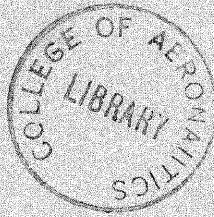


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ERGONOMICS IN MACHINE TOOL DESIGN  
FIRST PROGRESS REPORT ON M.T.I.R.A. RESEARCH PROJECT  
October, 1962

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This report is the first of a regular series of reports to be issued describing the progress of a research project on Ergonomics in relation to Machine Tool Design. The project is being carried out in the Ergonomics Laboratory of the Department of Production and Industrial Administration under the sponsorship of the Machine Tool Industry Research Association.

The report is in two sections, the first of which outlines the scope of Ergonomics in relation to Machine Tool design and the existing state of this aspect of design in various firms representative of the industry in the United Kingdom.

The second section details a project which was undertaken after consultation with one of the Research Association's members, into the problems of legend design. Here the design approach is probably applicable to similar problems on most machine tool types.



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Fig. 2. Original Legend Plate Design. (Full Size)

Fig. 3. Proposed Legend Plate Design. (Full Size)

## 1. Ergonomics in the Industry.

In the past the mechanical aspects of machine tools has been the primary preoccupation of designers with little consideration and knowledge of the limitations of the human operator. The price that has been paid for this lack of knowledge is long training times and potential and actual sources of errors and accidents. In many cases the only reason some machines have not been completely unusable is the very adaptable characteristics of the human operator.

A survey of the machine tool manufacturing industry and its users in this country proves to be quite revealing, for it shows the relative size and importance of the manufacturing industry in relation to national levels, and it also shows that a significant proportion of the working population are actually engaged in operating a machine tool of some kind. There are approximately one and a quarter million machine tools in use in industry <sup>(1)</sup> and this must mean at least one and quarter million operators who are part of a man/machine tool system.

On this basis alone then it appears justifiable to devote some considerable effort to the problems of machine tool design where it is affected by the limitations and capabilities of the human operator.

Close contact with the industry must be maintained in a research project of this type. An essential feature of the initial period has been visits to firms representative in their field of various machine tool types. As the organisational structure of these firms varies widely, this can radically influence the nature of the design team and the resulting product. With some firms there is an autocratic and

fairly reactionary attitude and they are not entirely convinced that Ergonomics has anything to offer and at the other extreme there are firms which are dynamic, outward looking and have built up well integrated design teams. The latter offer much more scope for utilisation of research, the individual designers being interested and eager for new ideas and techniques.

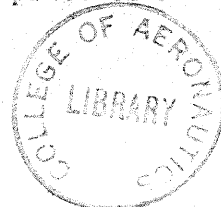
One all too often comes across design features, in some firms, which are there for their novelty or sales appeal value rather than as an effective contribution to the efficiency, accuracy and safety of the man/machine tool system. In these instances it is clear that sound objective ergonomic decisions will only be implemented if there is the possibility of the immediate pay-off in the sales gimmick form.

Notwithstanding these difficulties there is a widespread general interest at all levels in the fundamental principles of Ergonomics, and a very definite feeling that design decisions have in the past been based only on subjective and prejudiced attitudes, rather than on any quantitative data. More than in any other aspect of design, where human performance is concerned, every man believes he is his own expert. He is, in fact, a statistically bad sample which does not lend a great deal of validity to decisions based on individual experience.

An important implication of the setting up of a research programme is the very real difficulty of communication. The industry must define its problems and the research establishment must present its findings in a usable form and, for the industry to benefit, these findings must be

readily available and disseminated widely. It is just as important that design personnel are capable of interpreting and applying information to their own particular problem, and this is made more difficult because much of the data on human performance must be applied with caution. The simple 'cook-book' on Ergonomics is an ideal which will never be realised as there are always too many parameters in a particular situation to be able to give generalised answers. Much of Ergonomics involves the appreciation of the problem from the right viewpoint and there is as much need for reorienting the designers thinking as there is for supplying him with data sheets. In some instances the basic data is available but because of this lack of orientation the information is not utilised. This difficulty is not easily overcome, because to lay down specific principles often robs the results of research of its generality. It is to make the findings more generally applicable that they are often framed in the terminology of psychophysical and statistical measures, which to the engineering designer often appear obscure and useless.

