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THE COSTING OF TURNED COMPONENTS AT THE DESIGN STAGE

A Thesis presented to the Loughborough University of Technology for the Degree of Doctor of Philosophy.

by

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SUMMARY

A costing system has been evolved for turned components produced by a variety of machines; the system is based upon a fundamental cost equation which utilises in the main, the manufacturing time of the component, together with its material cost. A technique for predicting the floor to floor time Ft, has been established based upon the size and shape of the component in parameters readily available to the designer. The generally accepted setting times for various machines have been corrected to take into account the component complexity. In estimating the material requirements, allowances have been made for material wastage, due to schedule or quantity change, scrap losses and the effect of the operator learning curve on these losses. A graphical presentation of the floor time equation enables the designer to rapidly assess variations in F_t, if he chooses to vary one, or indeed all of the parameters within his control, i.e. Material, finish, size, features, etc. etc. in order to meet a certain cost target.

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Nomenclature

C	=	Cost/Component, (£)
C_f	=	Complexity Factor
D_m	=	Component mean diameter, (ins)
F_t	=	Floor to Floor Time, (mins)
f_s	=	Ordinate to Scrap learning Curve
f_r	=	Feed rate (ins/rev.)
K_1	=	Machining Factor
K_2	=	Machine Factor
$K_{mat.}$	=	Material Factor
K_c	=	Combined Factor ($K_1 . K_{mat.}\ K_2$)
L	=	Total Machined length, (ins)
LUL	=	Load and unload Time (mins)
M	=	Amount of material charged to cost equation, (lbs)
M_c	=	Material cost, (£)
M_s	=	Design Standard Material/Component, (lbs)
N_c	=	Number of cuts
N_d	=	Number of discontinuities (Discontinuity Factor)
N_T	=	Number of Types of cuts
P	=	Number of passes
Q	=	Batch quantity
R	=	Hourly labour rate (£/hr) (including Factory overhead)
RT	=	Rapid Traverse Time, (mins)
S	=	Scrap loss
S	=	Modified Scrap loss
S_t	=	Setting Time, (mins)

TCH	=	Tool Change Time (mins)
T_f	=	Feed Time, (mins)
V	=	Cutting Speed, (ft./mins)
W	=	Schedule or Quantity Change Waste, (lb)
X	=	Machine Tooling Factor

Abbreviations

CL	=	Centre Lathe
CNA	=	Component Numerical Analysis
H.S.S	=	High Speed Steel
M.S	=	Mild Steel
NC	=	Numerically Controlled M/C Tool
SLC	=	Scrap Learning Curve

INTRODUCTION

Cost estimating has the primary function for supplying cost visibility during the development of new products. One of the most critical and pressing needs in industry today is forecasting new product costs before the completion of the design. When the designer has developed the shape of his component, decided upon the material he is going to specify for it, chosen the means by which the ancillary parts are to be attached to it, and has specified particular tolerances and finishes, he has virtually set the price for his component, particularly if the equipment is to be manufactured by outside sub-contractors. The ultimate manufacturer has little room to use initiative or imagination(1). He is in no position to reduce the manufacturing cost of the component because design, material, quality, etc., are specified in minute detail. All the manufacturer has to manipulate is the application of his labour force, overheads and choice of machine.

Very often an expensive design is justified by the possibility of improved standards in safety and reliability, or by a predicted reduction in maintenance, installation, or operating costs.

This lack of cost-consciousness on the part of the engineering designer is primarily because cost information is seldom available to him in a meaningful form (2,3) if at all. He usually has neither the time nor the facilities to determine the cost of the various alternatives available to him in the highly competitive field of industry. The need has arisen for the designer to be able to estimate the cost of his component at the design stage (4). He can then alter his design by relaxing the tolerances, evading non-functional features or even change to a more machinable grade of material in order to meet the cost targets.

The primary object of this work is to evolve a costing system by which the engineering designer can estimate the cost of his component to a reasonable order of accuracy, and subsequently make the appropriate changes before the design becomes finalised and drawings are released to the shop floor.

Initially, thought was given to the establishment of a costing system to cover all manufacturing processes. However, it was quickly realised that the scope of the project was too wide to be carried out in the limited space of time allowed for this study. The work was directed to cover turning processes only. The reason for this choice is because it is believed that 70% of engineering components are either turned or that the turning process is the major operation in their manufacture.

The objective of finding a method of cost estimating is not achieved if the cost of using this method is greater than the savings achieved by employing it. Thus an essential requirement is that the costing method should be as simple and easy to use as possible. Nevertheless, the accuracy of the system should not be jeopardized by the search for simplicity, indeed the system should at least be as accurate as any existing system of cost estimating.

It has been suggested by many people that the production cost of a component depends to a great extent on its manufacturing time and therefore a technique has been developed to estimate this time. It was felt that there must be a correlation between the manufacturing time and a parameter representing the complexity of the component (5). After considering many concepts, such as the number of operations, the types of operations, the component volume, the component projected area ... etc., it has been found that the "number of discontinuities" of the machined surface, when computed in a certain manner, represents a linear relationship between a component and its machining time. A technique has, therefore, been developed to estimate the machining time using this "discontinuity Factor" in combination with the other physical parameters of the component.

The discontinuity criteria is defined and its concept is discussed in Chapter (4) and its derivation given in Appendix (1).

A cost equation has been evolved of terms comprising:-

1. The company hourly labour rate (including overhead),
2. The production time,
3. The component material cost.

Each term requires data normally available to the engineering designer.

It is clear that the most variable term in the cost equation is the production time and, in order to evaluate the system, actual examples, deliberately chosen to cover a wide range of component sizes, materials and lathes from a wide cross-section of companies, have been tested. Actual production times, when compared with the times given by the equation, indicate that for 90% of the components considered accuracy of prediction was within ± 10%.

CHAPTER 1

Literature Survey

To a very large extent, manufacturing cost is controlled by the efforts of the product design engineer, even though the cost is actually incurred at a later time, by different people. One of the most pressing needs in industry today is forecasting new product costs before completion of the equipment design. Fulfilling the forecast is the goal of the entire organisation but depends primarily upon the engineer's performance in designing a product consistent with technical and cost requirements (6).

The essence of the twin techniques known as value analysis and value engineering is the creation of maximum value in the product for minimum cost expenditure (7, 8). So, for the designer to be able to build optimum value into his design, it follows that an understanding of the way in which costs arise is fundamental. While the design is proceeding he must frequently compare the desirability of several alternative solutions to each individual design problem and select those most appropriate to his needs. It is here that a superficial knowledge of the techniques of the cost estimator can be of tremendous help (9).

Manufacturing cost estimation is an old activity in industry, carried out for a variety of purposes. In the area of machining economics, a considerable amount of research has been performed to determine the machining parameters to optimize some specific criterion (Gilbert, 1950, Brewer, 1958, Brown, 1962, Okushima and

Hitomi, 1964, Wu and Ermer, 1966, and Armanego and Brown, 1969) (10). The model usually considered is a single pass turning operation and the optimizing criteria commonly considered are minimum machining cost, minimum processing time and maximum profit or profit rate.

The problem of economic machining has been acknowledged for many years and there has been some appreciation of the solution from a qualitative angle which may be summarised as follows: Faster speeds and higher feed rates are required to reduce machining times and hence reduce costs, but the implementation of either leads to a shorter tool life, which increases cost. It is supposed that there is some optimum set of conditions which will lead to a minimum cost. It is because of the non-existence of this set of conditions that a great deal of research in metal cutting took place with the intention of optimizing the process. On the economics of the basic turning operation, Brewer, (11), proposed a cost expression composed of terms representing various cost elements. He then analysed these terms for the purpose of optimizing the cost expression to give minimum cost/piece. The equation involves, however, a great number of machining parameters which are unlikely to be available at the component design stage. Moreover, the equation considers only the simplified hypothetical case of turning a diameter D over a length L.

Looking into the consequences of introducing numerical control into machine tools, Brewer, (12), discussed the effect of this on scheduling and economics in the machining process. He arrived at a production cost equation in terms of machining time, programming and tape preparation time, computing time, magnetic tape cost ... etc. He suggested that the programming and tape preparation time can be assessed from the number of co-ordinate points. These, however, can hardly be known before the planning stage, i.e. it will be available only after manufacture planning has been completed. The magnetic tape cost and the computing cost have been taken as a percentage of the machining cost. This seems a reasonable suggestion provided that considerable experience exists in the company, but the main problem still lies in finding the machining time and hence the machining cost in the first place.

In general, almost all costing equations for a production process contain three terms which are functionally distinct (13, 14, 15). One expresses the time or cost consumed in setting up and loading the machine, another involves the active (actual cutting) time, and a third term involves the reconstitution of the tool and machine between active periods.

In the past, a widely known approach for the estimation of the actual machining time has been to apply an overall expression relating tool-life to speed, feed or other cutting parameters and to calculate the optimum speed which provides either minimum cost or maximum production rate (16, 17). One of the difficulties involved in this approach is that it is impossible, and oftentimes dangerous (18), to depend upon the relationship of tool life to speed and feed. The calculations of optimum speed and feed obtained in this way are often so general and approximate that their credence is questionable.

A popular approach to the problem is to predetermine, by laboratory or shop testing, the relationship of tool life to cutting parameters on various machining operations for various alloys (19). These tool-life data, together with time-study data are directly inserted into equations for the calculation of the production costs. Some of the equations, however, are lengthy and very difficult to apply (20). Others (21, 10, 22, 31), beside being based upon experimental observations and incorporating constants which are determined empirically would also require a comprehensive knowledge of economic terms and financial familiarity on the part of the designer.

Other equations (23, 24, 25, 26) are, however, simple but lengthy, and the availability of actual shop data is essential. Also they involve so many variables that a computer service is needed to perform the calculations, a situation which is both expensive and time consuming.

A rather naive approach to the problem is to estimate the cost of a component, subassembly, or finished product, from the cost of raw materials (27). This system suggests that the cost of materials in a part is the basis for all subsequent cost estimation regardless of whether the part is cast, machined, stamped or moulded.

In a costing system intended for use in teaching design for undergraduate students (28), the labour cost is based on the volume of the component before the operation is carried out, regardless of the nature of the operation or the amount of work done during the operation. The penalty paid for the simplification that this procedure offers is a tendency to over-cost or under-cost the larger or smaller components respectively.

An approach to the assessment of production times has been evolved based on the degree of complexity of the component (29). This approach describes the complexity factor as a number which depends upon the component features as well as other features determined during its manufacture planning. That part of the complexity number concerned with the shape of the component is easy to compute from the component drawings, but the remaining part of the complexity number which deals with the planning of manufacture (e.g. using 3 or 4 jaw chuck, hard or soft jaws, face plate, collet, with or without bar feed, loading by hand or jib, tool changing (centre lathe only)), are purely manufacturing features and the engineering designer is in no position to predict this part of the complexity number. Thus the complexity factor adopted in this approach is not an exclusive property of the shape of the component.

From the literature survey discussed above, it is clear that whilst a number of attempts have been made to cost components, with varying degrees of success, some are based on machinability data, which is very hard to obtain for every material/tool/machine combination, and time-study measurements which is both expensive and time consuming. Other systems deal with fine details yet are cumbersome to use and not particularly accurate. They do not meet the primary requirements of accuracy, simplicity or ease of use.

It was therefore decided to attempt to evolve a costing system for turned components which, if not eliminating the drawbacks of the above systems, would at least minimise them.

CHAPTER 2

Analysis of Cost In Manufacturing Industry

Broadly speaking, the production cost of any component is composed of two main elements, i.e. Manufacturing cost and overhead cost. This classification is by no means definite, as it may well be appreciated that some manufacturing cost items are best catered for by including them in the overhead element. The main reason for this is because these items, (e.g. cutting fluids, grinding wheel costs etc.) are difficult to quantify for each component, in many machining situations.

In order to establish a basis for developing a cost estimating system, it is necessary to examine the nature and composition of the costs in manufacturing industry.

2.1 Labour Cost

2.1.1 Direct Labour

Usually defined as the productive labour function (that is, machine operators, assemblers, welders, and so forth). The most appropriate definition of direct labour would be that activity which changes the form of the material.

2.1.2 Indirect Labour

This segment of labour cost can be broad or narrow, depending upon interpretation. In manufacturing industry, materials handling is often an integral part of productive work and, therefore, is often absorbed as direct labour. Auxiliary handling personnel working in production areas (for example, fork lift operators, crane operators) are also often included as direct labour. However, in an orthodox interpretation, all handling costs are considered to be indirect in manufacturing operations.

2.1.3. Labour Overhead

Indirect labour is often charged into the overhead account. However, true labour overhead costs develop from other more definitive sources. It has long been the practice to apply supervisory costs as an overhead item in costing operating departments. Recent practice (30), has expanded this procedure to include shop, clerical and dispatch labour, lead men, and, in many instances, maintenance personnel.

2.2 Material Cost

2.2.1 Direct Materials

This item usually covers the materials which become a part of the product and the scrap or waste accrued from the machining or fabrication of the product. In many instances the process requires catalysts or temporary materials (cutting fluids in machining, sand in a foundry, limestone and coke in steel making, wax in investment casting, and so forth). These materials can be, and often are, included in the direct material category.

2.2.2 Indirect Materials

These are usually the materials of production which are consumed but not necessarily used as a part of the product. Examples would be plating electrodes, welding rods, heat treating fuels and chemicals (nitrides, acids, cyanides, etc.).

2.2.3 Materials Overhead

These usually include shop supplies such as cutting oils and lubricants, emery paper, and consumable tools such as grinding wheels and drill bits, as well as sanitary supplies (toilet paper, soap, floor sweeping compounds, etc.) and shop paper supplies. Fuel, and in some cases, electric power, is often included in this category.

2.3 General Overhead Costs

This group of costs includes such items as rent or building depreciation, equipment depreciation, insurance, power and heating fuel, taxes, general and administrative expenses and others.

From the above survey it should be appreciated that, in manufacturing industry, it is almost impossible for either the designer or the manufacturing engineer to know precisely the share a turned component must bear from each of the above sources of cost, other than its direct material and direct labour cost. For this reason, it has been found convenient in the past, and indeed it is the current practice in industry today, to attempt to cost machined components by the amount of material and labour put into them. Other costs are normally catered for in the overhead item. Now, it is a common practice, to adjust the base wage rate, (that is the hourly wage or salary which is guaranteed to the worker for being on the job) by adding to it the company's overhead rate, and it is then known as the company's hourly rate.

From the above analysis it becomes clear that if a realistic costing system for turned components is to be evolved it should be based on an accurate estimate of the amount of direct material required by the component and also upon the amount of direct labour expended upon it, together with the company's hourly rate.

The estimate of the amount of direct material required to manufacture a component will be discussed later, and consideration will be given to the amount of wastage and the effect of applying the learning curve criteria in minimizing it. A method for estimating the direct labour cost for turned components will now be discussed.

CHAPTER 3

Manufacturing Cost In Turning

It has been recognised (23), that manufacturing costs could be divided into two main cost areas. These are:-

(a) the costs that are associated with the operation of the machine tool, (floor to floor, setup costs).

(b) those costs which are associated with the cutter or cutter reconditioning, (cutter depreciation, resharpening, rebrazing, carbide tip, and abrasive wheel costs).

As has been mentioned earlier, the latter group, (b), is best incorporated in the overhead rate of the company, because it is obviously clear that it is extremely difficult to quantify the cost of these items for each component, especially for the one-offs and small batch quantities (32).

It was, therefore, decided to build up the costing system around those costs incurred during the operation of the machine tool. That is to say that the manufacturing time will be taken as a measure of the production cost. This suggestion seems reasonable for any one industrial environment having almost the same degree of skills, financial burdens and obligations.

Manufacturing times, (i.e. Floor to Floor times and set-up times), can be obtained for any component, using time-study procedure and correct work-measurement techniques under actual cutting conditions.

Time study and work-measurement techniques have, in fact, been employed to estimate production costs in many costing systems (10, 12, 16, 21, 23). One of the principal objects of this work, however, is to find reliable short cuts to this lengthy procedure and predict manufacturing times, during the design stage, and without recourse to such expensive techniques. This will now be discussed.

CHAPTER 4

Factors Affecting Floor to Floor Time

4.1 Definition

The floor to floor time, (F_t), of a component is defined as "the time spent in loading the component in the machine, machining it, and subsequently unloading it from the machine". The machining time, however, is not meant to be the time spent in actual cutting, i.e. when the cutter is in the cutting feed situation alone, it also includes that proportion of time when the operator is handling the machine, i.e., turning handles in the case of rapid traverse, indexing or changing the tool.

4.2 Factors that influence F_t

4.2.1 Component size and weight

The component size and weight have a direct influence on the loading and unloading times depending on whether it is carried out by hand or with the aid of a handling device. The heavier and bigger the component, the more time is needed to lift, position, and locate it in the machine.

4.2.2 Component Material

The machinability of a material has a great influence in determining the values of machining parameters such as speeds, feeds, ... etc., that will eventually dictate the rate at which metal can be removed, and hence the ultimate machining time. Machinability ratings have been established for various materials, at specified conditions (33, 34, 35, 36). These ratings are based on material hardness because the hardness number is a practical and usually reliable indicator of a material's variation in machining characteristics.

4.2.3 Tool Type

Tool manufacturers normally supply machining recommendations regarding the use of their various types and ranges of tools. In general, metal removal rate, and hence machining time are largely affected by the type of tool material and its physical properties (i.e. hardness, wear resistance, micro-structure, chemistry ... etc.), and its geometry.

4.2.4 Tolerance and Finish

For tighter tolerances, this means smaller depths of cut and an increase in the number of tool passes, the result being an increase in the time needed to achieve the tolerance. If fine finishes are required, slower feeds are used. The nett outcome of both of these is to increase the time taken to perform the operation (43).

4.2.5 Machine type and condition

Lathes, and indeed all machine tools, differ in their ability to remove metal, according to their types, powers, and rigidities. The more powerful and rigid the machine, the greater the speeds and feeds that can be used, enabling heavier cuts to be taken and hence higher rates of metal removal. However, the variation in metal removal rates by different types of lathes is not primarily due to the greater speeds and feeds they can offer, but mainly due to their manoeuverability and built-in characteristics of carrying pre-set tools and performing overlapping operations.

4.2.6 Component Shape

The amount of metal removed is not a measure of machining time.

Consider two components of different shape, but having in common the same material, tool type and machine tool. Equal amounts of metal removed from each of them does not necessarily mean the same floor to floor time. This can be readily understood if these two components were, say, a plain shaft of uniform diameter, on the one hand, and a more complicated shape, like a valve body, on the other. Acceptance of this hypothesis leads to the conclusion that consideration of the volume of metal removed alone cannot be used as a measure of F_t, and that the shape of a component plays an important role in dictating its F_t. Thus a shape defining factor, which would serve as a criterion for determining the floor to floor time of a component needs to be established.

4.3 Complexity Concept

The first attempt to define components by means of a complexity factor C_f was made by P W Millyard and R C Brewer (5). Their investigations were carried out with the aim of deriving a complexity factor which would serve as a criteria for determining whether savings could be made by the application of NC machine tools. The factor serves to determine which components will give the greatest return from the use of NC equipment.

A similar attempt was made by A P Balding and G H Farnworth (37), for the same purpose of justification of the use of NC machines. In this approach components were machined in both conventional and NC machines and the machining times were recorded in each case. A graph was produced showing the time saved against the work content (complexity factor), that is the summation of the number of holes, the number of straight line cuts, the number of tool changes ... etc. Fig. (1) is a reproduction of the graph which indicates that time savings are possible, by the form of NC machine used, for components having complexity factors 'C_f' of 15 and greater. Thus for $C_f < 15$, conventional machining methods should be used.

