COLLEGE OF AERONAUTICS

(Proposed Cranfield Institute of Technology)

DEPARTMENT OF PRODUCTION ENGINEERING

THE DESIGN OF A NUMERICALLY CONTROLLED DRILLING SYSTEM USING FLUIDIC ELEMENTS

1966/7

MANAGEMENT & TECHNICAL SURVEY REPORT

Prepared by E. A. Powell
G. C. Boshier

Staff advisor C. J. Charnley

SUMMARY

This report outlines the aims of the project and procedures used to bring it to a successful conclusion. It also summarises the results of an investigation into the parameters which govern the specification of a numerically controlled point to point drilling machine.

CONTENTS

1.0 INTRODUCTION TO PROJECT

The post-graduate course in Production Technology (with specialisation in Automation and Precision Engineering) is comprised of a series of lectures, a group design project and an individual piece of research culminating in the writing of a thesis.

The project has the following aims:-

1) To act as a unifying link for the various lectures given to the students and to provide practical examples for the application of the theories developed.

2) To give experience of working as a group on an industrial design problem.

3) To provide a platform for the integration of teaching and research in the development of new automatic production systems.

The method of operation involves a Project Board made up of staff and students, together with a number of groups formed as required to meet particular design needs. Each group has to arrange meetings, consider design requirements and make recommendations to the board concerning its chosen area of activity. At the final project meeting each group is required to submit a detailed report outlining its design recommendations and presenting the drawings and design calculations involved.

During the course of the project each student takes it in turn to act as Secretary of the Project Board, write up the minutes and prepare an agenda and then act as Chairman for the following week. A typical project meeting is shown in fig. 1.

2.0 DRILLING SYSTEM PROJECT

For the session 1966/7 the initial terms of reference given were "To design a numerically controlled system for drilling holes using fluidic elements".

The following groups were formed:-

1) Management - to prepare a programme of work and monitor the performance of the other committees so that the project could be completed as planned.

2) Technical Survey - to investigate the requirements of industry for numerically controlled drilling machines so that a realistic specification could be written.

3) Control System - to prepare a scheme for a fluidic control system.

4) Drill Head & Frame Design - to design the drilling spindle and associated equipment and to be responsible for the functional design of the drilling structure.

The final configuration for the Numerically Controlled Drilling System is shown in fig. 2 while fig. 3 shows the one axis simulator which represents the stage reached in a related research project designed to implement the fluidic control system.

Drill Head and Frame

The machine shown in fig. 2 has been designed from a functional viewpoint with the specification based on a technical survey and has two independent worktables so that machining can be performed on one while the operator is loading or unloading the other with a consequent high utilisation factor. Loading is performed on a horizontal face at a convenient height for the operator while machining on a vertical face allows the swarf and coolant to fall freely onto the swarf disposal chute.

Unit construction has been employed throughout so that a range of machines can be developed from the initial concept with the minimum of additional work. For example although the tables are capable of taking the 18 x 18 x 12 in (460 x 460 x 300 mm) components specified in the technical survey report it would involve a relatively minor effort to increase the table size so that double the length of component could be accommodated. Another alternative for occasional longer components is to arrange for the 2 tables to move together for loading and subsequent machining.

The drill head has been designed on a unit basis initially for single tool operation but with sufficient flexibility for the incorporation of future refinements, such as automatic tool change, to be incorporated.

The spindle drive uses a hydraulic power system with a fixed displacement pump and variable displacement motor giving a speed range of 80 to 2000 rev/min.

Although careful consideration was given to the use of hydraulic feedrate control for the drill head it was eventually decided to employ an electric motor and multi-speed gearbox drive. For the depth control conventional gate stops were chosen with pneumatic sensing elements to provide compatibility with the fluidic elements of the control system.

The following advantages are claimed:-

1) Twin worktables increase machine utilization.
2) Fluidic control system gives low cost reliability.

3) Drilling on vertical face keeps workpiece clear of swarf.
4) Integrated conveyor belt aids swarf disposal.
5) Operator shielded from moving parts by worktable.
6) Tool changing and maintenance easily performed.
7) Ergonomic height of worktables increases operator efficiency.

Control System

The control system is capable of positioning the machine table relative to the spindle of the tool by moving the drill head along 2 perpendicular axes; the positioning accuracy to be maintained is within ± 0.001 in (25 μm) of the demanded position. The input is by tape reader reading I.S.O. coded information in block format with position feedback from drum encoders fitted to the moving members. The control logic involves 3 comparators and 2 subtractors per axis with final positioning always achieved from the same direction. The approach to position involves 3 speeds - a fast traverse at 300 in/min (125 mm/s), an intermediate speed of 40 in/min (16 mm/s) and a final creep speed of 4 in/min (1.6 mm/s).

The basic control circuit is shown in fig. 4 with the 4 digit binary comparator illustrated in fig. 5.

The full technical reports of the various committees, (refs. 1 & 2) together with other published information concerning the research activities of the department are available on request.

3.0 TECHNICAL SURVEY

At the first meeting of the Drilling System Design Committee it was realised that some detailed information was necessary to establish a basic specification for the drilling machine. The choice of fluidics for positional control would be a major factor in lowering the cost of the machine and the aim throughout the project should be "numerical control at a low initial cost".

To be able to establish and maintain this criterion it was apparent the machine would have to sell to a large market: specialisation, therefore, would have to be avoided. However, the use of integrated, interchangeable units would enable a wide variety of systems to be built up from a limited range of basic units.

With this formula in mind the Technical Survey Committee prepared a questionnaire to establish from industry the basic requirements for a machine of this type. Direct questions were asked on points which would be necessary at a later stage in the design as well as providing information for a basic specification. One hundred and twenty questionnaires were circulated to a very wide cross-section of firms, their products ranging from ships to electronic instruments. The forms, with an explanatory letter, see appendix, were despatched on

February 9th, 1967, since then fifty replies have been received (May 19th). Provision was made on the form for firms to suggest design features that they would welcome in the machine; this has produced some interesting and most useful ideas and each has been, or will be, investigated by the design committee responsible.

The Technical Survey Committee admit that the answers to the questionnaire show that the format could have been improved; mention should be made, however, that specialised knowledge in the preparation of such forms was not obtained as results were required quickly by all design committees. Recommendations by the Committee for compiling similar forms are shown in Appendix 2, which may be of use for later design projects.

The Committee has been heartened by the response and the thought that has gone into the answering of the questionnaires and would like to thank all those who have contributed to our effort.

4.0 DISCUSSION OF FREQUENCY DISTRIBUTIONS

The frequency distributions described below have been drawn up to guide the drilling machine design committees when determining their final specifications. The committees have indicated they would require a specification to meet at least 80% of British Industries requirements.

Frequency Distributions of Hole Sizes (Fig. 6, Question 1)

The distribution indicates that 86% of the holes drilled by British Industry are less than 1 in (25 mm) diameter.

Range of Cutting Speeds (Fig. 7, Question 2)

Although a large proportion (69%) of the cutting speeds used 100 ft/min (0.5 m/s) and under, to accommodate over 80% of requirements, 400 ft/min (2 m/s) must also be included.

Frequency Distribution of Industrial Tolerances (Fig. 8, Question 3)

The distribution shows that 85% of the positional tolerances required are ± 0.001 in (0.025 mm) or greater.