(2)  
An example of this is the research work of Corlett into machine dial design. Designers were aware of this work but have not troubled to apply the results because they do not appreciate the significant psychophysical variables in dial reading. They have found it difficult to transfer this information from an elegant piece of research work into a technique for dial design.





## 2. Problems in Ergonomics.

### 2.1. Systems Design.

The lack of any systematic collection and application of data is the major deficiency in machine tool design. Broadly speaking the design of a machine tool can be conceived as a piece of systems design i.e. a man and a machine together must process certain inputs to obtain the desired outputs. During the talks with industry it has not been apparent that this design method has been followed or appreciated. Most machines grow piecemeal based on some previous equipment, resulting in a machine which is a mass of compromises, has taken a long time to evolve through trial and error, and often has features which exist only for traditional reasons. So far, we are not aware of a study group examining critically the requirements and specifications of a machine and then systematising the initial design. There is of course the possibility of these groups being in existence and their work has not been discussed for commercial reasons e.g. One firm outside the Research Association declined to show us their research laboratories.

Systems engineering which is a vital feature of Ergonomics is seriously lacking in the industry. At the moment there is not very much that can be undertaken by the Research Project to collectively benefit the industry, although it would be possible for some independently commissioned design study to be undertaken. A start has been made on collecting basic data on operator utilization of the facilities on a lathe. A study of some Capstan Lathe operators has been made using Memo-Motion film techniques.

## 2.2. Display Design.

There is room for a great deal of improvement in display design. There are many examples of bad conceptual characteristics, unnecessary complication, overcalibrated scales, bad presentation of legend plate data and confusing stereotypes, and a general misuse of colour in coding design with a failure to realise that a high percentage of the male population suffers from some kind of colour blindness. Many of these features can and have been dealt with on an ad hoc basis, using the existing literature as there are extensive findings in the military sphere that are readily applicable.

The recently issued draft standard on 'Symbols on Machine Tool Indicator Plates' shows a surprising lack of knowledge of concept formation and deserves some sharp criticism on this account. There is surprisingly, no qualified ergonomist or psychologist serving on the committee and, as a result, there may be scope for organising some experimental work validating the usefulness or otherwise of these symbols. The chief criticism is that many of the signs are akin to drafting symbols instead of relying on well established and recognisable pattern forms and concepts. (e.g. screw thread symbol, feed symbol.) In addition the fundamental mistake of joining two conceptual forms by having combined written and graphic signs leads to considerable confusion.

## 2.3. Control Design.

It is disturbing to find such a wide variety of control types

and shapes even over a comparatively small range of machines. There is no consistent approach to the physical shape of a control and its function even within a particular machine. This inconsistency results from the use of a non-systematic design technique, and also from evaluating the control display interface from the machine side rather than the operator side. Handles tend to be placed where the shaft happens to appear. As an initial step it appears worthwhile to encourage a consistent approach within a particular machine rather than to lay down well defined standard control types for standard functions and movements.

The increasing use of power driven functions means there is a wider choice of control type and sensitivity, but also raises the problem of whether to use a position or velocity type control. It would be useful to investigate fully this relationship between the conflicting requirements of force and sensitivity in control design as they are affected by such parameters as the static and dynamic friction, inertia and out of balance forces. Examination of these basic ideas on a manual basis should lead to reasonable criteria for the selection and design of power operated machine functions. The type of information feed back to the operator and the general inter-relationship between display and control functions needs investigation. There is little information on such important parameters as the size of the critical detail in a machining task, the effect of its perception on skilled manipulative performance and how important it is to see

the actual workpiece.

#### 2.4 Anthropometrics.

The general physical sizes of machines have evolved over a long period and are still based on custom rather than on correct physiological principles. The tendency is to keep the centre height down to approximately 40", allegedly to assist in loading the workpiece. The machine operator bent over his machine is a common sight, and to obviate this machine heights could be increased. This should facilitate the manipulation of controls, but the actual machine height must be carefully considered in relation to the depth from the foremost projection of the machine to the centre line. The real difficulty lies not in the actual weight of the workpiece being loaded, but in the overbalancing caused by the movement of the body centre of gravity outside the line of the toes. Therefore there are no definite rules on machine height, but the solution to this problem can be eased by the provision of adequate toe room at the station by the head stock. In many cases projections such as drip trays and splash guards prevent the operator getting close enough to the headstock, and it is this factor which has forced down the height of machine tools.