The complexity factors described above, although they define the degree of complexity of the component in terms of their work content, they do not, however, serve the purpose of determining their machining times in real terms. They are only useful in deciding whether it is economical to use NC or conventional machines.

Another approach to the complexity criterion was a geometric system of component description which stemmed from the overall concept of component numerical analysis (CNA). The objective of that work (38), was to develop a system of component data retrieval that can be used without the need for detailed coding manuals or specialist staff. It is intended that ultimately the system will provide a means of retrieving component design and drawing detail together with associated information such as cost analyses, process planning, machining time estimates and so on, for the purpose of rationalization, standardization and variety reduction and group technology. The system, however, does not predict costs, it is only intended to retrieve the information that already exists.

In an attempt to estimate production times of form tools and press dies (39), equations have been established using the complexity of the die form in terms of the box volume, face area, perimeter of die, number of geometrical shapes ... etc. as well as other constants

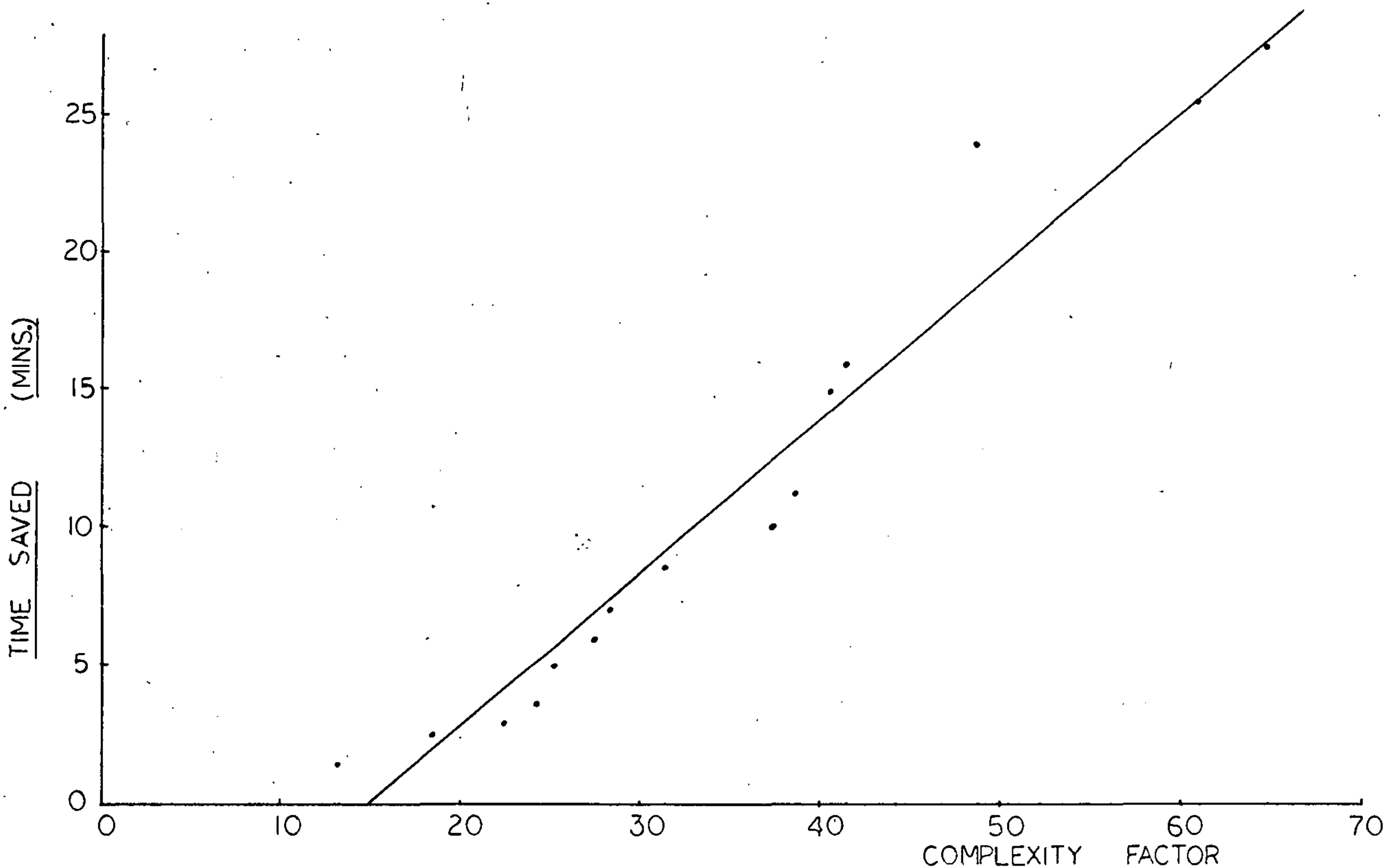


FIG I COMPLEXITY FACTOR V TIME SAVED
JUSTIFICATION OF USE OF NC MACHINES (REF. 37)

to be determined by time and work study. Although it is claimed that these equations have produced acceptable results, they cannot, however, be applied in the case of turning operations. They are only suitable for die machining operations i.e. milling, drilling, shaping ... etc.

It was felt, however, that a correlation between manufacturing time and some parameter representing the complexity of a component does exist, although the nature of this parameter was as yet, unknown.

CHAPTER 5

Derivation of Floor to Floor Time (F_t)

Initially, consideration was given to the simple case of turning a shaft of uniform diameter D inches, and length L inches. From first principles, the feed time T_f for a single pass is:-

$$T_f = \frac{\pi D L}{12 f_r V} \quad \ldots \text{(mins)} \qquad (1)$$

V, being the cutting speed in ft/min. and, f_r is the feed rate in inches/rev.

Now, if the component assumes a more complicated shape, compared to the shaft of uniform diameter, then equation (1) has to be developed in order to represent the changed situation. The feed time, $\frac{\pi D L}{12 f_r V}$, can be computed, step by step, for every diameter, taper, or thread assuming proper speed, feed and depth of cut for every case and $\frac{\pi D L}{12 f_r V}$ will give the total T_f. Although this method should give accurate results, its use would probably mean hours or perhaps days of sorting out various lengths, diameters, speeds, feeds ... etc. for each operation. As this mitigated against the whole object of the study, it was considered that this procedure was out of the question, and a shorter method had to be found.

In an attempt to discover a short method, several components having different size but similar shape (not necessarily geometrically proportional) were considered. The step by step method described above was applied to each component and the theoretical T_f for each diameter was established. Referring to Fig. (2) for example

$$T_f(A) = \frac{P.\ \pi\ D\ L}{12f_r\ V} \quad (A)$$

P is the number of passes anticipated for machining diamter 'A'.

D is the diamter of 'A'.

L is the length of diameter 'A'.

f_r and V are the appropriate feed and speed for diameter 'A'.

The total T_f, i.e., $T_f(A) + T_f(B) + T_f(C)$ was equated to $K.\frac{D_1\ L_1}{12f_r\ V}$, in an attempt to obtain a unified value of 'K' for all those similar components. 'K' was thought to represent that unknown parameter, which this family of geometrically similar components, (Fig. (2), have in common. The result was poor.

Another approach was to select reasonable values for the machining parameters, by assuming a certain machining situation, i.e. rough turning M.S., in a centre lathe, using H.S.S. tool. These values were :-

V = 200 ft/min.

f_r = 0.010 inch/rev.

d = 0.1 inch (depth of cut)

The feed time equation, thus becomes:-

$$T_f = \frac{P.\ \pi\ L\ D}{12x0.010x200} = \frac{P\ L\ D}{7.64} \qquad (2)$$

Where:-

D is any turned diameter, external or internal,

L, the specific length of that diameter, and

P is the number of passes over that diameter.

Threaded parts are to be treated as normal diamters but the number of passes are increased by 4 (A single point tool is considered to

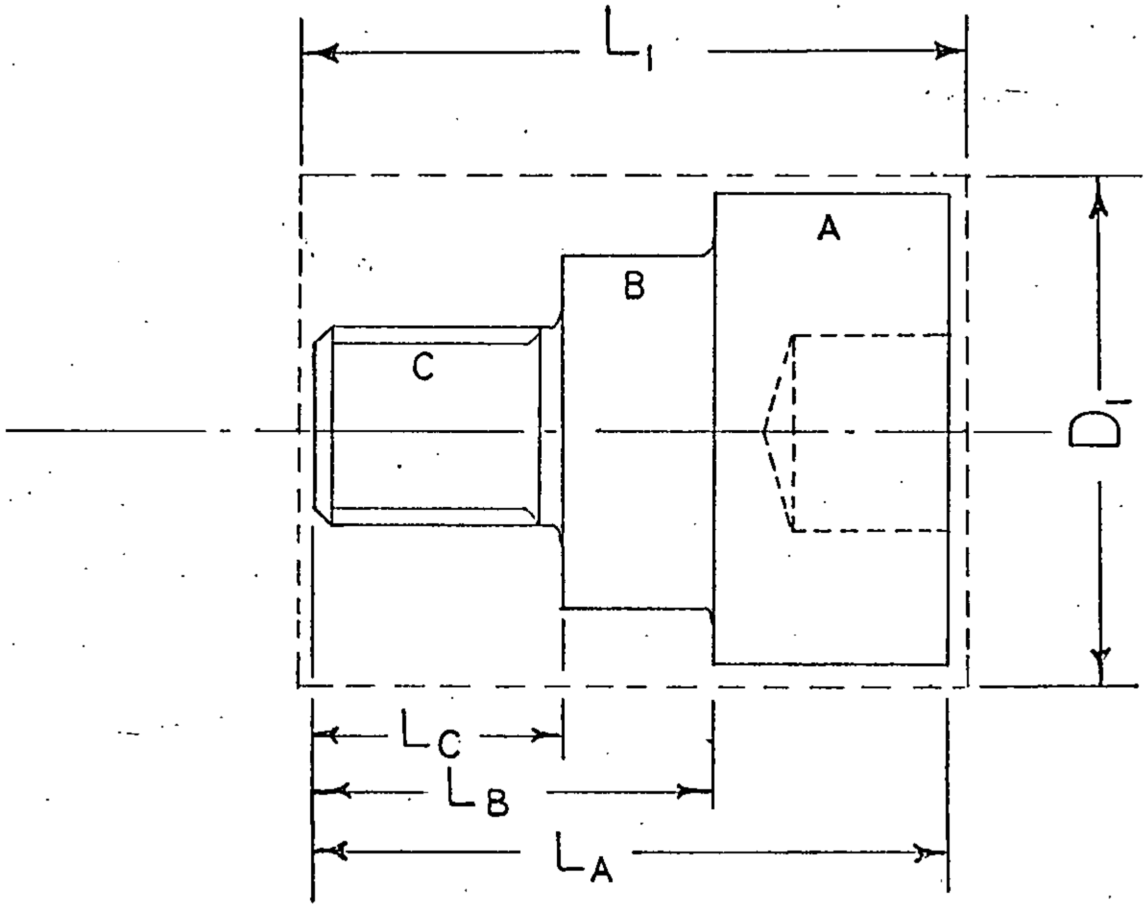


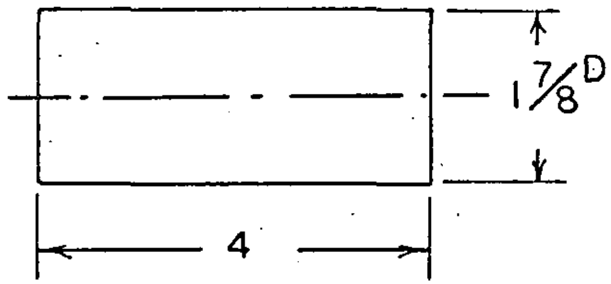
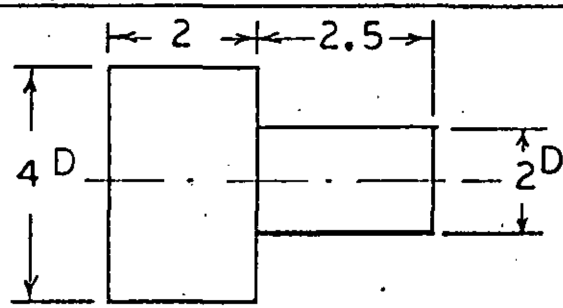
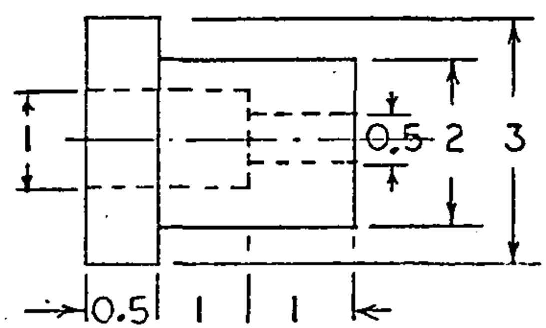
FIG. 2

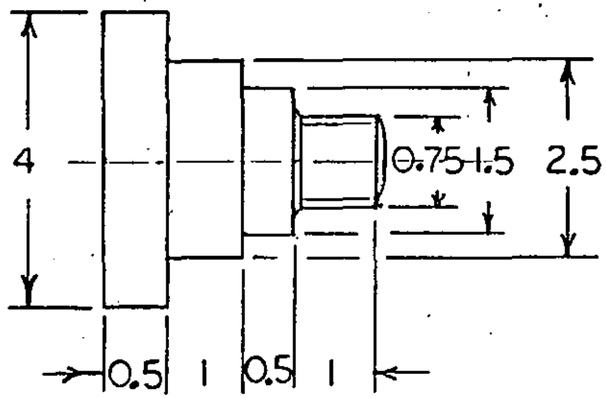
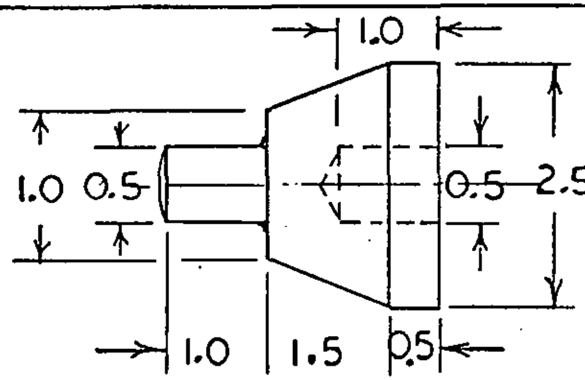
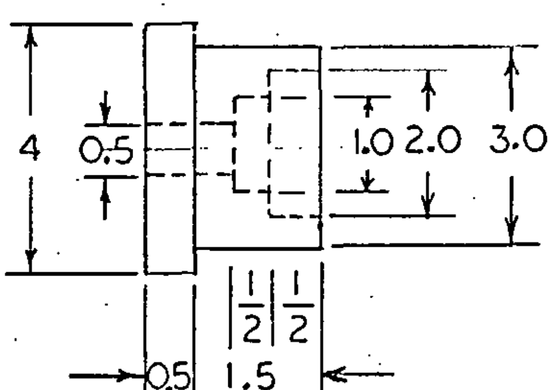
generate the full depth of a thread in 4 passes). The total feed time for all diameters will thus be:-

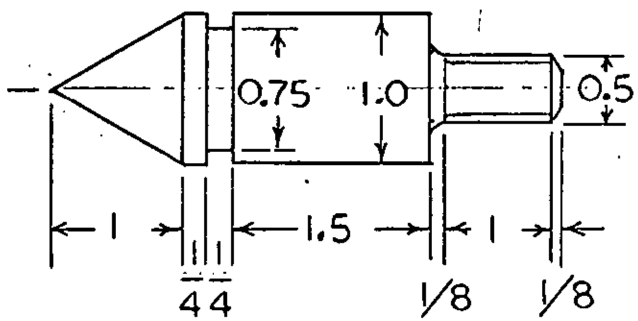
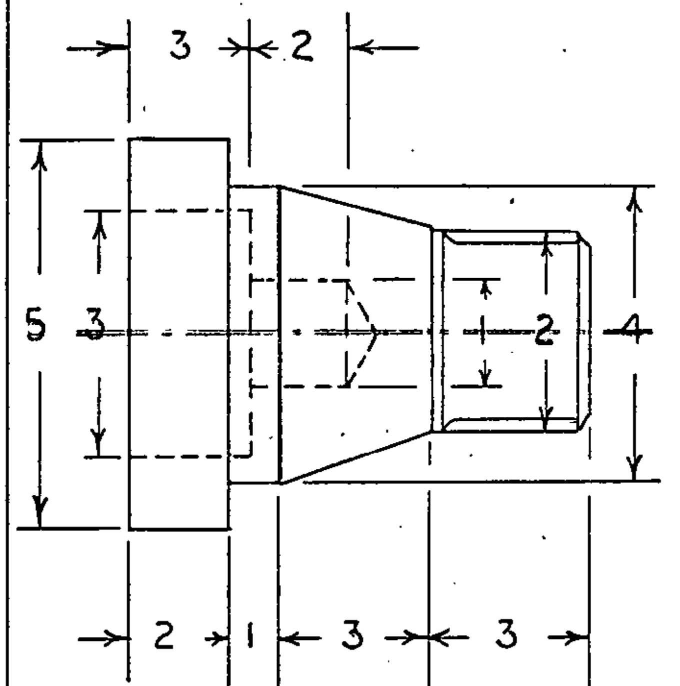
$$T_f = \frac{1}{7.64} \sum P\ L\ D \qquad (3)$$

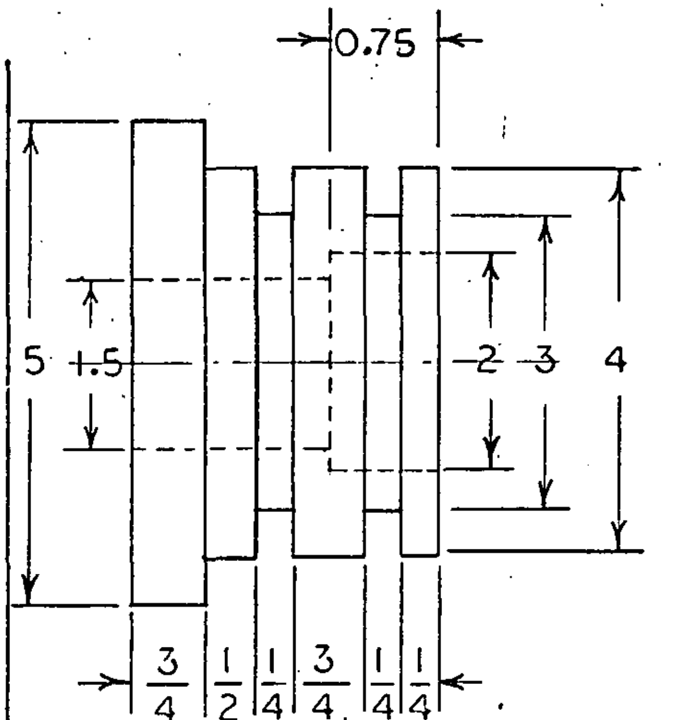
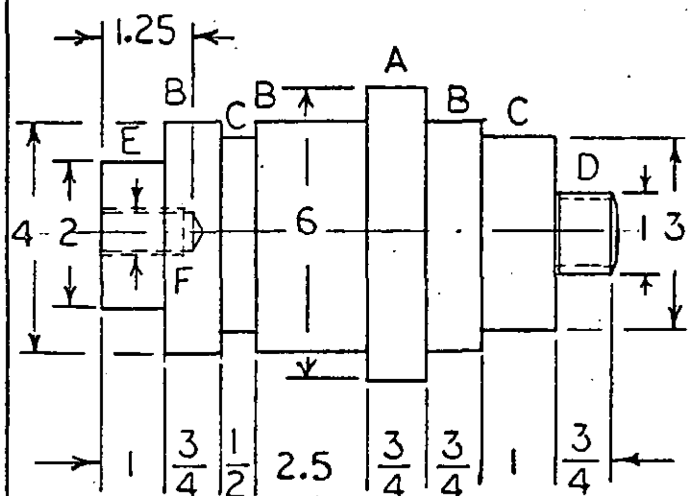
Ten components of different size and shape were investigated. The following tables show these components together with their feed times calculated both by the step-step method described previously and by equation (3). It should be noted from the last column in the tables accompanying the drawings that the times based on equation (3) are far lower than those computed by the step-step method for all components investigated. This is shown in graphical form in Fig. (3). By way of example, the following shows the procedure for computing the feed time for component No. 10, using both equation (3) and step by step method:-