Frequency Distribution of Length, Breadth & Height of the Majority of Components (Fig. 9a, b, and c, Question 4)

A cube produced from the dimensions indicated by the 80% limitation of each dimension would be 18 x 18 x 18 in (460 x 460 x 460 mm). As 79% of the heights are 12 in (300 mm) or less, the cube could be altered to 18 x 18 x 12 in (460 x 460 x 300 mm) if the design committee felt the 1% reduction below the initial specification was not significant.

Frequency Distribution of Components requiring a Multi-Tool Set up (Fig. 11, Question 6)

The distribution indicates that 92% of the components produced by British Industry require a multi-tool set up of 12 or less tools. 77% of the components require a multi-tool set up of six or less tools.

Frequency Distribution of Batch Sizes (fig. 12a & b, Questions 7 & 8)

Of the maximum batch sizes issued by British Industries 84% are 320 or less, whereas 88% of the normal batch sizes are 160 or less.

Frequency Distribution of Number of Faces Drilled (Fig. 13, Question 9)

If facilities for machining up to 4 faces of each component are provided 93% of the market would be included.

Frequency Distribution of Component Weight (Fig. 14a & b), Question 10)

The distribution indicates that 80% of the majority of components are 60 lb (270 N) or less in weight, and 86% of the heaviest components drilled by British Industries weigh 1000 lb (4500 N) or less.

5.0 SUMMARY OF REPLIES TO QUESTIONS 11, 12 and 13

QUESTION No. 11

80% considered numerical control was suitable for their needs.

QUESTION No. 12

87% considered they required an independent manual control on a numerically controlled drilling machine.

QUESTION No. 13

93% of the replies preferred programming in Cartesian (x,y) co-ordinates rather than in Polar (r,θ) co-ordinates.

REFERENCES

1. BOSHIER, G.C., PIKE, G.W.H., MORRISON, W., SUTCLIFFE, R.S. Drill Head and Frame Design Report, The Design of a Numerically Controlled Drilling System using Fluidic Elements. CoA Memo No. 138, Cranfield 1967.

References (cont.)

2. VEAZEY, R. POWELL, E.A. Control Systems Report, The Design of a Numerically Controlled Drilling System Using Fluidic Elements. CoA Memo No. Cranfield 1967.

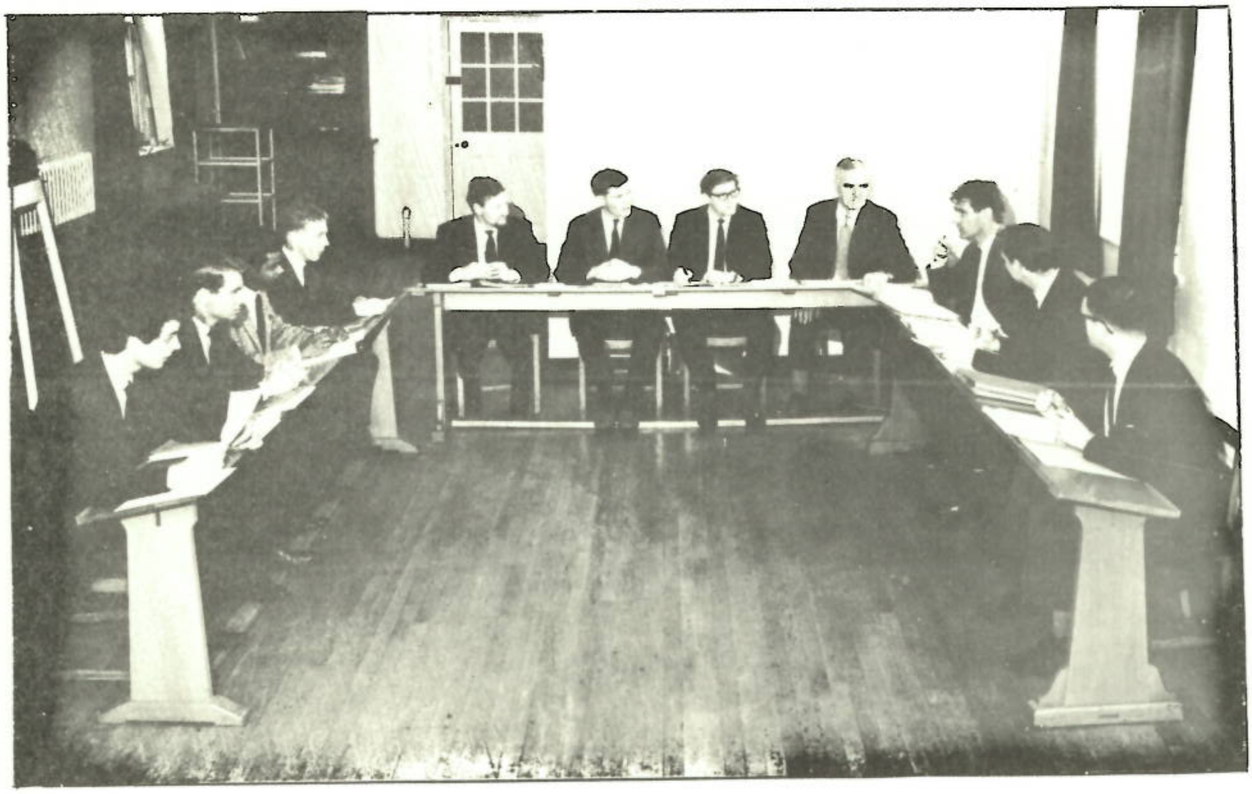


FIG. 1 - FINAL PROJECT MEETING

G.C. Boshier	student (sponsored by Pressed Steel-Fisher)
R. Veazey	student (sponsored by English Electric)
S. Ramanathan	Research Fellow (Fluidics)
E.A. Powell	student (previously with Rotax Aircraft Equipment)
C.J. Charnley	Senior Lecturer (Machine Tools & Automation)
W. Morrison	student (previously with I.R.D.C.)
G.W.H. Pike	student (previously with R.A.E., Farnborough)
Professor J. Loxham	Head of Department
R.E. Bidgood	Lecturer (Fluid Systems & Fluidics)
R.S. Sutcliffe	student (sponsored by I.L.E.A.)
P. Cooke	Senior Research Fellow (Machine Tool Design)

