flexible system for turned parts.  
Mach. Prod. Eng., February, pp 13 - 15.
- Machine Tool Task Force (1980) Machine Tool Technology - special report 726.  
Amer. Mach. (USA), Oct., pp 105 - 128
- Market Assessment (1980) Analysis of the lawnmower market.  
(available from Marketing Department, Qualcast Ltd., Sunnyhill Road, Derby, U.K.)
- Merchant, M.E. (1975) Long range trends in the automation of machine tools.  
Mach. Prod. Eng., Nov., pp 514 - 516.
- Merchant, M.E. (1976) Future trends in manufacturing.  
Annals of CIRP, v. 25, n. 2, pp 473 - 476.
- Merchant, M.E. (1977) Group Technology: a sound foundation for computer control of cellular manufacturing systems.  
Manufacturing Systems, n. 3, pp 147 - 156.
- Mintel (1980) Survey of lawnmower and garden product market: 1980.  
(available from Marketing Department, Qualcast Ltd., Sunnyhill Road, Derby, U.K.)
- Mitranov, S.P. (1958) The scientific principles of G.T.  
(Translated by the Nat. Lending Library, Boston Spa, U.K., 1966).  
Available from PERA, Melton Mowbray, Leics, U.K.
- Morishita, K. et.al.(1973) Group Technology; what role for robots.  
Autom., August, pp 27 - 30.
- Müller, S. (1977) Arc welding with industrial robots.  
The Industrial Robot, Dec., pp 183 - 187.

- Munson, G.E. (1978) Integrated machining systems using industrial robots. Proc. 8th Int. Symp. Ind. Robots, Stuttgart, 30th May - 1st June, v. 2, pp 778 - 793.
- Nadler, G. (1967, 1970) Work systems design, the ideal concept. Publ. by Richard D. Irwin Inc., Homewood, Illinois, USA.
- Nof, S.Y. et al (1979) Operational control of item flow in versatile manufacturing system. Ind. Journal Prod. Res., v. 17, n. 5, Sept.-Oct., pp 479 - 489.
- Novorsky, D.E. (1981) A guide to quenching factors for heat treating. Heat Treating, Oct., pp 39 - 44.
- Opitz, H. et al (1971) Group Technology and manufacturing systems. Int. Journal Prod. Res., v. 9, n. 1, pp 87 - 93.
- Orbzut, J.J. (1982) Robotics extends a helping hand. Iron Age, March, pp 60 - 83.
- Osborn, J. (1972) Direct online computer control of machine tools and material handling. Proc. 9th Ann. Meet. Techn. Conf., Num. Cont. Soc., April 17 - 26, Pap. 26, pp. 260 - 268.
- Page, M. (1976) Mindless welders boost production and profit. Metalworking Production, Dec., pp 57 - 61.
- Page, M. (1977) Welding robots scale up as designs meet industry needs. The Engineer (UK), Oct., pp 28 - 29, 35.
- Painter, C.W. (1982) Unpublished research work on the applications of MRP to FMS. Available from Mr Painter, 3 Temple Road, Stowmarket, Suffolk, U.K.
- Parrish, D.J. (1980) Robotic welding. Unpublished MSc research work. Available from Head of Eng. Prod. Department, Loughborough University of Technology, Loughborough, Leics, U.K.
- Parrish, D.J. & Painter, C.W. (1981) Flexible labour systems. Prod. Eng. (UK) Nov., pp 26 - 28.
- PERA (1977) Programmed manipulating devices. Report: 320 - Automation Available from PERA, Melton Mowbray, Leics, U.K.