TABLE 1

COMPONENT NO.	COMPONENT DRAWING (DIMS. IN INCHES) N.T.S	STEP–STEP METHOD TIMES (MINS)	TIMES BASED ON $T_F = \frac{1}{7.64}\sum PLD$	% AGE DIFFERENCE
1		0.98	0.98	0
2		8.9	7.59	–15
3		5.0	3.53	–29

4		9.34	3.28	−65
5		4.0	2.25	−43
6		5.99	4.19	−30

<table>
<tr><td>7</td><td>
</td><td>1.31</td><td>1.09</td><td>−17</td></tr>
<tr><td>8</td><td>
</td><td>56.5</td><td>25.3</td><td>− 55</td></tr>
</table>

9		13.5	7.95	−41
10		53.0	28.8	−46

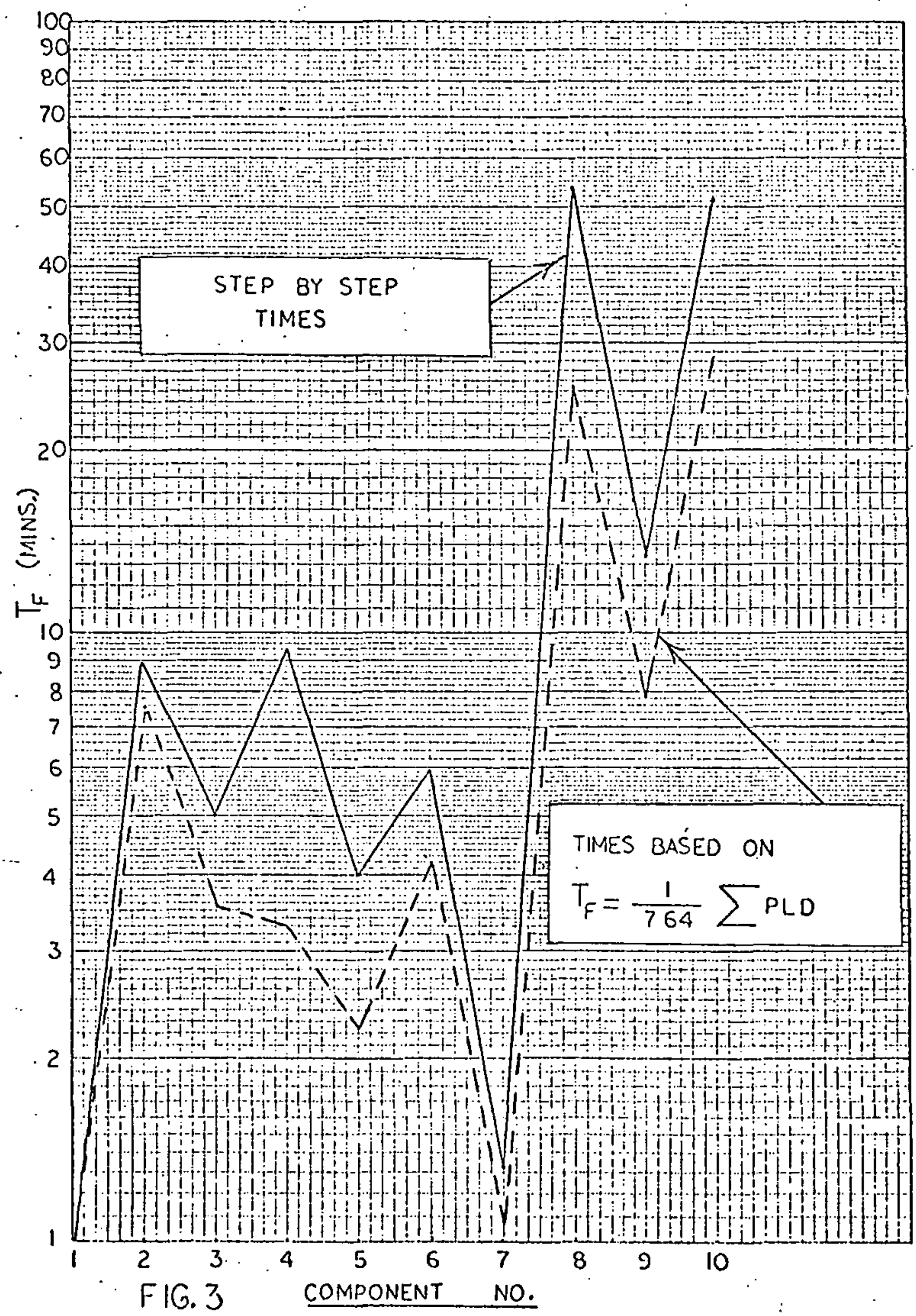

STEP BY STEP TIMES
TIMES BASED ON
$T_F = \frac{1}{764} \sum PLD$
T_F (MINS.)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
COMPONENT NO.

FIG. 3

(i) Equation (3):-

$$T_f = \frac{1}{7.64} \sum P\ L\ D$$

PART	Diameter D(in)	Length L(in)	No. of Passes P	P L D
Diameter A	6.0	0.75	1	4.5
Diameter B	4.0	4.0	10	160.0
Diameter C	3.0	1.5	5	22.5
Diameter D	1.0	0.75	10	7.5
Thread D	1.0	0.75	4	3.0
Diameter E	2.0	1.0	10	20.0
Thread F	0.5	1.25	4	2.5
				220.0

Therefore $T_f = \frac{220.0}{7.64} = 28.8$ mins

(ii) Step-Step Method

For any one diameter, the feed time $T_f = \frac{\pi\ D\ L\ P}{12\ f_r V}$ (mins).

Where:-

D is any diameter in the component,

L is its actual machined length,

P is the number of passes anticipated,

f_r is the particular feed rate in inch/rev. for that diameter,

V is the cutting speed, which has been taken for these examples as

200 ft/min.

N.B. This value of the cutting speed is the same value of cutting speed adopted when building equation (3).

PART	Diameter D inches	Length L inches	No. of Passes P	f_r in/rev.	$T = \frac{\pi D L P}{12 f_r V}$ (mins)
Diameter A	6.0	8.0	1	0.010	6.28
Diameter B	4.0	7.25	10	0.010	37.96
Diameter C	3.0	1.5	5	0.006	4.90
Diameter D	1.0	0.75	10	0.008	1.23
Thread D	1.0	0.75	4	0.125	0.03
Diameter E	2.0	1.0	10	0.010	2.60
Thread F	0.5	1.25	4	0.080	0.04
					53.04

From the above, the procedure more likely to be nearer to reality, is the step by step method because (other factors being equal), it takes into consideration the actual machined length for each diameter as well as the necessary change of feed for the different parts. Taking note of this and referring to Table 1 and also Fig. (3), it becomes clear that equation (3), as well as being tedious to apply, is not particularly accurate.

5.1 The Mean Diameter D_m

Ignoring the credibility of equation (3), at least for the time being, an attempt was made to improve the equation by introducing the concept of the mean diameter D_m, with the possibility of reducing the tedium. Instead of considering each diameter of the component individually, as in equation (3), all the diameters are summated in one "average" diameter - the mean diameter. The mean diameter for the component shown in Fig. (2) is:-

$$D_m = \frac{D_A + D_B + D_C}{3}$$

What the mean diameter concept does is that it equates any component, whatever its shape, to a shaft or disc of single diameter D_m. Equation (3), thus becomes:-

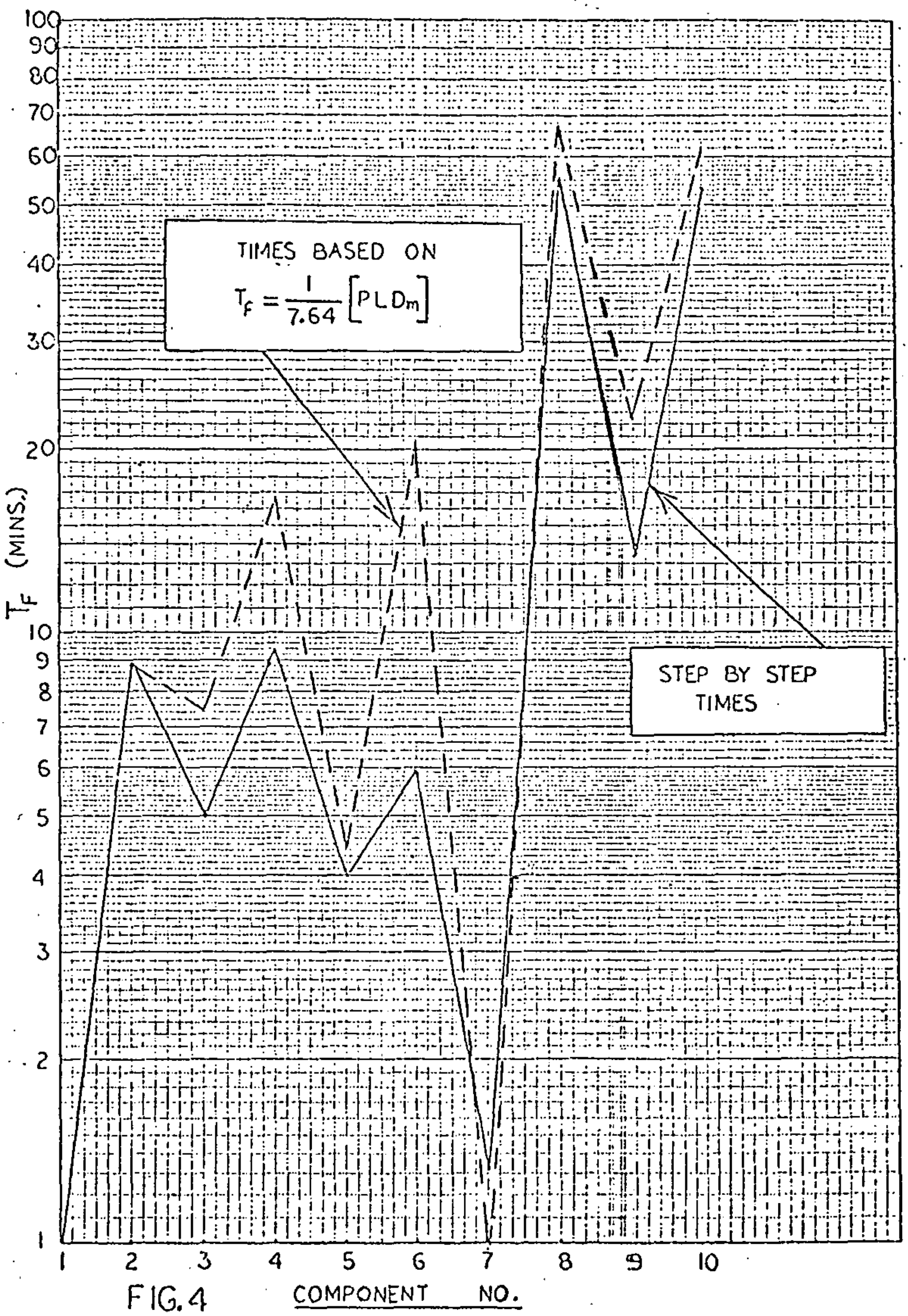
$$T_f = \frac{1}{7.64} \left[P\ L\ D_m \right] \qquad (4)$$

The mean diameter criteria is discussed further in Appendix (2).

Equation (4) was tested against the step by step method by applying it to the components shown in table 1. The results are tabulated below, and also shown in Fig. (4) in graphical form.

COMPONENT No.	TIMES BASED ON D_m (mins)	STEP-STEP METHOD TIMES (mins)	%AGE DIFFERENCE
1	0.98	0.98	0
2	8.83	8.9	- 0.8
3	7.44	5.0	+ 48
4	16.8	9.34	+ 80
5	4.45	4.00	+ 11
6	20.89	5.99	+250
7	0.967	1.308	- 26
8	66.75	56.47	+ 18
9	22.3	13.5	+ 65
10	53.0	61.19	+ 15

Table 2 D_m Times V Step-Step Method Times



TIMES BASED ON
$T_f = \frac{1}{7.64}\left[PLD_m\right]$
STEP BY STEP TIMES
T_F (MINS.)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
COMPONENT NO.

FIG. 4

Although the results from equation (4) are not significantly better or worse than that of equation (3), yet it proved to be very easy to apply and eliminated a great deal of tedium. It should perhaps be mentioned, however, that the step by step method, with which equations (3) and (4) were compared, may not in itself be particularly accurate, since although it is theoretically correct, it is based on hypothetical values of machining parameters and these may or may not reflect the real situation. It was considered, therefore, at this stage that equation (4), or indeed any proposed equation established for predicting production times, should be tested against actual examples taken from industry.

Before approaching companies for component data, however, it was considered necessary to modify equation (4) in order to yield the floor to floor time F_t, which is common to most companies, instead of the feed time T_f.

5.2 Rapid Traverse, Load, Unload, and Tool-change Times

As mentioned earlier in Chapter (4), the other elements of time which constitute F_t are:-

(a) The Rapid Traverse Time RT,

(b) The Tool Change Time TCH, and

(c) The Load and Unload Time LUL.

The rapid traverse time, that is the time taken by the tool in its return stroke, can be taken as a percentage of its feed time T_f. This assumption seems reasonable because, for both cutting feed and rapid traverse feed other parameters are the same, i.e. same diameter and length except for the feed rate itself. A rapid traverse feed rate 10 times faster than the cutting feed rate is considered realistic, and therefore the rapid traverse time has been taken as 0.1 T_f.

The tool-change, load and unload times, cannot be viewed in the same context as the rapid traverse time, because there is no direct relationship between them. It was recognised, however, that the load and unload times have a direct relationship with the component size (L D), and the component shape (complexity). So, it was considered reasonable to relate the load and unload times to the feed time of a component because the latter is itself a function of the size and shape of the component. Total tool changing or indexing time is not a function of the component size or shape, but the higher the number of tool changes made during the machining of a component, the greater the enhancement of the floor to floor time F_t.

Time-studies on turning (23, 25, 36), showed that values as much as 0.3 of the feed time for loading and unloading the component, and 0.2 of the feed time for changing tools, are not infrequent.

It was, therefore, decided, on the basis of the above reasoning, to incorporate these times into a modified equation (4) in order to obtain the floor to floor time F_t, thus:-

$$F_t = T_f + 0.1\ T_f + 0.3T_f + 0.2\ T_f$$

$$= T_f\ (1 + 0.1 + 0.3 + 0.2)$$

$$= 1.6\ T_f$$

i.e. $F_t = 1.6 \times \frac{P\ L\ D_m}{7.64}$

or $F_t = \frac{P\ L\ D_m}{4.8}$ (5) .

Equation (5), thus represents the floor to floor time for a certain machining situation, i.e. as stated earlier, rough turning M.S. in a centre lathe, using H.S.S. tool. Now in order to generalise equation (5) so as to make it applicable to all machining situations, constants representing the factors that influence F_t should be introduced. As has been mentioned earlier in Chapter (4), among the factors that influence F_t are:-

(a) The tolerance and finish required

(b) The component and tool materials

(c) The type of machine used.

The influence of these parameters is represented in equation (5) as follows:-

$$F_t = \frac{P\ L\ D_m}{4.8} \left[K_1 \times K_{mat.} \times K_2 \right] \qquad (6)$$

K_1 being the machining factor, i.e. a measure of the degree of tolerance and finish.

$K_{mat.}$ the machinability factor, i.e. the factor which differentiates between the more machinable and hard to machine materials.

K_2 represents the machine type.

Returning to equation (5), it can be seen that it represents a machining situation where the factors K_1, $K_{mat.}$ and K_2, each have a value of unity. This is intentional since the centre lathe, mild steel, and rough turning have been chosen as the datum each in its own field, and at the datum each factor was given a value of unity.

From equation (6), it follows that if the machining situation is changed, e.g., if a machine other than a centre lathe is used, and a material other than mild steel is being machined, then K_2 and $K_{mat.}$ should assume values according to the new machine capability compared to that of a centre lathe, and a new material machinability compared with that of the mild steel respectively.

In short, what these factors do, is that they adjust F_t, if the standard datum machining situation represented by equation (5) has changed, without the necessity for changing speeds, feeds, ... etc. for every material or machine combination. K_1, $K_{mat.}$ and K_2 values are given in Appendix (3).

Equation (6) was tested against actual times taken from typical examples supplied by a representative cross section of industry (40). The results of this comparison were very poor indeed. As shown in table (3), the times calculated by this method are far lower than those quoted in the examples.

COMPONENT No.	TIMES BASED ON EQUATION (6)	ACTUAL TIMES	%AGE ERROR
1	1.014	3.2	-68
2	1.29	3.2	-59
3	0.39	1.83	-79
4	0.77	1.00	-23
5	2.56	7.5	-66
6	3.83	7.5	-49
7	1.04	4.0	-74
8	5.69	15.5	-63
9	0.72	1.75	-59
10	6.54	14.00	-53
11	24.23	90.0	-73
12	0.76	3.5	-78

TABLE (3) Equation (6) Times V Actual Times

This poor result was attributed to the fact that the number of tool passes, P, in equation (6), were not realistic. Steps were then taken to investigate this phenomena further.

5.3 The Number of Cuts, N_c

It was felt that there must exist a component feature which is more representative of the actual number of tool passes than those calculated on a theoretical basis. After considering many concepts, the number of tool passes, P, in equation (6) when replaced with the number of cuts N_c, i.e. the sum of the machined diameters, tapers, chamfers, threads ... etc., the results have improved but still exhibit considerable errors. Table (4) shows a comparison between the times based on:

$$F_t = N_c \frac{L\ D_m}{4.8} \left[K_1 \times K_{mat.} \times K_2 \right] \qquad (7)$$

and actual times for 18 different components. Fig. (5) shows the result in graphical form.