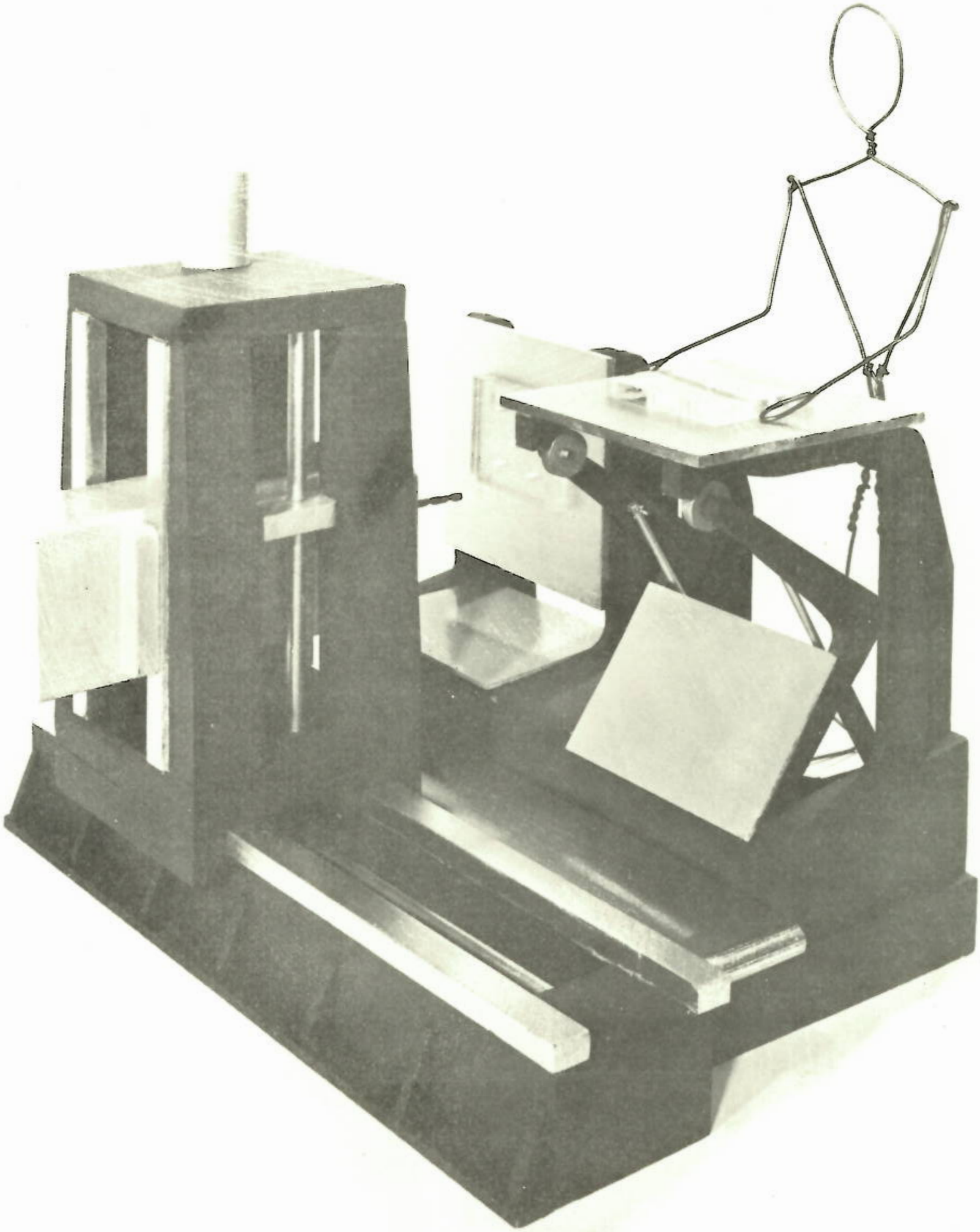


FIG. 2 - NUMERICALLY CONTROLLED DRILLING SYSTEM

The machine has been designed from a functional viewpoint with the specification based on a market survey.

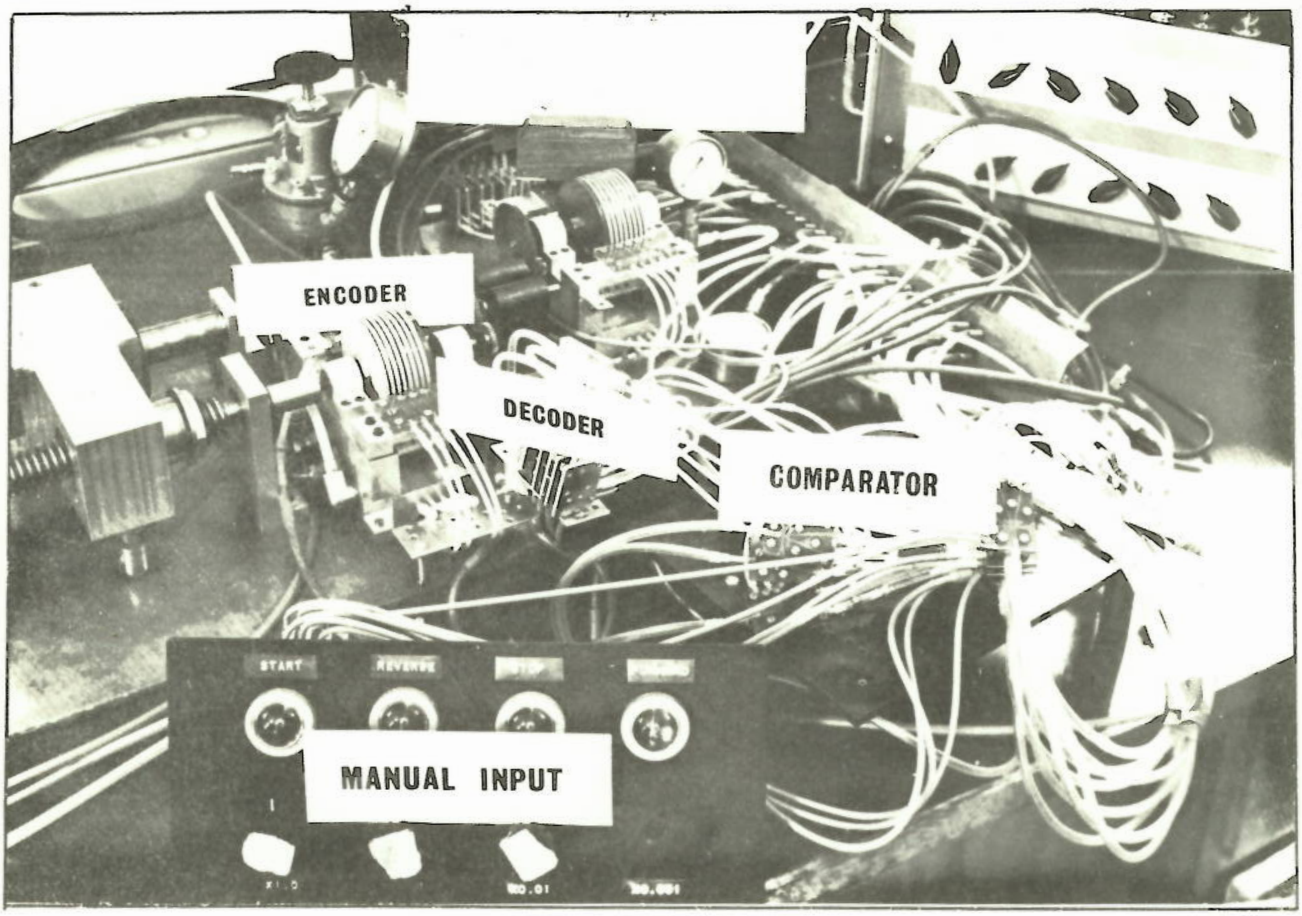


FIG. 3 - Machine simulator. The drive axis and control system have been designed to provide information for the design of a co-ordinate drilling system.

