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United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.87/33/Add.1
5 November 1971
ORIGINAL: ENGLISH

Regional Seminar on Machine Tools
in Developing Countries of
Europe and Middle East

Zlatni Pjassaci (Golden Sands) near
Varna, Bulgaria, 18 to 27 October 1971

THE MACHINE TOOL DESIGN PROCESS IN A DEVELOPING ENVIRONMENT

by

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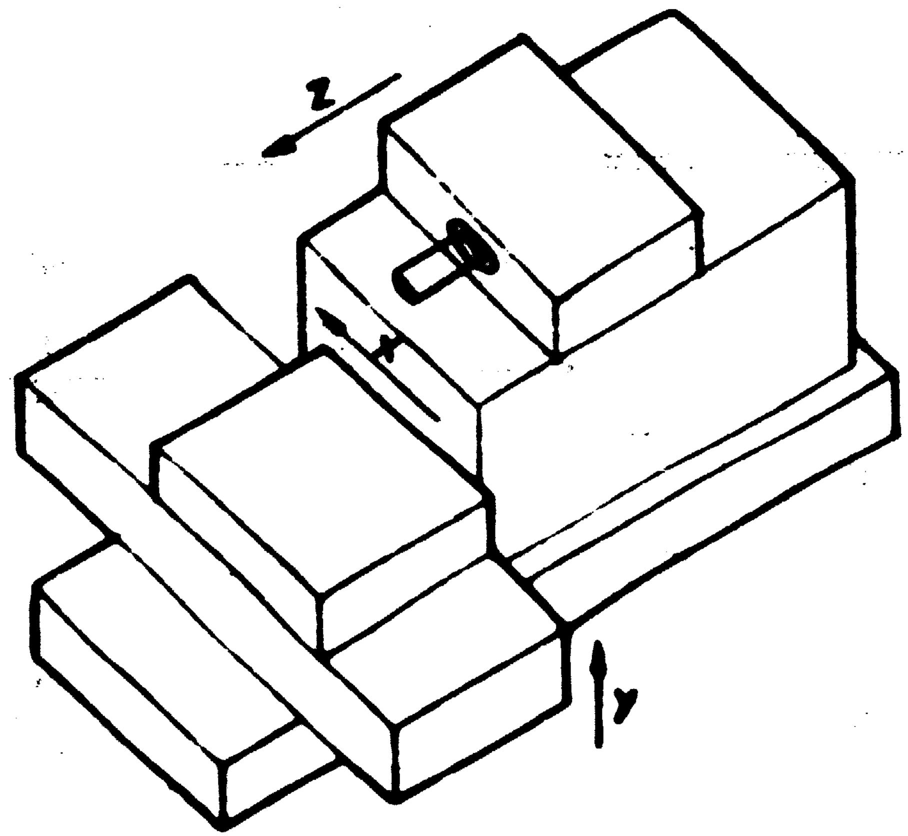
Addendum

