THE FACTORY

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FUNDAMENTAL PROBLEMS OF MATERIALS, LABOUR, OVERHEAD, PLANT, MANUFACTURE, MANAGEMENT, AND ECONOMIC CONTROL

BY

Dr. (Ing.) G. SCHLESINGER

Hon. Member of the Institution of Production Engineers; Member of the Institution of Mechanical Engineers; Life Member of the American Society of Mechanical Engineers; Formerly Professor of Production Engineering in the Technical University of Charlottenburg, Berlin; and Director of the Department for Production Research of the Institution of Production Engineers, Loughborough

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PREFACE

A BOOK on "The Factory" as an entirety, dealing with the major problems of layout, equipment, performance, management, administration, and its economic control, must be based on the detailed study of concrete examples, it cannot be based simply on abstract reflexion. There are many books which deal thoroughly and excellently with any one of these aspects, but wide experience and detailed facts are essential for a study of the whole range When such experience is supported by discussion and consultation with experts, it is possible to integrate divergencies of opinion and to derive fundamental rules, which may be applied to the problems of widely differing factories.

The layout and equipment of a factory are governed by the nature of the product. They differ widely according to whether the product should be a rifle or a motor car, copper bars and sheets or electrical instruments, textiles or oil products, for example This is obvious to all, but the reader will like to see it exemplified in the practical examples which follow The author has had the opportunity during fifty years of practical work to lay out factories from scratch, to superintend their erection, and to equip and organize more than fifty factories of different types and sizes, employing between eighty and six thousand workers, some doing jobbing work and others mass production on the largest scale.

In this book ten different factories have been selected as examples to illustrate how layout, performance, management, administration, and economic control form a unity, and to show that the organizer responsible for the creation of such a factory must be able to survey the whole task from the beginning to the end, from the planning of the layout up to the examination of the financial results. The copper and brass mill, the crucible factory, the rifle factory, and the electrical instrument works were built from scratch, the textile factory was rebuilt by the author, the British motor car and machine-tool factories and the oil refinery were only studied The writer is aware of the objection that one man cannot himself erect a copper mill and a rifle works, a motor-car factory and an electrical instrument works a weaving mill and an oil refinery, and he fully realizes that such work could be done only with the closest collaboration between the external organizer and the internal expert A fully-qualified production engineer should, however, be able to apply his training in objective and fundamental thinking to the problems of any industry. In the author's case, his long experience in designing, manufacturing, and investigating machine tools, tooling, jigs, and test gear for many mechanical engineering firms has been of great value, and he has had the satisfaction of having been engaged by the directorates of more than fifty factories on the European continent and of three in Great Britain, to advise on their problems. This has given him an unusual opportunity of making a careful study of factory management on the Continent, and in the United Kingdom, the U S.A., Russia, and Japan, and has enabled him to verify that his ideas on factory layout, manufacturing methods, and organization are sound The real criterion by which to measure the effectiveness of any factory organism is, of course, its financial results, it is from this standpoint that the author can claim that the layouts and methods which he has introduced have proved successful.

The author was specially fortunate in having been able, during the years 1939–1945, to study closely the production work of British factories in his capacity of Director of the Research Department of the Institution of Production Engineers.

He is grateful for the valued co-operation of those factories which he has used as typical British examples. viz. Morris Motors, Ltd., Cowley and Coventry; H W. Ward, Birmingham; A C. Wickman, Coventry; and the Manchester Oil Refinery, and he is indebted to these firms for providing him with necessary data. He also gratefully acknowledges the collaboration of Alfred Herbert, Ltd., Coventry; John Lang-Johnstone, near Glasgow, Webster & Bennett, Coventry; Kendall & Gent, Manchester, Swift-Summerskill, Halifax, Churchill Machine Tool Co, Manchester; John Lund, Keighley; Cook & Ferguson, Manchester, and the Norton Grinding Wheel Co., Welwyn Garden City. Further, he has pleasure in acknowledging the collaboration of some American friends: Cincinnati Milling Machine Co., and Cincinnati Planer Co, both of Cincinnati, Ohio, and also the Sheffield Corporation, of Dayton, Ohio.

These acknowledgments would be incomplete without special mention of the invaluable help given by Mr. L. Rutherford in the compilation of the work, and, finally, to the author's wife is due the credit for a great part of the unseen detail work in the preparation of the manuscript

G SCHLESINGER

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CHAPTER I

Introduction—Fundamental Methods

THE PRIMARY consideration in the organization of any manufacturing concern should be the factory. Although the sales department and the finance department usually hold the dominant position in any big enterprise, neither can commence effective work until the factory is in full swing.

The factory activities are of primary importance, to which all others are secondary. An organization which does not supply goods of high quality at reasonable prices, and on the promised delivery date, cannot sell, and therefore cannot remain in business and must eventually perish It is usually in the factory that manufacturing difficulties arise and in the factory that they must be overcome

It is quite impossible to organize a factory on "standard" lines, i.e. by means of elaborate schedules and forms, even though applied to works making the same type of product, e.g. motor cars, machine tools, or textiles A rigid system may prove successful in one place, but not in another. Every factory must be treated separately, in the same way that a doctor treats a patient. Every conscientious doctor knows that he cannot prescribe the same standard medicine in every case, even when the symptoms are similar. The patient's constitution, his age, his habits, his weaknesses, and his strong points, in short, his whole "law of life" must be taken into account in order to decide upon the correct course of treatment

Fundamental Methods

Despite this fact, the same fundamental methods of investigation and even the same remedies apply in many cases, for, in business as in medicine, the study of symptoms, even of common troubles, requires a great deal of routine work, and the final solution can be found only by a person who can combine correct diagnosis of the case with prescription of the most effective cure All professions have their difficulties and perhaps none has any of greater complexity than those affecting factory management, involving as they do the welding into one unity of labour, plant, processes, and commerce It is to clarify and point out a solution to some of these difficulties that this book has been written.

The Problem of Organization

Planning, management, manufacture and its economic control form a unity. If we commence with manufacture as the focal point, and study the effect thereon of planning, management, and economic control, we have to solve three main problems. i e.—

I. The problem of plant and equipment (factory planning)

II. The problem of production control (factory management).

III. The problem of economic control.

Each of these problems is again sub-divided into two parts, viz.—

I. (*a*) General equipment of the factory (transport, power, heating, etc).

(*b*) Special equipment for the manufacture of specified products.

II. (*a*) Production control (planning, manufacturing, progress, loading, dispatch)

(*b*) The supply of materials to the working places.

III. (*a*) General departmental expenses (overhead, works cost)

(*b*) Costing of the goods being manufactured.

If, to these, we add the general and basic problem of organization, we have seven main problems which must be dealt with, i.e.—

(1) Organization.

(2) General equipment of the factory.

(3) The installation of special manufacturing processes.

(4) Planning and production control.

(5) The supply of materials to the working places

(6) Departmental overhead.

(7) Costing of the goods being manufactured.

The preparation of monthly, quarterly or yearly summaries of accounts and balance sheets, and their use as a basis for the financial control of the undertaking, are not usually considered to be a problem affecting the production engineer.

The engineer is particularly interested in items (2) to (5), while the managing director will usually interest himself more in items (1), (6), and (7), because these furnish the essential basis for control, and an indication of the general success of the whole enterprise.

Whoever has the task of complete factory organization must consider the whole seven aspects in detail and see the work as a whole, because each aspect is related to the others and the success of the whole is dependent upon each of them. The management of a private or a public company should not forget for one moment that its main object is success, general and financial, everything must be organized with this purpose in view.

The running cost of a national postal, telegraph, and telephone service is met from the sale of stamps and the making of charges, a financial deficit is balanced either by raising the charges and postage rates or from the pocket of the taxpayer. A national railway service has similarly to rely on the income from fares and freights. As both services are vital to public welfare, they must be kept in operation and any financial deficiency has to be provided by the public, who enjoy the benefits of the services.

This fortunate position is not enjoyed by private, as distinct from public, enterprises, and if companies manufacturing, say, Diesel engines, electric motors, aeroplanes, shoes, soap, or matches, for sale to the public, were to continue to work at a financial loss, their liquidation would be inevitable. Naturally, they seek to work at a profit, for that is the only way in which they can continue in existence.

Private enterprise often needs financial support by way of loans or increases of capital, and unless the company has shown its profit-earning ability by the publication to shareholders of financially sound, properly audited, balance sheets, it cannot hope to obtain outside financial support.

In order to build up a sound financial position by the regular earning of good profits for its shareholders, a non-subsidized company must rely on efficient management, based on the careful study and practical application of the seven fundamental aspects of organization.

This can be seen more clearly by examining some practical examples Let us begin with (1) the functions of management, and (2) the manufacturing costs of production.

The completion of an order demands the collaboration of the following departments of the factory (Table I)—

1 Management,
2 Drawing office,
3. Purchasing department,
4 Works production department
   (*a*) Planning,
   (*b*) Production control,
5 Stores
   (*a*) Raw material,
   (*b*) Goods purchased,
6. Works (manufacture),
7. Dispatch,
8. Costing,
9. Accountancy

This review (Table I) shows some of the many functions of the nine main departments which, according to the size of the factory, are distributed over a varying number of persons, their work being directed in all cases by the necessity of the undertaking's financial success. The cost of production (items 8 and 9) must, therefore, be given first consideration.

Table II classifies the production cost of fifteen different types of product according to the three main components, i e —

(1) Material,

(2) Labour,

(3) Overhead.

The three items have quite different proportions in each industry, mainly because the methods of

TABLE I

Functions of Management

The functions of these departments in respect of the order are—

1. *Management*
   Inquiry
   Quotation, price, delivery date
   Order
   Confirmation

2. *Drawing Office*
   Design
   Drawings
   Parts List (Materials)

3 *Purchasing Department*
   Available Stock
   Sources of Supply
   Supplier
   Buying Order
   Progressing Supplies
   Acceptance
   (*a*) Quantity (*b*) Quality
   Invoice approved and paid

   Subjects of Contact between Purchaser and Supplier

Inquiry	Delivery
Quotation	Acceptance
Order	Invoice

4 *Works Production Department*

4*a*. *Planning*

Master Specification	Tooling
Processing	Jigging

   Test Gear
   Reproduction of forms—
   (*a*) Requisition Slips
   (*b*) Wages Dockets
   (*c*) Job Cards

4*b* *Production Control*
   Loading of
   (*a*) Machines (*b*) Workers
   Production Schedule
   Reception of
   (*a*) Material Slips
   (*b*) Wages Dockets
   (*c*) Progress Charts
   Arrears—Special Urges
   Jobs completed

5. *Stores*

5*a*. *Stores* (*Raw Material*)
   Actual Stock
   (minimum: reminder)
   Reception
   Binning
   Issuing
   Stocktaking

5*b* *Stores* (*Goods Purchased*)
   Intermediate Stores
   Work-in-Progress

6 *Works* (*Manufacture*)
   Workshop
   Foreman receives
   (*a*) Material Slips
   (*b*) Wages Dockets
   (*c*) Job Cards, and
   allocates Work to Operator
   Stores send Material
   Time Clerk checks Times "On" and "Off"

   Inspector
   1. Passes Parts
   2. Returns Parts for Rectification
   3 Rejects

7. *Dispatch*
   Reception of Completed Products
   Documents
   Final Dispatch

8 *Costing* — *As Affecting*

Costing	As Affecting
1 Material + 2 Labour + 3. Overhead	(*a*) Customers' Orders (*b*) Own Orders (*c*) Internal Orders

   1 + 2 + 3 — Manufacturing Cost
   Calculation of Factory Expenses (Overhead)

9. *Accountancy*
   Capital Account
   Works Accounts
   Cost Accounts
   Trading Results
   Profit and Loss Account
   General Finance

TABLE II

PERCENTAGE COSTS OF PRODUCTION

No	Analysis	Electro-motors	Machine Tools: Light	Machine Tools: Medium	Machine Tools: Heavy	Railway Vehicles: Pas-senger Cars	Railway Vehicles: Goods Cars	Motor Cars	Agricultural Machinery: Mass Produc-tion	Agricultural Machinery: Big Batch	Diesel Engines	Fittings	Drawing Instru-ments	Watches	Foundry (Pumps, Castings)	Cloth (Shoddy, Worsted)
1	Material (direct)	41	32	41	48	55	67	68	73	46	44	30	19	44·5	32	70
2	Labour (direct)	21	21	18	16	18	10	10	8·5	19	14	25	28	21·5	23	9
3	Overhead	38	47	41	36	27	23	22	18·5	35	42	45	53	34	45	21
4	Cost of Production (1 + 2 + 3)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
5	$\frac{\text{Overhead}}{\text{Wages}} \times 100\left(\frac{3}{2}\right)$ percentage	180	225	228	225	150	230	220	218	185	300	180	190	158	195	230
6	Labour + Overhead (2 + 3) units	59	68	59	52	45	33	32	27	54	56	70	81	55·5	68	30

manufacture vary considerably. Heavy machine tools (lathes, planers, plano millers, vertical and horizontal boring mills) are made singly or in batches of 2 to 5; light and medium machine tools (lathes, capstans, and drilling, milling, shaping, and grinding machines) in batches of 5 to 50; goods and passenger cars in batches of 10 to 100; Diesel engines in batches of 1 to 10; motor cars in batches of 10 to 1000, agricultural machines in batches of 10 to 100, newspapers, a quarter of a million to three million copies per issue; and clothing a hundred to ten thousand pieces, depending on fashion and on the education of the population to the use of standardized products of uniform design. The schedule (Table II) shows that in all the cases considered, with the exception only of delicate drawing instruments, the direct cost of material (1) is considerably higher than the labour percentages (2), that the proportion increases as improvements are introduced in manufacturing methods, and that the proportion reaches a particularly high level in the mass production of railway trucks and automobiles, reaching a peak in the case of a certain type of agricultural machines, in which case material cost is 8·5 times the amount for wages. The installation of modern manufacturing equipment (machines, tools, jigs, etc.) costs money, and causes an increase in factory expenses (overhead), but the cost of labour (wages) is thereby reduced. The net result can be profitable only if the combined sum of wages plus overhead can be reduced, the cost of material being assumed constant The table gives results on a percentage basis only. it shows under item 5 the percentage of overhead to wages, and under item 6 the sum of wages + overhead, expressed as a percentage of total production cost. This gives the results in an easily understandable form.

The essential characteristics are, therefore,

(1) item 5: $\frac{\text{Overhead}}{\text{Wages}}$,

(2) item 6: Labour + Overhead.

Item 5 indicates the efficiency of the works as a whole and of its single departments, item 6 is the criterion of the economic success of manufacture.