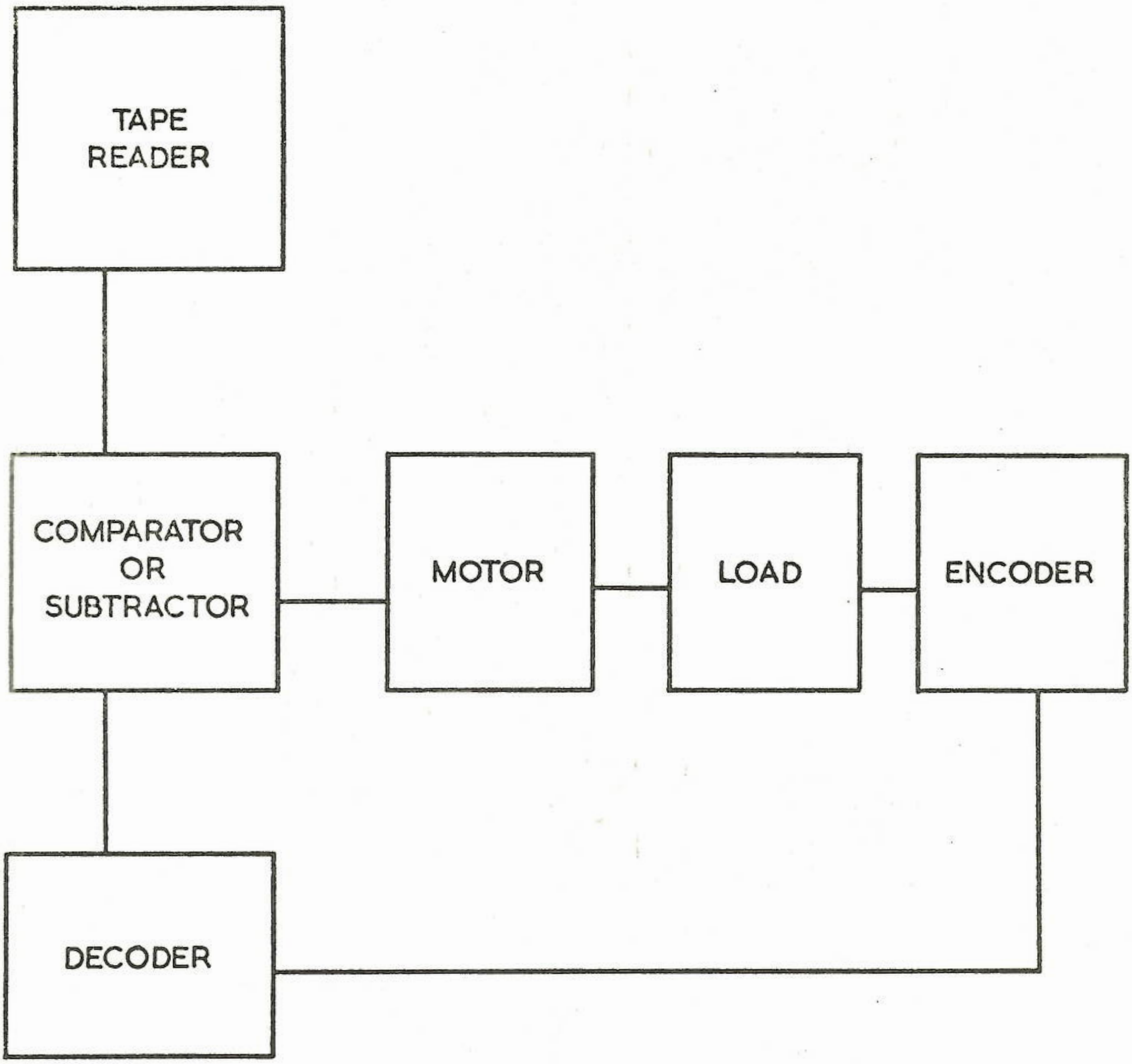
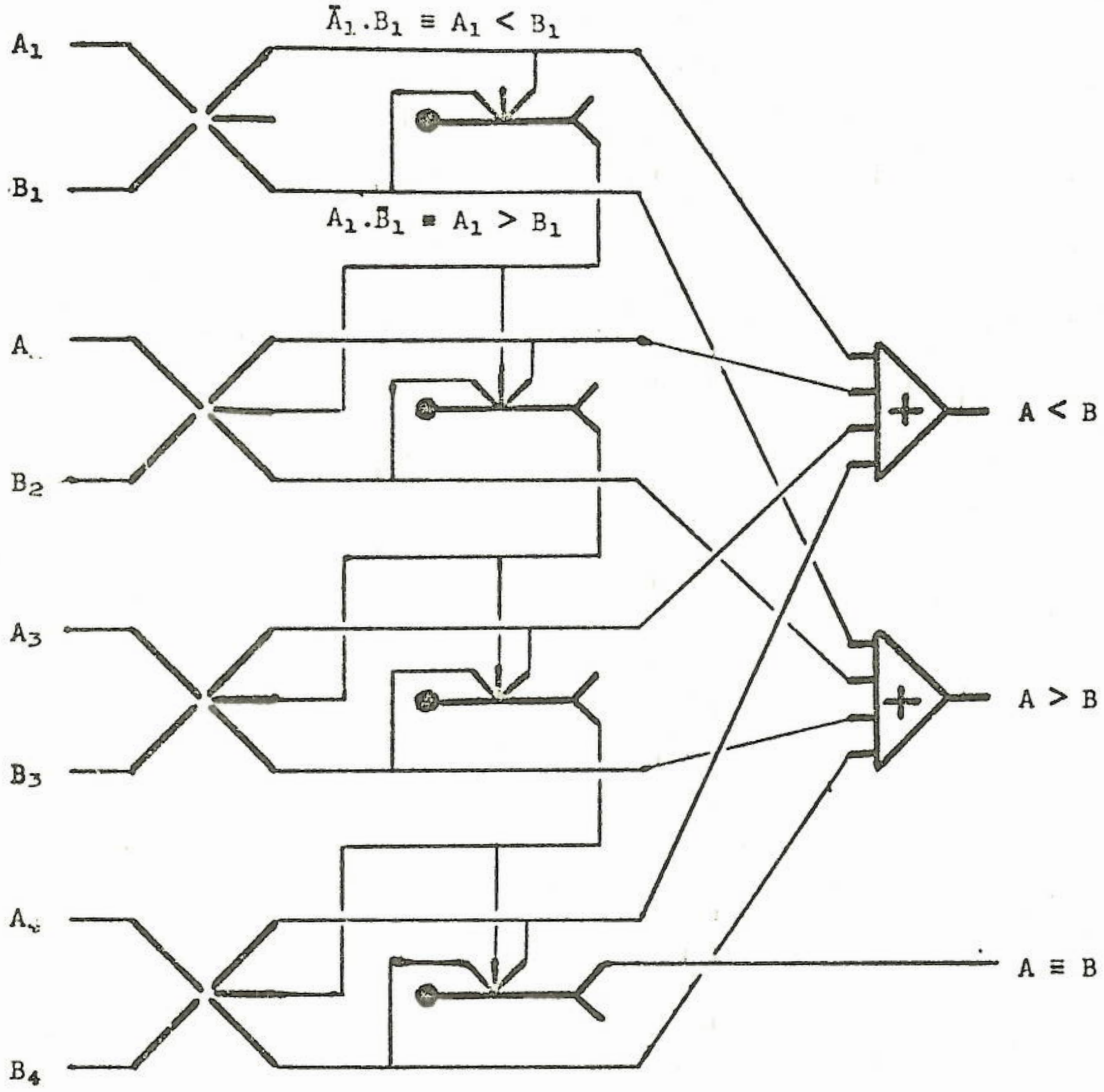


FIG.4. BASIC CONTROL CIRCUIT.