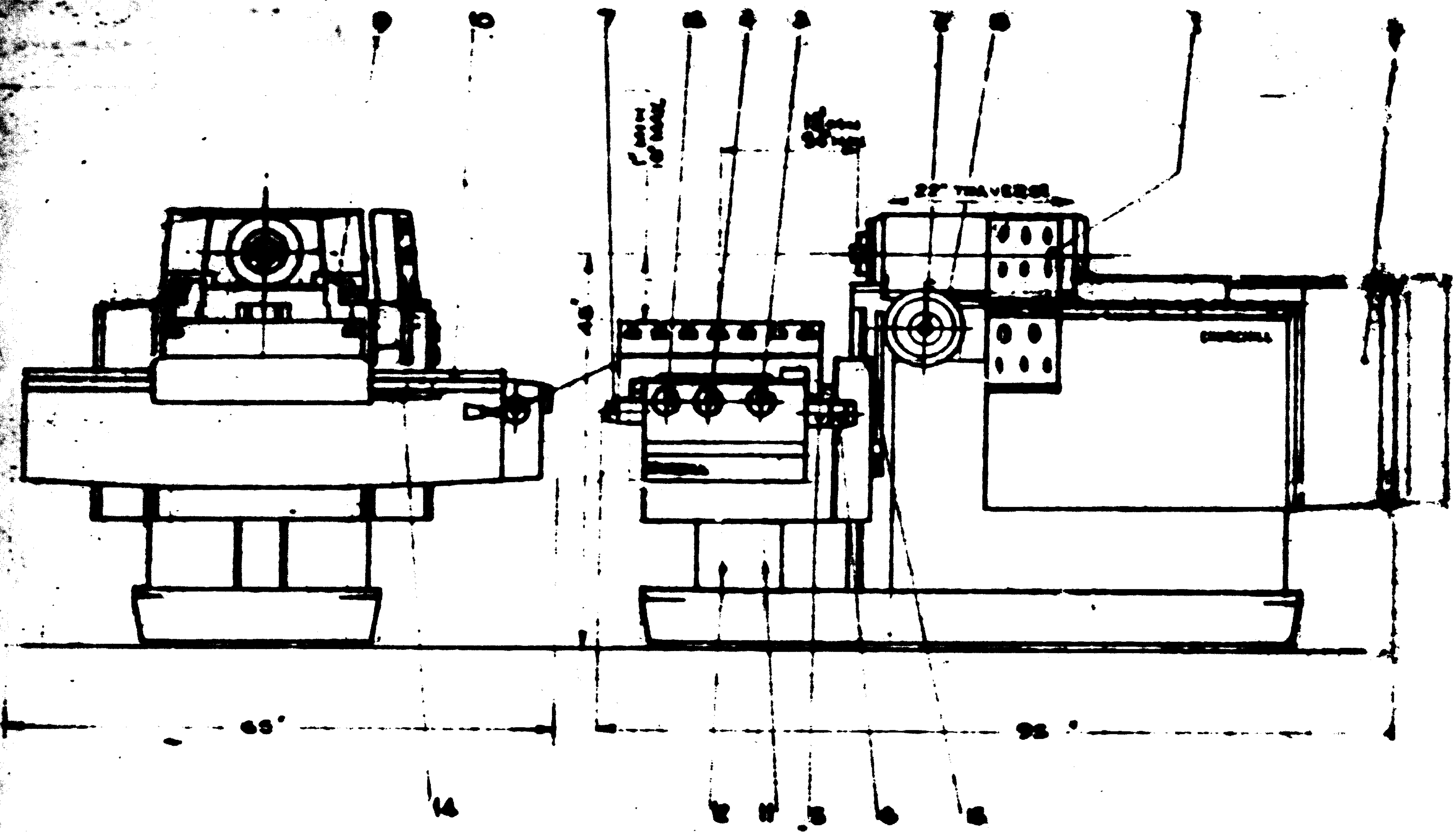
id.71-8471



CHURCHILL
JULY '67

FIG. 4 AXES DEFINITION SB24

RS. 1903



CHURCHILL
11 AUG 65

FIG. 5 CHURCHILL SD. 24. R. MACHINE

1316

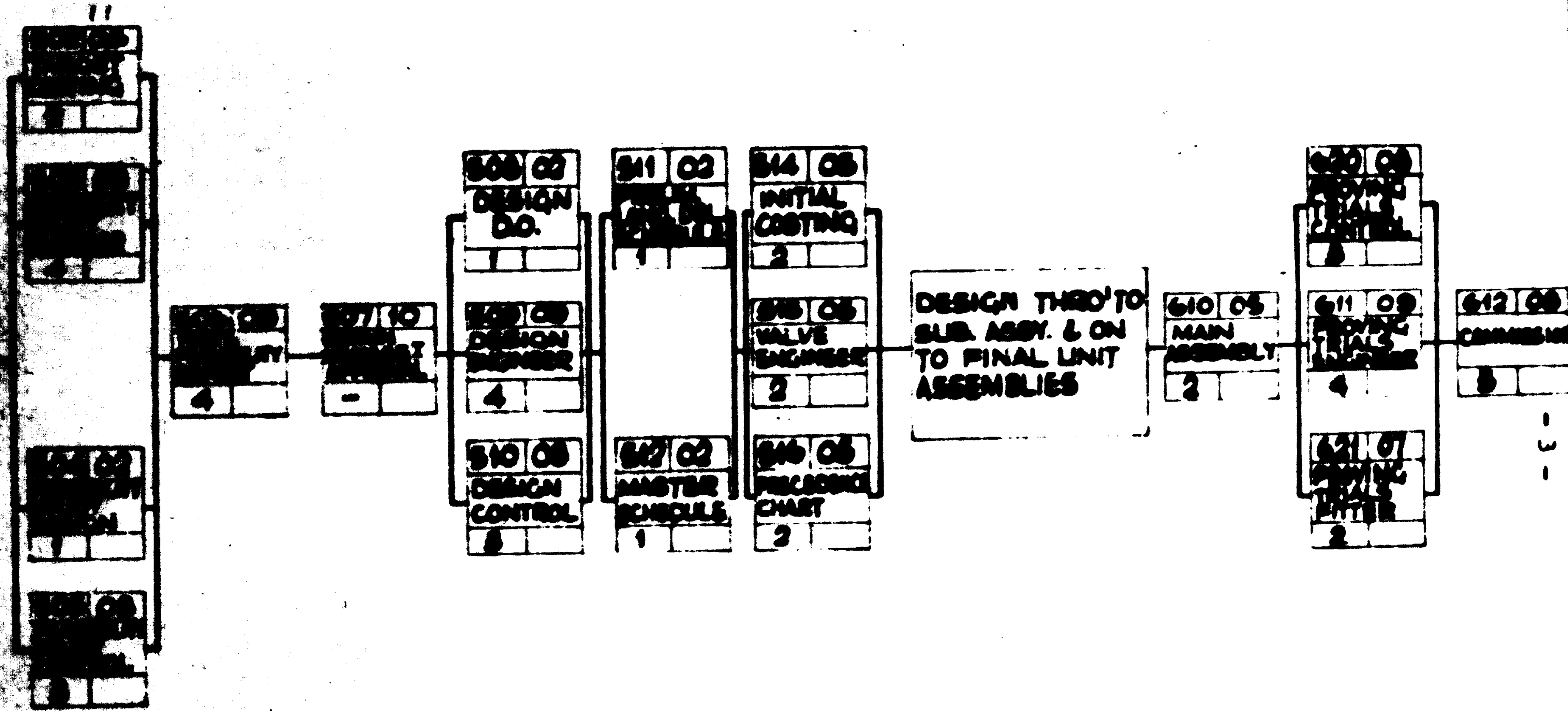


FIG. 7
PROJECT CONTROL - PRECEDENCE CHART.

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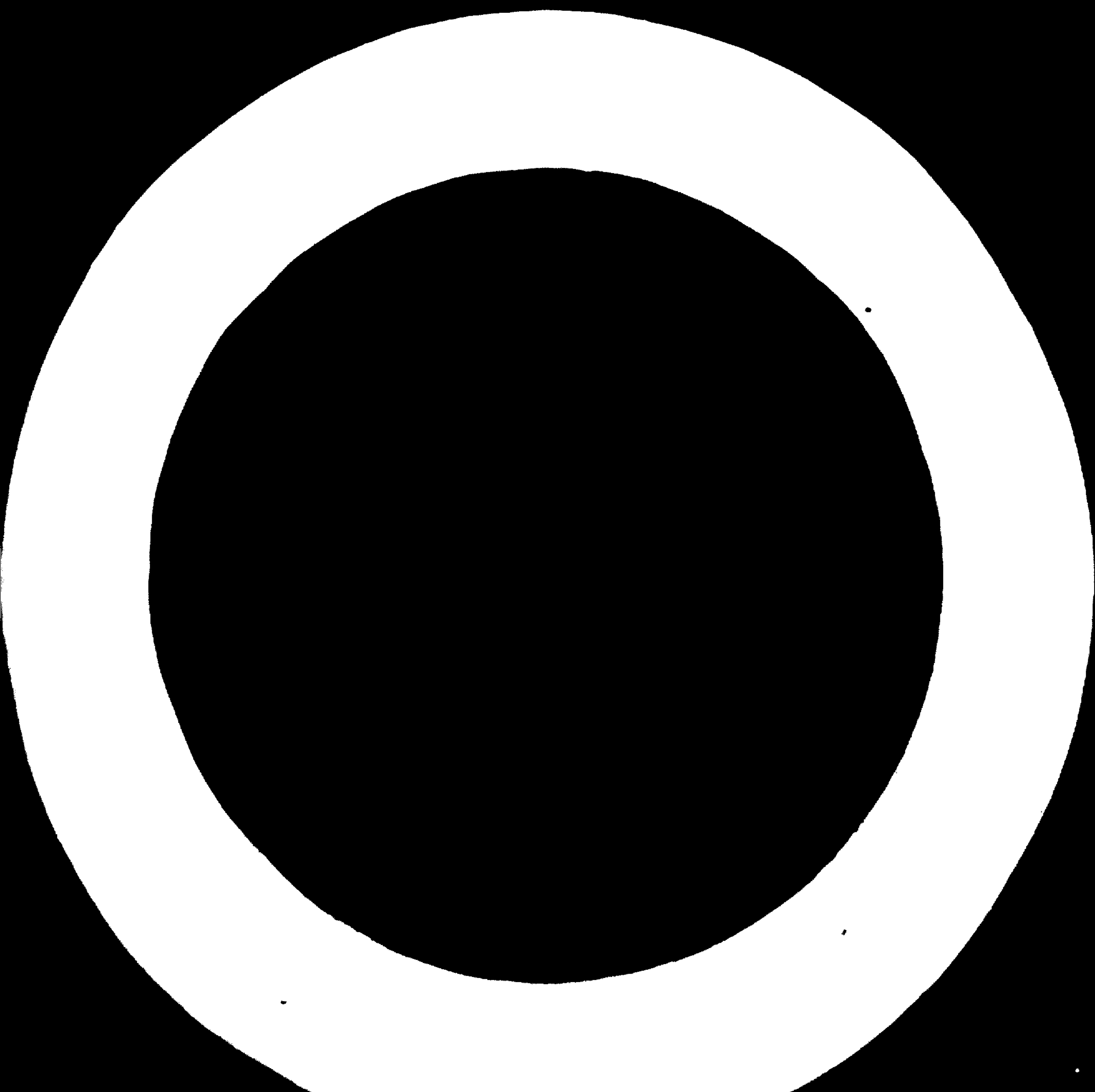