The figures of this table were procured from successful factories, but, of course, they are only examples and may vary considerably, depending on design, manufacturing equipment, and labour conditions They do, however, enable one to draw valuable conclusions for special cases, proving the decisive influence of costing as a means of economic control. Let us consider the table

Simple agricultural machines have the lowest labour percentage with 8·5 per cent, and cloth with 9 per cent, then follow goods cars and motor cars with 10 per cent In all four cases the percentage of overhead to wages is about the same, i e 220 to 230 per cent In view of the low labour costs it would appear that the problem of manufacturing equipment has been solved, and as the proportion of material costs is extremely high (between 67 to 73 per cent), the designer should try to decrease this amount by decreasing the weight, changing the materials, or simplifying the design, without of course lowering the safety, quality, or efficiency of the product

If a factory, as a whole, is regarded as an industrial enterprise, in which raw materials are changed into useful products by means of labour, then the principal task of the management lies in controlling "active" labour and "inactive" material in such a way that both shall always meet at the right place and at the right time (Fig. 1)

The presence of the worker at his or her workplace can easily be checked, simply by recording his times of entry into and exit from the department

The case of material is somewhat more complicated One can only broadly state that it arrives by train, road, or river at the store yard as raw material, is transported into stores, then into workshops for machining, then from department to department, with stoppages at various work places, stores, and inspection places; then to the fitting shop for first assembly of mating parts, then for sub-assembly into units, and so to final assembly into machines, and eventually to the dispatch department and to shipping

Its path depends partly upon the types of machines involved in manufacture One can easily see that if a part or a machine is to leave the factory at the correct date the material supply to the first operation positions requires special care in the issue of forwarding instructions, and the making of transport arrangements. The problem of material supply to the operating positions is therefore of primary importance in every factory

Engineer and Management

The work of the engineer, when he organizes the manufacturing processes of a factory, may be considered as a type of creative art, somewhat resembling that of the designer who creates a machine by virtue of his particular skill A machine achieves its purpose by the direction of natural forces (steam, gas, water, electricity) according to mechanical laws. It is a knowledge of the laws affecting these forces, together with his creative ability, which enables the designer to do his work

James Watt observed the formation of compressed steam, and its capacity for producing power, and because of his creative ability he was led to invent the steam engine Different methods were found of enabling the steam to do its work in the engine They are all further examples of the creative art of the engineer

Later, began the scientific investigation of their efficiency, based on exact measurement (Fig 2) Indicator-diagrams were used as a key to measure precisely what was happening within the steam engine and to discover how it could be made more effective The result has been a succession of improvements At last it was possible by this method to reach what seemed to be the limit of perfection In other words, detailed scientific study has led to a full knowledge of the working conditions of steam engines and hence to the constant maintenance under various conditions of work of their maximum power and efficiency

Using more advanced fuels, such as paraffin, petrol, etc, and by inventing the Diesel process, stations have been designed without boilers and chimneys In them the liquid fuel is vaporized in the engine itself. Fig 2 shows the results of fifty years' systematic international engineering research, which has increased thermal efficiency from 6 per cent using coal and boilers, to 19 per cent using liquid fuels The diagram also illustrates

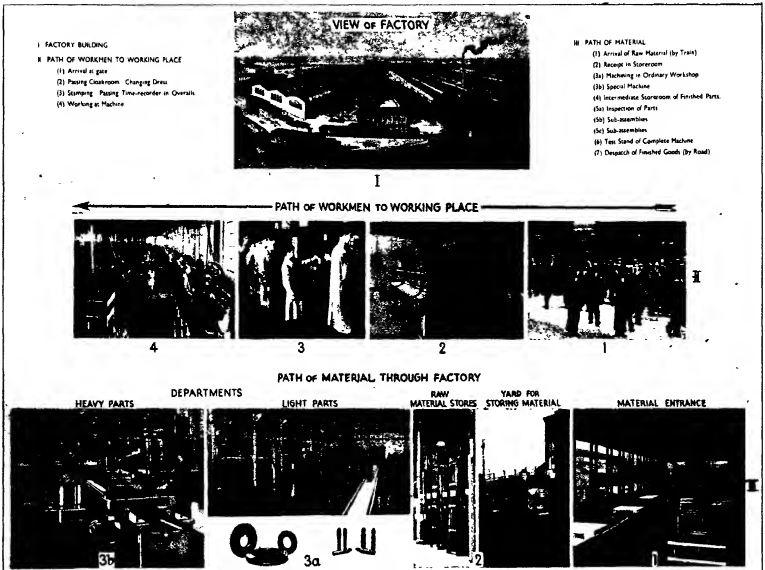

I FACTORY BUILDING
II PATH OF WORKMEN TO WORKING PLACE
(1) Arrival at gate
(2) Passing Cloakroom Changing Dress
(3) Stamping Passing Time-recorder in Overalls
(4) Working at Machine
VIEW OF FACTORY
I
III PATH OF MATERIAL
(1) Arrival of Raw Material (by Train)
(2) Receipt in Storeroom
(3a) Machining in Ordinary Workshop
(3b) Special Machine
(4) Intermediate Storeroom of Finished Parts.
(5a) Inspection of Parts
(5b) Sub-assemblies
(5c) Sub-assemblies
(6) Test Stand of Complete Machine
(7) Despatch of Finished Goods (by Road)
PATH OF WORKMEN TO WORKING PLACE
4
3
2
1
II
PATH OF MATERIAL THROUGH FACTORY
DEPARTMENTS
HEAVY PARTS
LIGHT PARTS
RAW MATERIAL STORES
YARD FOR STORING MATERIAL
MATERIAL ENTRANCE
3b
3a
2
1
III

FIG 1

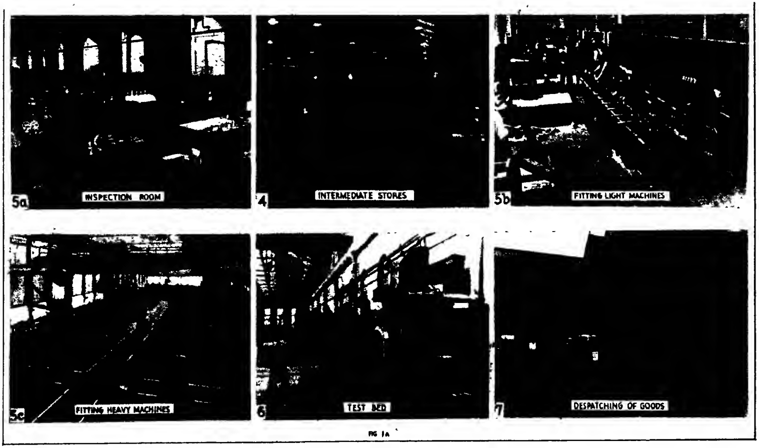


FIG 1 THE FUNDAMENTAL ELEMENTS OF A "FACTORY"

the sources of heat loss, beginning at the carburettor for vaporizing liquid fuel They show that 26 per cent of the heat in the cooling water is available for heating purposes. The total thermal efficiency of the liquid fuel is thus 26 + 19 = 45 per cent These exhaust losses represent heat values, the utilization of which, as *by-products*, allows the price of the power unit to be reduced considerably Their use for heating purposes of one kind or another may make even the obsolete steam plant economically tolerable under certain circumstances

The economic effect depends largely upon whether it is possible to make any use of the heated water, particularly during the summer period. A similar question arises in iron and steel works where blast furnace gases are used to drive gas engines and turbo-blowers. Their wastage, e g when the plant is working at reduced output, causes a drop in efficiency and a rise in production costs. Technical progress and economic success are two different points of view, but in all cases the economic result is decisive so far as factory management is concerned

The same fundamental ideas must guide us in the organization of a factory A factory may be

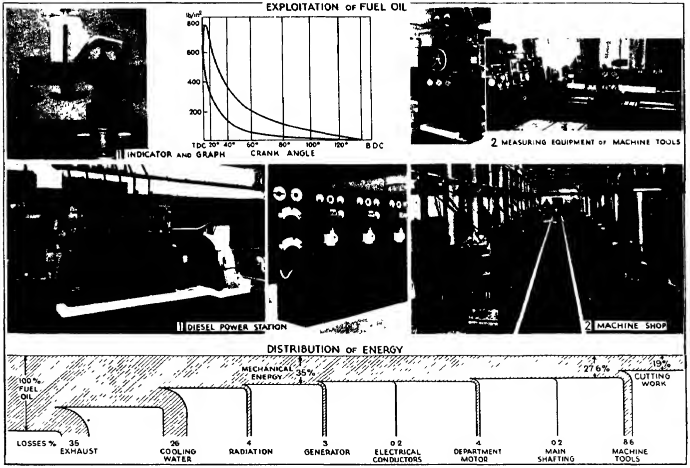


FIG 2 EXPLOITATION OF FUEL AND DISTRIBUTION OF ENERGY

Top (1) Measuring forces, fuel distribution, power by indicator and diagram (2) Measuring cutting balance of machining by testing lathe and testing drill

Centre (1) Diesel-generator and Switchboard (2) Mechanical Workshop

Bottom Economic result 100 per cent in fuel give 19 per cent on cutting edges of tools Where is the rest?

likened to a living being, whose organism must be carefully studied in order to find out how it acts and how it can be controlled. The means of observation must arise out of its own working activity, not just once, but permanently, not at long intervals after the job is finished, but accompanying the work, like a shadow following a man From this sharp silhouette, which gives, undistorted, all the essential data, the works manager must be able to make a useful instrument, not only to maintain the present level of production, but to improve it.

The engineer compares the amount of heat in the fuel with the power produced, as measured on the switchboard, and arrives at the ratio between the heat input and the power output

The accountant, by his double-entry book-keeping, compares expenditure with income The result shows clearly the profit or loss He is able to estimate whether the installation of new plant would be justified economically and to advise the management accordingly When plant is purchased, he is able to keep its results under permanent scrutiny, thus he knows whether it is profitable or not

So, too, the manager must have his criterion by which to measure the success of his work He must know exactly how much money a worker should be able to save daily in piece-work payments by the installation of new equipment, and must also be able to calculate how much the new working hour will cost if the plant is installed (allowing for decreased wages and increased overhead)

To obtain this information one must have a positive standard of measurement It is not sufficient simply to make tentative estimates or comparisons with competitors' prices In other words, the cost of each article or part must be readily calculable, and this necessitates that the prime cost of the article, i e material and labour, must be readily available

A properly designed works accounting system must measure cost, and therefore manufacturing efficiency, with the same instantaneous accuracy as a scientific measuring instrument It must also act as a recording instrument, leaving a permanent record of its findings.

The manufacturer is not a scientific research worker, to him practical economic success is the measure of technical efficiency. In manufacturing he demands that reviews of progress and performance shall be presented to him regularly and automatically in a form easily understood They are a summary of the findings of the cost accounts system, rendered daily, weekly, or monthly, ready for immediate comparison and obtained by the simplest and shortest method and with the minimum of writing and calculating work

How is this generally done to-day? Costing is frequently done without any contact between the staff responsible for technical estimating (pre-calculation), done before the work is undertaken, and that engaged on cost finding (post-calculation), or calculation of the actual cost of the finished product It is presumed that the estimated rate, carefully fixed by the ratefixer and written down on the piece docket, will be the same as that demanded by the worker when the work is finished, accepted by the foreman, and passed by the inspector It will further be presumed that the allocation of all costs incurred, including cost of material will be charged to the order by the accountant in the correct manner

In most cases little or no regard is paid to the accumulating costs of raw material and work during the actual process Between the rate-fixing (estimated before the work is commenced) and the cost-finding (recording of the actual costs) there is, so to speak, a deep schism, which separates costing from production Thus, in many undertakings, the fundamental principle of continuous and simultaneous control is destroyed, the management maintaining in some cases that technical performance has nothing to do with commercial book-keeping It must be said in fairness to the works accountants that they have proved worthy of the confidence which has been placed in them in bridging the gap which exists between technical estimating and commercial cost-finding They take over the monetary demands of the workmen, examine and transform them into wages, then re-arrange the work slips according to orders, examine them again, draw up accounts and additions, compare their results.

check the figures, and adjust the smallest errors so that their commercial conscience is satisfied. They are figure-conscious, they must be sure that everything is correct in the field of activity entrusted to them. The recording of the prime cost—for they do recording only—is their main objective They are aware of their responsibility for the handling of money in connexion with the workshop, though they are separated from the production work itself

Co-ordination

Here we find the modern conception, which culminates in the demand that there be full conformity between the physical movement of labour, material, and plant and its clerical recording, i e. between technical management and commercial administration (cf. page 114) The customer's order (see Table I, 1) rules the workshop. It comes complete from the drawing office, which, in most cases, also provides the design, and the material and parts list The order is passed in its original form, still accompanied by those two fundamental documents, on to the works production department (see I, 4). This office now divides the order into its details as they apply to the individual worker In the workshop nobody has time for meditation, every minute spent on real planning is an aid to the efficient execution of the work. In a well-managed factory every worker receives a clear and specific order consisting of a written slip for each single operation or series of combined operations. This slip, usually in the form of a wages docket, in some cases accompanied by the drawing, must be adequate to enable the work to be performed exactly as was intended by the designer, only, perhaps, the very first attempt at the job might require an oral explanation by the foreman. The completion of the operation is, of course, followed at the end of the week by the payment to the worker of his earnings The accountant credits each worker with the money earned from all orders on which he has been engaged and debits each order with the wages paid to all workers who have been engaged thereon. (See Figs 23*a* and *b*, and 46.)

The total wages of all workers in the same workshop are recorded in the pay-roll office on the correct departmental sheet. This represents the total productive wages cost for any department or workshop.

We have considered the evaluation and accounting in respect of wages, now we must consider the treatment of raw material. No work in the workshop, no manufacturing of any sort, can proceed unless the necessary raw material is available The issue of raw material by the stores requires an entry of withdrawal (credit) from the bin-card, which records the kind of material, a charge (debit) to the order, and a discharge (credit) to the storeroom from which the raw material is issued

The system used for routing the work through the shops should be in such a form as to afford the bookkeeper a means of costing control. The execution of each order should be carefully planned by the management and, as a first step, a complete series of blank forms should be prepared by the works production department, ready for immediate use No foreman should be required or allowed to write more than is absolutely essential, and still less should an operator be allowed to do so. For this reason, the parts lists (see Fig 21), which are mainly furnished by the drawing office at the same time as the drawings, are not in themselves sufficient as working instructions to the workshops, nor as a means of cost calculation later The parts list is indeed a valuable, and even indispensable, summary of materials needed for the order, but its main value to the production shops does not begin until it has been remodelled by the works production department into a series of single orders, arranged in the sequence in which they are to go through the workshops By means of this series of orders, in the form of slips, dockets, or cards, it is now possible to follow the manufacture of the piece from start to finish These documents comprise the worker's instructions, to be followed until the operations have been completed. Then, when the machining is done and the operation has been passed by the inspector, they become the means by which the book-keeper can calculate the cost. Furthermore, by checking the completed slips with the parts list, the book-keeper can verify that each operation has been done and that none has been done twice. This method ensures the making of all necessary preparations for the correct, quick, and orderly guidance of the work through the workshop. It is the basis for progress and production control By its use it is impossible for an order to be issued to the workshop until all preparations have been made for the worker to proceed with the work according to written instructions, i e. as regards the manner of machining, the sequence of operations, and the time fixed for each stage of the job

The final stage in cost-calculation, i e the *overhead*, has already been mentioned See Table XII, p 77 Overhead charges might be called "works costs," because they represent the costs arising out of the running of the works themselves, divided proportionately over the output of each department They are obtained directly from the overhead accounts, the purpose of which is to ascertain at regular intervals (usually monthly) the cost of each department, whether it be an administrative office, production workshop, or a supplementary or auxiliary shop. The charges have then to be allocated to the work done in the various production workshops, on the basis of standard rates calculated for individual shops and even for individual operations

These three main problems, i e.—

A Materials,
B. Labour, and
C. Overhead,

will now be examined as regards their individual and combined influence on factory costs They are closely connected with the seven basic problems of organization mentioned on page 3, in a manner to be made clear as we proceed

CHAPTER II

The Materials Problem

No OPERATOR is able to work without materials. From the outset, therefore, the question of control of material supply affects every operating point In each factory the question of material supply has three aspects, each with its peculiar problems —

I The actual handling of materials—raw, semi-finished, and assembled. This is a basic technical problem and its solution depends upon the weight, bulkiness, and delicacy or texture of the parts, and upon the type and sequence of machining operations

II. The many physical and mental operations necessary to procure materials from outside and to feed the right material to the right place, at the right time

III The clerical recording or reflexion of the physical movement of materials from the reception in the stores to the dispatch of finished goods, including costing operations The methods are fairly similar in all good factory organizations

(I) The Handling of Materials

The general technical equipment of a factory is determined by the nature of the materials which form the finished products. Apart from this general and obvious rule, it can only be stated that the specific needs of any particular case depend upon the nature of the actual products, therefore only practical examples, typically selected, can convey an adequate idea of the immense difficulties involved in finding a sound solution to the problem of materials handling

Handling devices and equipment will frequently cost less by being made an *integral part of the plant* This is the ideal solution from the engineer's point of view.