$A = f(A_1, A_2, A_3, A_4)$
$B = f(B_1, B_2, B_3, B_4)$

FIG. 5 FOUR DIGIT BINARY COMPARATOR USING JET IMPINGEMENT DEVICES

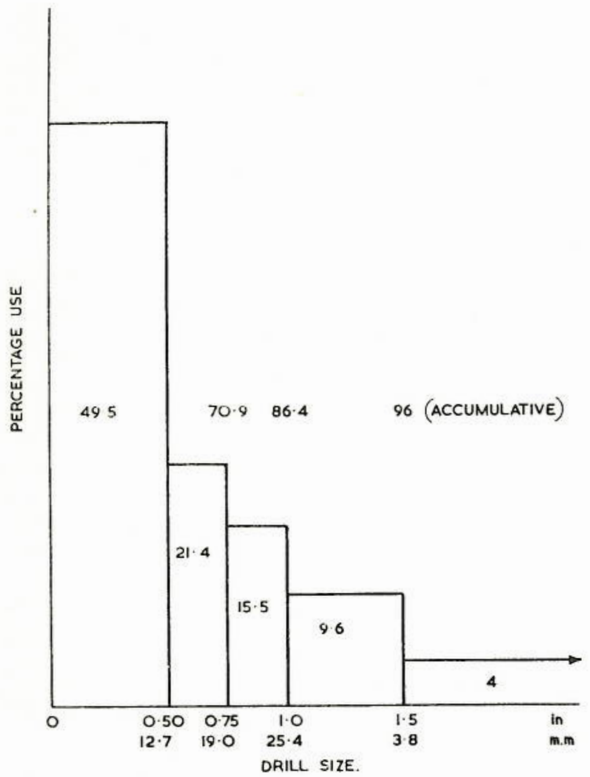


FIG.6.

MATERIAL	PERCENTAGE USE	CUTTING SPEED H.S.S. TOOL ft/min	m/s
MILD STEEL	39	100	0·5
C.I. & ALLOY STEEL	30	50	0·25
ALUMINIUM	23	400	2·0
BRASS	8	250	1·25

FIG. 7.

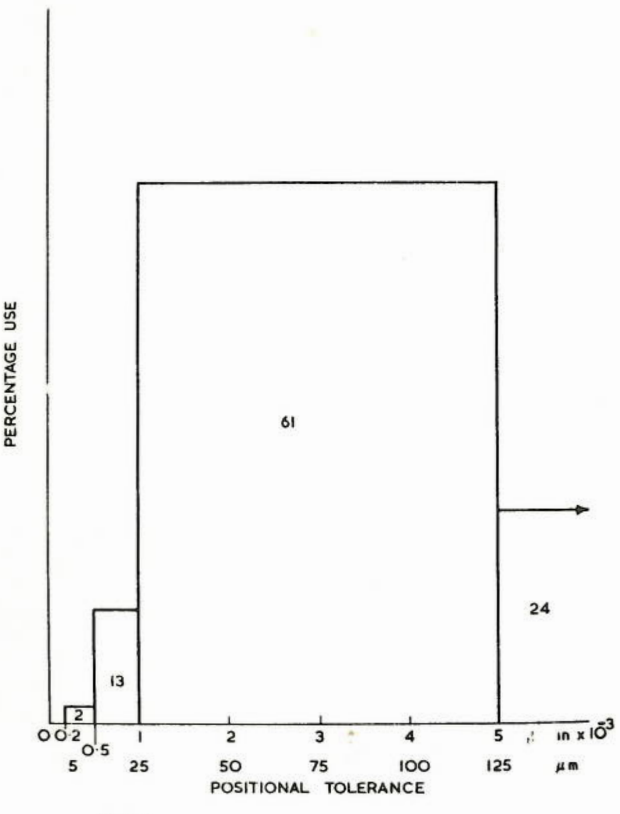


FIG.8.

FIG. 6. FREQUENCY DISTRIBUTION OF HOLE SIZES.
QUESTION. 1.

FIG. 7. RANGE OF CUTTING SPEEDS.
QUESTION. 2.

FIG. 8. FREQUENCY DISTRIBUTION OF TOLERANCES.
QUESTION. 3.

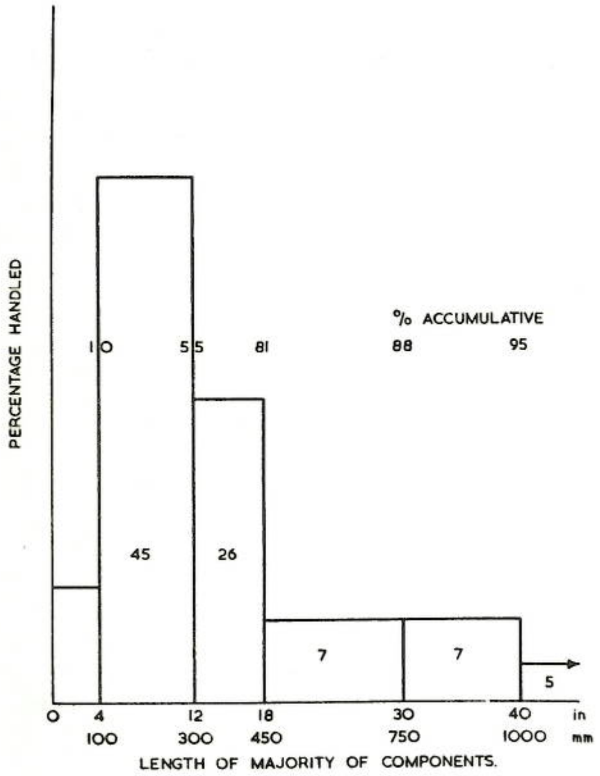


FIG.9a.

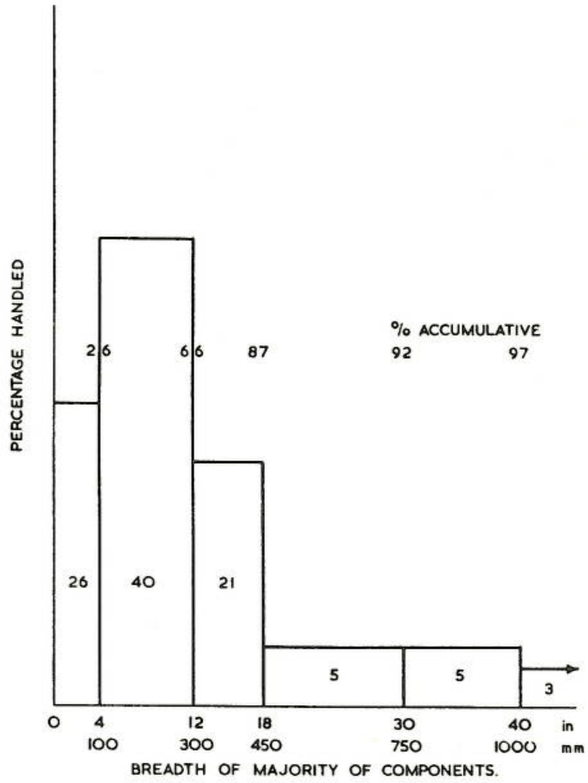


FIG.9b.