COMPONENT No.	COMPONENT SIZE $L \times D_m$	TIME BASED ON $F_t = N_c \frac{L\ D_m}{4.8}\left[K_1\ K_{mat.}\ K_2\right]$ (mins)	ACTUAL TIMES (mins)	%AGE ERROR
1	2.8	2.66	3.2	- 17
2	2.5	2.40	3.2	- 25
3	2.8	1.60	1.83	- 13
4	2.67	1.03	1.00	+ 3
5	6.52	6.69	7.5	- 11
6	14.9	5.35	7.5	- 29
7	11.5	3.54	4.0	- 12
8	45.0	22.6	14.00	+ 61
9	147.0	112.0	90.00	+ 25
10	4.5	1.9	3.5	- 46
11	6.0	8.5	9.0	- 6
12	14.75	9.7	9.2	+ 8
13	69	35.5	16.0	-122
14	0.62	2.1	2.6	- 19
15	2.11	1.2	1.5	- 20
16	7.5	5.34	5.3	+0.8
17	72	42.3	25	+ 69
18	7.2	3.97	3.9	+ 2

TABLE (4) N_C Times V Actual Times

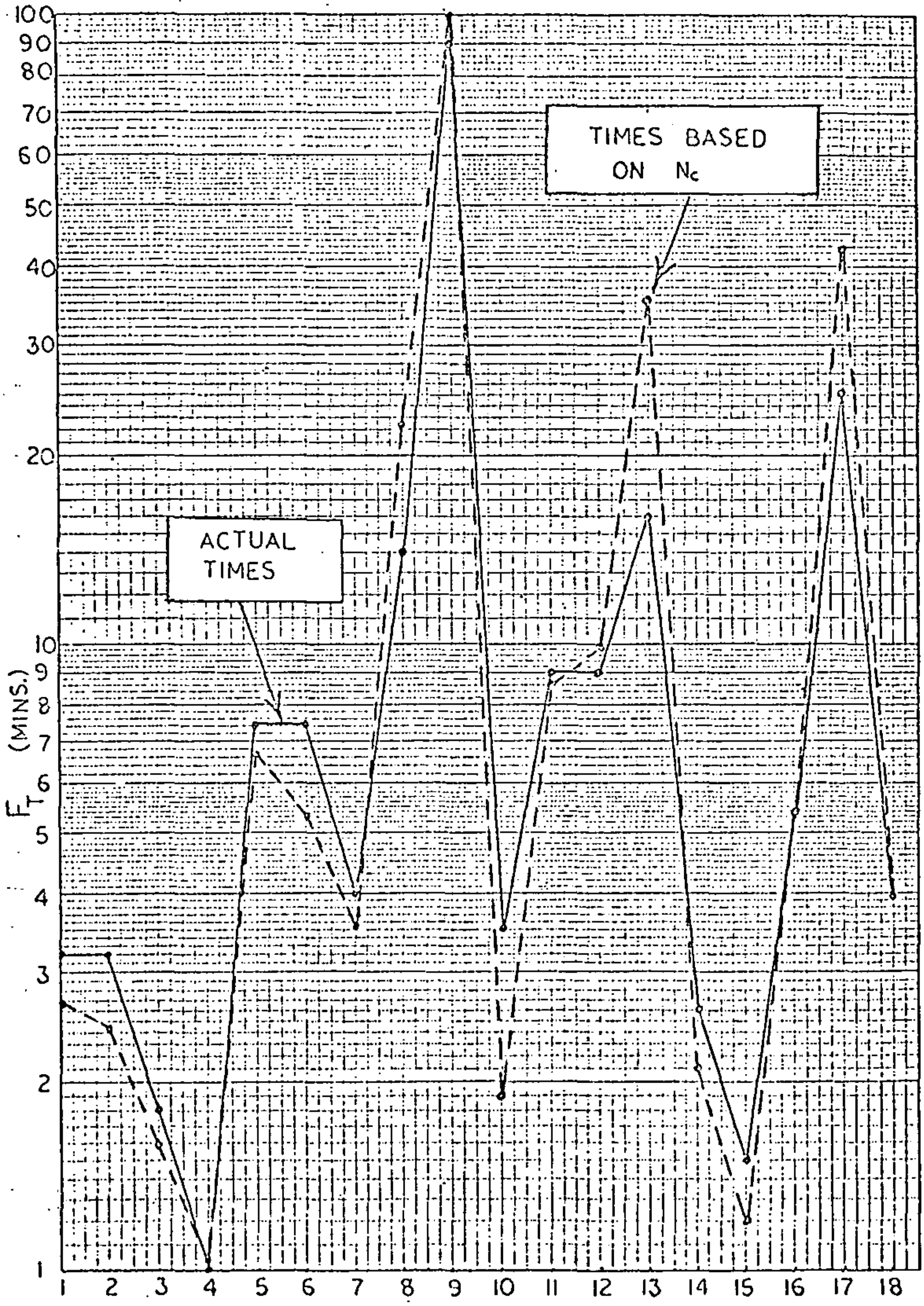

TIMES BASED ON N_c
ACTUAL TIMES
F_T (MINS.)
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
COMPONENT NO.

FIG. 5

From the graph in Fig. (5), it can be seen that whilst the 2 curves show close correlation on a number of occasions, they disagree in the majority of cases. This disagreement is particularly evident for components having either small or large size e.g. components 8, 9, 13, 14 and 17. Nevertheless, the N_c criterion, made equation (7) simpler and easier to apply because it eliminated the time for calculating the number of tool passes for every operation. It was decided, therefore, that this line of thinking was worthy of further investigation, i.e. replacing the theoretically based number of passes, P, by a parameter which describes the shape of the component.

5.4 The Complexity Factor C_f

The complexity of complete equipment has been quantified (44), and defined as being dependent upon:-

number of parts, P_p;

number of different types of parts, P_t;

number of interconnections and interfaces, P_i;

number of functions that the product is expected to perform f

Where complexity factor $C_f = \frac{K(P_p \, P_t \, P_i)}{f}^{1/3}$

K being a constant of convenience.

This approach seems to have met with success for electronic equipment. The result may be summarised as follows: the lower the complexity factor, the greater is the equipment's reliability, the lower is its cost, the higher is its quality. The originator of this approach, (44), suggested that it would be worthy of consideration in the field of mechanical engineering, and it should be particularly useful in the conceptual stage of design. An approach, analogous to the one described above, was evolved where a factor C_f was defined as being representative of the number of tool passes in the F_t equation, viz.

$$C_f = \left[N_c \times N_t \times N_d\right]^{1/3} \qquad (8)$$

Where, N_c is the number of cuts (as described previously)

N_t is a summation of the number of types of cuts (i.e. external turning, threading, taper turning, facing, ... etc.)

N_d is the number of discontinuities of the machined surface.

The factor 'C_f' was computed for every component shown in table (4). This resulted in lower numerical values than the corresponding N_c for each component. The reason for this was attributed to the fact that the middle term in equation (8), i.e., N_t, was far less significant than either N_c or N_d. It followed that F_t times calculated using factor 'C_f' were far lower than the corresponding times given by N_c alone, although 10 components out of the 18 in table (4), have already shown negative error with N_c. Moreover, factor 'C_f' is not particularly easy to apply since it requires a considerable amount of time to compute, especially for the more complicated components. This approach to complexity, the factor 'C_f' was abandoned and further consideration was given to N_d, the discontinuity concept.

5.5 The discontinuity factor N_d

The number of discontinuities N_d, when considered alone, as a replacement for N_c in equation (7), gave more encouraging results. The calculated times when compared with the actual times indicate a good agreement between the two. Table (5) gives the result of this comparison for the same conponents considered in table (4). Fig. (6) shows this comparison in graphical form.

Although the two curves do not absolutely coincide, they follow each other in a remarkable manner, thus it would appear that a firm base for the computation of F_t had been established. It is interesting to note that the discontinuity factor N_d has values slightly greater than the corresponding N_c, that is to say that the number of discontinuities in the surface of a component is slightly greater than the number of cuts performed for that component. This can readily be appreciated if, for example, we consider one type of cut - external turning - there could be more than one machined diameter, and for chamfering, there could be two or more chamfers in the component, and so on. This slight increase in the complexity factor brought about by using the discontinuity concept had improved the result of table (4) a great deal. In fact it brought all the times which showed negative error with N_c either closer to the actual times or slightly above them, (see components 1, 2, 3, 5, 6, 7, 10, 14, and 15). On the other hand, the components which exhibited positive error with N_c, (table 4), were expected to show more explicit positive error when employing N_d. Indeed this was the case, but, returning to table (4), we can see that most of the components which showed positive error with N_c were, in the first place, large size components - No. 9, 13, and 17 - (see comments on small and large size components on page 44). So, the use of N_d had, in fact, improved the result obtained by using N_c a great deal, while it worsened only those few components which were already in error because of their size effect. This size effect is corrected by amending the discontinuity criteria whenever such sizes arise. This amendment and its significance is explained in the discussion of the cost equation shown later in the text. The derivation of the discontinuity criteria for various types of component is given in Appendix (1).

Component No.	Times Based on $F_t = N_d \frac{LDm}{4.8} (K_1\ K_{mat}.K_2)$ (mins)	Actual Times (mins)	%age Error
1	3.10	3.2	-3.0
2	3.21	3.2	+0.3
3	1.86	1.83	+3.0
4	1.32	1.00	+32.0
5	7.65	7.5	+2.0
6	6.88	7.5	-8.0
7	4.13	4.00	+3.0
8	18.86	14.0	+35.0
9	86.29	90.0	-4.0
10	3.32	3.5	-5.0
11	9.45	9.0	+5.0
12	9.7	9.0	+8.0
13	17.76	16.0	+11.0
14	2.625	2.6	+0.9
15	1.466	1.5	-2.0
16	5.76	5.3	+9.0
17	24.2	25.0	-3.0
18	3.97	3.90	+2.0

Table (5) N_d Times v Actual Times

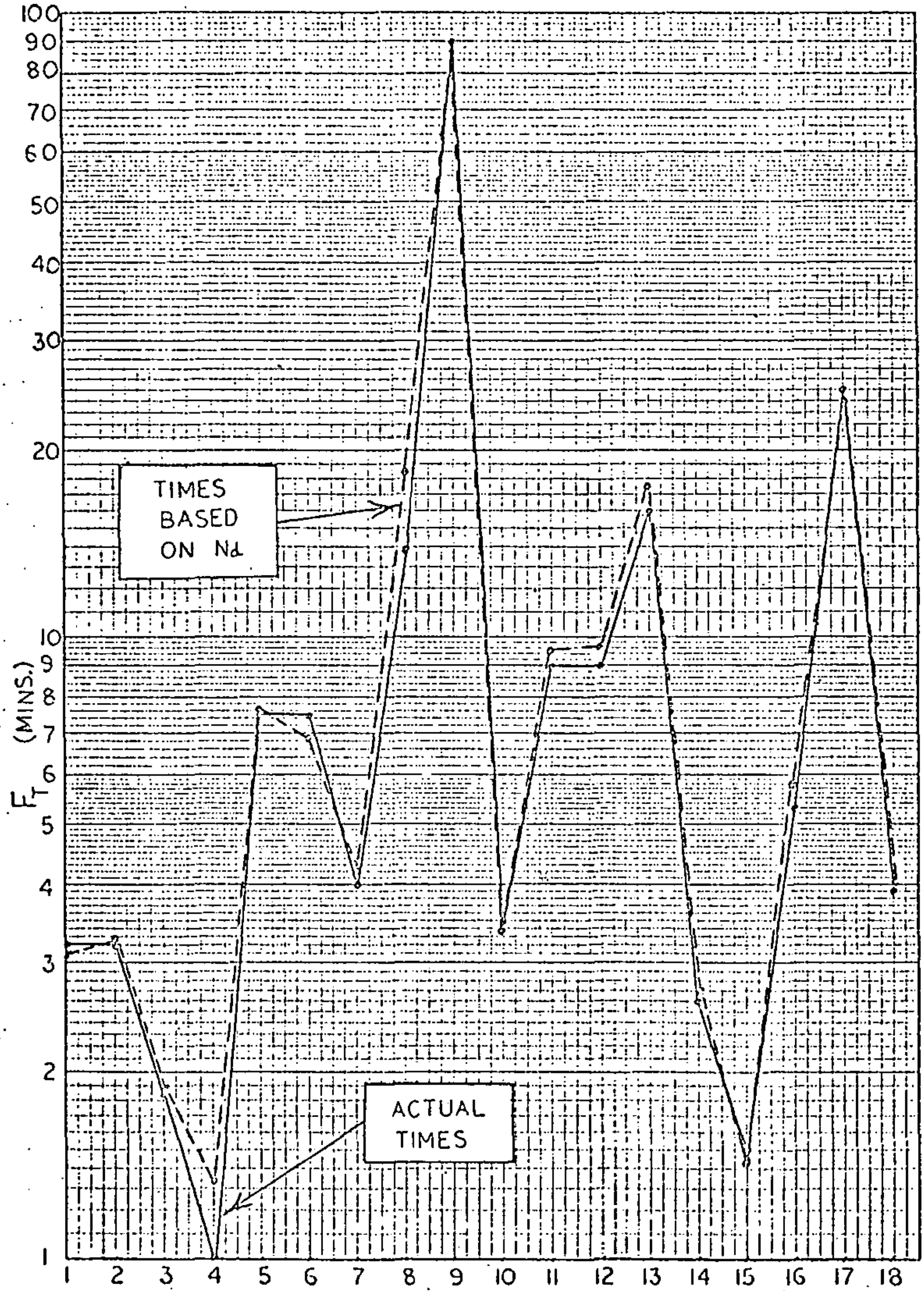


FIG. 6 COMPONENT NO.

Fig.(7) shows a plot of F_t (actual) versus F_t (calculated) for each one of the 18 components shown in table (5). The ideal situation is that the points representing the F_t's should all lie on the 45^o line. This is not exactly so, but the plot is reasonably close.

By way of comparison, Fig. (8) shows a plot of F_t (actual) v F_t (calculated), for the previously mentioned components, using a technique claimed to evaluate floor to floor times (29). It can be seen from Fig. (8) that this technique over-estimated the F_t's of all the components investigated (all the points being above the 45^o line), and knowing that the plot is in log-log form it can be appreciated that the estimates are highly exaggerated.

The floor to floor time equation:-

$$F_t = N_d \; \frac{L\;D_m}{4.8} \left[K_1 \times K_{mat.} \times K_2 \right] \qquad (9)$$

was further tested against 100 typical examples taken from a wide cross-section of companies and 90% of the calculated F_t's were accurate to within $\pm$ 10% of the actual F_t's. Figs. (9) through (11) show plots of F_t (actual) against F_t (calculated) for the components supplied by three different firms. It can be seen that the plots are reasonably accurate and the points are evenly distributed about the 45^o lines. The data provided by individual firms is given in Appendix (4).

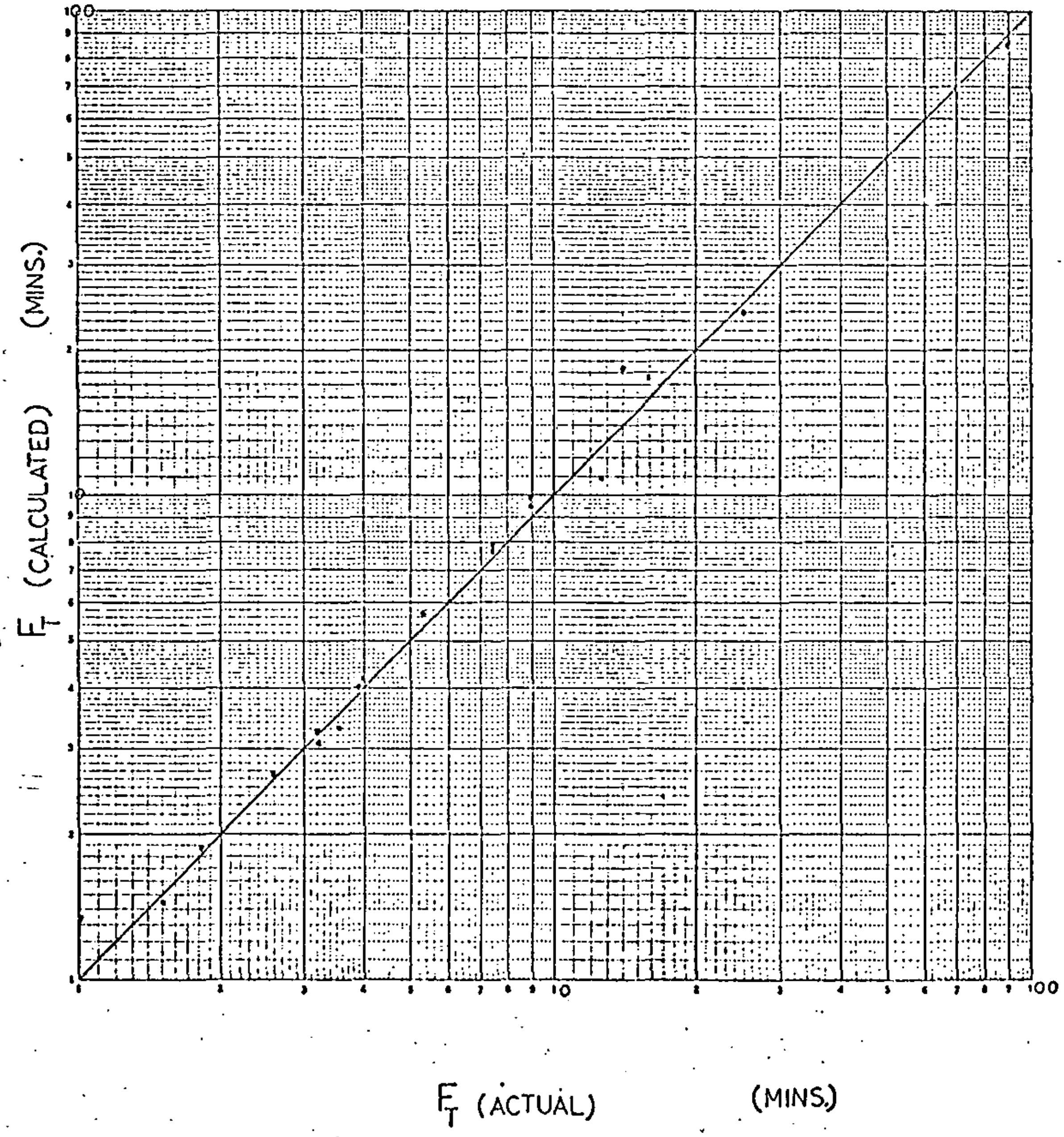


FIG. 7 F_T (ACT.) V F_T (CAL.) – SAME COMPONENTS

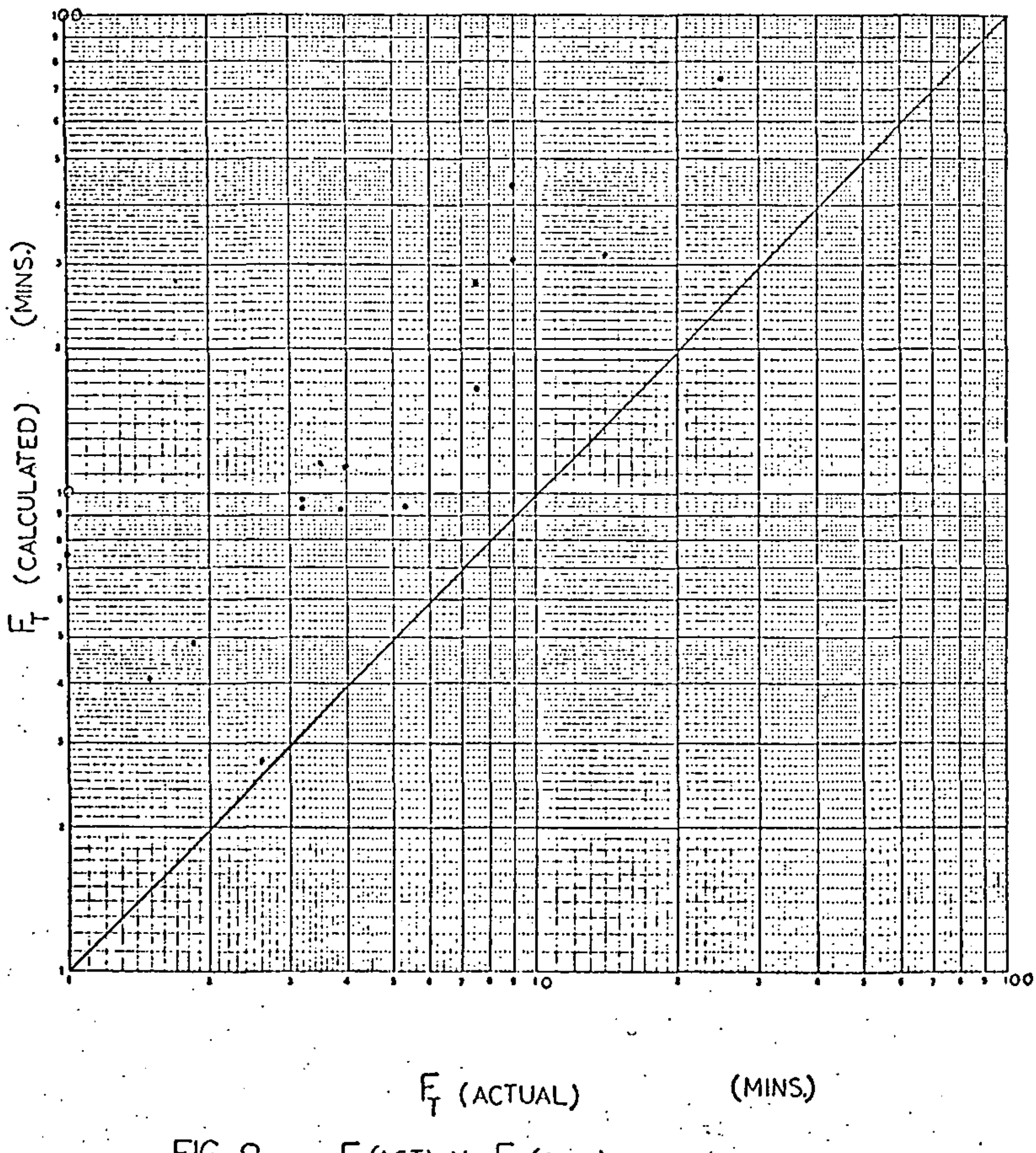


FIG. 8 F_T (ACT.) V F_T (CAL.) – SAME COMPONENTS AS FIG. 7 (REF. 29)