#### 2.5. Cutting Speed and Feed Rate Selection.

The major decision a machine tool operator makes is the relative speeds of the tool and the workpiece. The cutting speed is fairly well determined by the tool manufacturers for varying grades of tool and workpiece material. In general the range of facilities provided for spindle speeds, table speeds etc. is fairly satisfactory. What

is not so well defined is the feed rate determining the rate of removal of material. In deciding the range and number of feed rates to be provided there are two distinct factors which need to be taken into account.. First whether the change from one feed to another makes a significant difference to the finish, and second whether the operator is able to perceive this change. It obviously is no use having such a fine division of feed selections that the operator is unable to distinguish the effects between one feed rate and the next. The ranges are related to the ultimate precision and accuracy required of the machine, determined by factors not related to ergonomics. But the structure of the divisions within the overall range must be tied to the ability to perceive these differences, and the right compromise achieved between the engineering and psychophysical requirements. There appears to be no data on this aspect of machine tool design and this could be a useful area for research

### 3. Legend Plate Design Study.

#### 3.1. Scope.

Many of the functions of the machine tool operator involve him in a computation of some form and the subsequent feeding of this information into the machine as part of the setting up procedure of the job. Although not repetitive, in the sense that the same data and calculation is used many times, much of this type of work is still routine. Incorporated in many machines are tables and nomograms to assist the operator, and one such example studied is a table giving the settings of the levers on the feed, gear and screw cutting gear box for the correct relative rotational speeds of feed shafts and lead screw.

The setting of these boxes is not carried out often enough for the operator to be so familiar with them that various screw and gear cutting combinations are remembered. What is needed is a table relating the particular engineering system parameter (threads/inch, mm pitch, diametral pitch etc.) to the corresponding combination of lever settings.

#### 3.2 Effect of Thread Systems.

Feedbox design is a very determinate operation. The various thread systems give rise to an irrational set of numbers and the situation is further complicated by the differing methods of specification of threads and worm gears in the British and Metric system. In essence the box is a simple computer, dividing down the headstock speed to give the correct lead screw speed. In diagrammatic form the

functions of the box are shown in Fig. 1.

The design of the box becomes an iterative process whereby the correct numbers of teeth on the gear wheels are selected to fit the number series and also to combine as many of the functions as possible in each of the two measurement systems.

A logical consequence of this type of design is that the legend plate design must also follow the same rationale.

### 3.3. Design Philosophy.

In the past the lever settings in the form of code letters have been presented as the independent variable, with the dependent variable the threads per inch, mm pitch etc. (Fig. 2.) In practical use of the table, the independent variable is the basic data on the thread or gear which the operator extracts from working drawings. Another result of this inverted construction is that for the sake of completeness a large amount of redundant data is often displayed to fill the spaces in the table. The general effect is to provide a jumble of letters and figures, usually too small to be conveniently read, and the process of extracting the information is lengthy and may often lead to errors.

The first requirement is a specification of the range of threads and gears to be catered for on the machine and a survey of the number series of the various thread and gear systems. (Although not concerned with the mechanical design details of the feed box this survey prompted thought about the number series used, and how the ratios should be subdivided amongst the various control levers to achieve a minimum number