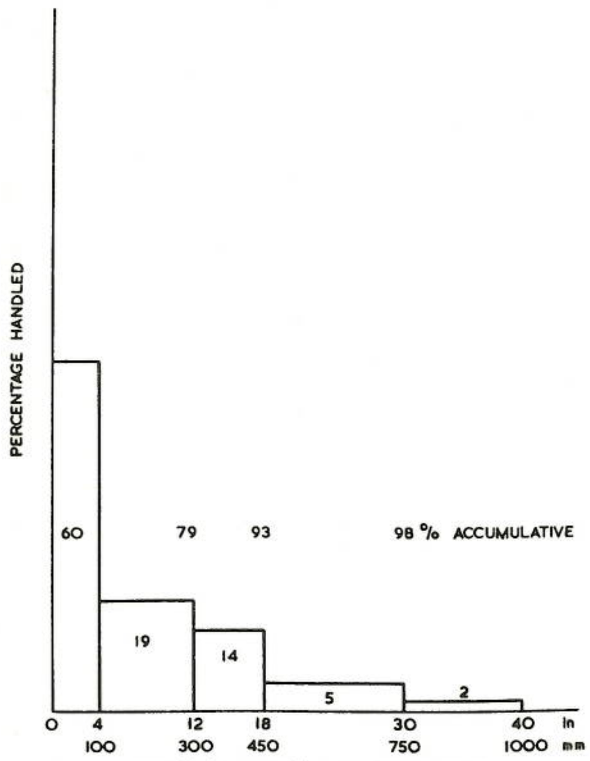


FIG. 9c.

FIG. 9. FREQUENCY DISTRIBUTIONS FOR THE MAJORITY (80%) FOR COMPONENTS. QUESTION. 4.

a.- LENGTH.

b - BREADTH.

c - HEIGHT.

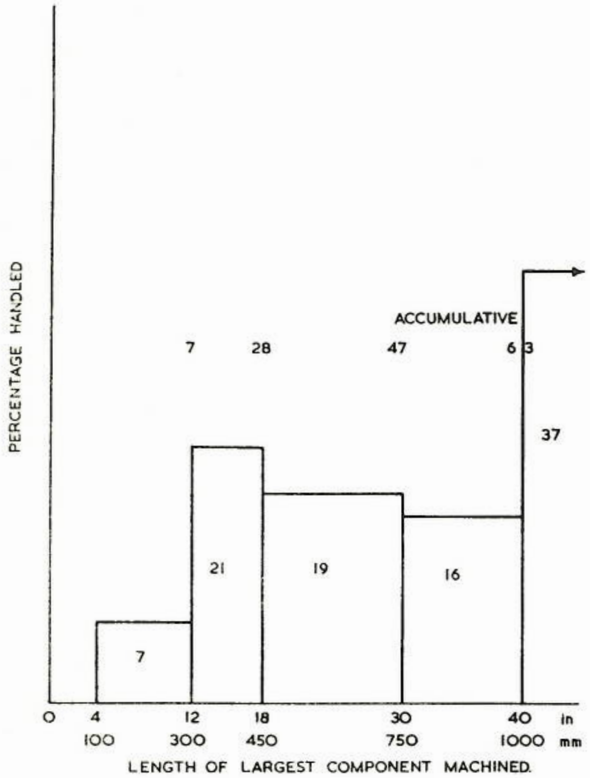


FIG.10a.

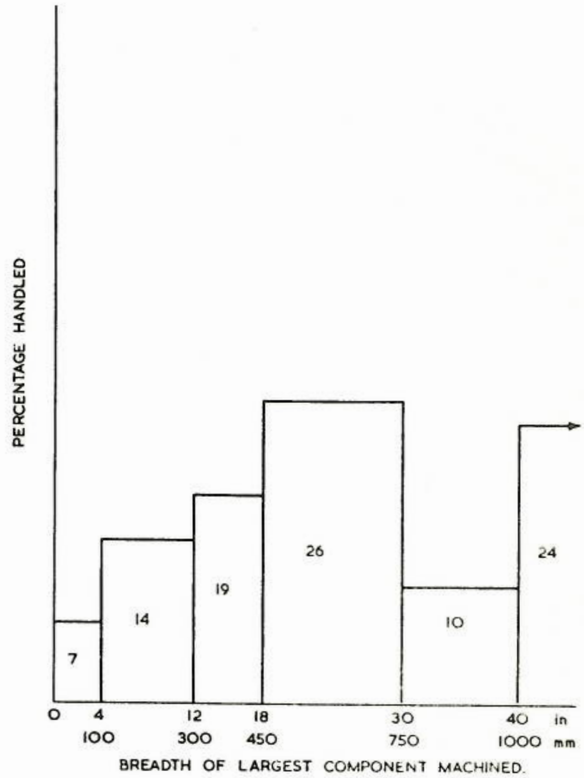


FIG. 10 b.

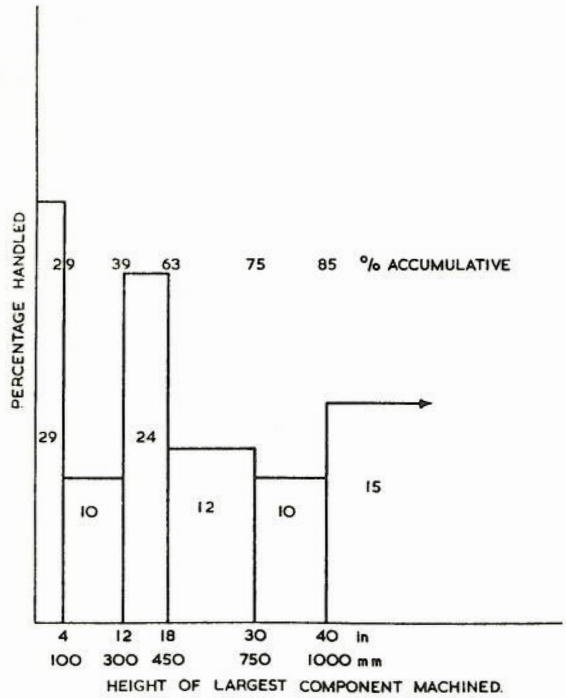


FIG 10c.

FIG. 10. - FREQUENCY DISTRIBUTIONS FOR THE LARGEST COMPONENTS.

QUESTION 5

a - LENGTH

b - BREADTH.

c - HEIGHT.