(II) Plant Location

The external supply to the works of raw and prefabricated materials such as meters, chains, oilers, nuts and bolts, pins, ropes, belts, small tools, machines, and other auxiliary materials, etc., requires transport and this should be available at all times The ideal solution is a combination of railway, road, and waterway both for providing raw material and for dispatching finished products

Typical solutions* are shown for—

1. Copper and brass mill (Figs. 3, 4*a*–*c*)
2. Rifle factory (Figs. 5, 6)
3. Factory for producing electrical and mechanical instruments (Figs 7*a* and *b*, 8)
4. Heavy machine tools (Fig. 9).
5. Light and medium machine tools (Figs 10, 11*a* and *b*)
6. Motor cars (Figs 12, 13)
7. Iron and steel works (Figs 14, 15*a* and *b*)
8. Textile manufacture (Figs 16*a* and *b*, 17, 18)
9. Oil refinery (Fig 19)
10. Crucible factory (Fig 49)

The factories Nos. 1 to 4, 6, 7, and 9 have railway, road, and water connexions, but in the centre of a town it is often difficult or even impossible to obtain sites with such an ideal combination of facilities

The copper and brass mill uses large quantities of heavy metals and fairly bulky scrap for production, and coal, briquettes, and bricks for furnaces, as well as of acids and other auxiliary materials

The electrical instrument works need light and medium bars, sheets, and strips of steel, copper, brass, etc., and an amount of small rubber and plastic finished components, as well as auxiliary materials of various types

The rifle factory uses mainly alloy-steel bars for the firing mechanism parts, most of which are made as drop-forgings, and fresh wood for the rifle stocks These require careful handling.

The factory for heavy machine tools up to

* Factories 1, 2, 3, and 10 were newly erected, equipped and put into action, and Factory 8 redesigned and organized, by the author

700 tons total weight and up to 60 tons for single parts has both river and railway connexions, water transport is of course necessary for the handling of such weights

Works Nos 5, 8, and 10 were restricted to either railway and road or road only, as they were situated in the centre of a town Roads are very useful when the goods are not too heavy and are partly consumed by the neighbouring population, or when road transport to the railway and reloading into trains does not involve exorbitant expense, or when the finished goods are self-transporting, such as motor cars

The oil refinery is a unique example, as it uses pipe lines for transporting its raw material from ocean-going tankers to the main crude-oil storage tanks Canal, road, and rail services handle the finished products in bulk and in containers

The first three factories mentioned were erected by the writer, using the practical experience he had acquired after very many years' contact with old works which suffered severely from the effect of slow and unplanned growth The neglect to plan future expansion often causes bottlenecks in internal transport which considerably impede the uninterrupted flow of the manufacturing processes, even in workshops not engaged in quantity production of a single product

The eighth factory (textiles) was established fifty years ago and was partly rebuilt and partly converted by the author The result was a restoration of full and regular flow production, instead of the awkward and expensive manufacturing sequences which had arisen out of the factory's former unplanned expansions

The tenth factory, producing simple crucibles by an almost automatic process, the technical control of which is easily understandable, is selected to exemplify the inseparable connexion between the flow of material, the manufacturing process, and its economic control (See page 114, Fig 49) This factory will therefore be dealt with in Chapter VI as a typical, though simple example

Layout, Production, Equipment, and Sequence of Operations

The *internal transport* of raw material and parts decides the entire layout of the factory and its final economic success. Quick transport, with a minimum of personnel, is absolutely essential for efficient manufacture at a minimum of overhead expense.

The feeding of material from the store to the first production stage and then from machine to machine is the main task of all internal transport, and must be controlled by the planning department, so that the right quantity of right material is punctually at the right machine

Fig 1 illustrated the general idea of any factory, i e the movements of material and workers in the factory building, as exemplified at a factory producing large Diesel and small petrol engines The illustration stresses the short route taken by the workers from factory gate to place of work and the complicated route taken by all types of raw materials from the stores to the dispatch departments

The functioning of the management and of the planning and costing departments as regards the administrative aspect of material control will be described later (See page 42) Here we will consider only the solution of the mechanical problems.

The working conditions of material transport depend upon—

(*a*) Type, weight, and bulkiness of material
(*b*) Layout and sequence of operation
(*c*) Production equipment and sequence, e g ,
  (i) cold machining,
  (ii) hot processing
(*d*) Situation of stores in relation to workshops
(*e*) Dispatch of finished goods

We will now see how this general plan was applied in the selected factories, commencing with the copper and brass mill, and restricting the review to the manufacture of brass sheet and strip only

1 *Copper* and *Brass Mill* (*Figs* 3, 4*a*–*c*)

(*a*) Influence of Type, Weight, and Bulkiness of Material

The raw material for the rolling mills is supplied from the foundry in the form of slabs between 0·32 and one ton in weight, and measuring from 32 in × 24 in × 3¼ in up to 40 in × 32 in × 6 in. They are heavy, but of simple standard

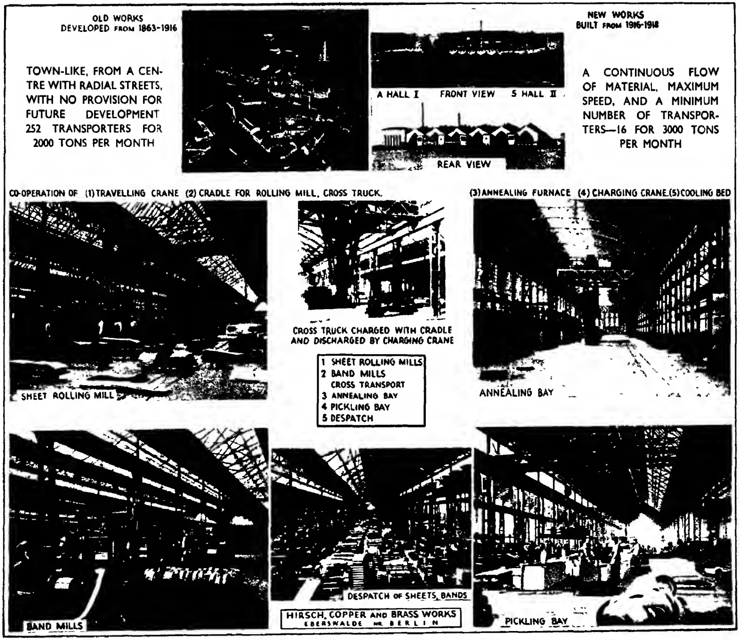


FIG 3 COPPER AND BRASS MILL

shape, and are not bulky. The intermediate store for the ingots is a work-in-process place in front of the special three-bank cogging mill (Fig. 4a (G)), from which one slab at a time is lifted by the overhead travelling crane and put on the conveyor Then it passes the triplex cogging mill, which it leaves with the dimensions of 80 in $\times$ 24 in. $\times$ $\frac{1}{2}$ in. The material is then so hard that it must be annealed before further treatment. Three further rolling and annealing operations follow, which reduce the thickness of the plate, according to the flow chart (Fig 4b), to 0·422 in and 18 ft in length, which is the maximum length of the annealing furnace The latest development is the use of red-hot ingots, heated in furnaces directly facing the three-bank cogging mill, which enables thickness of the original brass slab to be reduced in one passage from say $3\frac{1}{4}$ in to $\frac{3}{8}$ in, but after this first big reduction the hot-rolled and annealed sheets are again cold-rolled in the same way as described above

(b) Sequence of Machining Operations

The different machines used for the cold-rolling procedure are shown in the sketches, it will be easy therefore to follow the process

The main difficulty on this type of work is that the cold processes such as rolling, shearing, parting, surfacing, straightening (for sheets), winding (for strips), pickling, and inspecting are periodically interrupted for heat-treatment in the annealing furnaces. The cold operations are all done in fairly short times, the heat treatment lasts several hours and requires a substantial work-in-progress stock of valuable material in order to overcome the delay caused by the unavoidable hot operations Furthermore, annealing furnaces cannot be placed in line with the rolling mills, etc., but must be arranged in a separate bay.

Because the material changes its shape considerably during the process, i.e it becomes longer and longer up to forty-five feet (operations *I* and *J*), whereas the furnaces are limited in length and cross-section as shown in Fig 4c, the size and position of the furnaces relative to the cold-machining bay decide the plan of the factory and location of plant

We have here a strange task, for one heavy but compact slab of one ton is transformed into several large light sheets, which are very awkward to handle They are passed through the rolls one at a time but must go into the furnace in quantities in view of the great difference between rolling time and annealing time.

(c) Arrangement of Machining Equipment

Sheets of say 0·04 in thickness (1 mm), warped and bulky, are made into piles of generally not more than twenty to twenty-five sheets, trimmed sideways to 32 in width, and cut lengthwise to 18 ft, or sometimes into two piles each 16 in wide, arranged side by side on a quarter-inch common sheet-iron base plate to facilitate transport and charging into the furnaces (Fig 4c) This base plate represents a dead-weight to be annealed, weighing about 4 per cent of the total charge This is an important factor, as it lengthens the annealing time, if the base plate is too thick.

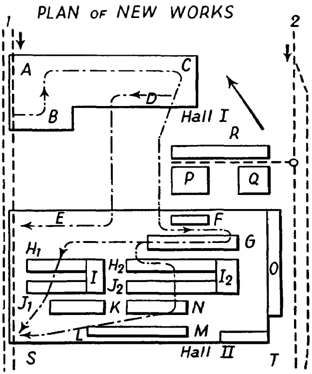
The thin base plate of steel rests on cradles made of I-iron, which can easily be picked up by the special lifting gear of the travelling cranes, which run in each of the six parallel bays with a speed of some 600 ft per minute.

Strips are rolled up to 2000 yards long depending on their thickness, and the same arrangement can be used to transport as many strip-rolls as can pass through the furnace door. A cross-section gauge is used to align them and to save the furnace walls from damage

The final step in reorganization was to arrange for a quick means of connexion between the six "cold" bays and the one furnace bay This was done by using cradles of such a shape that they also formed detachable platforms of trucks (Fig 3, centre), which could easily be moved on narrow gauge rails laid to connect all the bays crosswise

The travelling crane in the bay adjacent to the annealing bay deposits the platform and load of four tons in the "work-in-progress" store parallel to the furnaces, where it is left to cool down

To move the piles after they have cooled and to transfer piles which are still hot, the annealing bay is served by a specially-designed crane (Fig. 3) fitted with two lifting arms which can enter below the prepared loads of sheets or coils



A = Raw Material B = Dressing Station C = Foundry D = Bar Pressing Dept	Hall I Foundry
E = Tubes and Wire Rolling Mill F = Ingot Furnace G = Cogging Mill H_1 = } H_2 = } Rough-Rolling Mills J_1 = } J_2 = } Finishing Mills I = } I_2 = } Shearing and Straightening Machines K = Pickling Machines L = Annealing Furnaces M = Punching Machines N = Pickling Tanks	Hall II Mechanical Manufacture
O = Heaters and Ventilators P = Boiler House Q = Generators R = Coal Stores	Auxiliary Depts
S = Despatch and Finished Goods T = Despatch of By Products	Despatch

PLAN OF NEW WORKS

FIG. 4a. COPPER AND BRASS WORKS

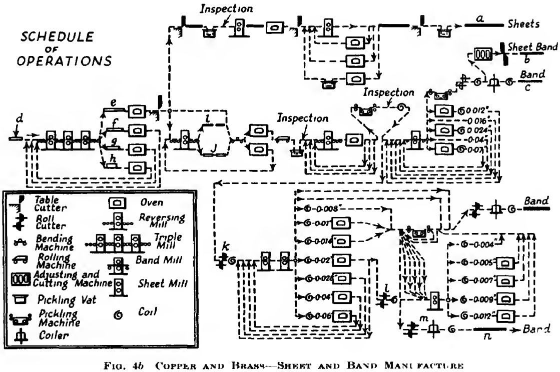


FIG. 4b COPPER AND BRASS—SHEET AND BAND MANUFACTURE

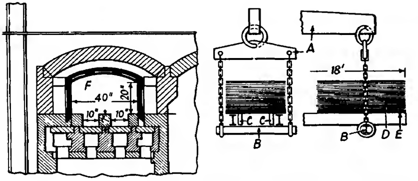
(Fig. 4c—*C C*), revolve them through 180°, and place the whole load of four tons weight and 18 ft length straight into the furnace without manual contact

An electric signal lamp on the front of each furnace shows the crane driver the exact point where the lifting arms of the crane are in line with the furnace door, thus avoiding possible damage to the furnace One driver for the special crane and one operator for the thirty muffle-furnaces were thus able to work the whole annealing service per shift, controlling the temperature of the furnaces, and loading and unloading them, without being overworked In 1939 heating by generator gas was partly replaced by electric heating so as to avoid the sheet surfaces being detrimentally influenced by the gaseous atmosphere

The maximum size of sheet was 36 in wide and 18 ft long The maximum height of a package or of a roll was limited to 20 in (Fig 4c) The annealing periods of the different alloys used were carefully studied by the research department of this big rolling mill, and precise instructions were given to the furnace operator and carefully noted on the operation slip The times of the beginning and end of the annealing period were stamped on the operation slip by an automatic control clock so that they appeared alongside the annealing instructions, thus providing confirmation that the instructions had been carried out When the annealing was complete, the red-hot load was removed from the furnace by the special crane, turned through 180° and lowered on to the cooling bed in the adjoining bay, formed by the detached platforms of the cross-truck. These platforms could later be picked up by the travelling crane and carried straight to the next rolling operation if in the same bay, or by means of the cross-trucks if required in another bay

The furnaces were worked on three full eight-hour shifts (i.e. twenty-four hours daily) whilst the rolling bays worked only one eight-hour shift per day This reduced the loss of time caused by annealing, lowered the capital value of idle stock, lowered the process costs, and at the same time increased the life of the furnaces

The whole of the transportation services in this large works employing 3000 people was done by sixteen operators, as against 252 before reorganization and rebuilding Furthermore, the weight transported was increased from about 2000 to 3000 tons per month



A = Suspension Tackle of Travelling Crane
B = Cradle
C = Fingers of Charging Crane
D = Stack of Rolled Sheets
E = Bottom Plate of Mild Steel
F = Cross-Section of Furnace

Conformity of—
1. Transport Cradles (B)
2. Platform of Cross Track (B)
3 Fingers of Charging Crane (C)
4. Furnace Section (F)

FIG. 4c TRANSPORT OF SHEET STACKS FROM ROLLING MILL TO FURNACE AND BACK

(*d*) SITUATION OF STORES IN RELATION TO WORKSHOPS

The materials were divided into (1) raw materials for the actual manufacturing process, e g copper, zinc, tin, aluminium, etc , and (2) auxiliary materials such as coal, bricks, cement, acids, abrasives, etc (Fig. 4*a*). The manufacturing materials come in and go out on the left (*A* to *S*) side of the building, the auxiliary materials and by-products are concentrated on the right side (2 to *T*) so that the two separate lines of traffic do not interfere with each other.