- PERA (1979) Analysis of cylinder vs hover mower performance.  
Privately sponsored research available from Eng. Department, Qualcast, Sunnyhill Road, Derby, U.K.
- PERA (1982) Group Technology: Spec. report 365.  
Available from PERA, Melton Mowbray, Leics, U.K.
- Perry, C.B. (1969) Variable system manufacturing systems.  
Proc. 1st Internat. Conf. Product Dev. Tech., September. Editor D.S. Ross, University Strathclyde, Scotland.  
Publ. by MacDonal, London, U.K.
- Pfeifer, T. (1973) The 6th International m/c tool exhibition in Tokyo. Industrie Anzeiger, v. 95, n. 14, February, pp 241 - 248.
- Rathmill, K. & Leonard, R. (1975) An evaluation of production cost and control effectiveness in Group Technology. Proc. 5th Group Tech. Conf., Nov. Instit. Prod. Eng. (UK) pp 31 - 35.
- Rathmill, K. et. al. (1977) Characteristics of future batch production systems.  
CME (UK), v. 24, n. 3, March, pp 60 - 63.
- Rathmill, K. (1980) Computer simulation in the factory. Infotech Factory Autom: ser. 6, n: 2, Publ. by Infotech Ltd., Maidenhead, Berks, U.K., pp 177 - 206.
- Rathmill, K. (1981) FMS developments in the U.K. Tooling, June, pp 5 - 19.
- Rathmill, K. (1982) How fast can you run with a robot. The Engineer (UK) February, p. 27
- Rembold, U. (1973) Management aspects of In-Plant process control computers.  
Proc. 2nd Texas Conf. Computing Sys., Nov., University of Texas, Austin, Texas.
- Rembold, U. (1977) Production automation technology.  
Publ. by Marcel Dekker Inc., New York.
- Rosenof, H.P. (1980) Multiple PCs share scans.  
Instrum. Cont. Sys. (USA), v. 53, n. 3, March, pp 118 - 119.
- Roth, B. (1978) Robots  
Appl. Mech. Rev., v. 31, n. 2, Nov. pp 1511 - 1519.
- Sandford, J.E. (1973) Direct NC revs up plant of the future.  
Iron Age, February, v. 211, n. 5, pp 51 - 53.

- Savelyev, M.K. (1979) Some sample applications for programmable controllers.  
Autom. Cont., v. 9, n. 6, pp 634 - 637.
- Shaw, F.D. (1980) Programmable control concepts.  
Electron. Power (GB) May, v. 26, n. 5, pp 391 - 394.
- Sherman, R.H. (1979) Peer-to-peer communications distributed control among programmable controllers.  
Cont. Eng. (USA) Nov., v. 26, n. 11, pp 53 - 57.
- Schwarz, H.R. (1976) Distributed processing links centralised planning with distributed control.  
SME Tech. pap. 76 - 743, pp 1 - 13.
- Sim, R.M. (1981) FMS - some examples.  
Session 2A, CAD/CAM (paper 2).  
Available from Manufacturing Systems Div., NEL, East Kilbride, Glasgow, Scotland.
- Sims, R.B. (1982) The year of the FMS.  
The Production Eng. (UK), February, v. 61, n. 2, pp 33 - 36.
- Sinha, R.K. et.al. (1980) Cellular manufacturing systems.  
Chartered Mech. Eng., December, pp 37, 40 - 41.
- Spur, G. et.al. (1973) Entwicklungstand integrierter fertigungssysteme.  
ZWF 68, Heft 5, pp 229 - 233.
- Spur, G. et.al. (1975) Entwicklung einers modularen flexiblen fertigungssysteme mit automatisierter informations - verarbeitung.  
ZWF 70, Heft 1, pp 9 - 11.
- Spur, G. et.al. (1976) Flexible manufacturing cells in multiple station production - realisation of a modular FMS for rotational parts.  
CIRP Annals, v. 25, n. 1, pp 329 - 334.
- Spur, G. et.al. (1977) Computer control of a flexible manufacturing cell.  
9th CIRP Int. Seminar on Manufacturing Systems, v. 9, n. 3, pp 11 - 18.
- Spur, G. (1979) Produktionstechnik im Wandel  
Produktionstechnisches Kolloquium, Berlin, PTK, July, pp 3 - 14.
- Spur, G. (1980) Industrieroboter.  
Published by Carl Hanser Verlag, Berlin,  
Available from PERA, Melton Mowbray, Leics. U.K.
- Spynu, G.A. et al (1976) Industrial robots for arc welding.  
Autom. Welding, n. 9, available from PERA, Melton Mowbray, Leics, U.K.