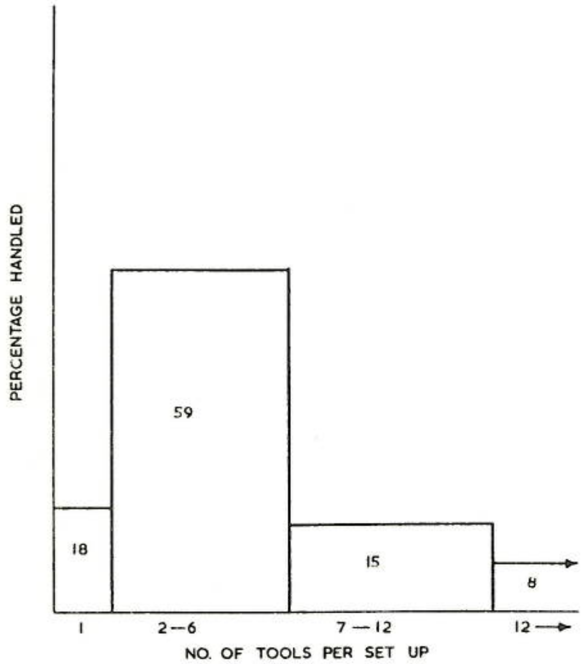


FIG.11.

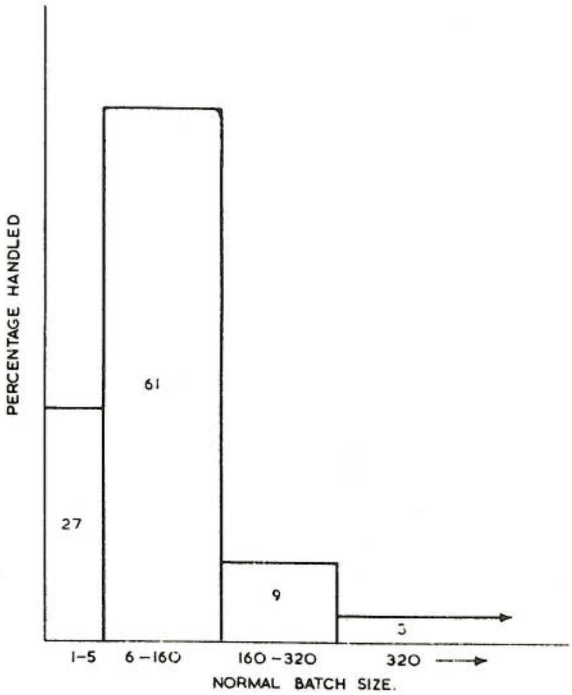


FIG.12a.

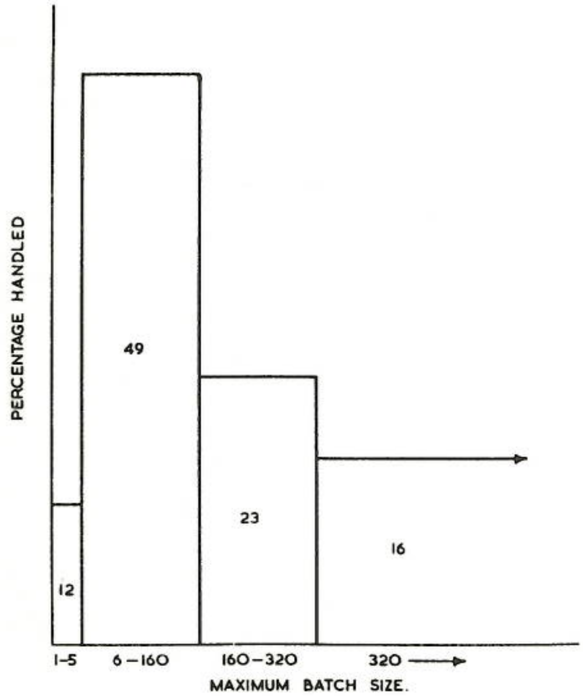


FIG. 12b.

FIG. 11.- FREQUENCY DISTRIBUTION OF COMPONENTS REQUIRING A MULTI-TOOL SET UP

QUESTION. 6.

FIG. 12.- FREQUENCY DISTRIBUTION OF BATCH SIZES FOR DRILLED COMPONENTS.

QUESTION. 7.

a - NORMAL BATCH SIZE.

b - MAXIMUM BATCH SIZE.

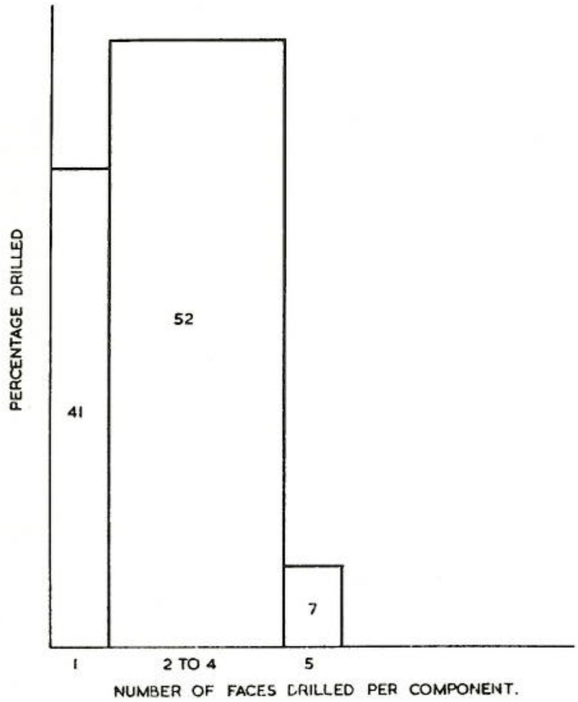


FIG.13.

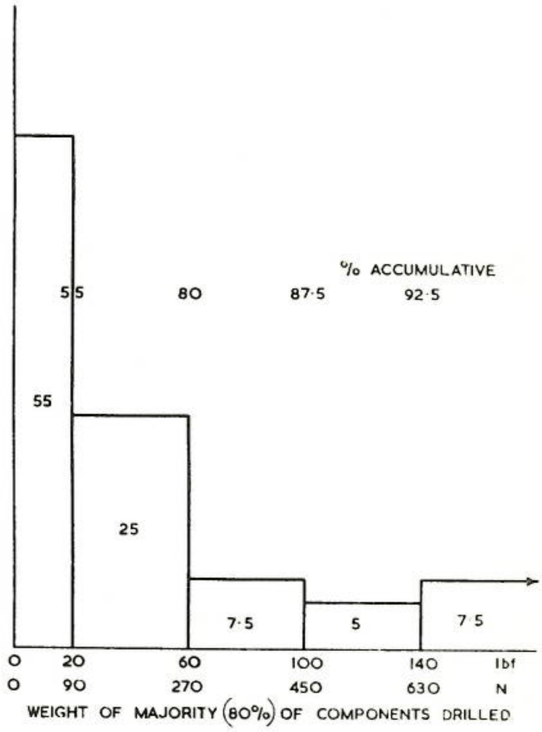


FIG.14a.