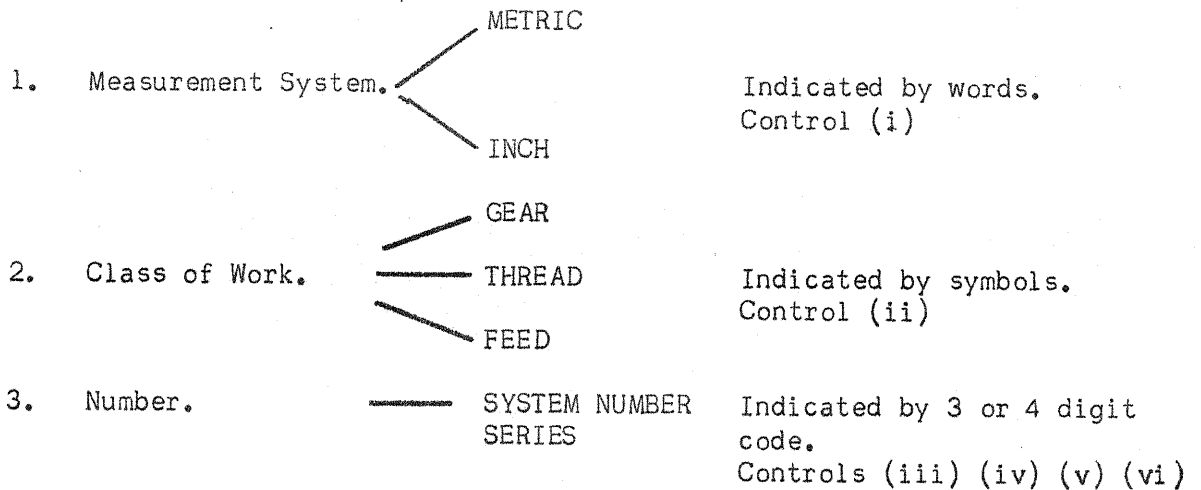
of gear wheels. It is apparent that at the moment the design depends very much on the ingenuity of the individual engineer, and to date no sophisticated computing techniques have been devised for this type of calculation. e.g. using a digital computer) Although there are a considerable quantity of individual numbers to be catered for, better utilization of space in the new design allows larger size figures and more agreeable spacing to be devised.

The gear box design involves six control functions.

- ( i ) A two position control giving inch sizes or metric sizes using a standard 4 TPI lead screw.
- ( ii ) A two position control giving direct inch and metric ratios or IT multiplied forms for gear work.
- ( iii ) A three position control giving a shift of a factor of  $4/5$  in the number series to give the required ranges with the smaller metric threads. The third position on this lever puts the lead screw into neutral and corresponds to a feed position.
- ( iv ) A two position control covering 3 octaves of speed, gearing the spindle speed up by 4 or down by 2.
- ( v ) A three position control expanding the range of speeds to five octaves.
- ( vi ) A ten position control giving division of each octave into the required number series.



The table should relate the form of the initial information obtained from the working drawing to the code letters and the control configuration. The sequence of presentation on a drawing is:-



#### 3.4. Use of Symbols.

With the expansion of export markets, there is increasing pressure to make legend plates international to avoid carrying a large stock of multi language plates. The use of language (with the exception of INCH and METRIC) has been avoided in this design. Symbols for gear, thread and feed have been devised which do not suffer from the shortcomings of the proposed British Standard. The symbol is also utilised on the appropriate position of the corresponding control lever, which minimises the number of translations from code letter to function.

#### 3.5. Table Layout.

For convenience of display location the table is laid out on either side of the ten position gate selector lever, the inch system on the left, and the metric on the right. (Fig. 3.). Notice that the

temptation to 'balance' the table by having a symmetrical layout with respect to threads, gears and feeds, has been resisted. The similarity of the numbers series in a given measuring system could lead to gross errors unless the gear table is always the left hand one in a given pair.

To facilitate the scanning operation, two features have been incorporated. No horizontal dividing lines have been placed between successive entries in the table, and the table has been structured vertically in threes by using spaces rather than lines to facilitate location without impairing the vertical scanning. Secondly no vertical lines have been placed between the number and its associated code letters to facilitate the horizontal scanning. The grouping in threes assists in this respect as it prevents the slippage of line, each line in a group of three being uniquely defined in its relationship to the other two lines.

### 3.6. Summary.

From the study the following general principles can be laid down on legend plate design.