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United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.87/33
12 October 1971

ORIGINAL: ENGLISH

Regional Seminar on Machine Tools
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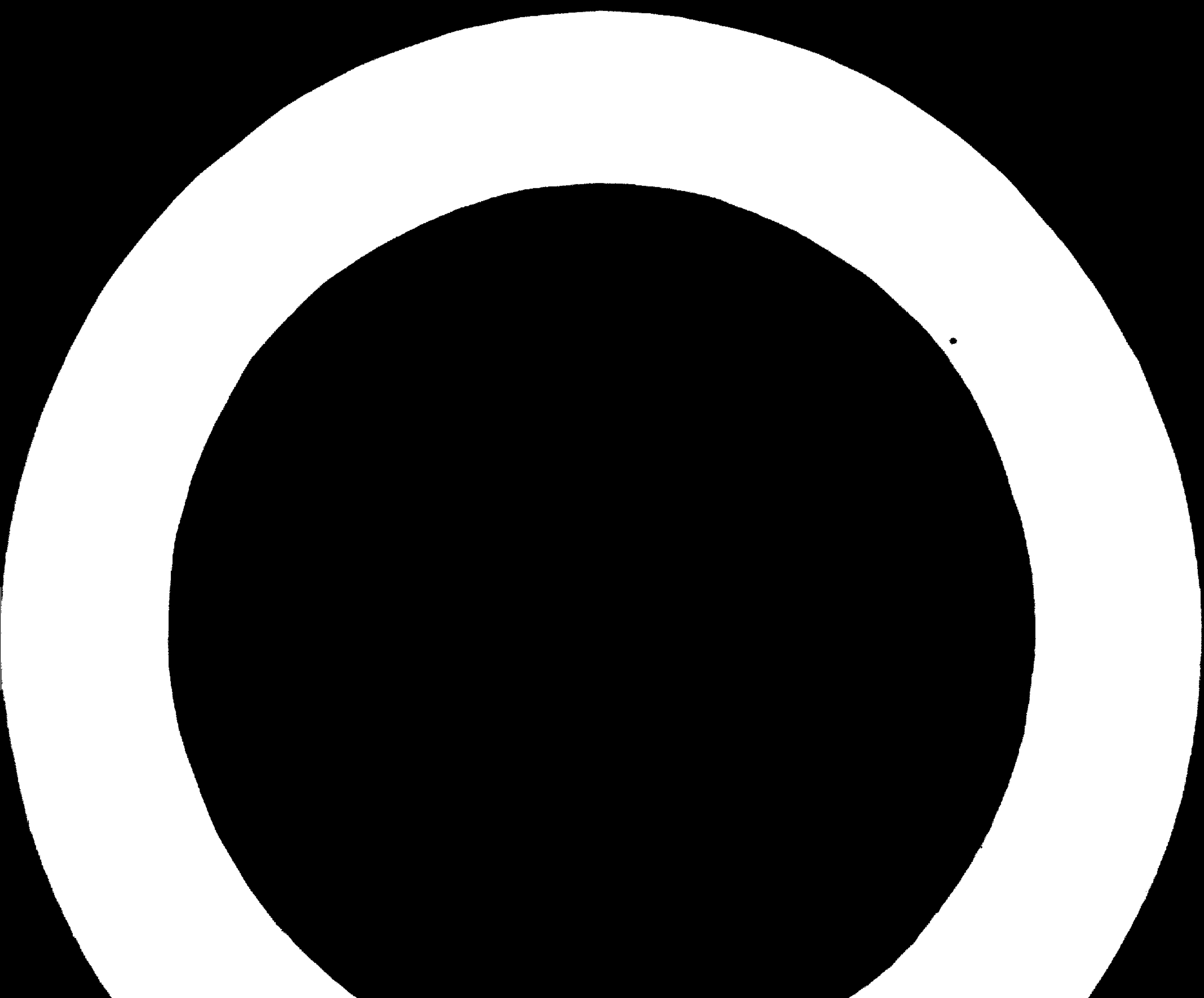


SYNOPSIS

The machine tool design process is looked at in the context of the introduction of a new product into an already existing manufacturing operation. Reference is made in a qualitative way to all of the phases of a new product project and to the philosophy of the engineering design process rather than to the detailed technical factors involved in machine tool design, these being already adequately covered in numerous papers and publications already existing.