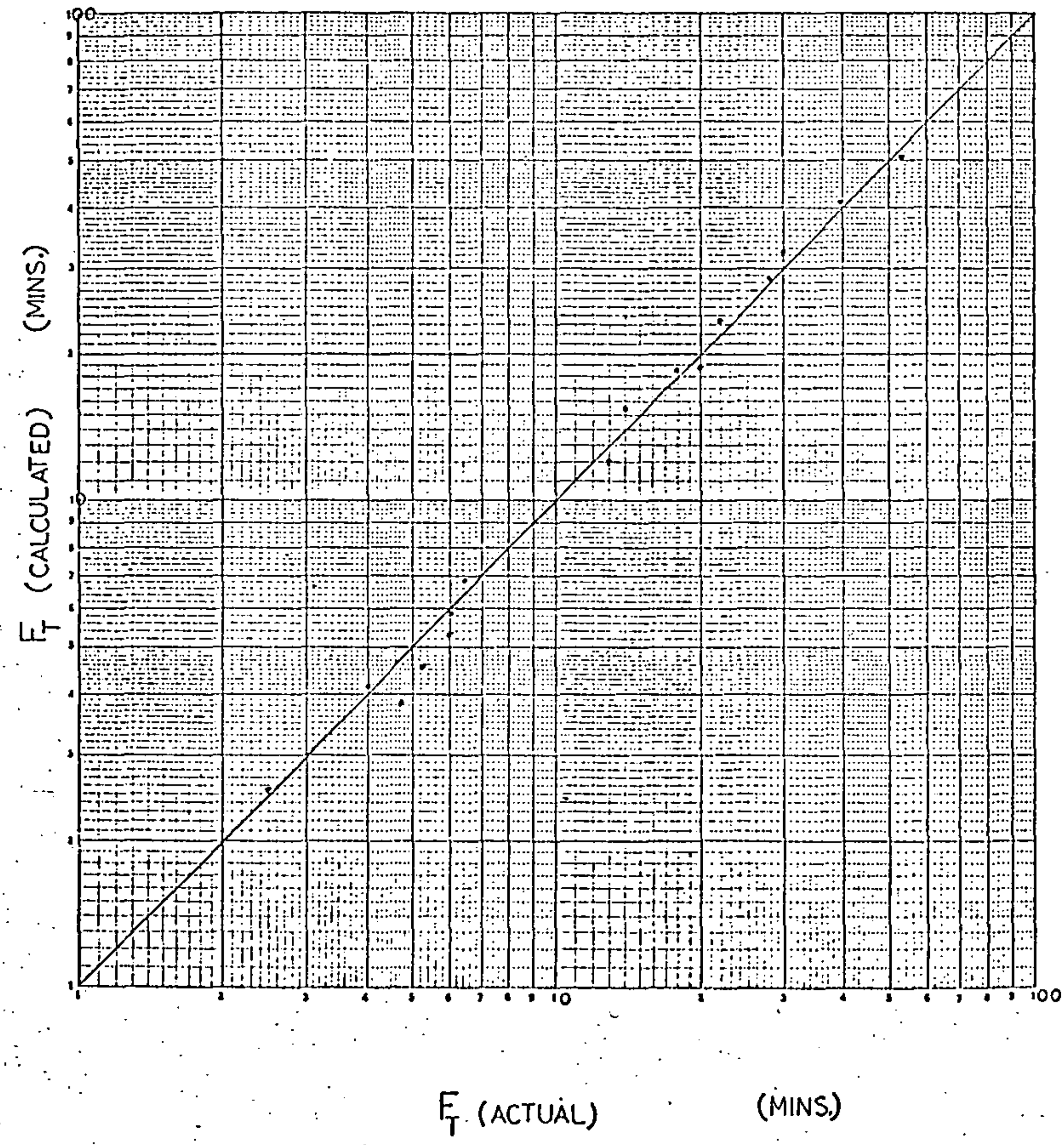


FIG. 9 F_T (ACT.) V F_T (CAL.) FIRM 'A' EXAMPLES

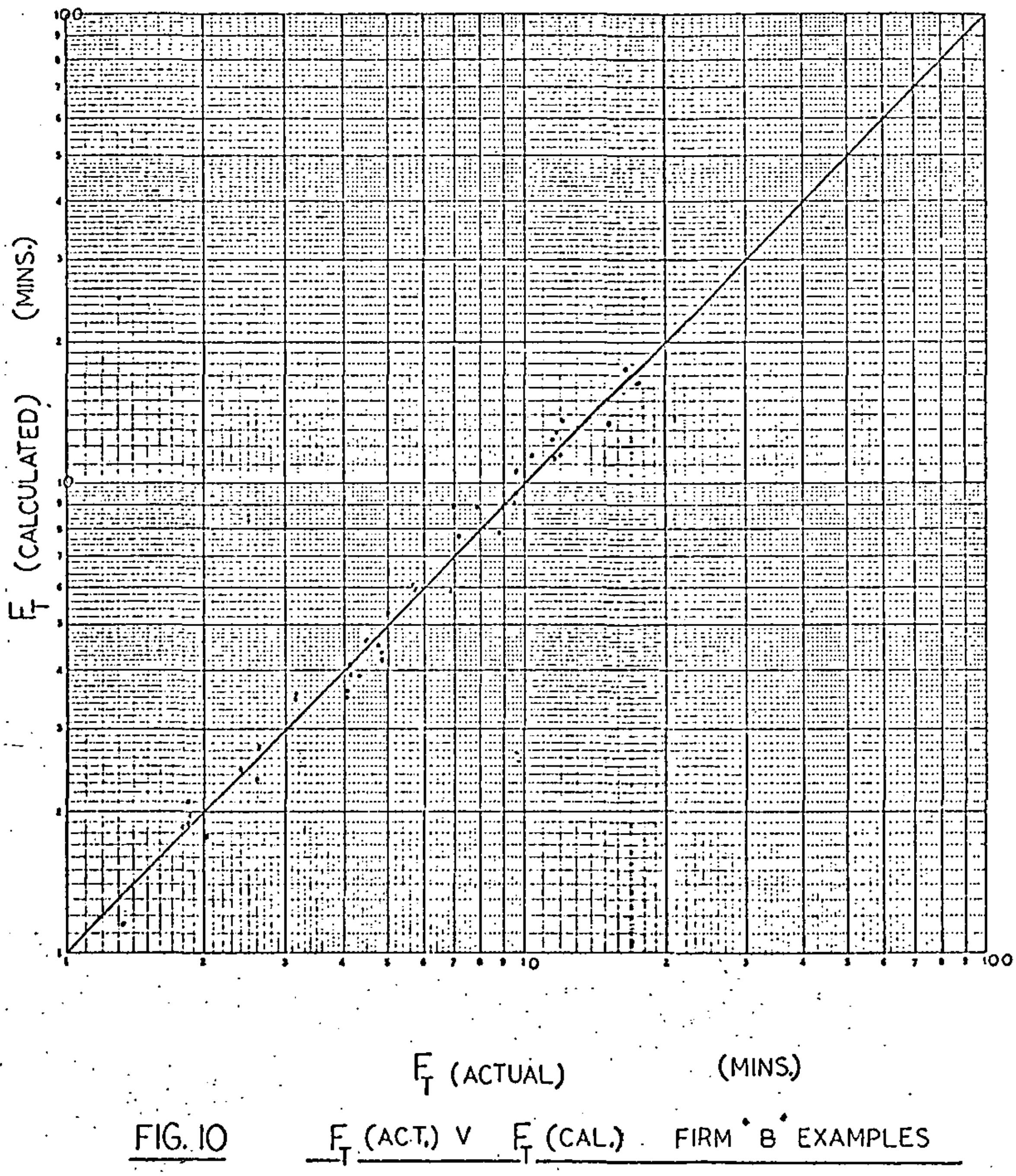


FIG. 10 F_T (ACT.) V F_T (CAL.) FIRM 'B' EXAMPLES

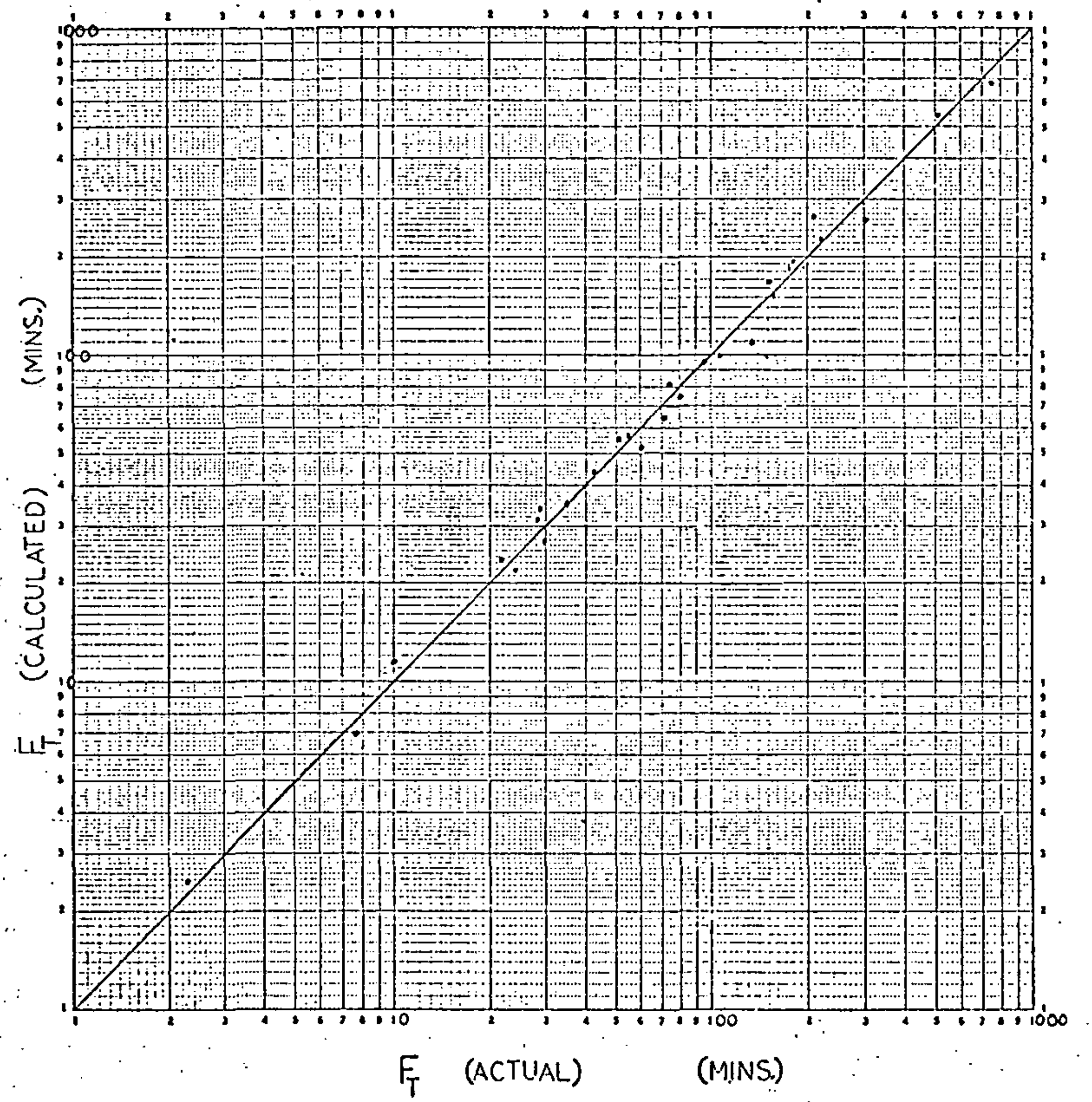


FIG. 11 F_T (ACT.) V F_T (CAL.) FIRM 'C' EXAMPLES

CHAPTER 6

The Setting Time

As has been mentioned earlier in Chapter 3, the setting time and the floor to floor time costs constitute the cost of the component associated with the operation of the machine tool. Having settled the question of the floor to floor time, the setting time will now be discussed.

6.1 Definition

The setting time of a machine in this work is defined as the time that elapses from the moment the operator receives the drawings of the component to the moment when the machine is ready for production. This time includes the time needed by the operator to study the drawings, to prepare his list of tools and production aids, to bring them from the stores, and to actually set the tools onto the machine. For NC machines, programming and tape preparation times, however, are not considered as part of the setting time. They should be charged against the production planning item. The reason for this distinction is because the programming and tape preparation costs are usually incurred once in the lifetime of the component production existence, so it is very difficult to forecast the number of components, or indeed the number of batches, which will share these costs.

6.2 Setting Time Dependency

There has long been a debate about the question of whether the setting time is machine or component dependent. From the above definition it is dependent upon both, since the component size, shape, and batch quantity affect the selection of the type of machine to be used. Having selected the machine, then it is the number of operations to be carried out on the component which determines the amount of tooling required on the machine, and hence the setting time.

The setting times generally accepted for various types of machines (See Appendix 5) are, therefore, not necessarily valid all the time because they are not exclusively dependent upon the machine type, but also upon the component shape and complexity, i.e. it should not remain a constant figure for each type of machine, but should assume varying values according to the components complexities. The traditional setting times have, therefore, to be corrected in accordance with the above definition.

6.3 Setting Time Correction

The ratio $\frac{N_d}{x}$ is suggested as a correction factor for the generally accepted setting time S_t. X is the machine tooling capacity, that is, the maximum number of tools that can be loaded in that particular type of machine. The corrected setting time is $\frac{N_d}{x}$ S_t, a fuller description of the correction factor is given in Appendix 5.

Now, if $N_d \geqslant x$, the correction factor is assumed to be 1.0, and the setting time will remain S_t - the accepted setting time. If, however, $N_d \leqslant x$, then $\frac{N_d}{x}$ is a fraction, and the accepted setting time S_t will be reduced accordingly. Typical setting times and tooling capacity factors are discussed and given in Appendix (5). for a range of machines. The corrected setting time per component is thus:-

$$\frac{N_d}{x} \cdot \frac{S_t}{Q} \qquad (10)$$

CHAPTER 7

Material Cost

It is considered essential when considering the true costs of components, that allowances should be made for material waste and scrap losses (41). The design standard Material M_s, i.e., the amount of material specified by the drawing to produce a particular component is seldom representative of the material used. Material variances develop from:-

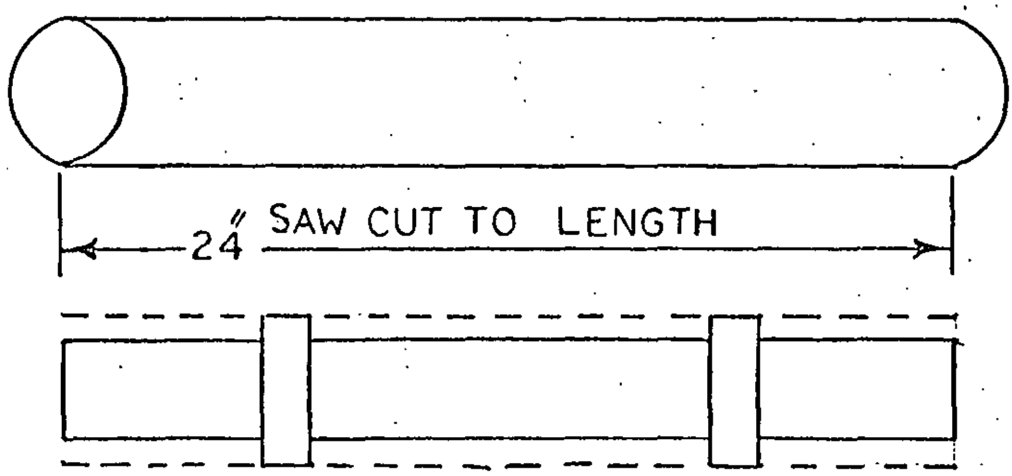
1. Schedule or quantity changes,
2. Scrap losses, and
3. Learning effect on scrap loss.

7.1 Schedule or Quantity Change Effect

One of the most important, and most frequently overlooked factors, is the waste which results from changes in quantity or schedule. This waste W, is generated by the different methods and sequences of production. Fig. (12) shows the effect of quantity change on a typical bar stock item and the resulting bar end loss. This material excess variance is purely a result of schedule and quantity. Failure to recognize this will result in an underestimation of the material quantity and hence cost.