There were two main separate buildings Building Hall I included the raw material stores (*A*), which consisted partly of pure metals and partly of scrap and recovered materials. There was also a special dressing station (*B*). Then these prepared materials came to the Foundry (*C*). Some round ingots went to the pressing department (*D*) for the production of various sizes of rods, tubes, etc., by hydraulic extrusion presses; whilst the flat ingots went to Building Hall II for rolling operations. This building contained the bays for the rolling mills, draw-benches for tubes and bars (*E*), and the annealing furnaces for the ingots (*F*), which were passed through the rough cogging mills (*G*). The ingots were then passed through the mills (H_1 and H_2) for rough rolling into strip or sheet, and finally to the finishing mills, J_1 and J_2 The rolling mills were connected with shearing and straightening machines *I*, I_2 A special bay contained pickling machines (see Fig 3), and the last bay the annealing furnaces The transport arrangements between rolling mills and annealing is illustrated in Fig 4*b*, which shows the vital importance of the factory's material transportation system. Part of Building II east of the annealing bay was reserved for punching machines (*M*) Also, a storeroom for the pickling containers was established in the right-hand corner at (*N*), where they could be filled direct from the railway tank trucks. The briquette-heated generator (*Q*) supplied the steam-boilers (*P*) for heating and ventilating the whole factory and also supplied the annealing furnaces with the necessary quantities of gas. The briquette store at (*R*) has a rail connexion. Current for power and light was supplied by a county power station in the neighbourhood

(*e*) Dispatch of Finished Goods

The finished goods—sheets, strips, tubes, bars, wires, punchings, and pressings, etc —in almost innumerable dimensions and quantities (Fig. 3, bottom-centre) left the factory on the west side (*S*), the by-products on the east side (*T*) by railway.

The plan (Fig. 4*a*) shows the movement of the raw materials of production from the stores (*A*) alongside the railway tracks to the dispatching stations as finished goods. To dispatch approximately 3000 tons a month is not an easy problem, especially if we have to deal with heavy, long, wide, and sometimes fragile items. Tubes and sheets of 0·004 in. thickness must be handled very carefully, so much so that the materials problem in this case rules the layout of the entire factory with all its transportation equipment and machining plant.

2 *Rifle Factory* (*Wooden Rifle Stocks*) (*Figs.* 5, 6)

An ordinary rifle consists of about fifty-five steel parts, which form the firing mechanism, and the wooden stock, which is the frame or basis of the weapon Fig 5(*a*) shows the whole plant, Fig 5(*b*) and (*c*) illustrates some of the important steel parts, such as body, bolt, magazine, and the wooden stock. Here we will deal only with the materials problem as it affects the manufacture of the wooden stock and illustrate the equipment which was found necessary to guarantee maximum production in the shortest time with the minimum number of men. The material of the stock has to be "seasoned" before it is sufficiently stable to be machined The machining operations will change its weight and dimensions, but they cannot change its consistency This is a particularly simple example which illustrates some of the difficulties encountered when handling a sensitive material in the workshop

The material is generally walnut, the weight of the raw material to make one stock is about 13 to 14 lb The material arrives at the factory roughly cut to shape (Fig. 6(*b*) and (*d*)), and the rough stocks are quite easy to handle.

Internal transport is served by means of a travelling crane which is used for loading and unloading trucks and boats, goods of all kinds being handled for the whole factory. The crane must of course have a jib long enough to cover the full width of the boat (Fig. 6(*c*))

The roughly-shaped unseasoned timber stock is transformed into a machinable dry specimen by means of debrining, steaming, and drying processes These operations are done in the drying shed (Fig 6(*e*)), from whence the dry stock is dispatched to the machining departments, remaining in the same special iron container from the first unloading operation near the ship or the truck to the store place in front of the first

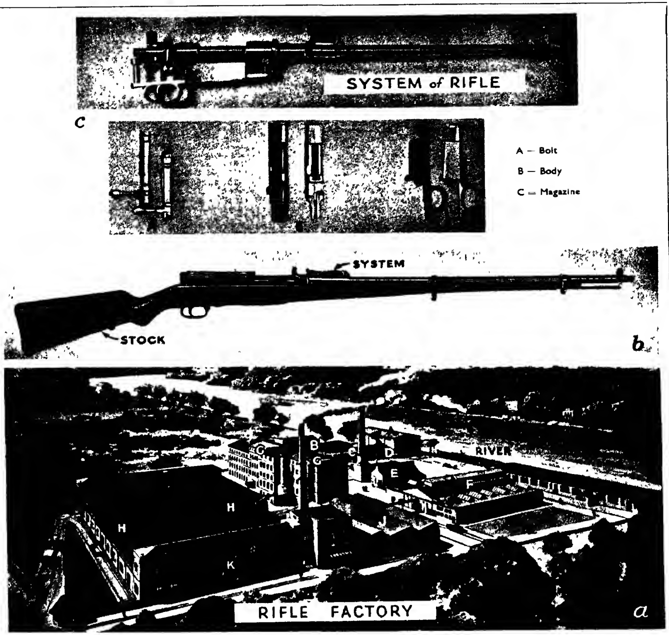


FIG 5

A = Wood Drying Dept
B = Wood Stores
C = Steel Stores
D = Bridge Crane
E = Power Station
F = Forge
G = Multi-story Building (Small Parts and Stock)
H = Ground Floor Workshop for Heavy Parts
J = Toolroom
K = Offices

milling machines. No intermediate work-in-progress stores are provided The weight and dimensions of the stock are constantly decreasing, and it weighs only about 8 lb when it is finished and ready to take the firing mechanism

artificial drying process had to be designed and put into practice Here is how this peculiar heat-treatment and transport problem was solved

It was learnt from the experience of a much larger rifle factory making 2000 rifles per day

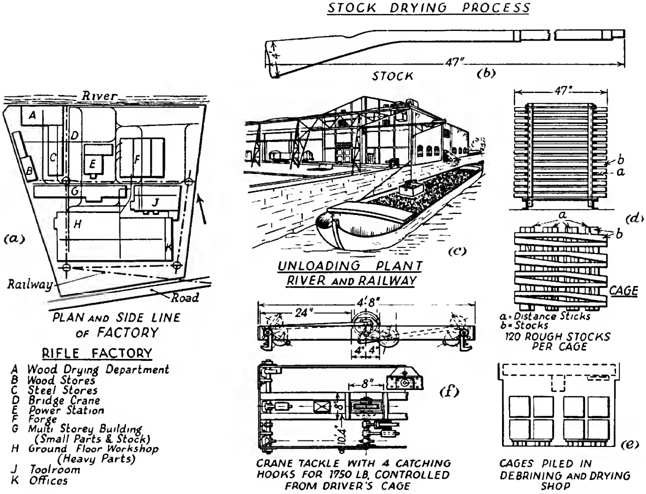


FIG 6 RIFLE FACTORY

(a) Plan of Factory (b) Wood Stock (c) Unloading Plant (d) Cage for 120 Rough Stocks (e) Arrangement of Cages in Drying Shop (f) Crane for Handling a Loaded Cage

The factory was manufacturing 400 to 450 rifles in two shifts of eleven hours each.

In peace-time the stocks were very slowly and "naturally" dried, first in the yard, then in a hot-air drying chamber. The seasoning period in the open air was at least one year. During the war not more than six weeks could be allowed for the complete seasoning process; therefore a special

that about 20 per cent scrap was customary 2400 against 2000. This old-fashioned works piled the rough cut stocks for eight to twelve months in the fresh air in stacks up to 25 ft high Then the air-dried stocks were moved again by hand from the yards to hot-drying and debrining chambers 20 ft square and about 7 ft high For 2400 stocks per day, 175 full-time operators were required. By reducing the figure in the ratio 1 to 5 (450 to 2400) it was reckoned that at least thirty-five hands would be needed for the smaller factory. They were to be distributed, following the example of the larger factory—

(1) Seven operators unloading the railway trucks,

(2) Twenty male and female operators occupied with piling, re-piling, brushing, and cleaning the pre-dried and dried stocks,

(3) Four operators serving the drying rooms, heaters, etc.;

(4) Four men for inspection,

i.e thirty-five in all

The main problem was the lengthy seasoning period in the open yards (taking many months) as well as the piling and re-piling, and the brushing and cleaning by hand of the half-dried stocks which were sometimes covered with mould, mildew, and fungus when they came from the heating chambers Furthermore it was not possible to be sufficiently systematic in the re-piling operation, as 2400 stocks per day could not be handled in such a way as to guarantee that the moist surfaces would be uniformly dried all around

A new plan was contrived whereby the stocks should not be touched by hand from the moment of their arrival by train or ship (Fig 6(*c*)) until they were perfectly dry and ready for machining on the milling machines, which carve the complicated recesses to receive barrel and body, and the odd shape of the butt and of the fore-part of the stock If the stocks were warped by only 0 001 in to 0 005 in in their length when completed, the rifle would not give accurate fire at a target at, say, 500 feet

The drying equipment was organized on the following plan. The roughly-shaped unseasoned stocks arrived by railway or boat directly in front of the drying shed and there two men arranged them in iron cages (Fig 6(*d*)) each of which could take about 100 to 120 stocks The cages were then lifted by a special crane which held the four corners by means of four controllable hooks (Fig. 6(*f*)) directed by the crane driver from his cabin. Each cage was taken by this means into the first-floor drying room and placed either on the floor or on top of the lower row (Fig. 6(*e*)). The tops and bottoms of the cages were of standardized shape so as to fit each other. It was necessary to employ a second man in the drying room to steady the cages and to see that each fitted exactly in its place either on the floor or on top of the lower row. Up to 1600 stocks, i e sixteen containers per day, could easily be arranged by four men, two of them being only half-occupied The two men in the drying room were able to do all the clerical work of receiving, re-arranging when necessary the cages by turning through 180°, and generally supervising the drying process

The two transport workers who did the outside work on the railway or on the boat could also be used for other transportation work. Altogether four operators were sufficient instead of the estimated thirty-five, and even these were not fully occupied

The first manufacturing process was a chemical one unusual in mechanical workshops. Its purpose was to remove the salt, and other natural impurities, from the wood by the use of saturated steam of 80° to 90° C, and to wash them out They came out first as a brown lye After three to four days of steaming the brine became as clear as water, proving that the first stage of the process was finished Then the steam was replaced by heated air beginning with 45° C and ending with 35° C, supplied in a low pressure stream so as not to split or injure the sensitive wood. There were only two vertical rows of cages each about 10 ft high Had they been piled higher, the stream of drying air would have needed to be stronger, and might have caused harm to the wood.

In five to six days the steaming and hot-drying was finished and the cages, having been twice re-arranged in the "hot chamber," were transported by the same crane to the finish-drying room alongside. Here five cages, up to 25 ft high, were piled one on top of the other and a temperature of 25°–30° C. was created by ordinary low-pressure steam radiators, bedded into the floor of the room itself, so that the heated and water-saturated air could escape by an opening in the roof, helped by low-pressure suction. In three to four weeks the last drying was finished, and the stocks came out free from mould or fungus, requiring no brushing or touching up. Their weight was reduced from about 13 lb for the fresh stock to about 9 to 8 lb of dried stock. Altogether five to six weeks were necessary to make them ready for machining

The debrining and hot-drying chambers could take 10,000 stocks, the two finish-drying chambers 25,000 each This made it possible to hold 60,000 stocks in process of which 20,000 covered the needs of the rifle factory for approximately 45 days. As new supplies of unseasoned pieces could be bought at short notice, no additional stores were necessary in the factory Scrap was reduced from approximately 15 per cent to 20 per cent down to 8 per cent to 10 per cent. 440–450 stocks per day were sufficient to meet the maximum needs of the whole rifle factory, so that a desirable reserve for unavoidable interruptions was secured. The problems of material planning, buying, storing, treating, and transporting, from the boat or the railway truck to the machining department were solved by integrating all the essential details As only a minimum of labour and space was used, expenditure on power, steam, maintenance, and repairs was moderate and overhead charges were therefore reasonable. The basis for a very clear and reliable costing system, so far as the wooden stocks were concerned, was well prepared.

3. *Electrical and Mechanical Instruments (Figs. 7a and b and 8)*

The third example shows a factory (Fig. 7*a*) making telephones, telegraph and radio equipment, teleprinting apparatus, fire alarms, etc. (Fig 7*b*) The telephones were made in mass production quantities, the telegraph and radio equipment in large batches, and the other products in small quantities, using standardized components and sub-assemblies where possible. The raw materials in this case were the ordinary types of ferrous and non-ferrous metal in sheet form and in round, square, and hexagonal bars, as well as manufactured items such as metal castings, stampings, wires, cables, rubber and plastic articles, and wood. The wooden parts, such as cabinets, shelves, etc., were of no great functional importance

Bars, rods, tubes, etc., were used of sizes of between ⅛ in. to 3 in diameter strips and sheets of 0·004 in. to 1 in. thick, stampings and pressings were made from bars hot or cold by power presses, punches, drawing machines, etc. Swarf

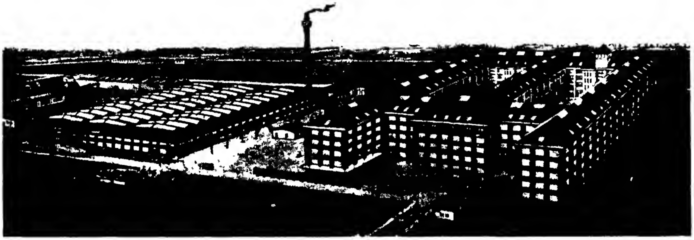
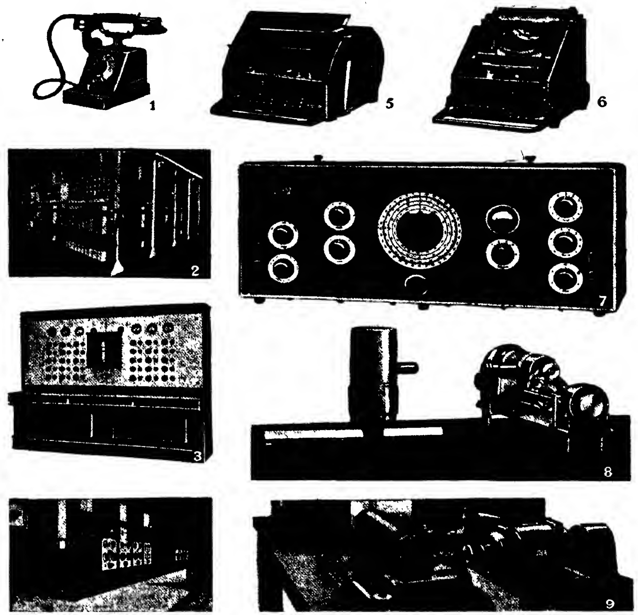


FIG 7*a*. VIEW OF TELEFUNKEN WORKS—C LORENZ, BERLIN MANUFACTURE OF ELECTRICAL INSTRUMENTS

PRODUCTS OF FACTORY FOR TELEPHONE, TELEGRAPHS, WIRELESS TELEPRINTER, PICTURE TRANSMITTERS



1. Dial Telephone
2. Automatic Exchange for more than 1,000 Subscribers
3. Fire Alarm Control Switchboard
4. Front View of Two Automatic Transmitters
5. Tape-teleprinter
6 Sheet-teleprinter
7 Modern 6-valve Radio Telephony and Wireless Telegraphy Receiving Set
8–9 Radio Pictures Transmitting Equipment

Fig 7b

and scrap varied between 5 per cent and 30 per cent according to design, but in all cases the weight of the parts was small from the beginning, being of fairly heavy generators and high-frequency equipment, which the firm produced.