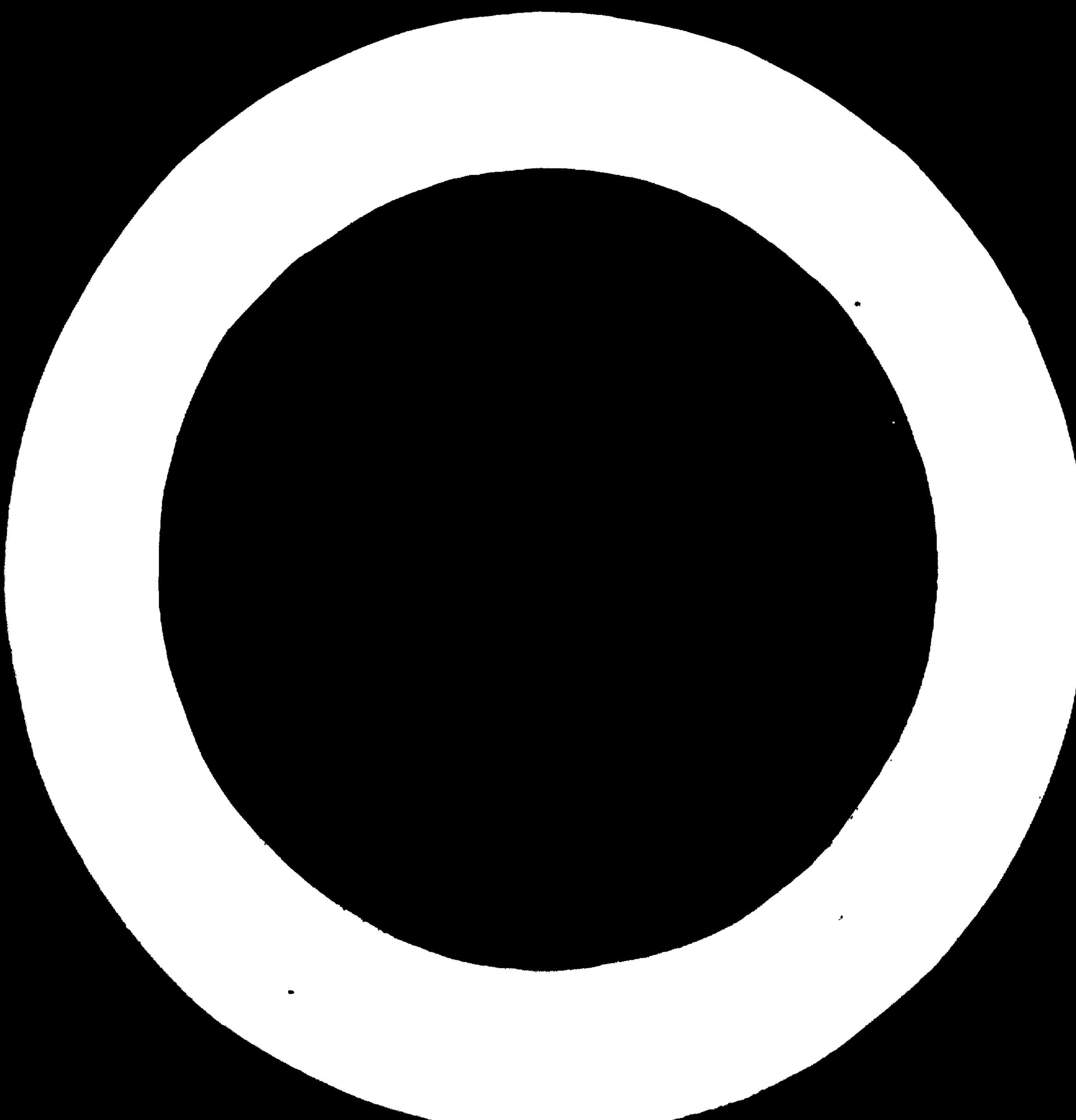
Whilst not wishing to instil undue pessimism into those intending to embark upon machine tool design, emphasis is placed on the need for people with not only academic knowledge over a wide range of engineering disciplines, but with creative ability that is normally only acquired as a result of experience. The dependence upon availability of supplies of certain specialist types of component and services is also pinpointed.

The decision to enter the field of machine tool design and development, without an association with someone with long experience of proven capability, should not be undertaken lightly.

C O N T E N T S

F I G U R E S

* For figures 4, 5 & 7, see ID/WG.97/33/Add.1



COVENTRY GAUGE LIMITED

THE MACHINE TOOL DESIGN PROCESS IN A DEVELOPING ENVIRONMENT

1.0 INTRODUCTION

Establishing a viable autonomous machine tool operation will involve the creation of satisfactory product designs. The machine tool design process is relatively complex and involves numerous basic engineering disciplines. As always, however, the engineering design process is only partially a science, it involving a degree of art generally depending upon the state of the relevant technologies.

Developing the art is a time-consuming process, necessitating long experience of practising the design process in an environment where not only the relevant scientifically based data is available, but in which the opportunity to evaluate and observe the performance of the product in real working conditions also exists.

It is most unlikely, therefore, that satisfactory designs of anything other than the simplest of machine toolswill be created unless the relevant skills are acquired from existing more highly developed countries. There is no reason, however, why simple machines should not be designed by an embryo machine tool engineering establishment provided that its members are made aware of, and appreciate the need to consider very carefully, all the factors that contribute to satisfactory engineering product design.

2,0 THE TOTAL OPERATION

The design process must be regarded as only one element of the overall project associated with the introduction into production of a new machine tool product. There is a considerable requirement for preliminary work prior to embarking upon the design stage if the ultimate product is to have real use value. User needs must be established in not only technical terms, but economic values in order that the value of the work ultimately produced on the machine bears a satisfactory relationship to the work involved in manufacturing the machine. This latter will be dependent upon the rate at which the machines are to be manufactured and hence estimates must be prepared of the anticipated demand for the product. A typical marketing specification is depicted in Fig. 1.

After the specification of the product has been finalised, it is necessary to determine the feasibility of satisfying the specification. This is invariably an iterative process, involving the progressive development of an initial conceptual idea terminating when it is considered that the optimum compromist between the demands of the technical specification and the usually conflicting need to achieve a specified manufacturing cost has been reached.

Having established the feasibility of the project, it is then necessary to embark upon the more technically oriented design stage or the process. (An extract from a design specification is depicted in Fig. 2.) This is followed by the preparation of detail drawings and schedules of all the individual piece parts involved together with the preparation of arrangement drawings to facilitate the assembly of the piece parts into working systems.

On having built the first, or prototype, machine steps must be taken to ensure that the performance meets the original specification and that satisfactory endurance characteristics have been incorporated. A typical proving trial schedule is depicted in Fig. 3.

On completion of the proving trial programme any modifications found necessary may be incorporated into the design prior to embarking upon the initial, or pre-production, batch of machines. These machines will provide a means of proving the production engineering content of the design and on satisfactory completion will provide data to enable any further modifications that might be found necessary, to be incorporated prior to embarking upon full scale production.

3.0 USER NEEDS

In the case of a developing country, these are likely to comprise the means for carrying out the basic metal-working processes with, however, a minimal need for skill on the part of the machine operator. It is necessary to establish these needs and express them in terms of a general specification of the required product, a forecast of demand expressed, for instance, in terms of units per annum, and an associated product manufacturing cost expressed at least in terms of material cost content and machining and fitting labour input content.