- Stephenson, P.H. (1969) The manufacturing systems concept. Proc. 1st Int. Conf. on Product Development and Manufacturing Tech. Editor D.S. Ross, University of Strathclyde, Scotland.
- Stute, G. et.al. (1974) Programmierbare steuerungen für festigungseinrichtungen. WTZ Ind. Fertigung, November, v. 64, n. 11, pp 657 - 665.
- Stute, G. et.al. (1975) Die steuerung flexible fertigungssysteme. Werkstattstechnik, v. 65, pp 313 - 318.
- Stute, G. et.al. (1976) How to find the optimal configuration for an FMS. Proc. NAMC - IV, 4th North American Metal-working Conf., May 17 - 19, pp 408 - 415. Available from PERA, Melton Mowbray, Leics, U.K.
- Stute, G. et.al. (1977) Grundlagen der prozessautomatisierung für die fertigung/prozess - steuerung. (KFK - PDV 107), February. Available from PERA, Melton Mowbray, Leics, U.K.
- Stute, G. & Woern, H. (1978) Mehr prozessor steuerung - systeme für industrieroboter. Proc. 8th Int. Symp. on Industrial Robots. Inst. for Prod. and Autom. Conf., May 30 - June 1, Stuttgart. Publ. by Int. Fluid Services Ltd., Kempston, Beds, U.K., v. 2, pp 631 - 639.
- Szumanski, S. (1979) Method of evaluation for integrated flexible industrial systems. 9th Int. Symp. on Industrial Robots. Washington D.C., March 13 - 15. Publ. by SME, Dearborn, Michigan, pp 657 - 677. 677.
- Tanner, W.R. (1977) Basics of robotics. SME Tech. pap. Ser. MS for Robots. 2nd Conf. Detroit, Michigan. Oct. 31 - Nov. 3, (pap. MS 77 - 734).
- Usui, N. (1982) FMS transforms a creaky plant. American Machinist, April, pp 132 - 133
- Wadsworth, P.K. (1982) Robotic arc welding of lawnmower cutting cylinders. An unpublished research paper obtainable from Eng. Prod. Department, Loughborough University of Technology, Loughborough, Leics, U.K.
- Warnecke, H.J. & Schraft, R.D. (1979) Industrieroboter. Krausskopf - Verlag Mainz. Publ. by IFS Ltd, Kempston, Beds, U.K. (revised edition 1982).
- Warnecke, H.J. & Kampa, H. (1980) Flexible production systems in Western Europe - state and trends. Proc. 4th Int. Conf. Prod. Eng., Tokyo, pp 185 - 195.

- Weck, M. & Schuering, A. (1975) What aids are available for design and development of computer controlled manufacturing systems. Proc. 3rd North American Metalwork Des. Conf., Pittsburgh, Pa, May 5 - 7, pp 751 - 770. Publ. by Carnegie Press, Pittsburgh, Pa.
- Weck, M. & Mambauer, N. (1977) Programmable controllers: state of the art. Annals CIRP, v. 26, n. 1, pp 217 - 222.
- Weck, M. et al (1979) New developments of data processing in computer controlled manufacturing systems. (DNC, FMS). SME Tech. Pap., Ser MS, n. MS 79 - 161.
- Weck, M. et.al. (1980) Concept of integrated data processing. Int. Journal of Prod. Res., v. 18, n. 3, pp 295 - 306.
- Weston, J. et.al. (1979) Robot arc welding developments. The Industrial Robot (UK), December, pp 187 - 189.
- Weston, J. ( 1981) Robotic welding. The Welding Institute Research Bulletin, v. 22, n. 12, December, pp 339 - 344. Available from The Welding Institute, Abingdon, Cambridge, U.K.
- Willhelm, R. (1976) An analysis of the material flow in FMS. Wt-Z Ind. Fertig. v. 66, n. 9, September, pp 529 - 536.
- Williams, V.A. (1979) DNC for flexibility. Production, v. 74, n. 3, September, pp 70 - 75.
- Williamson, D.T.N. (1968) The patterns of batch manufacture and its influence on machine tool design. James Clayton Lecture. Proc. Inst. of Mech Engrs., pp 182 - 190.
- Witte, K.W. (1980) Auswahl von NC geeignetenwerk-stücken. Industrie Anzeiger 102 Jg., v. 9, n. 28, pp 4-7.
- Wood, L. (1981) FMS: the only future for manufacturing. Production Engineering, April, v. 6, n. 4, pp 38 - 39.
- Wood, L. (1982) Flexible automation or liquidatation Paper, 5th British Robot Assoc. Ann. Conf. May 10 - 12. Stratford-upon-Avon, U.K. Available from B.R.A. Kempston, Beds, U.K.
- Wynne, B.E. & Hutchinson, G.K. (1974) Simulation of advanced manufacturing systems. Winter Simulation Conf. Ann. Proc., Washington D.C., January 14 - 16, v. 1,

pp 38 - 44. Available from ACM,  
New York.

Yoshikawa, H. (1980)

Factory automation: the state of the art.  
v. 2, Invited papers. Publ. by Infotech  
Ltd., Maidenhead, Berks, U.K.