The solution of the material transportation

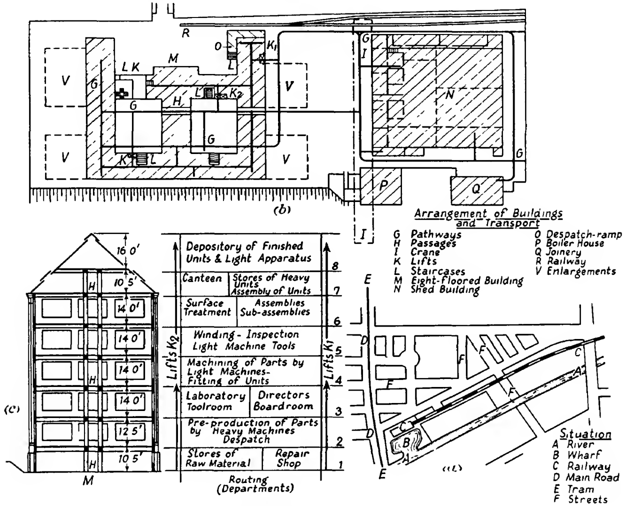


FIG 8. LAYOUT OF THE FACTORY SHOWN IN FIG. 7*a*

(*a*) Situation (*b*) Plan—Arrangement of Buildings (*c*) 8-Floors (*M*) showing Distribution of Work

easily transportable by hand. Weights and sizes were of course further reduced by machining, bars being transformed into single pieces by the lathes, capstans, and automatics, etc., and the same being done to sheets and strips by shearing and punching presses.

Sub-assembly and assembly creates larger and heavier units, but they are still well within the limits manageable by ordinary means. This is a typical case of light production with the exception problem is therefore divided into two parts, i.e. those affecting—

(1) Light parts concentrated in a multi-storey-building (*M*), and (2) heavy parts in a ground-floor building (*N*), (Fig 8(*b*) and (*c*)).

All the large parts, such as castings and stampings, and heavy bars are machined in the ground-floor workshops of the multi-storey-building and ascend by lifts. Auxiliary materials, especially coal for the boiler house and wood for the carpenter's shop, are unloaded direct from the railway or ship to their respective stores without touching the workshops.

The layout consisted of an eight-floored building including a basement, which was useful as a raw material stores and repair shop, and an attic as a storeroom for semi-finished and finished goods (Fig 8(*c*)) The factory was well sited and each floor received daylight through large windows Operations on the light and medium parts commenced in the basement and the flow of work was upwards to the stores in the attic Finished goods were sent down by lifts and dispatched from the ground floor Vertical transport was facilitated by fast lifts (K_1, K_2) for the light parts, and spacious (10 ft × 6 ft) lifts of three-ton loads for medium and heavy machines and large apparatus A whole capstan or a lathe could be transported from the railway to its working place without being dismantled Horizontal transport was originally provided by a narrow gauge line (20 in gauge) but this was later replaced by trackless electric trucks running at four to five miles per hour Numerous roads paths (*G*), and passages (*H*) provided access to every corner of the factory The site of the factory was so chosen that railway (*C*), waterway (canal and wharf (*B*)), main road (*D*), and several streets (*E*) could be used for the receipt and dispatch of raw materials and finished goods (Fig 8(*a*)) Railway (*C*), tram line (*E*), and streets (*F*) facilitated transport of labour from the neighbouring town and suburbs

The layout provided for 3000 workmen at full capacity Each floor of the eight-floor building (*M*) (including attic) had 47,000 sq ft, providing a total of 376,000 sq ft plus a separate ground floor building (*N*) of 30,000 sq ft working area (Fig 8(*b*))

To unload or load trains or ships, a travelling crane (*I*) crossed the yard from the canal to the railway tracks

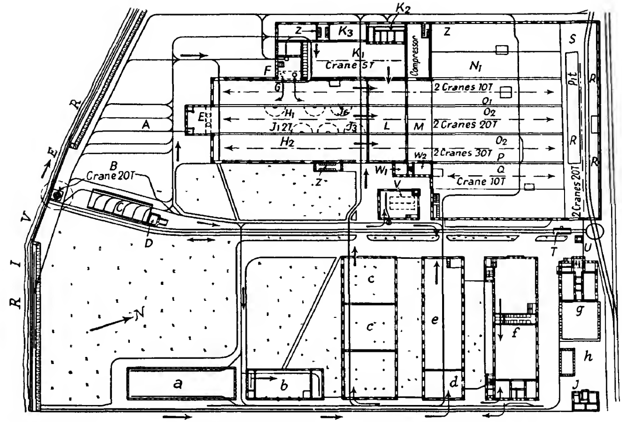
Only the heavy machines of the ground floor (*M*) and some parts of the separate ground-floor building (*N*) were served by swivelling cranes, for handling heavy castings Additional means of transport were unnecessary because of the lightness of single parts and sub-assemblies Assembly lines with conveyors, etc., were used wherever possible, when warranted by large batch production (cf. page 271).

Sawing, parting, centring, and other simple preparatory operations were usually done near the material stores in the basement (Floor 1) and the material was transported by fast lifts (K_1, K_2) to the different floors according to the machining operations required. Sometimes heat-treatment was needed between some machining operations. Facilities for this were provided on Floor 6 so as to disturb the correct "flow" as little as possible The finished goods stores in the attic (Floor 8) were directly connected with the dispatch department (*O*) on Floor 2 by the lifts (K_1, K_2) light or heavy according to size and weight of the products The problems of material handling with products differing widely in weight, bulk, and, fragility, in a multi-storeyed building, are much more complex than when a single-floor arrangement is possible

4 *Machine Tool Factory Making Heavy Machines (Fig. 9)*

The articles manufactured were heavy lathes planers, horizontal and vertical boring mills, etc , weighing up to 700 tons each Individual parts such as bedplates, stands, columns, tables, etc , weighed up to 60 tons per piece The foundry, the heavy machining plant, and the fitting department were therefore kept under one roof, enabling the same cranes to be used to carry the castings from the moulds to the fettling department, then to the heavy machine tools, and finally to the erecting bay For the heaviest pieces, two travelling cranes of 20 to 30-ton capacity each, were used together. The objection that dust, smoke, and moisture from the foundry might penetrate the manufacturing departments and spoil the plant, was solved by having a vertically sliding partition between the fettling department and the casting stores which was lowered only in the evenings. The cranes were able to pass with their loads through the openings beneath the roof

Pig-iron, coke, coal, wood, and non-ferrous materials, etc., usually arrived by river (south side) direct to their stores, but sometimes they came by railway (north side), from whence they were distributed by means of the turntable to their respective stores



A = Iron stores.
B = Coal stores.
C = Coke stores
D = Oil stores.
E = Cupolas.
F = Cupolas.
G = Light foundry.
H_1 = Heavy foundries
H_2 = Heavy foundries.
J_1 = Slewing cranes
J_6 = Slewing cranes.
K_1 = Core making.
K_2 = Core drying
K_3 = Core-box shop
L = Cleaning.
M = Castings store.
N_1 = Light turnery, Heavy turnery.
O_1 = Light planing.
O_2 = Heavy planing
P = Vertical boring mills.
Q = Fitting department.
R = Fitting department of heavy machines
S = Dispatch carpenters
T = Weighing machine
U = Gate porter
V = Boiler house.
W_1 = Offices.
W_2 = Offices.
Z = Lavatory
a = Timber store
b = Brass foundry.
c = Pattern shop and store.
d = Steel store
e = Forge.
f = Cloakroom, baths.
g = Office building.
h = Bicycle stand
j = Staff lodgings

FIG. 9 PLAN VIEW OF FACTORY FOR HEAVY MACHINE TOOLS

Dispatch of the finished machines, either complete or dismantled into their heavy parts, was done either by railway trucks, which could enter the erecting bay, or, when the pieces were too heavy or bulky for railway transport, they were loaded on to ships by the thirty-ton travelling cranes.

The layout of this factory was governed by the need for moving a variety of supplies, some light, some of medium weight, but mostly heavy and bulky, through the factory in a straight flow, using a cross-track only for moving parts to a parallel bay.

5. *Manufacture of Light and Medium Machine Tools* (*Figs.* 10, 11*a and b*)

Most of these machines have a heavy bed, stand, upright or table, the handling of which requires heavy travelling cranes, while the fairly light cast or forged parts can be moved either by one or two men, when the weight is below 100 lb, or by auxiliary revolving cranes or other suitable lifting tackle where they are heavier than 100 lb Much of this tackle can be controlled by the machine operator.

For example the main parts of a capstan lathe are—

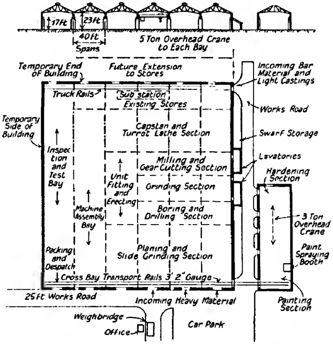
Bed with feed-gear box and accessories, headstock, turret, cross slide, and aprons for turret and cross saddle

The main building (Fig 10) was made up of six bays, each 300 ft long and 40 ft wide. Additional buildings house the spray-painting shop, the heat-treatment section, and the boilers for steam heating, and adequate space exists for extensions should these be necessary in the future Each of the bays in the main factory building is served by a five-ton overhead crane, while the spray-painting shop and heat-treatment department, which are housed in the building seen to the right, are served by an overhead crane of three-ton capacity Trucks running on roads at each end of the main building provide for transport between the various bays

Material arriving at the factory passes to the works road (25 ft wide) by way of the weighbridge and checking office The heavy castings are passed straight into the planing and slide-way grinding section which is arranged at one end of the building, while the light castings and other material are driven along to the farther end of the factory, where they are passed into the stores. After the initial machining operations have been performed on the heavier castings, they are taken to the paint shop by factory bogie or narrow-gauge trucks, and are returned later for the remaining machining processes Castings such as beds, when completely machined, are passed directly into the machine assembly bay, while the smaller machined castings, such as saddles and headstocks, are sent to the unit-fitting and erecting section in the centre of the factory.

The flow of the lighter castings, stampings, and other smaller components, is from the stores to the unit-fitting and erecting department by way of the various machine shops. Various blanks cut from bar material, stampings, and small castings are, for example, dealt with in the capstan- and turret-lathe section, and are later passed to the milling, drilling, or gear-cutting departments before being sent to the unit-fitting and erection department

The completely machined beds are arranged in rows in the machine assembly bay, and here



Ward, Birmingham

FIG 10 LIGHT AND MEDIUM MACHINE TOOLS FACTORY

the various units such as the headstock and the turret slide are mounted in position and the machines are prepared ready to be moved into the inspection and test bay At one end of the inspection and test bay is the packing and dispatch departments, where tested machines are prepared ready for dispatch

In the unit-fitting and erecting shop, benches are arranged across the bay, and between the benches are fitted assembly stands for the various units such as the headstock, turret rest, and auto-feed box. The weight of the headstock necessitates special means for handling. The benches and stands used in connexion with headstock assembly are, therefore, provided with overhead runways, from which the castings are slung when they have to be moved.

The factory is light and airy, and there is no suggestion of crowding in any of the various departments. Wide gangways are arranged between the different lines of machines, the gangways being clearly defined by white lines so that they may be kept clear of obstructions.

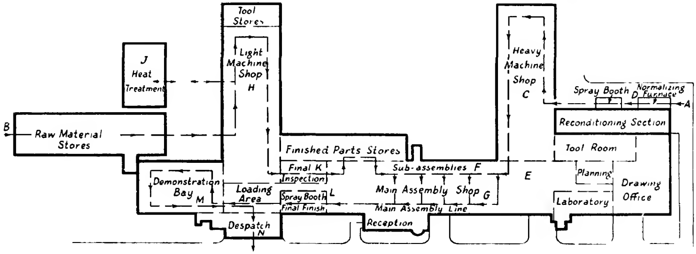
Fig 11*a* shows yet another factory for manufacturing multiple spindle automatics, etc It is built in rural surroundings, five miles from the centre of a large town It stands in 100 acres of wooded countryside and is dependent on road transport only

The ground floor is taken up with production shops, and the first floor is used for the technical and commercial offices of the organization.

With regard to the plant layout of the factory, the flow of material is indicated by arrows in Fig. 11*a*

Heavy material enters at one end of the factory at (*A*), while light material enters at the other end (*B*). Before the heavy castings enter the main heavy-machine shop (*C*), they pass through the casting-treatment section. Here rough-machining is done prior to ageing. The larger castings are allowed to age outside the factory, but a special ageing furnace (*D*) is installed for the smaller castings. Shot-blasting equipment is installed for cleaning the castings before rough-machining and also after the ageing treatment

In the heavy-machine shop (*C*), the castings pass up one side and down the other, in the directions indicated by the arrows. The machines are arranged as nearly as possible in the sequence in which they are used, so that a steady flow of castings through the shop is maintained. Leaving the heavy-machine shop, the large castings are inspected and passed to the assembly lines (*G*), where they are required for subsequent operations



A C Wickman, Coventry

Fig 11*a* Light and Medium Machine Tools

Materials and parts for the light-machine shop (*H*) enter through the goods received stores and steel stores Here power-driven saws are used for cutting bar material into pieces of suitable length before passing into the machine shop. Adjoining the stores is the heat-treatment department (*J*), through which some materials and parts pass before being sent to the machine shop. Parts are also sent for heat-treatment during the sequence of machining operations, and are returned to the machine shop for finishing after cleaning

The machines in the light-machine shop (Fig 11*b*) are arranged in accordance with their *type*, thus there are separate sections for automatics, milling machines, grinding machines, etc. The layout of the machines is such that a continuous flow of work in the directions indicated is maintained as far as is practicable. With this end in view, the grinding machines are arranged close to the inspection department (K), which adjoins the assembly shop, while the gear-cutting machines are placed close to the grinding machines

In the assembly shop, the work from the light-machine shop goes first to the sub-assembly lines (F) As the sub-assemblies are built up, they are passed to the main assembly lines (G) for building into machines The finished machines, after final inspection, pass through the spray-painting shop (L) to the demonstration and test bays (M), and thence to the dispatch department (N)

This type of construction gives light, airy, workshops and it is a simple matter to extend when necessary by enlarging one or more of the bays, or by adding new side bays As all machine tools are driven by individual motors, they could be re-arranged quickly, if required without disturbing the flow of materials through the shops from stores to dispatch

6 *Motor Car Works* (*Figs* 12, 13)

The manufacture of cars is well known as being the first application of mass-production principles to the making of a very complicated machine composed of several thousands of components These are built up to form three main assemblies viz chassis, engine, and body. Both in the manufacture of components and in the sub-assemblies and assemblies, the huge internal transport system not only governs the layout of the factory, but it also determines the speeds of all manufacturing processes and forces the men on the various machines and on the progressive assembly lines to work to definite output cycles. (See page 272.)