The specification, at this stage, will govern the basic type of metal-working process to be carried out on the machine, the size of the workpiece components to be accommodated and the level of automation that will be incorporated. It will not, at this stage, include any detailed items such as it will be found necessary to specify during the subsequent design stage. The forecast of production rate is necessary to enable the manufacturing cost to be estimated and compared with the specified values in addition to providing the designer with information as to the manufacturing processes that will be most economically applicable.

4.0 FEASIBILITY STUDY

This is primarily the responsibility of the engineering personnel concerned. In simple terms it is the means whereby the feasibility of achieving all aspects of the specification can be determined. In some cases it must be accepted that in a particular environment it may be concluded that it is not possible to satisfy the technical specification without exceeding the manufacturing cost target, particularly when the available manufacturing facilities are taken into account.

This stage is basically iterative, involving a sequence of 'creation' expressed in sketches or scheme drawings, 'analysis' (of the creation) and its 'development' in the light of that analysis. A typical preliminary sketch is depicted in Fig. 4 * whereas the final design is depicted in Fig. 5.* It is most unlikely that the truly optimum solution will be obtained because of the need to limit the time taken by the study and hence the number of iterative steps it is possible to take.

The resulting scheme drawings will enable preliminary manufacturing cost estimates to be prepared and the need for particular scientific data to be identified.

On completion of the feasibility study it is usual to insert a "go" "no-go" type decision-making point into the overall project programme. Satisfactory completion will result in the decision to proceed to the next phase which is the engineering design process.

* See ID/WG.87/33/Add.1

5.0 ENGINEERING DESIGN PROCESS

The engineering design process is a complex operation, the main attributes of which have been found difficult to define. Only recently has any success been achieved in identifying those factors which affect and govern the quality of such design. The need for a logical approach achieving solutions to the problems posed is paramount however, and the first step involves the preparation of a list of all the factors that must be taken into account. In the case of machine tool design, these factors are numerous and involve not only a wide range of engineering disciplines, but also a considerable number of practical influences, not to mention the influence of economic and ergonomic constraints.

Ensuring that the practising designer is aware of all the factors that must be considered constitutes the relatively simple, science-based, element of the overall process. Satisfactory design will only result if each of these factors is given only that precedence which will enable the optimum solution to all of the problems to be obtained. Deciding upon the relative importance of each influencing aspect requires skill and judgement which is usually only present in those people who have both the basic academic capability and the experience of practising the art over an appreciable period of time.

6.0 MACHINE TOOL DESIGN FACTORS

The specification established in consideration of the user needs will govern the size and type of component to be machined together with the degree of automation to be incorporated. The basic geometry of the machine, in so far as the relevant motions between the workpiece and tool are concerned, is therefore defined.

In simple terms a machine tool may be regarded as being no more than a means of ensuring that the relative motion between the workpiece and the tool, or tools, may be controlled in a pre-determined manner. Means must be provided for achieving a relative 'speed' between the tool and the workpiece and in most machines this is brought about by rotation of either the workpiece, as in a lathe, or of the cutter, as in a milling machine.

In order that there shall be progressive removal of material from the workpiece, the tool must be provided with an additional form of motion relative to the workpiece, invariably described as the 'feed' motion. The direction of the feed motion will govern the shape of the workpiece.

A relative force between the workpiece and tool will be experienced and the combination of the relevant component of cutting force and the cutting speed implies that power will have to be provided to the rotating member. In the general case another component of cutting force in combination with the feed motion will bring about a need to provide 'power' means within the feed mechanism.

The final size of the workpiece will, in addition to being determined by the geometry of the feed motions, also be influenced by any deflection between the tool and the workpiece. Since both the workpiece and the machine tool will always have some elasticity the cutting force will give rise to some relative displacement. In order to ensure that the ultimate workpiece size is not unduly influenced by this deflection the relative 'static stiffness' must, of course, exceed a certain minimum level.

Examination of the relationship between cutting force characteristics of workpiece materials, and the dynamic deflection characteristics on machine tools shows that under some combinations of cutting speed and width of cut, dynamic instability may well occur, resulting in high amplitude vibration which, at least, may detrimentally affect the surface finish but which in some cases may result in tool failure. It is thus essential to consider 'dynamic stiffness' of the machine tool involving a knowledge of not only its elastic, but also of its damping characteristics.

The power input to the feed and speed systems will be dissipated as heat. A high proportion of all the heat generated will typically be conveyed from the working area in the swarf removed from the workpiece. However, the temperature of certain parts of the machine tool will undoubtedly increase either as a result of the heat generated in the cutting process, or as a result of the losses incurred in the kinematic train connecting the prime mover to the spindle. These temperature rises will cause growth and change of shape of those parts affected thus, if they are not adequately controlled, so changing the geometry or alignments of the machine that the shape of the finished workpiece will be unacceptable.

In nearly all machine tools the feed motion will be of a rectilinear nature. Typical feed rates expressed in absolute terms are quite low and problems are sometimes encountered in connection with instability of motion of the sliding members supporting either the tool (lathe) or workpiece (milling machine). This instability arises from a combination of the lubrication characteristics of the slideways and the deflection characteristics of the feed mechanism. At the low feed rates necessary many slideways are operating under boundary lubricated conditions and invariably the friction velocity characteristic is such that it appears, when considered as an element of the feed motion system, as having negative damping. The resultant instability, often described as stick-slip, will occur at very low feed rates and additionally make it difficult to control the final position of a sliding member prior to performing a cutting operation such as, for instance, a drilling or boring process.

The machine tool slideways will also be subject to wear and in addition, therefore, to controlling the stick-slip characteristics, surfaces and lubricants must be so chosen as to minimise wear if the geometrical accuracy is to be maintained over a longer period of time.

Having provided the basic means of achieving relative speed and feed motions, it is, of course, essential to ensure that at least the final size of the workpiece can be controlled. There must, therefore, be suitable means of measuring, not particularly the workpiece, but the displacements of the slideways on the machine such that, assuming a known machine geometry, the size of the workpiece may be implied.