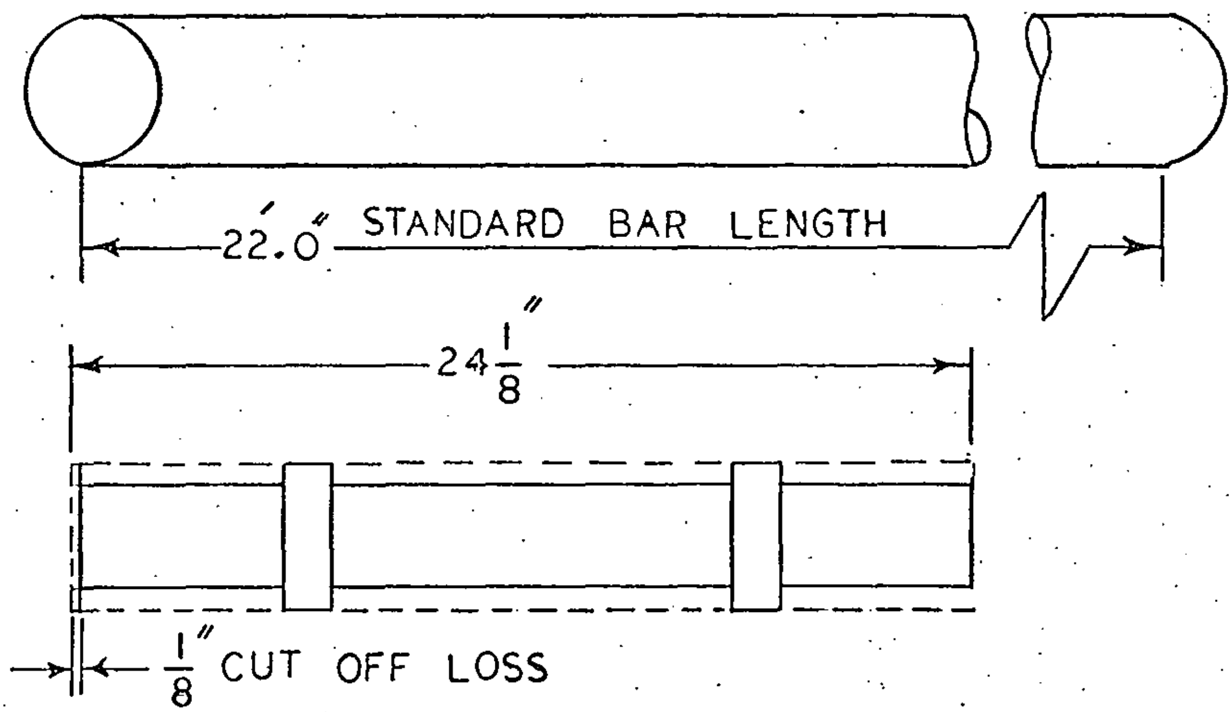
7.2 Scrap Loss

Scrap losses are caused by random error, machine or material



Ⓐ ONE PIECE ORDER

CENTRE LATHE



Ⓑ 1000 PIECE ORDER

TURRET LATHE

10 PIECES AT $24\frac{1}{8}'' = 241\frac{1}{4}'' = 20' - 1\frac{1}{4}''$

BAR END (WASTE/BAR) $= 22\frac{3}{4}''$, WASTE/PIECE $= 2.275''$

FIG. 12 EFFECT OF QUANTITY CHANGE, (REF. 30) failure, operator's error, and design errors. In all cases they tend to vary with quantity, precision, and production experience. A realistic figure (30) for predicting scrap losses for a batch of Q is:-

$$S = \sqrt{Q} \qquad (11)$$

Therefore an extra S pieces are needed to assure order quantity completion.

7.3 Learning Curve effect on Scrap Loss

However, in most operations, experience causes a reduction in scrap loss. The learning curve technique is often used to project this "experience effect". The learning curve is a graphic representation of the improved performance growing out of increasing quantities and increasing skills and experience (42). In an 80% learning curve situation, each time the quantity of units produced is doubled, the cumulative average pieces scrapped will approach 80% of the average scrap in the initial quantity. Thus if for a batch of 100 components, 10 components were scrapped, then for a batch of 200 components, 8 components will be scrapped/100 components produced, and for a batch of 400 components, 7 components* will be scrapped/100 components produced, and so on.

* The theoretical figure is 6.4, rounded to 7.

The learning curve appears as an exponential curve if plotted in linear graph paper. If log-log paper is used the characteristic appears as a straight line. Fig. (13) demonstrates the latter type of presentation for a 90% learning curve.

Learning curve performance varies from a low of 65% to a high of 100%. A completely automated operation would most likely result in a 100% curve and it is almost impossible to utilize a learning curve of 50% or less because its application would theoretically eliminate all possible scrap on the second or third doubling of the quantity. A lower limit of initial batch quantity (Q) of 10 components seems realistic in the turning process, after which the operator should gain enough experience and the effect of 'learning experience' in decreasing scrap loss should result. For the turning process a 90% learning curve is not uncommon, but again this depends upon the company's staff experience and also upon the equipment type and conditions.

It is interesting to note that the scrap allowance given by equation (11), i.e. $S = \sqrt{Q}$, is identical with a 71% learning curve.

Now, for material requirement predictions, the scrap allowance given by equation (11), should be modified to respond to 'experience' as follows:-

$$S' = f_s \sqrt{Q} \qquad (12)$$

Where:-

f_s is the ordinate to the scrap experience learning curve adopted.

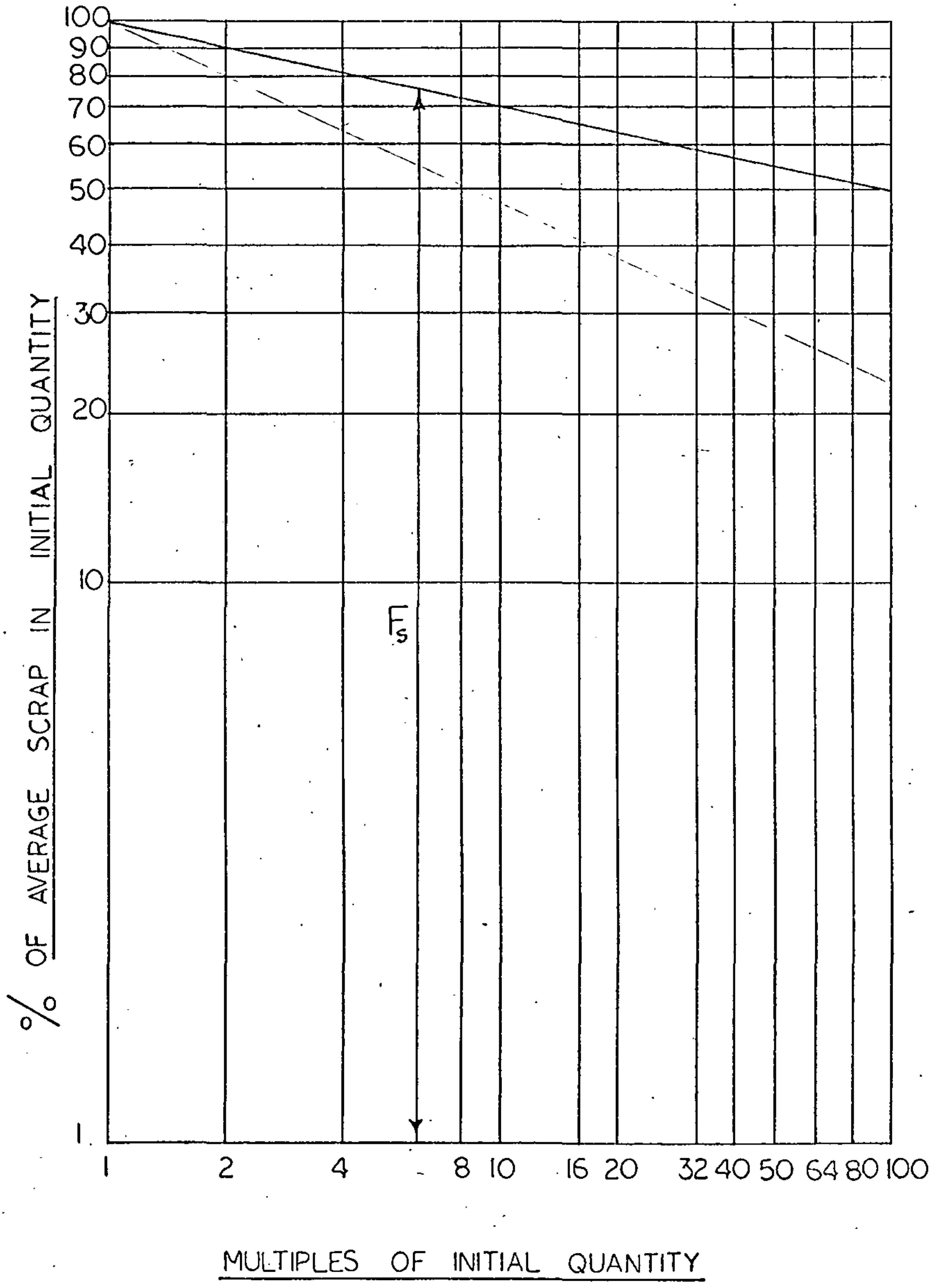


FIG. 13 A 90% LEARNING CURVE

Plotted on log-log paper, the curve shows ratios rather than absolute values, and the data plots in a straight line as shown. The straight line presentation makes it easier to project the learning curve (with a straight edge) in order to predict anticipated scrap losses at various levels of production.

Summarising; the amount of material to be charged to the cost equation should include, as well as the design standard material M_s, the schedule or quantity change waste/component 'W', and the modified scrap loss/component, i.e. the material M, is:-

$$M = \frac{M_s \, (Q + S')}{Q} + W$$

$$= M_s \left[1 + \frac{f_s}{\sqrt{Q}} \right] + W \qquad (13)$$

and the material cost to be charged to the cost equation M_c, is:-

$$M_c = M \times (\text{standard cost/unit of material}) \qquad (14)$$

CHAPTER 8

The Cost Equation

The cost/component C, which utilises the manufacturing time of the component, together with its material cost is the sum of equations (9), (10), and (14), thus:-

$$C = \frac{R}{60} \cdot N_d \left[\frac{L\ D_m}{4.8} \cdot K_c + \frac{S_t}{XQ} \right] + M_c \qquad (15)$$

Where:-

R	=	Company's hourly rate, (£/hour)
N_d	=	Component Complexity factor,
K_1	=	Machining factor,
$K_{mat.}$	=	Material factor,
K_2	=	Machine type factor,
K_c	=	The Combined factor ($K_1 \cdot K_{mat.} \cdot K_2$),
L	=	Total machined length (ins),
D_m	=	Component mean diameter (ins),
S_t	=	Machine Setting time (mins),
X	=	Machine tooling factor,
Q	=	Batch size,
M_s	=	Design standard material required to produce a single component. (lbs.),
f_s	=	The ordinate to the scrap experience learning curve,
W	=	The schedule or quantity change waste, (lbs.),
M	=	The actual amount of material to be charged per component = $M_s \left(1 + \frac{f_s}{Q}\right) + W$, (lbs.)
M_c	=	Material cost/component (£) = M_x(standard cost/unit of material).

For equation (15) to be adapted for metric units, a slight modification is necessary, and the figure 4.8 should read 3100, L and D_m being in millimetres, M in Kilogrammes.

Thus for metric units:-

$$C = \frac{R\, N_d}{60} \cdot \left[\frac{L\, D_m}{3100} K_c + \frac{S_t}{XQ} \right] + M_c \qquad (16)$$

8.1 Discussion of the cost equation

The most significant element in equation (15) is the floor to floor time F_t. It is in this portion of the equation that the greatest errors are likely to occur in practice. As it has been shown in Figs. (7) and (9) through (11), the floor to floor times for 90% of the components supplied by different firms were within $\pm$ 10% margin. The discrepancies which have been encountered with the small and large size components were thought to have resulted from the load and unload element of F_t equation (being suggested earlier in Chapter 5 to be 0.3 of the feed time T_f). The load and unload time seems to have little correlation with the feed time T_f in the two extreme cases of small and large size components, i.e., Components having L D_m $<$ 2in.^{2} or $>$ 50in.^{2} ($<$ 1300mm^2 or $>$ 3200mm^2). The F_t equation tends to underestimate the small size components. It seems that the reason for this is that the part representing the load and unload time in F_t is not representative of the actual time spent in loading and unloading the component. Small components are difficult to handle, locate, and adjust in a machine, so, it was considered that the actual load time in these cases is far in excess of that given by 0.3 T_f, (since the feed times, T_f's for these sizes are normally very small). On the other hand the F_t equation tends to overestimate the large size components because the suggested $0.3\ T_f$ is far too great for the actual loading time of these sizes, (T_f's for these sizes are normally too large). These two phenomena have been catered for by amending the criteria for computing the discontinuity factors for these extreme sizes. Although N_d does not have a direct relationship with the load and unload time, its value affects the amount of the feed time, T_f, and hence the figure suggested for the load and unload time ($0.3\ T_f$). The amendment made to N_d is such that it is increased for small size components, in order to increase the value of $0.3\ T_f$, and decreased for large size components, in order to reduce the value of $0.3\ T_f$, so as to represent the actual load and unload times in each case. Thus, for components having $L\ D_m < 2\ in^2$, the compensation of N_d should take into account every discontinuity of the machined surface, irrespective of its size or nature. On the other hand, for components having $L\ D_m > 50\ in^2$, the compensation of N_d is effected by ignoring minor details such as cavities, recesses, chamfers ... etc. of sizes of the order of $\frac{1''}{8}$ and less, in the big castings and the like components. The examples to come will show the procedure for computing N_d for these two size groups.

The setting time per component is not particularly critical, but for one-off orders it becomes necessary to estimate accurately the amount of the setting time. The correction made for the setting time, equation (10), is mainly intended to alleviate the possible error in estimating the setting time for the small and one-off orders. In the setting time term, $\frac{N_d}{X} \cdot \frac{S_t}{Q}$, it may be argued that the designer will not be in a position to know the type of the lathe that is going to be used and hence the value of the tooling factor X. This argument, in fact, also applies to the machine type factor K_2 in the F_t equation. These fears are not really well founded because the designer should not be totally isolated from the rest of the production team. He should have some liaison with the process planning engineers and know from previous experience the types of machines that are available on the shop floor. He might not know the exact machine to be used but he must have a clear idea about the options open to him which, on many occasions, are very few and specific to his job.*

This costing system does not provide material costs, but requires it as one of the inputs. The reason is obvious, i.e., the constantly changing price of materials. Price lists and catalogues issued from time to time by the material suppliers normally contain, among other descriptions and properties of the product, the standard sizes and lengths of these products. The engineering designer, therefore, in liaison with the stores of his company, should find no difficulty in recognising material waste, from various stocks, that is likely to result from scheduling or change of quantity.

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* The selection of machines for particular jobs is normally the responsibility of planning engineers, but the criteria for choosing these machines, for example, the component size, batch quantity, precision required ... etc. should be a familiar activity for the in-house designer.

As has been discussed earlier, the most critical term in the cost equation is F_t. The following examples illustrate how N_d and F_t are computed for various sizes and types of components.

8.1.1 N_d Computation for Components machined from solid, $L\ D_m > 2$ and $< 50in^2$

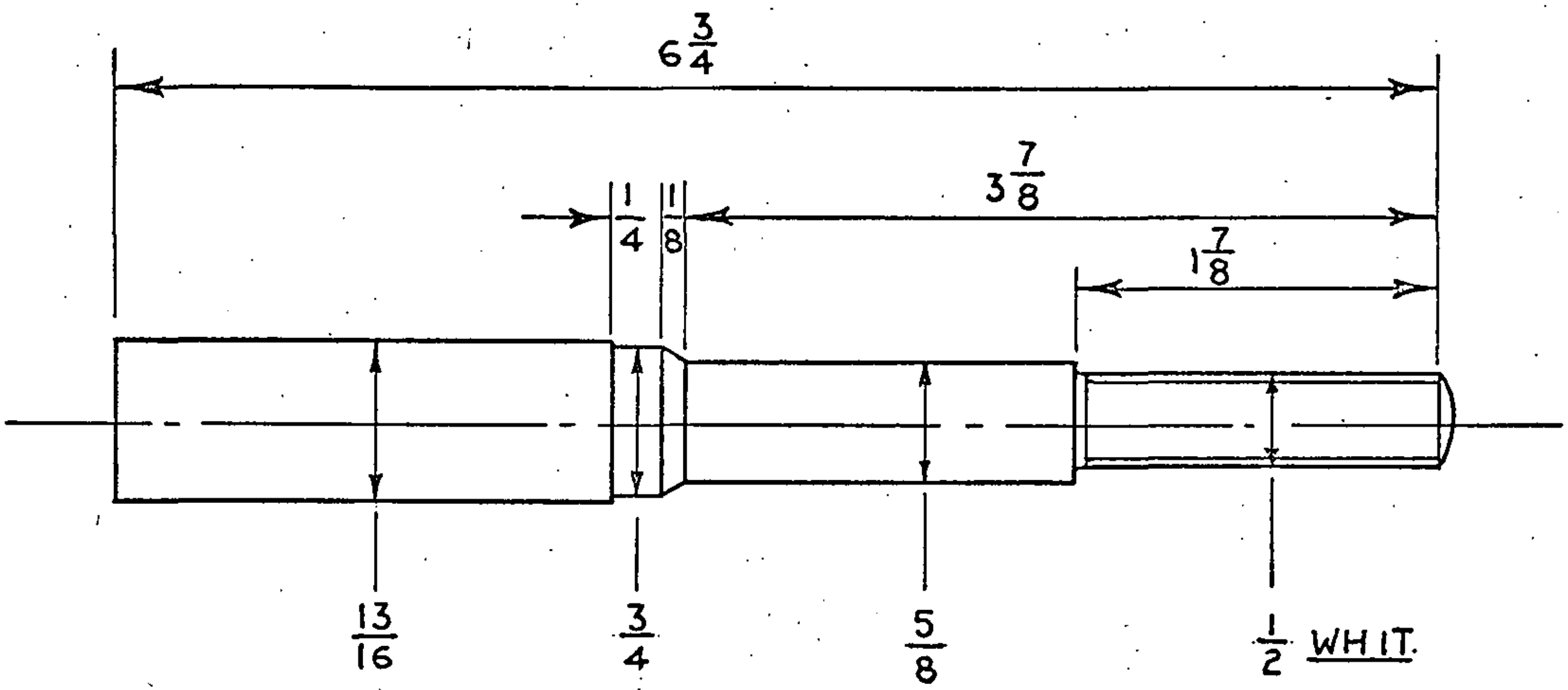
The axle shown in Fig. (14) is machined from a $\frac{13"}{16}$ diameter bar stock. The calculation of D_m, L, and N_d are carried out as shown in the illustration. The various factors are:-

$K_1 = 1.0$, $K_{mat.} = 1.0$, and $K_2 = 0.75$ $K_c = 0.75$

Therefore

$$F_t = 7 \times \frac{4.75 \times 0.625}{4.80} \left[1.0 \times 1.0 \times 0.75 \right] = 3.27 \text{ mins.}$$

Alternatively, in order to speed up the process and reduce computation, the F_t system expressed graphically in Fig. (15) may be used. For the above example $K_c = 0.75$, $N_d\ L\ D_m = 20.8$, giving the F_t value directly.