As a fascinating example of detailed planning and correct operational sequence and of the complete co-ordination of the efforts of several factories in the production of first-class, interchangeable, high-quality goods at low price and with quick delivery we shall consider the factories of Morris Motors, Ltd

Fig 12 shows the plan and the progress key of Morris Motors, Ltd., at Cowley, Oxford, for the 8 h p and 10 h p car, Fig 13 shows the plan of the new Courthouse Green Factory at Coventry.

A C Wickman

Fig 11*b*. View into Light Machine Shop

At the Cowley Works only assembly work is done It is the main stream, into which flow the products manufactured in specialized engineering shops of different cities, there to be assembled into finished motor cars at the rate of 500 or more per day. The Morris method at Cowley is one of flowing assembly of interchangeable components or sub-assemblies. The production of the parts is performed entirely in other factories. The works at Cowley are only the finishing link in the chain of operations through which the car has to go There are some 300 different manufacturing concerns each specializing in a narrow range of products, which together supply the 19,000 components of an average car.

The average number of engines produced in the

Courthouse Green Factory (Fig. 13) is in the region of 3000 per week. Engine dispatches, therefore, are taking place at the rate of approximately one per minute during working hours. These engines are dispatched by road in large specially-built vehicles capable of carrying from thirty-seven to fifty-four engine and gearbox units at a time, the number depending upon the size of the units concerned

Henry Ford himself, the original master mind of mass production in the U.S A., declared after an inspection of the Morris plant that "they had nothing to learn from the U.S.A on this subject."

With so many engineering works each specializing in its own range of major parts, a problem arises of adapting their various rates of output to that of the assembly factory of Cowley There must be no bottleneck; therefore great vigilance and effort must be used constantly to ensure that a shortage of a particular item or items is not going to bring the whole complex production machine to a standstill.

To ensure uninterrupted line-assembly of parts and sub-assemblies supplied by different factories in different parts of the country, a special system of inspection testing, and acceptance of incoming supplies is required

The great factory at Cowley (Fig. 12) comprises a series of engineering shops, separated only by brick partitions and connected up by conveyors, transveyors, travelling bands, belts, chains, and cranes Several miles of these conveyors and belts ensure the automatic flow of work The coming and going of parts is always timed so that they are delivered to the works at exactly the right moment. The whole is served by a central electric power and steam-heating plant

The assembly plant at Cowley is capable of dealing with 150,000 cars per year.

The layout of the engine factory at Coventry (Fig 13) shows three main sections—

1. The foundry, which is completely mechanized.

2. The building which houses the production lines for the cylinder blocks and heads, crankshafts, and housings, together with the engine-assembly department and test bed.

3. The building in which are the gear-box shops with their heat-treatment department, together with the other engine component sections.

The last-mentioned building houses also the toolroom, the demonstration shop, and shops for the millwrights, carpenters, electricians, and the canteen.

The foundry was built adjoining the railway, so that truck-loads of raw material can be delivered close to the point where they are required. Pig-iron for the castings is lifted from the railway trucks on to delivery lorries by means of automatic cranes and deposited into convenient storage bins. The sand for moulding is taken from the trucks and delivered to rotary driers capable of dealing with ten tons of sand per hour When dry, the sand is delivered automatically to the main bunkers by a bucket-type conveyor Coke and limestone are transferred from tipping wagons in the sidings to another bucket conveyor, which delivers them direct to the cupola platform, small particles of coke being separated *en route*

Between the foundry and the machine shops for cylinder blocks and cylinder-head castings are to be found the rough-casting stores in which is located the casting pickling plant From the pickling shop, the cylinder-block castings are taken to the machine shop by pendulum conveyor, means being provided for side-tracking the various castings automatically as they reach their appropriate lines of machines

Adjoining the cylinder block and overhead-valve cylinder-head section, are the lines of machines for dealing with side-valve heads, manifolds, crankshafts, and various small components. The valve section conveniently adjoins the cylinder-head lines, so that the completed valves may be fitted to their appropriate heads and ground-in with a minimum of intermediate handling Completed cylinder blocks are sent by conveyor to the washing and storage department which adjoins the stores for the other completed engine components.

Cylinder blocks are taken by a conveyor from the stores to the ends of the engine-assembly tracks and lowered to the ends of the tracks from overhead storage runways as required. The other engine components are passed to the engine assembly tracks from the finished parts and

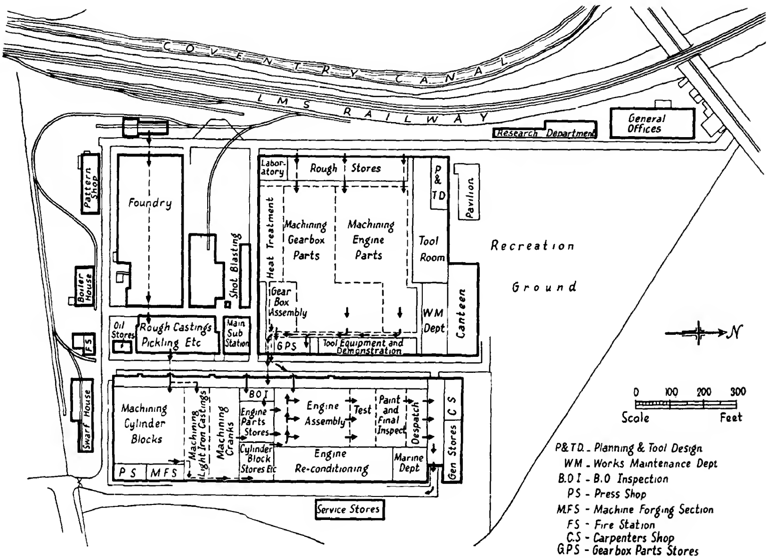
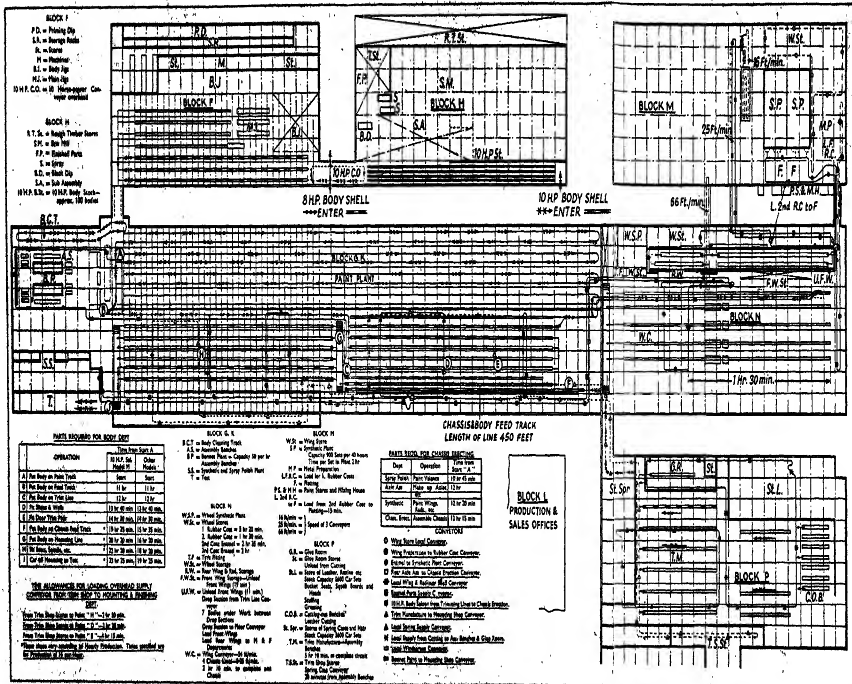


FIG 13 MORRIS MOTORS ENGINE WORKS, COURTHOUSE GREEN FACTORY, COVENTRY



PARTS REQUIRED FOR BODY DEPT

	OPERATION	Time from Start A: 10 H.P. Sal. Model M	Time from Start A: Other Models
A	Put Body on Paint Track	Start	Start
B	Put Body on Feed Track	11 hr	11 hr
C	Put Body on Trim Line	12 hr	12 hr
D	Fit Slides & Wells	13 hr 40 min	13 hr 40 min.
E	Fit Door Trim Pads	14 hr 30 min.	14 hr 30 min.
F	Put Body on Chassis Feed Track	* 19 hr 25 min.	15 hr 35 min.
G	Put Body on Mounting Line	* 20 hr 30 min	16 hr 20 min.
H	Fit Seats, Squabs, etc.	* 22 hr 20 min.	18 hr 20 min.
J	Car off Mounting to Test	* 23 hr 25 min.	19 hr 25 min.

TIME ALLOWANCES FOR LOADING OVERHEAD SUPPLY CONVEYOR FROM TRIM SHOP TO MOUNTING & FINISHING DEPT.

From Trim Shop Stores to Point "H"—2 hr 50 min.
From Trim Shop Stores to Point "D"—3 hr 30 min.
From Trim Shop Stores to Point "E"—4 hr 15 min.

*These times vary according to Hourly Production. Times specified are for Production of 16 per Hour.

PARTS REQD. FOR CHASSIS ERECTING

Dept	Operation	Time from Start "A"
Spray Polish	Paint Valance	10 hr 45 min
Axle Ass	Make up Axles, etc	12 hr
Synthetic	Paint Wings, Rads., etc	12 hr 20 min
Chas. Erect.	Assemble Chassis	13 hr 15 min

(B.466)

FIG. 12. MORRIS MOTORS, LTD., COWLEY, OXFORD
Assembly Works of 8 h.p. and 10 h.p. Car

components stores, while the gear boxes reach the assembly lines at the points where they are required for bolting to the engines. Completely assembled engines finally arrive at the test department Thence they pass to the spray-painting section Here the engines pass through the various booths, in which they are spray-painted and dried before being transferred to the engine stores and dispatch department

The third main section of the factory is employed for the manufacture of gear boxes and for machining various engine components. The components machined here include clutch parts, piston casings, and connecting rods As the plan indicates, the various machine shops have their own raw material stores, while adjoining the gear-box components machine shops are the heat-treatment department and the gear-box assembly shop There is a separate store for finished gear boxes from which the assembly belts are served.

7 *Iron and Steel Works* (*Figs.* 14, 15*a and b*)

Here is a strange personal experience of foreign methods of transportation.

The writer had to spend a day in Moji harbour, Japan, in 1929 while his ship was being coaled, and was very surprised to see the work being done entirely by hand. It made one think of pyramid building 4000 or more years ago

The coal collier was teeming with labourers who carried flat willow baskets on their heads,

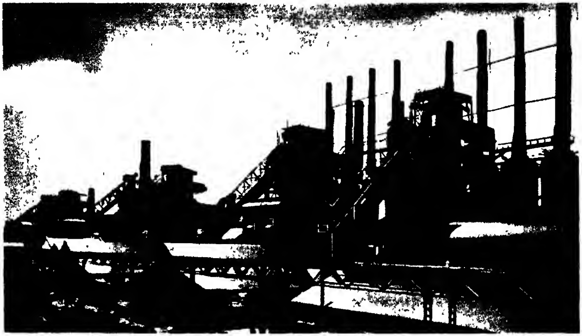


Fig 14 Yawata Iron and Steel Works in Moji, Japan

each holding twenty to thirty pounds each In the scorching heat, a team of sixty men loaded the ship with 1800 tons of coal from a collier in about twelve hours, the working teams being changed every two hours The man in charge told us that the total wages for his team were less than half of what it would have cost to have used modern loading apparatus, which was, in fact, available.

On the other bank of the harbour one could see, not more than half a mile away, the chimneys and blast furnaces of the Yawata Works (Fig. 14), the largest and most modern steel factory in Japan, employing between 18,000 and 20,000 people in normal times, and making the fullest use of automatic elevators and conveyors, etc. The procedure was to employ "hands" by the day and to dismiss them without consideration whenever there was insufficient work for them Such a method is not tenable in an orderly and well-managed factory The instance only proves that when there is abundant cheap labour and insufficient regular work to avoid unemployment, the weaker partner can be grossly exploited. However, the example causes one to consider very carefully whether or not *it* is advisable, from the economic point of view, to replace manual labour by automatic methods of transport and to install equipment on which standing charges (depreciation and interest) alone amount to more than the alternative labour cost. On this point, the degree of activity of a works is a decisive factor It makes a great difference if an iron and steel works produces, say, 100,000 tons or 300,000 tons per annum. Fig. 15*a* illustrates continuous material transport through a modern steel mill from the convertor to the rolling mills, replacing manual labour by machines wherever possible. Also, as a safety measure, men are kept off the dangerous ground floor as much as possible, being replaced by men sitting high up in the safety of crane cabins, steering machines instead of carrying loads and working near hot metals

Table III compares the costs before and after mechanization and a threefold increase of output The costs are in shillings per ton, based on pre-war (1935) prices

The diagram (Fig. 15*b*) illustrates clearly the decisive influence of labour cost in both cases and

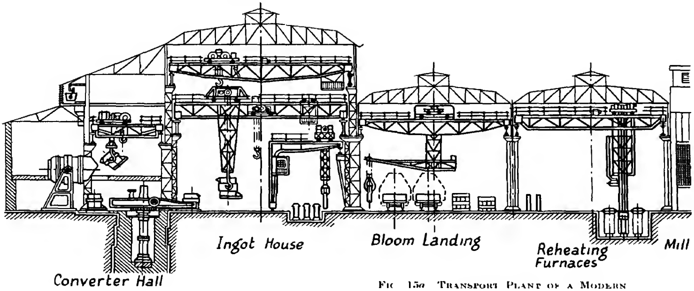


Fig 15*a* Transport Plant of a Modern Steel Mill.