The various machine motions must, of course, be controlled. The control means can be considered to be one of two basic types. On the onehand there must be control of a displacement involving use of the measuring means, and on the other the control of sequence in which the various motions must be started, stopped or, in some cases, have their speed changed. The degree to which such controls must be provided will depend upon the level of automation that is required. In the simplest machines, which will nevertheless, it is assumed, each be provided with their own prime mover most likely in the form of an electric motor, control of the power to that motor can be effected directly with a simple contactor. The addition of even the simplest sequence control circuitry, however, invariably implies the use of a control system voltage more suited to frequent switching rather than the provision of power and lower, alternating voltage supplies are frequently employed. The use of hydraulic means for providing feed motions has been found very suitable for many machine tools and in some cases the sequence control of such machines may be effected hydraulically. Where smaller, higher speed machines are concerned, compressed air has been found to be of advantage and whilst it is still possible to use electrical control circuitry, in more recent years "fluid logic" has found a number of applications. In more sophisticated types of machine, such as numerically controlled machines, in which error control techniques are employed, the problems arising are of an even more complex nature and a much wider and deeper knowledge of the relevant technologies is required.

In nearly all machine tool situations, however, there is the need to employ a human operator. In the case of the simpler, more operator-dependent machines, it is particularly important that adequate consideration be given to the ergonomic aspects in which the machine is matched to the capability of a human being.

Even when all these factors, and some others which it has not been possible to mention here, have been duly taken into account, it is important, particularly in a highly competitive environment, to ensure that the machine will be visually attractive and aesthetics must, therefore, be regarded as an important design factor.

In finalising the range of topics that the designer must consider, consideration must be given not only to those factors mentioned above which are primarily concerned with the function the machine has to perform, but also with those associated with the endurance characteristics of the product, the means available for its manufacture and the environment in which it is ultimately going to be employed. This latter involves not only consideration of climatic conditions, but also of the type of labour available for both operation and maintenance of the machine.

7.0 PROTOTYPE EVALUATION

After the user need survey, and the subsequent feasibility study and engineering design stages have been completed, the prototypes which will be used for proving trial purposes must be built. Manufacture of prototypes can only be undertaken when detail drawings, parts schedules, fitting instructions and final quality control standards in the form of acceptance test charts have been prepared. Experience has shown that it is very desirable to have more than one prototype machine available. This arises from the trend towards a modular approach to machine tool design in which a relatively wide variety of user needs can be provided from a minimum number of piece parts and assemblies. There is thus the facility available to offer not only a very simple machine, but rather more complex versions built up from the basic (simple) machine augmented by optional extra features. The first prototype should be to the simplest possible specification and will enable the basic design parameters to be proved. The second, and possibly subsequent, prototypes will provide a means for proving the various optional features.

The first phase of prototype testing will necessitate the use of measuring equipment and instrumentation to ensure that the original specification for performance has been satisfactorily achieved. These tests will normally be performed in laboratory conditions. Following these proving trials it will be necessary to obtain as quickly as possible, knowledge as to the performance of the machine when employed in a typical manufacturing environment. This is often described as machine shop evaluation. The objective of this latter phase is to determine the way in which the machine stands up to handling by a typical human operator and to show the ability to [illegible] the often relatively dirty and uncontrolled conditions which cannot be satisfactorily reproduced in the laboratory or development facility.

During the proving trial and machine shop evaluation phases preparatory work is put in hand for subsequent manufacture of a pre-production batch. This will be the first time in which the machine is manufactured in a typical environment. It provides, amongst other things, an opportunity to prove the suitability and economics of the production engineering aspects of the production engineering aspects of the design prior to entering into a commitment often involving the expenditure of considerable sums on tooling and fixtures associated with full-scale manufacture. The pre-production batch must also be checked for performance, since the use of typical production facilities, as opposed to those which will have been used for the manufacture of the prototypes, may well have brought about a situation resulting in detr mental changes to the f unctioning of the achine.

8.0 PROJECT CONTROL

A typical machine tool project would invariably extend over a number of years; (a typical programme is depicted in Fig. 6) involving the expenditure of quite large sums of money and involving the employment of marketing, design, development and manufacturing personnel all of whom will typically be concerned with a wide range of activities other than those specifically associated with the new product project. It is essential, therefore, to ensure that adequate control is exerted over the project if the forecast time scale is to be achieved and the cost of the project is to be minimised.

A project control system based on net-work analysis techniques is to be recommended in all other than the simplest of projects. Such a system can yield worthwhile improvements even when employing manual processing, the application of computerised techniques only being necessary in the larger projects involving a very high number of work items or events. A typical precedence chart is depicted in Fig. 7*

It is customary to monitor the progress of new product projects at corporate level through the auspicies of a body such as a product review committee. This Committee is interested only in the more important, or key, decision points being achieved according to the pre-agreed time-scale and with the project cost estimates. A typical monitoring chart is depicted in Fig. 8.

* See ID/WG.87/33/Add.1

9.0 ORGANISATION FOR DESIGN

In addition to the design team itself there is a need for proving trial facilities manned with suitable development personnel. The design organisation must, therefore, comprise not only drawing office facilities but suitable laboratory facilities adequately equipped.

The most successful machine tool designs have been produced by product oriented teams in which the person responsible for design has built up, over a period of time, extensive knowledge and know-how of a particular type of machine tool. This product designer will control a team, typically of two or three persons, who will have the ability to develop ideas and concepts, most of which will have been put forward by the product designer, into practicable schemes. A production engineer reporting to a manufacturing executive will be available for consultation purposes particularly in connection with problems associated with manufacturing cost. Preparation of detail drawings and schedules would normally be the responsibility of a technical services manager, thus relieving the product designer of the responsibility for the more routine matters arising.

A development engineer, preferably with specialist knowledge of the type of product involved, would be given the responsibility for carrying out a pre-agreed schedule of proving trial tests and, in order that the results of these tests are incorporated in a purely un-biased way, it is essential that the development engineer is not made subordinate to the product designer.

The organisation chart would typically be as depicted in Fig. 9.

It is most unlikely that all of the technical support facilities required to enable satisfactory completion of the design and development phases of the project be implemented without the need to resort to external sources of specialist information. There are Universities with world-wide reputation in machine tool technology that are capable of providing assistance of a generalised nature and in certain countries there are other organisations supported by predominantly governmental funds which are prepared to not only provide information as a result of their general research programmes, but are capable of taking on specific projects under sponsored conditions.

The ability to obtain support from academic institutions and organisations of this type will be of considerable value to all machine tool design and manufacturing operations particularly those, usually the smaller ones, which areunable to provide their own research and development facilities.