MACHINE : HERBERT NO. 2S CAPSTAN

MATERIAL : M.S BRIGHT BAR

D_m = 1/3 (3/4 + 5/8 + 1/2) = 0.625

L = $3\frac{7}{8} + \frac{1}{8}$ + 1/4 + 1/2 = 4.75

N_d = 1 set up Dia 3/4 Chamfer 1/8 Dia 5/8 Dia 1/2 Thread 1/2 End face
1 + 1 + 1 + 1 + 1 + 1 + 1 = 7

FIG. 14

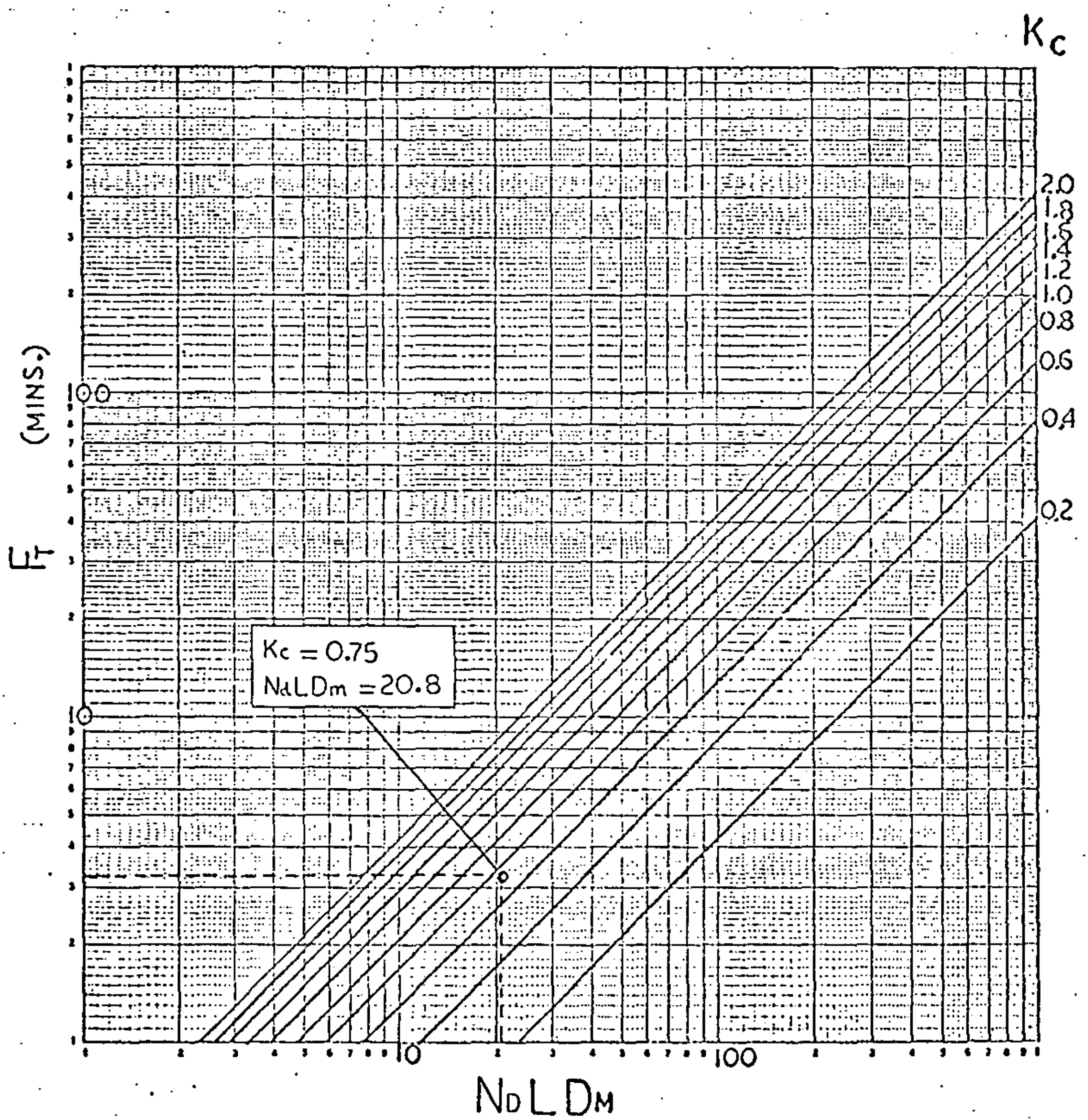

Kc
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
F_T (MINS.)
100
1
Kc = 0.75
NdLDm = 20.8
10
100
NDLDM

FIG. 15.

8.1.2 N_d Computation for components having $L\,D_m < 2in^2$

The exhaust-valve cone shown in Fig. (16) is machined from 1" diameter M.S. bar. It is a small size component, ($L\,D_m = 1.66in^2$). In the case of such a small size, every discontinuity of the surface should be counted, as shown below:-

N_d = chucking + diameter 0.332 + bottom face F + 90^o angle + diameter o.5" + end face E + diameter 0.625 + thread 0.625 + shoulder H + diameter 0.59 + shoulder G + diameter 0.945 + Parting Off = 13.

The procedure for calculating F_t is detailed in Fig. (16).

8.1.3 N_d Computation for components having $L\,D_m > 50in^2$

The cylinder liner shown in Fig. (17) is machined from an iron casting. It is a large size component having($L\,D_m = 766in^2$). As has been mentioned earlier, regarding the large size components, the small details will not be counted as discontinuities. These are the small outside diameters, recesses, grooves ... etc. The discontinuity factor, therefore, will be counted as follows:-

N_d = chucking the piece + outside diameter + end face + inside diameter + parting Off = 5

The details of calculating F_t for this component is shown in Fig. (17).

8.1.4 N_d computation for components machined from castings.

The motor casing shown in Fig. (18) is an aluminium die casting. The areas requiring machining are shown shaded in the drawing. The cast spigot and recess at the face 'F' of the casting are not to be considered as discontinuities because there is not much metal to be removed, and since the discontinuity factor N_d represents the number of tool passes and hence the amount of metal removed, then one tool

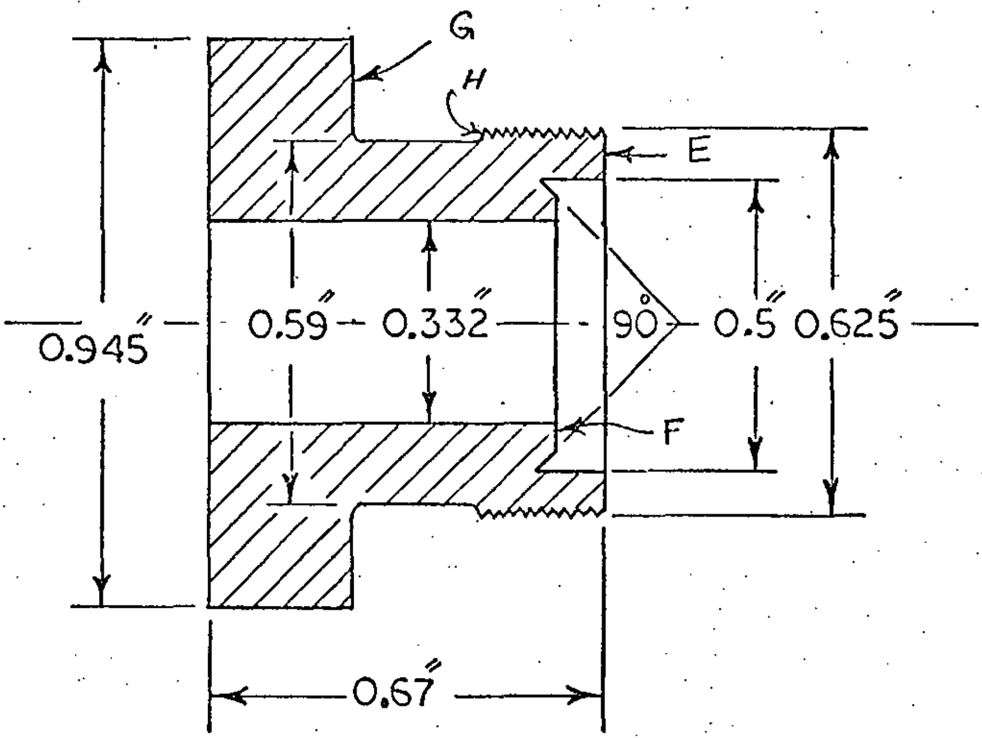


FIG 16 EXHAUST-VALVE CONE

MATERIAL M.S BAR

TOTAL TIME $3\frac{3}{4}$ MINS.

MACHINE HERBERT NO 2D CAPSTAN LATHE

$N_d = 13$; $L = 2.113''$; $D_m = 0.785''$; $K_1 = 1.0$; $K_{mat.} = 1.0$; $K_2 = 0.75$

$$F_T = \frac{13 \times 2.113 \times 0.785}{4.8}\left[1.0 \times 1.0 \times 0.75\right] = 3.39 \text{ MINS.}$$

ERROR — 10%

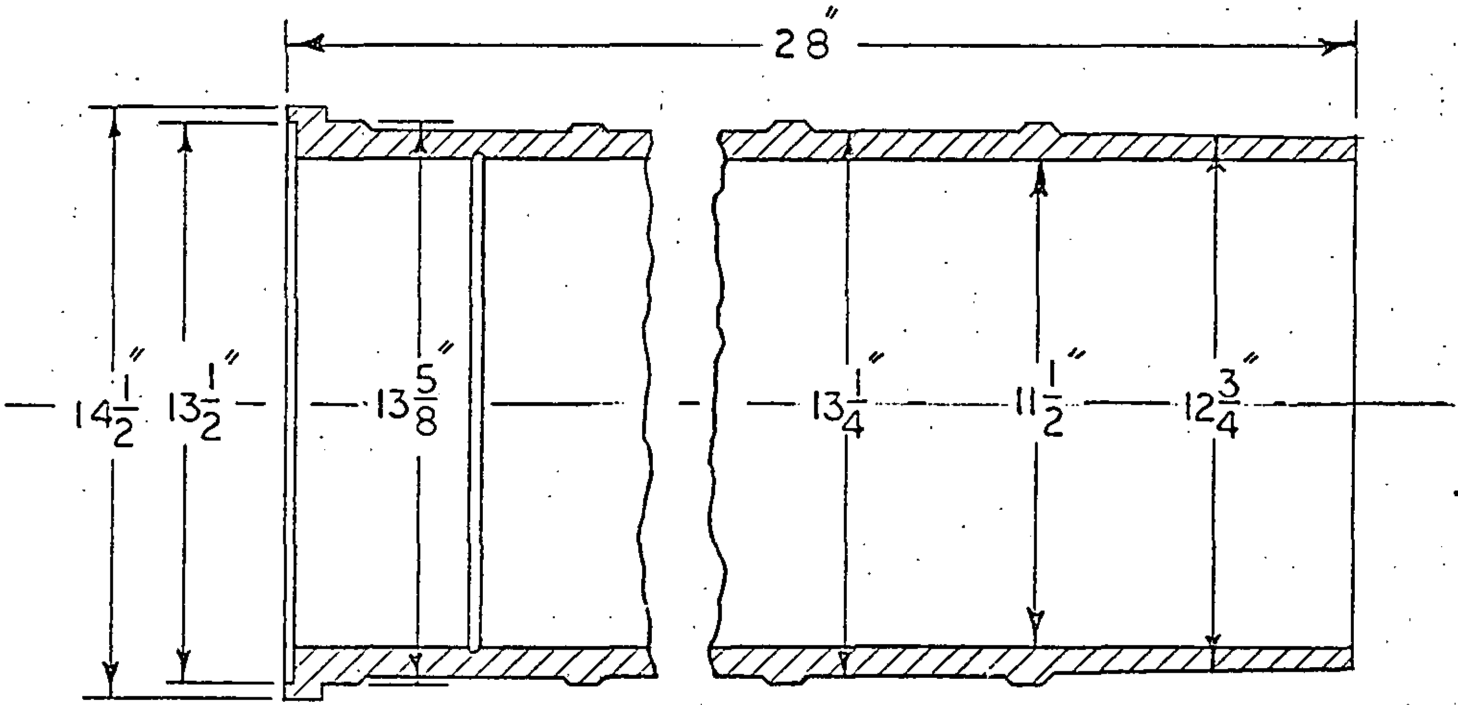


FIG.17 CYLINDER LINER

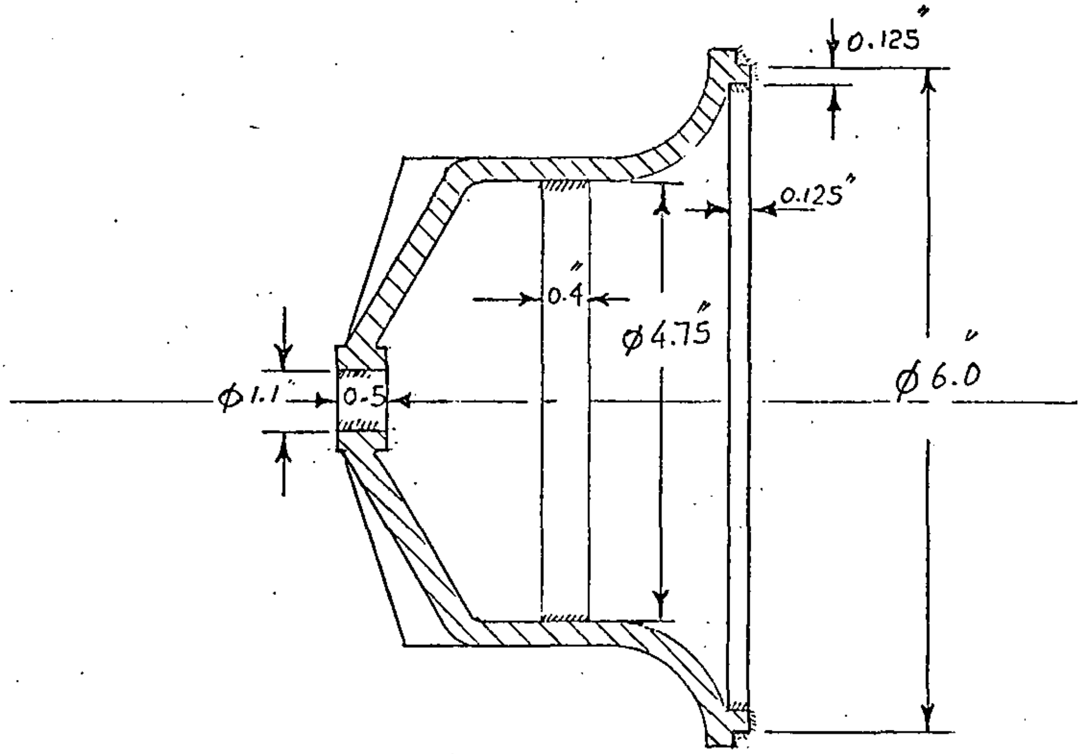
MATERIAL CAST IRON

TOTAL TIME $3\frac{1}{2}$ HOURS (210 MINS.)

MACHINE HERBERT NO 9B/30 COMBINATION TURRET LATHE

$N_d = 5$; $D_m = 13.2''$; $L = 58''$; $K_1 = 1.0$; $K_{mat.} = 0.7$; $K_2 = 0.4$

$$F_T = \frac{5 \times 58 \times 13.2}{4.8} \left[1.0 \times 0.7 \times 0.4 \right] = 224.7 \text{ MINS.} \quad \text{ERROR} +7\%$$



MATERIAL : ALUMINIUM ALLOY DIE CASTING,

TIME : 1.75 MINUTES,

MACHINE : HERBERT NO. 4 S CAPSTAN

$N_d = 4$; $L = 1.275''$; $D_m = 3.95''$; $K_1 = 1.0$; $K_{mat.} = 0.6$; $K_2 = 0.7$

$$F_T = \frac{4 \times 1.275 \times 3.95}{4.8} \left[1.0 \times 0.6 \times 0.7 \right] = 1.77 \quad \text{MINUTES}$$

ERROR $+1\%$

FIG. 18 MOTOR CASING.

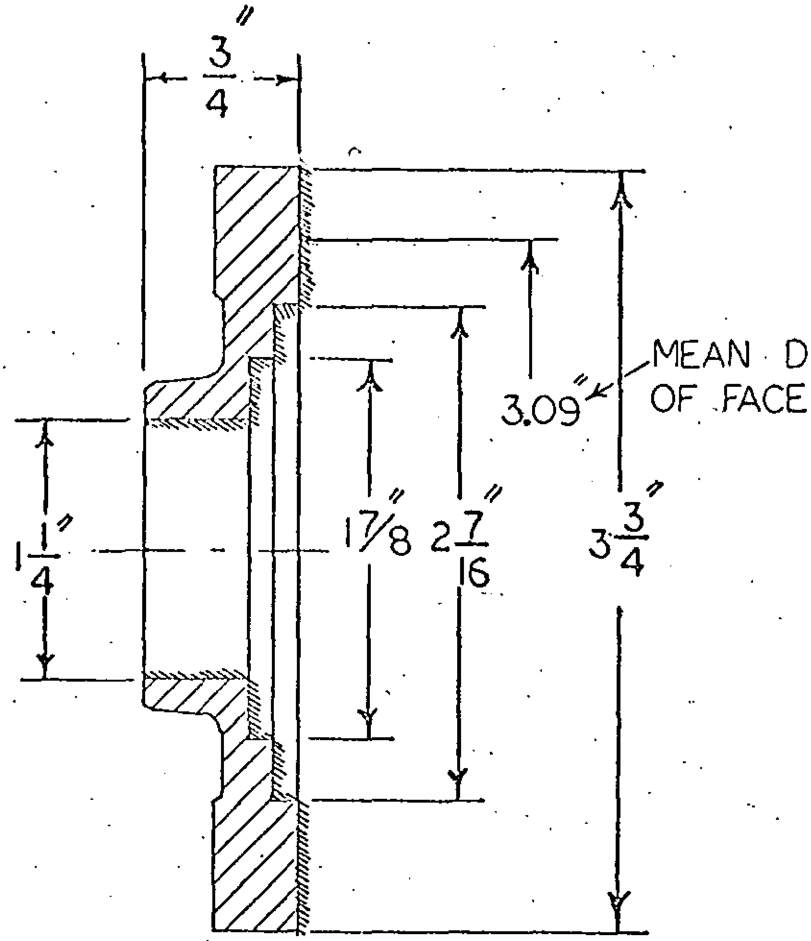
pass is considered necessary to generate this part of the component. The calculation of F_t for this component is detailed in Fig. (18).

8.1.5. N_d Computation for Components machined from fabrications

The bevel pinion housing cap shown in Fig. (19) is an example of a component which has to be machined after a stamping operation is carried out. Initially a 1" diameter hole was drilled before the component was brought to machining. This hole requires boring to $1\frac{1}{4}$" size - There should be no consideration given to the drilled hole when computing the discontinuity factor, but the bored hole should be considered. This is one of the differences between components previously cored or drilled and those machined from solid. The calculation of F_t for this component is detailed in the note accompanying Fig. (19).

8.2 F_t display in graphical form

There is one overwhelming benefit from having the information for computing F_t in graphical form, (Fig. 15), in that the designer can rapidly assess variations in F_t, and consequently the cost, if he chooses to vary one, or indeed all of the parameters within his control, i.e., material, size, features, tolerance ... etc. For instance, the designer can always change the work content (N_d L D_m), by changing the dimensions (L D_m), or alternatively make his component less complex, (thus reducing N_d), by avoiding unnecessary non-functional features that interrupt the component surface. On the other hand, if he is satisfied with the component shape and size (i.e. N_d L D_m), then he can optimise the choice of his material ($K_{mat.}$), machine (K_2), and tolerance (K_1), in order to obtain an



MATERIAL : M.S STAMPING WITH 1" HOLE PREVIOUSLY DRILLED.

TOTAL TIME : 3.5 MINUTES.

MACHINE : HERBERT AUTO JUNIOR.

$N_d = 7$, $L = 2.0''$, $D_m = 2.16''$, $K_1 = 1.0$ $K_{mat} = 1.0$, $K_2 = 0.5$

$$F_T = \frac{7 \times 2.0 \times 2.16}{4.8}\left[1.0 \times 1.0 \times 0.5\right] = 3.18 \quad \text{MINS}$$

ERROR $-9\ \%$

FIG. 1.9 BEVEL PINION HOUSING CAP.

overall optimum value for the combined factor (K_c) that will lead to the lowest F_t, and hence minimum cost.

One might ask, whether the display of F_t information will be any better if a computer was used! The answer is no for two main reasons. Firstly, the information regarding F_t, displayed in Fig. (15), is so simple and straight forward that the user can rapidly judge the parameters which he can alter, in an endeavour to minimise F_t, and indeed the cost equation itself is a linear equation and a direct computation of the cost is possible. Secondly, the use of a computer would mean unnecessary time and money spent in computation which defeats the first objective of the proposed costing system, in that it should be simple, easy to use, and inexpensive.

CONCLUSIONS

An attempt has been made to aid designers, not only in terms of familiarity with costs, but also by providing them with an accurate method for computing the costs of turned components. The discontinuity factor can be calculated at an early stage, thus enabling preliminary costing to be carried out at that point and before the component design becomes finalised. It is suggested that the time and consequent cost of applying this system would be very small in comparison to the time and cost savings achieved. The graphical display of the floor to floor time F_t (Fig. 15), saves extensive computations and enables the designer to rapidly assess variations in F_t if he chooses to vary any one of the parameters within his control.

The system developed has been extensively tested in a wide range of manufacturing environments. It is so simple that it can be used by any level of engineering designer, provided they have knowledge of their company's machines, wage rates, and material costs.