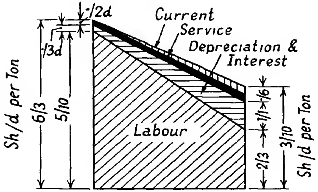


Fig 15*b* Comparison of Working Cost of the Old Plant with Much Hand Service and of the Mechanized Plant

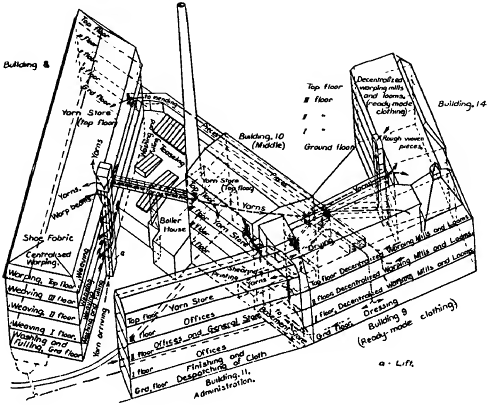


FIG 16a REBUILT WEAVING MILL—FLOW OF MATERIAL FROM THE ATTIC TO THE BOTTOM

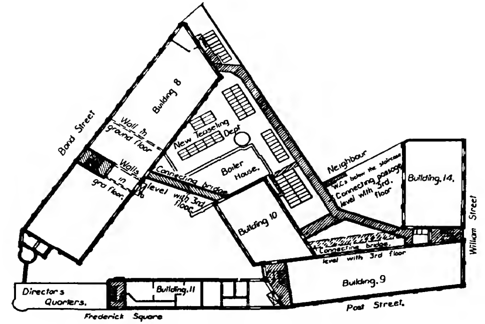


FIG. 16b. PLAN OF REBUILT WEAVING MILL

the effect of the standing charges of the new plant, which naturally consumes considerably more current and has higher depreciation and maintenance charges than the original hand-operated equipment. The cost of transport directly affects the price of the material, but the total production costs of the steel were almost halved by the installation of the expensive new plant

TABLE III

INFLUENCE OF PLANT AND QUANTITY ON PRIME COST

OUTPUT IN TONS PER YEAR	OLD PLANT 100,000 t/year			MOD PLANT 300,000 t/year		
	p c	per ton		p c	per ton	
		s	d		s	d
Wages for skilled and unskilled labour	93.4	5	10	58	2	2
Depreciation and interest (12½%)	4		3	28	1	1
Plant maintenance	2		1.5	7		3
Electric current	0.6		0.5	7		3
Total	100.0	6	1	100	3	9

8. *Textile Manufacture* (*Weaving Mill*) (*Figs.* 16*a* *and b*, 17)

In many cases, reorganization involves modernization of plant, and especially in such a reconstruction does the efficiency of a works manager become apparent New factories with large financial resources as those of Figs 3 to 15*a* and *b* are comparatively easy to erect from scratch. Figs 16*a* and *b*, however, show elevation and plan of a fifty-year-old textile factory which has been converted into a technically well-designed plant by erecting bridges, elevators, transport gangways, etc , changing the previous irregular and disorganized methods of transport and manufacturing operations into a steady and well-organized flow The diagram (Fig 17) shows the flow of the material from the yarn store, where finished and dyed yarns arrive from the yarn mill, through the warping, weaving, dyeing, and finishing departments where they are manufactured into cloth of different designs, sizes, textures, and weights.

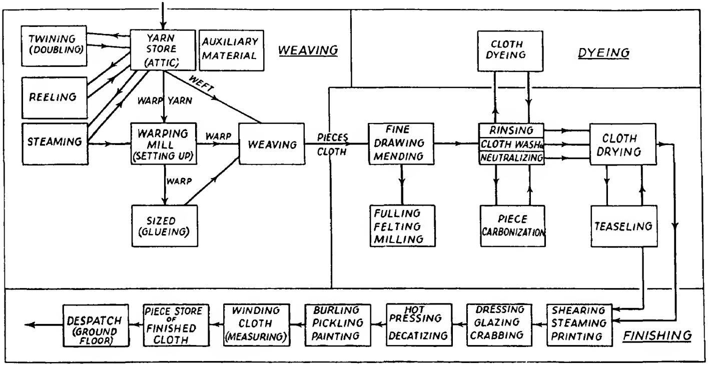


FIG 17 TRAFFIC PLAN OF WEAVING MILL

Yarns are woven into textile fabrics, which undergo complicated finishing processes to give them the required colours (or mixtures of colours) and textures according to the dictates of necessity or fashion The technical problem is to design a fundamental manufacturing arrangement which will provide for a continually changing design of cloth to be produced from the same plant

Yarn and dyestuffs are the direct materials, while soap, grease, acids, neutralizing chemicals and numerous other supplies form the auxiliary materials, which have to be transported to the different places of consumption The very light units of yarn (bobbins) are made up into fairly heavy finished pieces of cloth, but the latter are quite manageable by hand. However, the warping beams when loaded with cloth, are heavy and long, and as the factory (Fig. 16*a*) was a six-storey building it was necessary to have suitable lifts, *a*, of adequate width, to provide vertical transport from the yarn store in the attic to the dispatch room on the ground floor

The factory was one of 200 looms, obtaining its yarn by road transport from a spinning plant some miles away. After arrival in the factory yard, the cops or bobbins, which were shipped in baskets, were taken by fast elevators to the yarn store, located on the top floor, and from there moved down in the various forms of yarn, twist, warp, weft, and cloth, in one uninterrupted process to the bottom of the factory where they emerged as finished cloth. To accomplish this, a new top floor (attic) was added as storeroom for the yarn. In this textile factory, the writer, as the engineer in charge of reconstruction, not being handicapped by too profound a knowledge of textile details, was given the task of carrying out economies in yarn material by introducing new methods but without disturbing output The weaving mill consumed about 30,000 lb of wool a week. The wool in its raw state represented about 70 per cent of the final costs of the cloth (see Table II) and it was therefore of considerable importance to protect it from transport damage, if economies were to be made.

The old way of handling the yarn in the spinning mill was—

(1) Production of cops by automatic spinning machines, self-acting mules, and flyers, removing and packing the doffings into a transport container (wooden box, wicker baskets, etc , Fig. 18*A*).

(2) Forwarding to weighing machine, weighing the gross weight, deducting the tare—then on to yarn store.

(3) Repacking into storage shelves by female workers

(4) Repacking again into a transport case. and forwarding a certain proportion of the bobbins to a damping apparatus to eliminate the curling tendency of thread on the warping mill.

(5) Transferring the cops to a steam-resisting container and then damping them in the steaming box.

(6) Transferring the steamed cops back to the transport containers

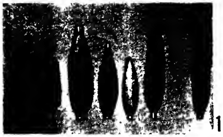
(7) Forwarding all cops to the loom as weft for the shuttle or as warp on the warping machine

The damage which occurred to yarn during all this handling was between one-quarter to one-half per cent material loss per week according to reliable figures furnished by the accountant. As the factory handled 30,000 lb yarn per week at 1s. 6d. per pound, this meant that between £6 to £12 per week, or up to £600 per annum, could be saved if all damage could be eliminated

This was in fact achieved by designing a container in which the yarn was transported from the spinning machine to the loom or warping mill, including the damping operation, without touching the cops. This was the solution of a technical problem involving the safe handling of very light and very delicate material

The container had to withstand rough usage in the factory, i e. be sat on by heavy operators, be pushed across the concrete floors, etc., and had to resist moisture (damping) without corroding and be unaffected by change of temperature

After some trials a suitable basket was successfully made, which has proved itself satisfactory in three large textile factories and although the equipment of a large factory with such baskets required quite an amount of capital, their introduction has paid for itself in less than two years, quite apart from the savings due to acceleration and simplification of the manual handling and the cost control.



1 DIFFERENT SHAPES OF BOBBINS

Effect of Welded Yarn Container on
- Yarn-Store in Transformation (A, B) (Tidiness, Savings)
- Self-acting Mule, Flyer (C)
- Balance (D)
- New Yarn-Store (E) (One Storekeeper stacking full Containers)
- Steaming Apparatus closed-opened (F)

FIG 18

YARN—TRANSPORT

from Flyer or Self-acting Mule to
Stores
Steaming Apparatus
Warping Mill or Loom

Fig 18 shows, by actual photographs, the difference between the old untidy wooden store (*A*) and the neat new baskets (*B* to *F*) which replace the storage shelves as well as providing means of transport

Especially noteworthy is the simplicity of weighing (*D*), as it is possible to manufacture the baskets to practically the same uniform weight with plus or minus one per cent deviation The frame is made of welded iron, the walls consisting of aluminium wire or galvanized netting, polished so as not to leave projections on which the fibre might be torn By adjusting the weighing machines accordingly, one is able to read off directly the correct weight without having to make the deduction for the *constant tare* This is a great advantage as it saves time and avoids errors

The number of porters is reduced to a minimum and the female packers of yarn-cops in the storeroom are completely eliminated One man looks after the store containing 60,000 to 80,000 lb of yarn, including necessary reserves, building up the yarn shelves by piling up the baskets as they come in The standardized bottom frame of each basket fits on to the top recess of the basket below (Fig. 18 *E*). Furthermore, the container is made so rigid that it can replace the usual stationary wooden or steel-shelving in the yarn storeroom It eliminates the special storeroom equipment for cops, i.e shelves, bins, etc , and permits of a permanent visual check on the colour of the yarns in stock and the contents of each basket, and finally, it provides automatic ventilation of the yarn from top to bottom, which is the best protective measure against damage by moths The whole extent of the problem is thus clarified and solved, minimum handling, greatest care of material, and smallest expense for weighing, transporting, storing, and packing

9. *Oil Refinery* (*Fig.* 19)

In the previous eight sections indications have been given as to the organization required in the mechanical manufacture of various machines, textiles, and other products.

In the concluding section an entirely different concept will now be considered In the manufacture of petroleum products it is not possible to think of the finished substance as so many articles requiring individual handling. We are concerned in the main with fluids, and fluids must be handled in bulk The refining of crude oil is almost wholly the practical application of the two fundamental problems of chemical engineering, the flow of fluids and the transfer of heat This is shown in diagrammatic form in Fig 19, which represents a scheme for the manufacture of a range of special products from crude oil

The crude oil is transported by pipeline or ocean-going tanker from the producing field to the refining centre, which in this particular case is located in a consumption area Tankers may carry up to 22,000 tons of oil, and normally can discharge their cargo at a rate of 10,000 tons in twenty-four hours The oil is first split up by distillation into a series of fractions, which differ from each other in their boiling ranges, a lower boiling point normally indicating lower molecular weight In Fig 19 the fractions are kerosene, gas oil, three distinct lubricating oil fractions, and a heavy residuum The lubricating oil fractions go by way of intermediate storage to the solvent extraction and dewaxing plant, the function of which is to separate each fraction into the three constituent parts of stable component (saturated molecules), unstable component or extract (unsaturated molecules), and wax The primary product, the stabilized component, passes on by way of intermediate storage to the chemical treatment section, where the treatment given depends on the final product required For the production of normal lubricants, treatment with activated Fuller's earth at a fairly high temperature is usually sufficient (shown in red) In the production of white oils and medicinal paraffin (blue on illustration) the stabilized component from the solvent extraction plant is reacted with oleum (fuming sulphonic acid) and all but the completely saturated molecules are sulphonated and removed. These sulphonated compounds are important by-products of the process, and are made into emulsifiers, etc , as shown again in blue The primary product, which is unaffected by oleum, has a final treatment with Fuller's earth and is then packed into containers according to the use for which it is intended and the destination to which it is going.

The control of the quality of the various products to a rigid specification is achieved only by the following—

1 Maximum installation of automatic control instruments, which reduce any reliance on the human element to a minimum

2 Continuous operation, which eliminates variation due to start-up and shut-down periods

3 The intelligent use of intermediate storage, which allows a particular plant to run the maximum time on one product and therefore, under one set of conditions

4 Continuous laboratory control of all products at each stage of production

Add to this, constant research and development work in the utilization of by-products, and as a result the crude oil can be transformed into forty-five different useful products, with an overall loss of only two to three per cent

As distinct from other organizations, storage space for products in the course of treatment is only available in the form of tanks and vessels, for which a company has to lay down a considerable amount of fixed capital The accommodation is therefore limited, but the transporting of products from one storage tank to another by pipeline and pumps is considerably cheaper than the handling of the products dealt with in the previous chapters, such as heavy ingots of steel or copper

In some cases, the whole organization of an industry can depend upon the successful movement and flow of its raw material and semi-finished stocks and on the manner in which they travel from one workshop to another In the case of a refinery the pipeline systems are so arranged that transfer of oil stocks from any one section of the refinery to another can be effected at a moment's notice by the mere switching on of valves and pumps by one operator, and thus the movement of thousands of tons of products—which is a major operation in the heavy steel industries—is a one-man operation in a refinery

The costing organizations of other industries will therefore have very many variables that will affect their final production figure, which are quite irrelevant to an oil refinery.

Supplying Material to the Machines

As already mentioned (page 15), the managerial aspect of the material supply problem may be analysed on the following lines (see Table IV)—

(1) Drawing office design of product, preparation of parts list

(2) Works production department determination of material, type, dimensions, and quality, standardization

(3) Purchasing

(4) Obtaining supplies

(5) Receiving, checking (laboratory), preparing the invoice

(6) Storing and issuing.

(7) Feeding to working places.

(8) Dispatch of finished product.

(9) Costing as a means of economic control

The design of the product and preparation of parts list, as well as the determination of type, dimensions and quality of material is done in the drawing office. The standardization of materials is a natural consequence and is the basis of economic design

Preparation for buying, as regards determination of quality and quantity, is done by the works production department (planning) in consultation with the buyer and the designer (items 2 and 3)

The selection of the supplier and the decision as to quantities required is a matter for the purchasing department, after consultation with the managing director where large quantities are involved (3 and 4)

Receiving and checking of incoming goods according to quantity and quality are done by the technical control and the stores (5 and 6)

Storing and issuing of material, against requisition slips only, are done by the storekeeper, using the parts list and the planning department's time-schedule as a means of control, in close co-operation with the foremen, for the feeding of materials to the departmental work-in-progress stores or directly to the machine-tools (6 and 7)

Goods, after passing final inspection, are dispatched either directly or indirectly by the finished goods stores (8). The effect is that the customer and the planning department are pushing, while the workshops are pulling to

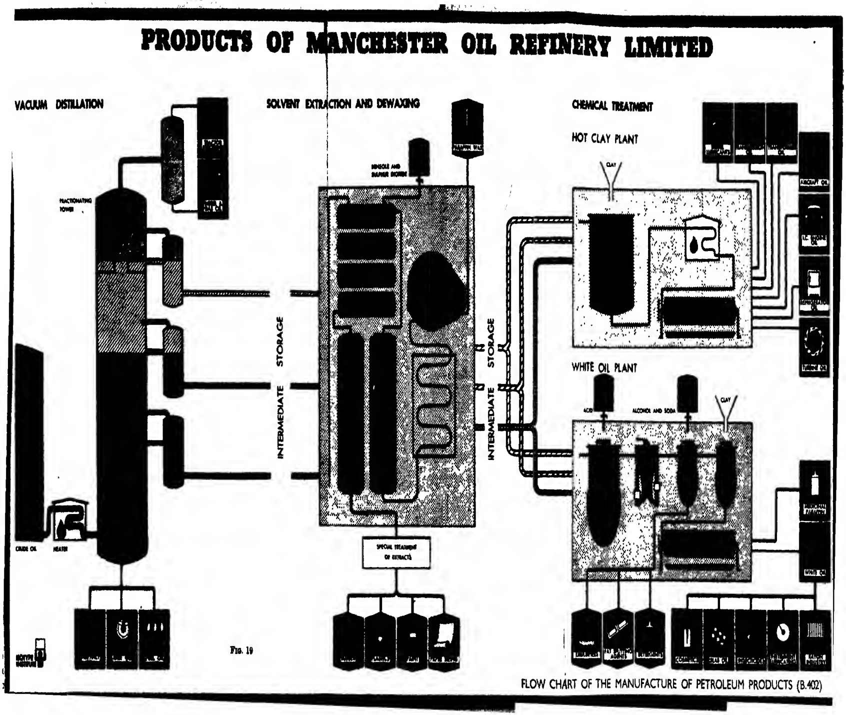
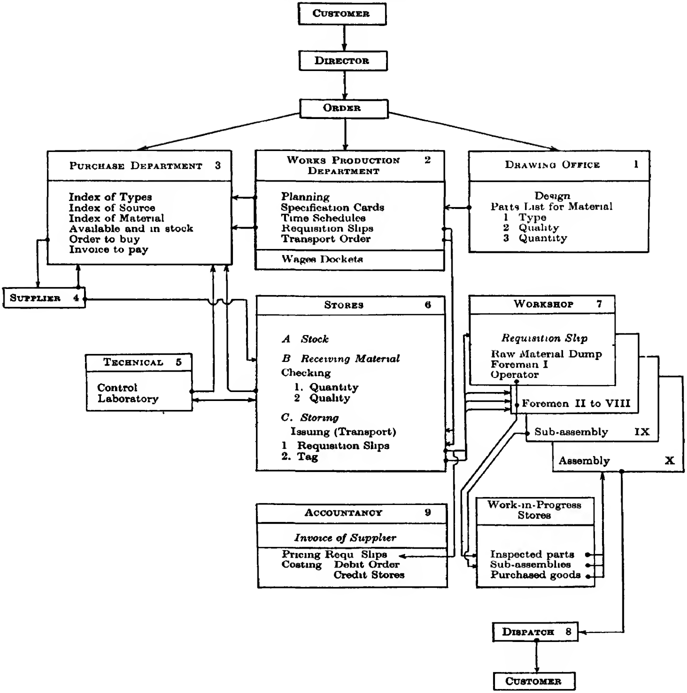