10.0 THE FINANCIAL ASPECTS OF MACHINE TOOL DESIGN

In a competitive economy, particularly where profit and/or public investment is involved, it is of course essential to show that expenditure incurred in the introduction of a new product, such as a machine tool, will be financially rewarding. Having established the user needs, therefore, consideration should be given to the most satisfactory means of satisfying them, rather than taking it for granted that in-house design and development will be embarked upon. In order to estimate the financial benefits that will be derived as a result of incurring design and development expenditure, estimates must, of course, be made of this expenditure, followed by some estimate of the income that will be derived from sales of the product. Having evaluated the project on this basis, comparisons can be drawn with alternative means, such as licensed manufacture, and the relevant decision be made.

In some cases in-house design and development has been justified using a discounted cash flow project and a typical set of tabulated data is shown in Fig. 10.

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TITLE	CONFERENCE DATE
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1.0 **[illegible]**

An automatic horizontal spindle chucking lathe and ram type configuration.

Chuck Size	12"
Spindle Power	20/40 h.p.
Spindle Speed Range	30/1500 r.p.m.
Tool Stations	8
Turret Stroke	12"
Infeed Slide Stroke	6"
Control System	Electro-hydraulic
Tooling	Pre-Set and Standard

2.0 **SALES FORECAST**

Units Per Annum	50
In First Year of Sales	1.5 units

3.0 **SELLING PRICE**

Basic Machine S.P. (Each) [illegible]

FIG. 1
MARKETING SPECIFICATION. OCTOBER '71

1.0 GEOMETRIC CAPACITY

Workpiece Size	27" dia. x 18" long
Cutting Zone	15" dia. x 18" long

2.0 SPINDLE

Input Power	40 h.p.
Speed Range	30 - 1200 r.p.m.
Number of Speeds	30 (G.P.)
Maximum Torque	1600 ft/lbs
Minimum Speed for Maximum Power	100 r.p.m.
Spindle Nose	ASA A1 - 11

3.0 [illegible]

Longitudinal (x axis) stroke	12.5"
Transverse (y axis) stroke	12.5"
Feed Force (x axis)	3000 lbs
Feed Force (y axis)	2000 lbs
Feed Stiffness Minimum Static x and y axes	10 lbs/inch
Feed Rate - Maximum x and y axes	30"/min.
Feed Rate - Minimum x and y axes	5"/min

4.0 [illegible]

Tool/Workpiece Stiffness (minimum static)	0.25 lbs/inch

FIG. 2
DESIGN SPECIFICATION
(EXTRACT).

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1.0 All machine functions and cycles will be checked against spec.

2.0 Machine alignments will be checked as per alignment charts

3.0 Machine stiffness will be measured - static and dynamic tests will be carried out

4.0 Machine alignments in a number of thermal states will be checked

5.0 Ergonomic aspects of the machine will be elevated; ease of operation, ease of maintenance, adequacy of guarding and the control functions will be checked.

6.0 Thermal variation of the machine during a day's cutting and the thermal variation of the machine under different loads will be measured

7.0 The kinematic accuracy of the transmission will be measured with seismic transducers

8.0 The power versus metal removal rates of the hobber will be measured during cutting tests

9.0 Noise levels will be measured during cutting tests and any source of noise identified with a view to reduce their intensities.

10.0 Cutting tests:

These will consist of tests to check particularly:

(i) Machine capability
(ii) Machine cutting accuracy
(iii) Machine stability during cutting
(iv) Production time during cutting cycle
(v) Reliable operation of machine over a number of hours under high production conditions.

FIG.5 PROVING TRIAL SCHEDULE | OCTOBER '71

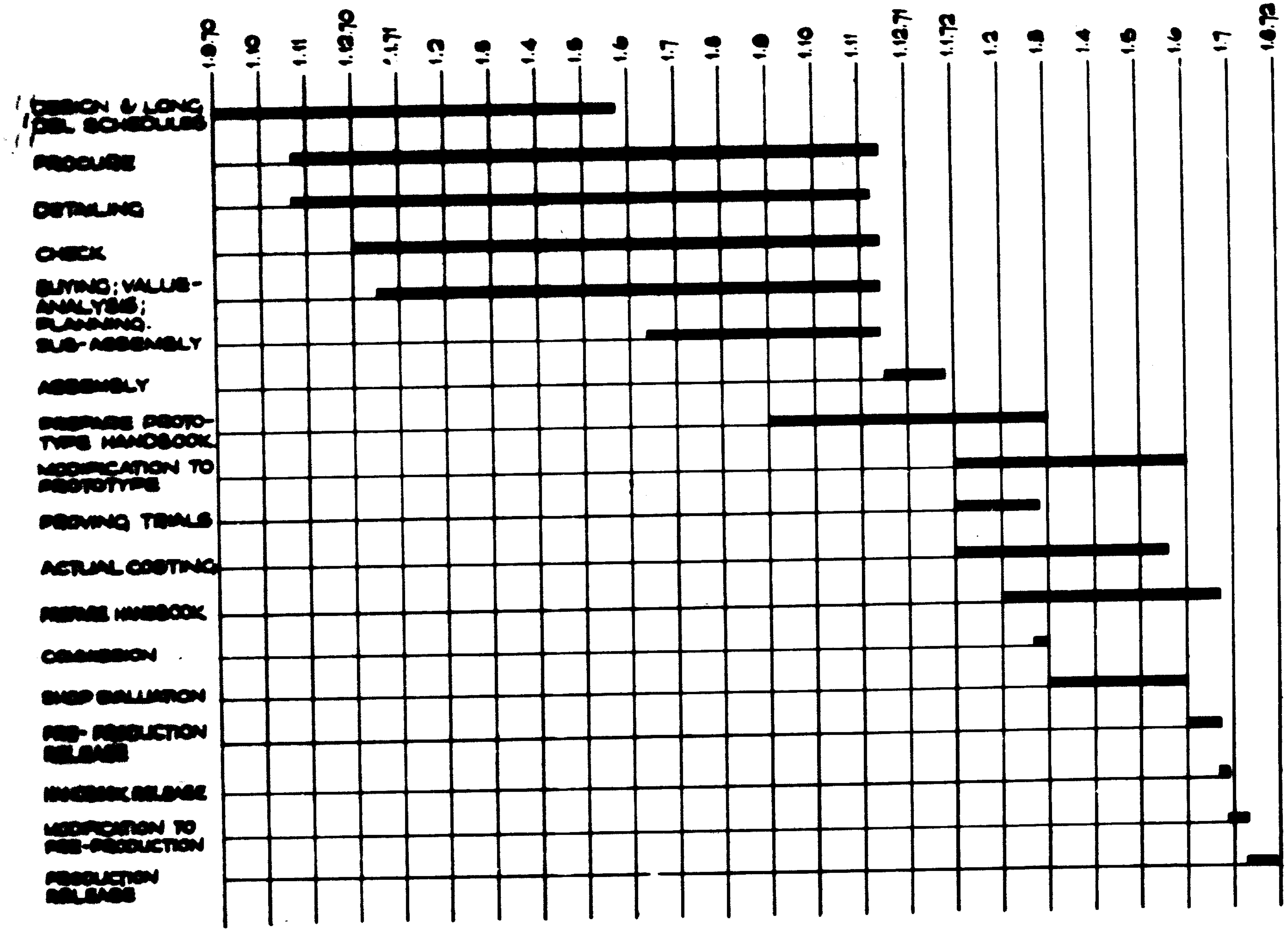

FIG. 6
PROJECT PROGRAMME.