However, because of the limited time available for this work, the system does not cover all the existing machines or, indeed, all engineering materials. It is expected, therefore, that the user will develop the necessary factors which correspond to these variables according to his own company's situation. It is also envisaged that this system will be of considerable help to other users such as production engineers, process planners and estimators.

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Appendix 1

The Discontinuity Factor N_d

The discontinuity factor is a number equal to the sum of the discontinuities of the machined surface of a component plus the number of set ups of the component in the machine. It is an exclusive property of the shape of the component and is representative of the number of passes the tool makes over the machined surface. Table (6) shows the criteria for establishing N_d for the various features in the turning process. It can be seen how cast and fabricated components should be treated when computing N_d, e.g. Cored holes, or previously drilled holes.

Table (6) Criteria for establishing N_d

	Machining Feature	Discontinuity Rating
1.	Number of set ups	1 for each
2.	Unmachined surface	0
3.	Machined surface	1
4.	Threaded parts - if unmachined before threading	1
	- if machined before threading, e.g. turned or drilled	2
	- if machined before threading, e.g. Drilled and bored	3
5.	Shoulders or faces - if $\leqslant \frac{1"}{16}$	0
	- if $> \frac{1"}{16}$	1
6.	Chamfers - if $< \frac{1"}{8}$	0
	- if $\geqslant \frac{1"}{8}$	1
7.	Radii - if $< \frac{1"}{8}$	0
	- if $\geqslant \frac{1"}{8}$	1
8.	Drilled holes	1
	- if bored	2
	- if bored and reamed	3
9.	Bored holes - previously cored or cast	1
10.	Reamed holes - previously drilled or bored	1
11.	Recesses - if $\leqslant \frac{1"}{4}$ wide	1
	- if $> \frac{1"}{4}$	3

By way of example, the discontinuity factor, N_d, for the component shown in figure (20) is tabulated in table (7).

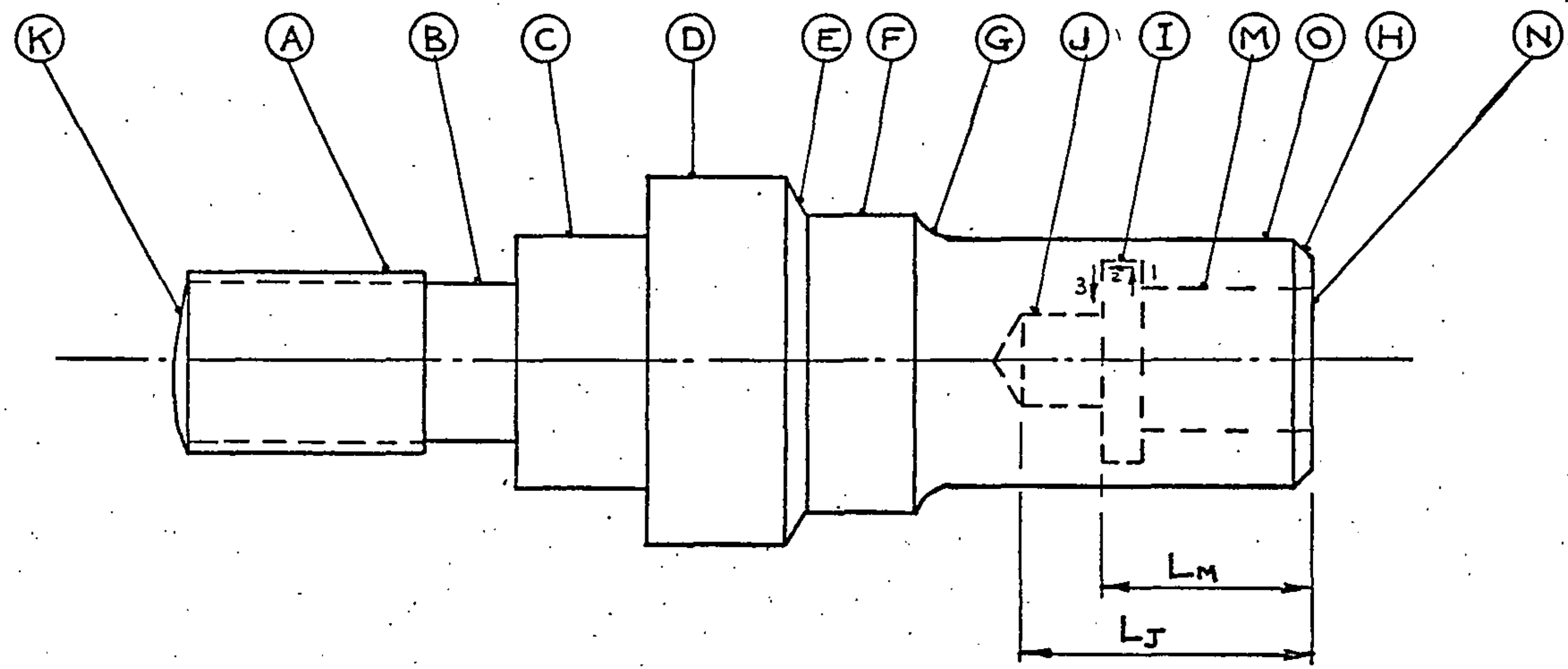

FIG. 20

Component Feature	Discontinuity Rating	Remarks
Set ups	2	
End K	1	
Diameter 'A' and Thread 'A'	2	
Diameter 'B'	0	Shoulder between A & B $< \frac{1''}{16}$
Shoulder between 'B' and 'C'	1	
Diameter 'C'	1	
Face between 'C' and 'D'	1	
Diameter 'D'	0	Bright bar
Chamfer 'E'	1	Chamfer = $\frac{1''}{8}$
Diameter 'F'	1	
Radius 'G'	1	Radius $> \frac{1''}{8}$
Diameter 'O'	1	
Chamfer 'H'	0	Chamfer $< \frac{1''}{8}$
Face 'N'	1	
Hole 'J'	1	Drilled only
Hole 'M'	1	Bored
Recess 'I'	3	$\frac{3''}{8}$ wide
Total	18	

Table (7), N_d Calculation for component Fig. (20).

As has been mentioned earlier, N_d criteria have to be amended for large and small size components in order that equation (9) gives acceptable floor to floor times for these categories of components. The amendments needed and their significance were stated earlier in the discussion of the cost equation in Chapter 8.

Appendix 2

The Mean Diameter D_m, and Total Machined Length L

As mentioned earlier in the text, the purpose of adopting the mean diameter criterion is to replace the complex shape of a component with a uniform shaft or disc of diameter D_m. The mean diameter D_m, is the summation of all individual machined diameters, external and internal, of the component divided by the number of those diameters i.e.

$$D_m = \frac{\sum D}{\text{No. of } D's}$$

Drilled holes, like J in Fig. (20), however, are not to be included because they are not turned diameters. Drilled holes which are subsequently bored, like M in Fig. (20), are to be included because the boring operation is internal turning.

Total Machined length L

The machined length L, in equation (9) is the total machined length of the component. This includes all chamfers, shoulders, radii and faces of the component. Threaded lengths are not to be included, but drilled, bored, or reamed lengths should be added individually. Examples of computing length L for various components are shown in Fig. (21). Component shown in (i) is machined over the length 'L' and faced with a spherical end. No parting off had taken place, the total length is $(L + \frac{D}{2})$. Where parting off takes place,

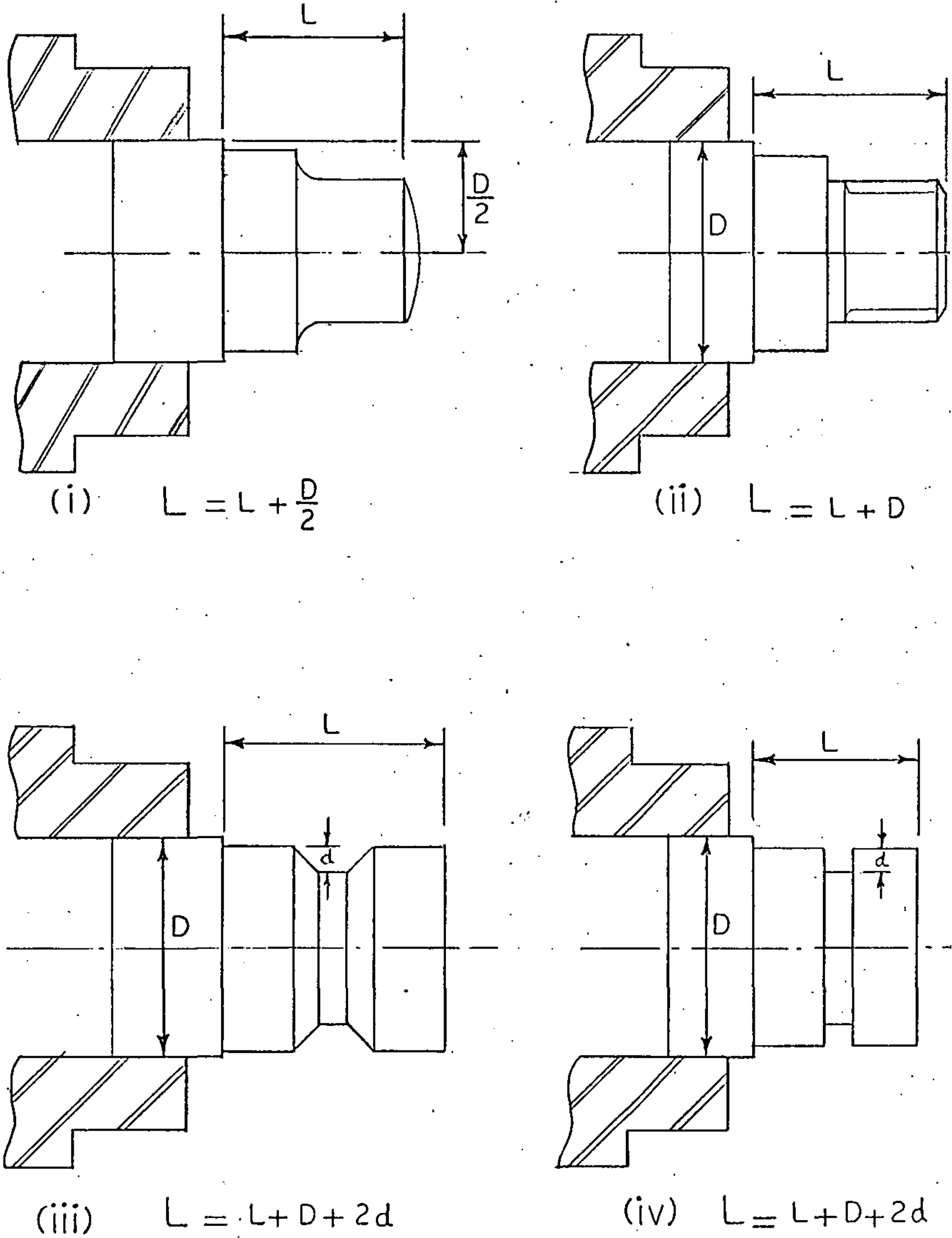

FIG. 21 TOTAL MACHINED LENGTH FOR VARIOUS COMPONENTS

as in case (ii), the tool is assumed to pass halfway through the diameter, and the total length is considered as $L + \frac{D}{2} + \frac{D}{2} = L + D$. As stated above, the threaded length was not considered when computing L_T. The V-shape of component (iii), and the groove of component (iv) were both catered for by adding twice the depth 'd' of the groove to the total length. Both components were parted off. It should be noted that internal grooves, recesses, chamfers ... etc. are to be treated in the same way as the external ones.

ADDENDUM

to APPENDIX 2

The mean diameter D_m.

It should be noted that if external and/or internal diameters are not machined but the faces or shoulders between them are, then the mean diameters of these faces or shoulders should be considered when computing the mean diameter of the component D_m. This is illustrated in figure (19) when the mean diameter, 3.09", of the face was taken into account when computing D_m of the cap.

Appendix 3

The Combined Factor 'K_c'

The Machining Factor K_1

The combined factor K_c, which is the product of K_1, $K_{mat.}$, and K_2, modifies the floor to floor time equation (9) in sympathy with a changed machining situation.

The machining factor K_1 represents the tolerances and degree of finish required by the component. K_1, initially, has a value of 1.0 which represents a situation where a roughing cut is being taken, and tolerances are generally wide. For tighter tolerances, this means smaller depths of cut and an increase in the number of passes, and, if fine finishes are required, slower feeds are used. The nett outcome of this, is an increase in the time taken to perform the operation, therefore the value of K_1 must be increased to cater for this situation. K_1 has values ranging from 1.0 to 2.0 depending upon the accuracy and surface finish required. Typical examples of values of K_1 are shown in table (8).

K_1	Typical tolerance	Typical finish Ra (microinch)
1.0	$>0.010''$	500
1.5	$>0.005'' < 0.010''$	250
2.0	$<0.005''$	125

Table (8) Machining Factor K_1

Material Factor, $K_{mat.}$

Materials differ in their readiness to accept machining according to their type, chemical composition, microstructure, hardness ... etc. A material factor $K_{mat.}$ is deemed necessary in equation (9) in order to differentiate between difficult and easy to machine materials. The metal removal rate per horsepower has been suggested as being a suitable criteria for machinability of metals (34). A machinability index based on this criteria has been evolved. Charts of relative cost of machining different materials (43) have confirmed the proposed index. Values of $K_{mat.}$ for a range of materials are shown in Table (9).

Material	$K_{mat.}$ (Tipped tools)*
Mild steel	1.0
Duralumin	0.6
Cast Brass	0.35
Cast Iron	0.70
Aluminium Die Cast	0.50
Bronze	0.60

Table (9) Material factor, $K_{mat.}$

*A survey among various companies regarding their policies of purchasing different types of tools revealed that 80% or more of their purchases are of the carbide, either brazed or throwaway types. The remainder being H.S.S. It was, thus, thought appropriate to associate the machining factor, $K_{mat.}$, with the type of tool which is most popular on the shop floor. It would have been ideal, if a range of machining factors, $K_{mat.}$, was developed for H.S.S. tools, but because of the uncertainty, on the part of the designer, surrounding the type of tool that will be used, and also because of the lack of data of machinability of metals with H.S.S. tools, it was thought reasonable to adhere to the proposed range of $K_{mat.}$ for carbide tools.

Machine Type Factor, K_2

Machines differ in their capabilities for the machining of metals, they do not, however, vary very much in the mechanism by which they cut the metal. However, there is a marked difference in the way they manipulate the tools and handle the various machine movements. Utilising data from a number of companies, a machine factor, which reflects the machine capability has been evolved. Table (10) shows this factor for the range of machines considered in this study.

Machine Type	Machine Factor K_2
Centre lathe	1.0
Capstan lathe	0.75
Combination Turret	0.80
Automatic Junior	0.50
N.C. Lathe	0.33

Table (10) Machine Type Factor, K_2

Appendix (4)

Data Supplied by Industry

to test Equation (9)

Component No.	Times based on Equation (9) (mins)	Actual Times (mins)	%age Error
1	4.31	4.0	+7
2	2.52	2.5	-3
3	6.87	6.5	+5
4	3.85	4.75	-19
5	4.50	5.25	-14
6	5.36	6.0	-10
7	18.77	18.00	+4
8	15.5	14.0	+10
9	32.8	30.0	+9
10	40.45	40.0	+1
11	12.0	13.0	-8
12	28.7	28.0	+2
13	23.5	22.0	+7
14	51.26	53.0	-3
15	18.97	20.0	-5
16	5.9	6.0	-2

Table (11) Firm 'A' examples (Refer to fig. (9))

Component No.	Time based on Equation (9) (mins)	Actual Times (mins)	%age Error
1	1.87	1.86	+1
2	3.95	4.19	-5
3	5.28	5.0	+5
4	4.65	4.5	+3
5	8.97	7.96	+13
6	1.85	1.81	+2
7	5.93	5.79	+2
8	12.9	11.85	+8
9	7.88	8.78	-10
10	6.1	5.72	+6
11	9.09	7.06	+28
12	4.42	4.85	-8
13	16.35	17.7	-8
14	12.62	11.72	+8
15	9.5	9.4	+1
16	4.2	4.9	-13
17	17.48	16.33	+7
18	9.14	9.42	-2
19	5.84	6.88	-15
20	1.15	1.32	-12

Table (12) Firm 'B' examples (Graph fig. (10))

Continued...

Table (12), Continued

21	11.4	11.62	-2
22	11.4	10.32	+12
23	10.7	9.6	+12
24	3.9	4.27	-9
25	7.74	7.05	+9
26	4.2	4.24	-2
27	2.76	2.62	+5
28	2.45	2.41	+2
29	1.77	2.04	-13
30	1.94	1.88	+3
31	2.37	2.6	-9
32	3.56	3.17	+12
33	11.76	12.05	-2
34	13.73	15.2	-10
35	3.6	4.09	-12
36	3.52	4.08	-14
37	13.59	12.1	+12
38	4.58	4.7	-2
39	2.1	1.84	+13
40	3.6	3.17	+13

Component No.	Times based on Equation (9) (mins)	Actual Times (mins)	%age Error
1	169.0	150.0	+12
2	100.87	105.0	-4
3	74.0	80.0	-8
4	266.0	300.0	-11
5	188.7	195.0	-3
6	265.0	210.0	+26
7	224.4	221.0	+2
8	698.2	720.0	-3
9	96.7	96.0	+0.7
10	523.0	504.0	+4
11	44.7	43.0	+3
12	64.5	70.5	-8
13	55.4	51.6	+7
14	52.0	60.0	-13
15	27.0	30.0	-10
16	11.66	10.05	+16
17	22.0	24.0	-8

Table (13) Firm 'C' examples (see fig. (11))

Continued...

Table (13), Continued

18	2.48	2.25	+10
19	56.9	54.6	+4
20	23.4	21.3	+10
21	6.96	7.5	-7
22	7.8	7.5	+4
23	10.49	9.45	+11
24	58.74	70.5	-16
25	185.0	175.0	+6
26	35.0	35.0	0
27	31.8	28.2	+13
28	81.8	75	+9
29	110	135	-18
30	194.8	180.0	+8
31	153.0	155.0	-1
32	34.6	29.3	+18

Appendix 5

Setting Times and The Tooling Factor X

The setting times generally accepted for various types of machines are not necessarily valid all the time, because setting times are also component dependent, and for this reason they should be corrected to take into account the degree of complexity of the component. The factor X represents the tooling capacity of a particular type of machine, that is, the maximum number of tools that can be loaded onto the machine. The ratio $\frac{N_d}{X}$ is the correction factor, and the corrected setting time is $\frac{N_d}{X} S_t$; S_t being the generally accepted setting time for that particular machine.

If $N_d \geq X$, the correction factor is assumed to be 1.0, and the machine setting time will be taken as the accepted setting time S_t. If, however, $N_d < X$, then $\frac{N_d}{X}$ will be a fraction, and the accepted setting time will be reduced accordingly. The significance of the correction factor $\frac{N_d}{X}$ is that it does not increase the traditionally accepted setting time, but it will adjust it to the actual need of the component (i.e. according to its complexity). The following tables give the setting times for a specimen set of machines and their tooling factors X.

Machine Type	Setting Time S_t. (Hours)
Standard Centre lathe	1.0
Herbert 2D, 4S with preoptive headstock	2.0
Auto Junior	4.0
Batchmatic	3.0
Dean Smith and Grace (NC)	2.0

Table (14) Machine Setting times

Machine Type	Tooling Factor X
Centre Lathe	6
Herbert 2D	9
Herbert 4S, Preoptive headstock	11
Auto Junior	9
Dean Smith and Grace (NC)	10

Table (15) Tooling Factors for the machines considered