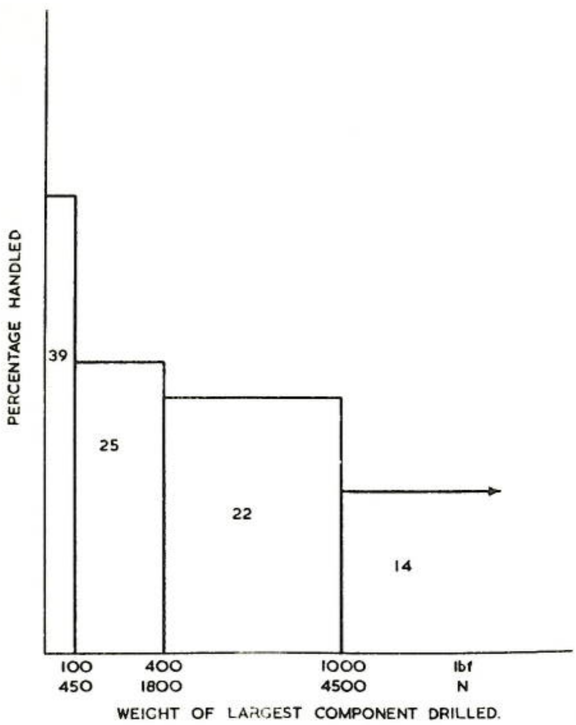


FIG.14b.

FIG. 13. FREQUENCY DISTRIBUTION OF NUMBER OF FACES DRILLED.

QUESTION 9.

FIG. 14. FREQUENCY DISTRIBUTION OF WEIGHTS OF COMPONENTS DRILLED.

QUESTION. 10.

a. - MAJORITY (80%)

b - LARGEST

THE COLLEGE OF AERONAUTICS

CRANFIELD, BEDFORD

Tel.: Cranfield 321

DEPARTMENT OF PRODUCTION AND INDUSTRIAL ADMINISTRATION

Professor of Production Engineering:

Head of Department:
Professor : JOHN LOXHAM
C.G.I.A., M.I.Mech.E. M.I.Prod.E., F.B.I.M.

Professor of Industrial Management:
Professor P. G. FORRESTER
M.Sc., F.I.M.

GCB:JER

9th February, 1967.

Dear Sirs,

QUESTIONNAIRE - NUMERICALLY CONTROLLED DRILLING MACHINE

An important feature of the post-graduate course in Production Technology at Cranfield, is the study of machine tool automation and design.

In order to make this study realistic, a machine is taken from basic concept through to detailed drawing for manufacture; throughout this project close contact is maintained with manufacturers and users of the machine we are designing.

A numerically controlled drilling machine using fluidic positioning, has been chosen for this years project. It is hoped that such a machine can be produced for substantially less than the present electro-hydraulic positioning machines.

Would you be kind enough to fill in the enclosed questionnaire and return it as soon as possible, in order to assist with a basic specification.

Yours faithfully,

G C Boshier

G.C. Boshier,
Secretary - Market Research Committee.

COLLEGE OF AERONAUTICS, CRANFIELD

DEPARTMENT OF PRODUCTION ENGINEERING

AUTOMATION DESIGN PROJECT 1967

PLEASE TICK APPROPRIATE SQUARE

1. HOLE SIZES DRILLED

	APPROX PERCENTAGE						
	0	20	40	60	80	90	100
UNDER 0.5 in							
UNDER 0.75 in							
UNDER 1 in							
UNDER 1.5 in							
OVER 1.5 in							

2. DIFFERENT MATERIALS DRILLED

	APPROX PERCENTAGE						
	0	20	40	60	80	90	100
ALUMINIUM							
BRASS							
MILD STEEL							
ALLOY STEEL							

(eg. 60/80 ton/in^2 TENSILE)

3. NORMAL POSITIONAL TOLERANCE OF DRILLED HOLES

Less than 0.0002	0.0002 to 0.0005	0.0005 to 0.001	0.001 to 0.005	Greater than 0.005

4. OVERALL DIMENSIONS OF THE MAJORITY OF COMPONENTS

	DIMENSION (in)					
	0 to 4	4 to 12	12 to 18	18 to 30	30 to 40	Over 40
LENGTH						
BREADTH						
HEIGHT						

5. SIZE OF LARGEST COMPONENT DRILLED

	DIMENSION (in)					
	0 to 4	4 to 12	12 to 18	18 to 30	30 to 40	Over 40
LENGTH						
BREADTH						
HEIGHT						

6. PERCENTAGE OF COMPONENTS REQUIRING A MULTI-TOOL SET-UP (ie. Drill, tap, bore etc.)

No. of tools per set up	APPROX PERCENTAGE					
	0	20	40	60	80	100
1						
2 to 6						
7 to 12						
over 12						

7. NORMAL BATCH SIZE OF COMPONENTS TO BE DRILLED

BATCH SIZE			
0 to 5	6 to 160	160 to 320	Over 320 please specify

8. MAXIMUM BATCH SIZE

BATCH SIZE			
1 to 5	6 to 160	160 to 320	Over 320 please specify

9. NO. OF FACES OF COMPONENT DRILLED

No. of faces	APPROX PERCENTAGE					
	0	20	40	60	80	100
1						
2 to 4						
5						

10. WEIGHT (if known) OF

i) MAJORITY OF COMPONENTS:

ii) HEAVIEST COMPONENT :

11. DO YOU CONSIDER A NUMERICALLY CONTROLLED DRILLING MACHINE SUITABLE FOR YOUR NEEDS

YES	NO

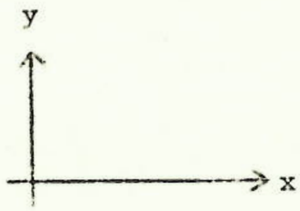
IF ANSWER YES

12. DO YOU CONSIDER AN INDEPENDENT MANUAL CONTROL A NECESSITY ON A NUMERICALLY CONTROLLED MACHINE

YES	NO

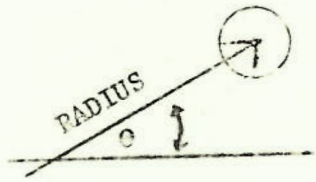
13. WOULD YOU PREFER TO PROGRAMME A TAPE IN TERMS OF

(i)



or

(ii)



14. HAVE YOU ANY OTHER COMMENTS (eg. SWARF DISPOSAL. LOADING FACILITIES etc.)

APPENDIX 2

DISCUSSION AND CONCLUSIONS ON QUESTIONNAIRE

Due to the difficulties some people had in answering the questionnaire, the following recommendations have been made to clarify the ambiguous questions. The reason is to help any further investigators when compiling similar papers.

QUESTION No. 1

Several replies showed that this question was not worded as clearly as is required by a survey of this type. An alternative is as follows:-

Less than 0.5 in
between 0 and 0.75 in
between 0 and 1.0 in
between 0 and 1.5 in
greater than 1.5 in

The replies indicated that most people preferred to answer the type of question shown below, where actual percentages are requested rather than to place a tick in one of a large number of squares.

	State Percentage
less than 0.5 in	
0.5 in - 0.75 in	
0.75 in - 1.0 in	
1.0 in - 1.5 in	
greater than 1.5 in	

QUESTION No. 4 and 5

The word majority has no clearly defined value and could be interpreted by a person answering the question as any value between 51% and 99%. The recommendation therefore is to combine questions 4 and 5, so that the actual percentages falling in each category are requested.

QUESTION No. 7 and 8

Question 7 has a similar fault to that mentioned above - the word normal has no defined mathematical value. The recommendation therefore is to combine questions 4 and 5, so that the actual percentages falling in each category are requested.

QUESTION No. 10

This question should be reworded to ask for the range of component weights.