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Quarters	1st (197…)	2nd	3rd	4th	1st (197…)	2nd	3rd	4th	1st (197…)	2nd	3rd	4th	
MARKET RESEARCH													
PRODUCT PROPOSAL **													
DESIGN, DETAIL & SCHEDULING													
MANUFACTURING COST ESTIMATE													
FIRST PROTOTYPE BUILD - FINISH													
MANUFACTURING PLAN													
MARKETING PLAN													
CASH FLOW													
MARKET LAUNCH PROPOSAL **													
MARKET LAUNCH DATE													

** Indicates formal Go/no Go reports to be submitted to Division. See separate notes for content.

FIG. 8
PROJECT CONTROL - MONITOR CHART

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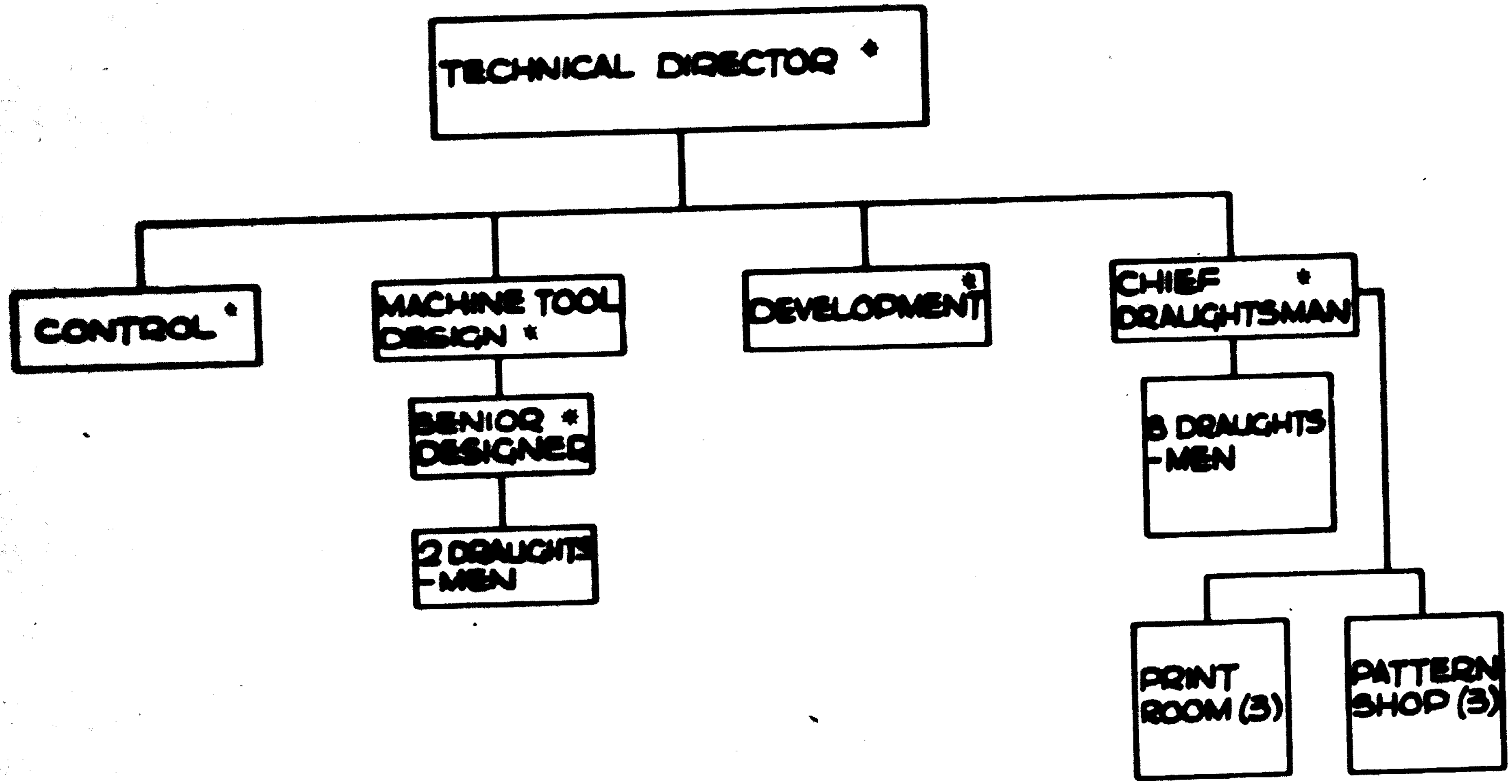

* Q.S.E. NECESSARY

FIG. 9
DESIGN ORGANISATION CHART.

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CASH FLOW **FINANCIAL STUDY 200 N.C. Machine** **D.C.F. RATE OF RETURN 22%**

CASH OUT FLOW										
COST OF TWO PROTOTYPES	43,500	39,392	4,108							
OTHER DEVELOPMENT COSTS	39,520	28,120	11,400							
INCREASE IN W.I.P.	214,006		103,263	71,787	38,956					
TAXATION	251,136					42,355	52,031	52,180	52,258	52,332
TOTAL	548,162	67,512	118,771	71,787	38,956	42,355	52,031	52,180	52,258	52,332
CASH IN FLOW										
NET PROFIT ON SALES	597,632				103,040	123,648	123,648	123,648		
SALE OF PROTOTYPE	20,000				20,000					
DECREASE IN W.I.P.	234,006							234,006		
TAXATION CREDITS	23,267		11,951	10,392	924					
TOTAL	874,905		11,951	10,392	123,964	123,964	123,648	123,648	357,654	
NET INFLOW/(OUT FLOW)	326,743	(67,512)	(106,820)	(61,395)	85,008	81,293	71,617	71,488	305,398	(52,332)

FIG. 10
FINANCIAL JUSTIFICATION - DISCOUNTED C⁄ SH FLOW CHART.

OCTOBER '71

8 . 8 . 73