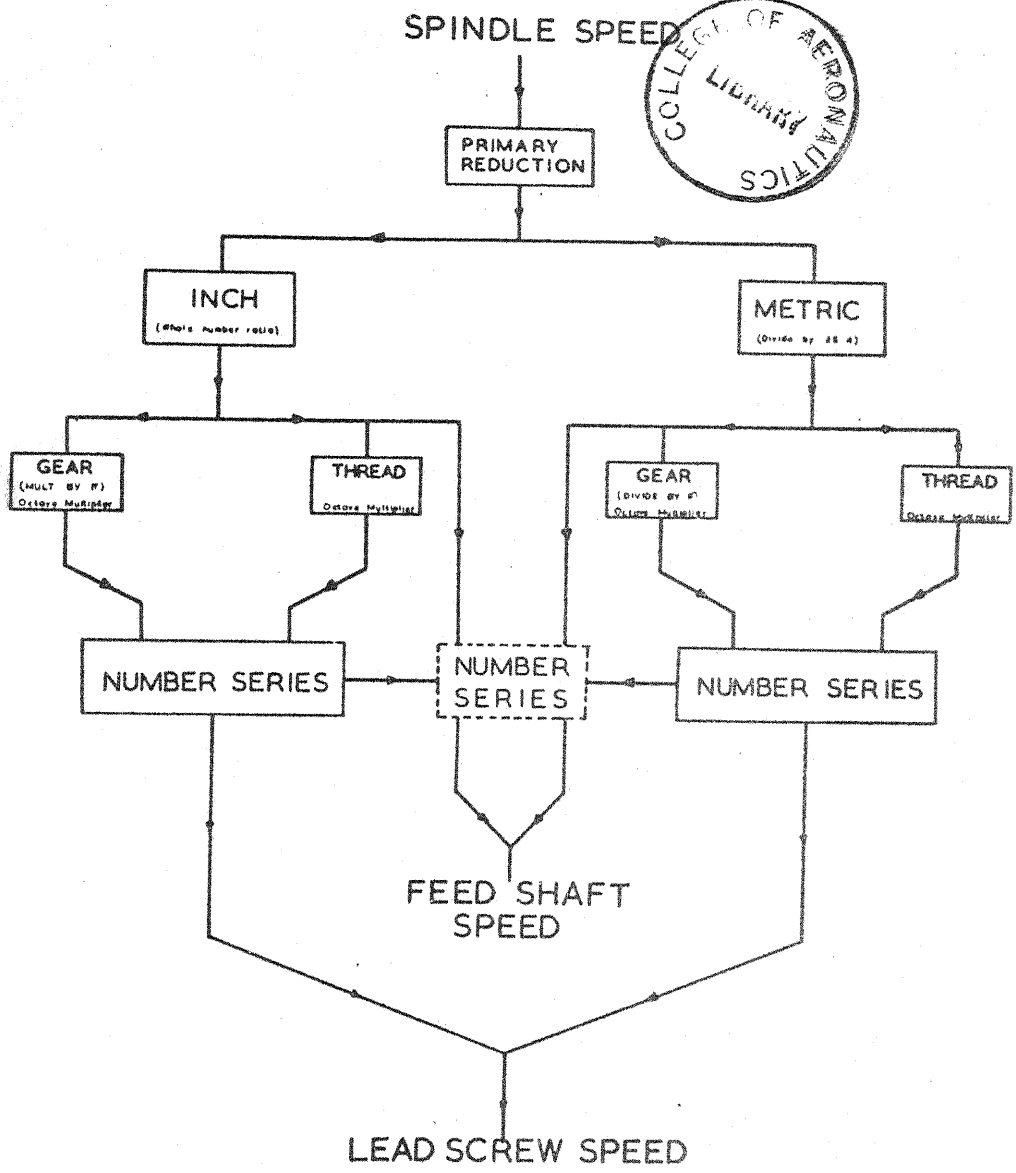
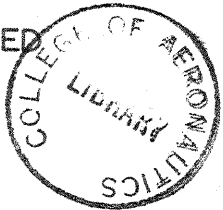
- (a) Study systematically the data to be displayed and eliminate any redundant information.
- (b) Evaluate the form of the input and output information. If necessary re-appraise the design of the control levels to rationalise and simplify the method of setting.
- (c) Devise symbols based on recognisable patterns and concepts

and not on arbitrary symbol codes.

- (d) Structure the layout of the table by grouping of data and judicious use of both vertical and horizontal dividing lines and dividing spaces, and variation of lettering size and stroke width.
- (e) For maximum legibility avoid using lettering sizes under  $\cdot 120''$  high.
- (f) Make the width/height ratio of letters at least  $0\cdot 7$  and and preferably  $0\cdot 85$  if space allows.
- (g) Avoid mirror image layouts.
- (h) Do not insist on balanced symmetrical layout unless the data lends itself to this form of presentation.

References

1. Metalworking Production - "First Census on Machine Tools"  
December 1961. (McGraw Hill)
2. Corlett. E.N. - "The Accuracy of setting of Machine Tools by means  
of Handwheels and Dials" Ergonomics p.53. January 1961.



**FIGI FEEDBOX SYSTEM**