PRODUCTS OF MANCHESTER OIL REFINERY LIMITED
VACUUM DISTILLATION
FRACTIONATING TOWER
CRUDE OIL
HEATER
SOLVENT EXTRACTION AND DEWAXING
BENZOLE AND SULPHUR DIOXIDE
PARAFFIN WAX
SPECIAL TREATMENT OF EXTRACTS
INTERMEDIATE STORAGE
INTERMEDIATE STORAGE
CHEMICAL TREATMENT
HOT CLAY PLANT
CLAY
AIRCRAFT OIL
REFRIGERATOR OIL
TURBINE OIL
WHITE OIL PLANT
ACID
ALCOHOL AND SODA
CLAY
MEDICINAL PARAFFIN
WHITE OIL
EMULSIFIERS
DETERGENTS
COSMETICS
FLOW CHART OF THE MANUFACTURE OF PETROLEUM PRODUCTS (B.402)

Fig. 19

TABLE IV

MATERIAL MANAGEMENT



achieve the result of getting the right material to the machines at the right time

The accounts department (9) pays to the material supplier (4) the amount on the checked invoice (5), and the costing department (9) debits external and internal orders and credits the stores with the cost of materials listed on the receipts and requisition slips, as checked by the parts list Thus the circle is closed drawing office—planning department—purchaser—supplier—stores—laboratory—workshop—costing—accountancy The "Circulation Chart" (Table IV) shows in detail how this is done and how the various departments collaborate in the task of executing an order

We will now consider the departments individually —

(1) *The Drawing Office*

The designer determines from his drawings the shop requirements type of raw material (e g Ni. Cr steel bar 3·5 per cent Ni of 1⅝ in diameter), its quality and quantity or length.

Associated with the drawing (e g. tailstock Fig. 20) but suitably separated from it is the parts list (Fig. 21) showing in detail the materials required This most important list is prepared by specially trained men.

The parts list is divided into the main sub-assemblies e g in the case of a lathe—the head-stock, carriage, apron, tailstock, and bed, in the case of a motor car—the chassis, wheels, engine, carburettor, radiator, transmission gear, brakes, steering, tank, and in the case of a bridge—girders, bearings, piers, roadways, etc These groups are subdivided according to the assembly requirements of the fitting department, for every good designer (who gives his work adequate thought) puts himself into the position of the fitter, who actually has in front of him all the separate manufactured parts and/or sub-assemblies and must assemble them according to a definite plan. Because the assembly viewpoint is predominant when making the parts list, one finds in it a wide variety of items For instance, in the tailstock of a lathe there are: the body

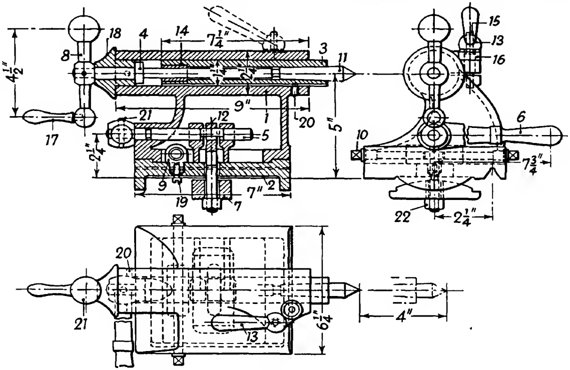
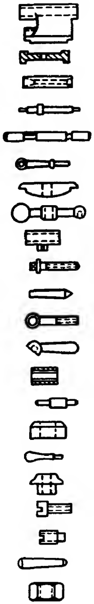


Fig 20 Design of Tailstock



Drawing No	Pattern No	Pos	Pieces	Part	Material	Sketch	Material Weight Lb	Material Price s d	Parting	Forging	Planing (Shaping)	Slotting	Vertical Drilling	Horizontal Drilling	Turning (Capstan)	Tapping	Milling	Grinding	Hardening	Painting	Fitting	Total Time
									Working Time in Minutes													
300	23	1	1	Tailstock body	C I		18 2	9 10	—	—	170	—	37	70	—	39	170	—	—	—	112	598
301	24	2	1	Plate	C I		7 92	4 3	—	—	—	—	3	—	—	—	63	—	—	—	—	66
302	—	3	1	Sleeve	Steel 40 tons		1 98	2 7	4	—	4	—	3	9	140	—	—	12	—	—	—	172
3	—	4	1	Spindle	Steel 40 tons		0 55	9	3	—	—	—	5	—	120	—	14	—	—	—	—	142
4	—	5	1	Eccentric shaft	Steel 40 tons		0 44	8	Capstan	—	—	—	—	—	9	—	—	10	—	—	—	19
5	14	6	1	Lever	Malleable I		1 10	6	—	—	—	—	4	—	9	—	4	—	—	—	3	20
6	16	7	1	Strap	C I		0 44	2½	—	—	—	—	—	—	—	—	9	—	—	—	—	9
7	—	8	1	Ball handle	Steel 30 tons		0 71	10	Capstan	—	—	—	5	—	16	—	4	—	—	—	—	25
8	12	9	1	Adjusting nut	C I		0 40	2½	—	—	—	—	—	27	21	23	—	—	—	—	—	71
9	—	10	2	Adjusting screw	Steel 40 tons		0 22	4	Screw m/c	—	—	—	—	—	3	—	2	—	—	—	—	5
10	—	11	2	Centre	Cast steel		0 29	11	3	—	—	—	—	—	15	—	—	12	10	—	6	46
11	—	12	1	Eye bolt	Steel 40 tons		0 22	4	—	8	—	—	5	—	3	2	4	—	—	—	—	22
2	—	13	1	Handle	Steel 30 tons		0 33	5	Capstan	—	—	—	3	—	4	2	—	—	—	—	—	9
3	17	14	1	Sleeve nut	Bronze		0 40	9	—	—	—	—	—	—	20	—	—	—	—	—	—	20
4	—	15	1	Pivot bolt	Steel 40 tons		0 12	2½	Screw m c	—	—	—	—	—	3	—	—	—	5	—	—	8
5	—	16	1	Clamping ring	Steel 40 tons		0 08	1½	Screw m c	—	—	—	—	—	2	—	—	—	—	—	—	2
6	—	17	1	Handle	Steel 30 tons		0 16	3	Screw m c	—	—	—	—	—	4	—	—	—	—	—	—	4
7	18	18	1	Bushing	C I		0 78	5	—	—	—	—	—	—	55	—	—	—	—	—	—	55
8	—	19	1	Screw	Steel 40 tons		0 07	1½	Screw m c	—	—	—	—	—	0 8	—	—	—	—	—	—	0 8
9	—	20	4	Grub screw	Steel 40 tons		0 018	½	Screw m c	—	—	—	—	—	0 5	—	—	—	—	—	—	0 5
20	—	21	2	Taper pin	Steel 40 tons		0 022	½	Screw m c	—	—	—	—	—	0 6	—	—	—	—	—	—	0 6
21	—	22	1	Hex nut	Steel 40 tons		0 055	1		—	—	—	—	—	1 2	—	—	—	—	—	—	1 2
							34 505	23 10	10	8	174	—	65	106	427 1	66	270	34	15	—	121	1296 1

Fig. 21 Parts List of Tailstock

Used for 1 Purchase of Material 2 Ratefixing 3 Time and Price Control made of cast iron, the quill of mild steel, the nut of bronze, the spindle of hard steel, the low-stressed screws of semi-mild steel In the complete lathe there are highly stressed gears and shafts of nickel-chrome steel, lower-stressed gears of mild steel there are also ball and roller bearings, grease wicks, copper tubes, bolts, and other purchased items

(2) *The Works Production Department*

Such a designer's list, although suitable for the manufacturing side, is of no use to the material buyer who, in order that the parts of the tailstock can be manufactured, has first to obtain the material *not already in stock or due for supply against orders already issued* Therefore the engineer's parts list must be rearranged according to materials e g cast iron, semi-mild steel, alloy steel, copper alloys, aluminium alloys, etc, owing to the fact that one cannot obtain all these different materials from one source The supplier works according to types, therefore the purchasing list must contain type, quantity, and quality, as well as raw and finished weights of parts, so that one is able to compare the actual delivery (gross weight) approximately with the details set out by the designer (net weight)

A number of essential points are added which must be considered in preparing buyer lists, so that the material can be dealt with in the correct way on arrival For instance, in iron construction and bridge design, or in goods and passenger cars, short pieces for different parts are combined by the purchasing department into long bars or girders, and the storekeeper must be able to determine clearly how the ordering took place, so that when the bars or sections arrive in the store-yards they are not cut up wrongly

The raw and finished weights vary, of course according to the type of manufacture The amount of material allowance for machining depends upon the type and quality of the raw material, it is naturally quite different for bright-drawn bars and for black bars of the same nominal dimensions

As the type of material depends on practical needs, the best and cheapest way is for a technical person in the works production department to change the parts list into a buyer's list, rearranged according to types of materials However, it is rather difficult to work with "lists" as such, particularly when copies are needed to be kept in the workshop, stores, and book-keeping departments, and there is always the difficulty of inserting forgotten or added parts in the right place on the list In any case the parts list has at some time to be broken down later into requisition slips for each single part The best solution is therefore to write out another set of material requisition slips and to fill in the necessary dimensions, etc, and to use these for purchasing purposes This can simply be arranged by persons who design such forms as are used by the company

The great advantage is that the ordinary parts list is now split up into single slips, which can be easily sorted by the purchaser according to kinds of materials, quantities, and suppliers, without additional clerical work The slips for those parts which he may wish to combine into rods, bars, sheets, etc (as mentioned above), are pinned together and a note is made on the duplicates issued to the storekeeper of the method in which they have been combined (See page 44)

The writing out of requisition slips for the withdrawal of material from the stores by the workshops can be therefore combined with the preparation of the parts list for buying The feeding of material to "work-in-progress" stores or to machines is arranged by issuing material slips to the foremen according to schedule by the works production department

(3) and (4) *Purchasing and Obtaining Supplies*

The activities of the purchasing department are manifold and its manager must possess a good technical knowledge to aid him in his commercial functions As soon as the purchaser receives a copy of a new order, he has to follow out the following plan—

(*a*) From the modified parts lists, either in the form of requisition slips or of a re-arranged material list, to find out which materials are not available in the works, and must therefore be ordered at once from outside. Actual stock in the stores may have been already allocated for orders in hand, additional material required must be ordered at once without prompting by the storekeeper. (See page 56.)

(*b*) Keep an up-to-date card-index of sources of supply

(*c*) Prepare and maintain an allocation card-index for material still to be purchased. (See Table VIII.)

(*d*) Maintain a record of incoming material by means of delivery cards.

(*e*) Issue delivery reminders to suppliers, using a datal index system with signals

(*f*) Continue to urge the supplier until the material arrives in the stores

(*g*) Check the invoice and sanction payment to the supplier.

(5) and (6) *Reception and Stores*

(*a*) Supply of material, its acceptance, inspection for quality, shortages, returns

(*b*) Classification in store, marking, and protection.

(*c*) Issue of material (against requisition slip only)

(*d*) Delivery of receipted slips to stores account for costing.

The laboratory, where this exists, checks the chemical analysis, the material strength and the machining index It is an error to believe that the carbon content figure of mild steels or their Brinell hardnesses are sufficient to indicate their machining properties Carburizing steels with 0·10 to 0·15 per cent carbon are often less machinable than ordinary fairly hard steels with 0 3 to 0·4 per cent carbon and, say, 35 tons/sq in ultimate tensile strength Therefore, both chemical analysis and physical strength (Brinell hardness or tensile strength) together give only an approximate idea of the machining properties of materials For example, pure copper is very soft and is yet one of the least machinable metals; the same is true of stainless austenitic steels, self-hardening (manganese) steels, and other materials which combine low resistance with dulling properties. (See Machinability Conditions page 125)

Control of quality decreases costs of production and distribution, increases output of saleable goods, and makes economic mass production possible.

The highest efficiency in the *storage* of materials, tools, and supplies is obtained by providing a definite place to store every type of item, by keeping it invariably in its assigned place, and by keeping adequate records thereof

Castings should have the number cast in, stampings and forgings should have it pressed in. Bars should be stamped on both flat ends and coloured over the total length with a resistant adherent colour to avoid mixing during the machining processes.

(7) *Issue of Materials to the Workshops*

Issue should be made only against requisition slips, which should be sent from the works production department to the foreman and the storekeeper only after the production control has verified that the material is on hand in the stores This information comes from the storekeeper and the technical control who automatically and simultaneously inform the purchasing department, the works production control, and the accountant's department of the receipt of every consignment by means of acceptance and invoice slips

Material Standardization*

The importance of material standardization is indicated by the fact that the outlay for materials is the largest single item of cost for the average manufacturer. The last American census report showed that, for all manufacturing industries, the combined cost of materials, fuels, etc , was about 55 per cent of the value of output which confirms fairly closely the figures shown in Table II on engineering factories of all kinds

Material standardization is especially necessary in order to systematize the supply function, to render production materials readily available, and rapidly to train new employees in the company's material requirements. It tends to eliminate industrial waste, conserves raw materials, finished products, and labour, and generally helps to increase production and reduce costs

Material standardization affects every phase of design, procurement, and production; the more

* "Benefits of Material Standardization," by F G. Jenkins, *Mechanical Engineering*, Vol 64, July, 1942 "Material Standardization," by S B Ashkinazy, *Mechanical Engineering*, April, 1944

important gains achieved include a reduction of direct and indirect costs, a systematizing of business, an increase of the size of batch, and an improvement in the quality of the manufactured products In the industries to which it has been applied, the systematic standardization of manufacturing materials has succeeded in bringing about major economies in material, labour and administration, and a better control of operations

Material standardization in a particular firm is carried out by a material standards engineer or department in collaboration with the purchasing, engineering, inspection, and stores departments, and with the co-operation of the suppliers This organization, through an inventory analysis and research, establishes and maintains—

1 Material standards
2 Standards book.
3 Purchase specifications

1. *Material Standards* A material standard is defined as that material which, at any given time is the best and most economical quality, form, and size for the service required It is established by general consent as a result of engineering study combined with experienced operation

The types, grades, forms, or sizes of materials employed should be reduced to the fewest number consistent with successful operation A standard also comprises the establishment of preferred dimensions, grades, and tolerances as well as chemical and physical, and other serviceability factors

2 *Standards Book* The backbone of each materials standardization programme is the "Material Standard Book." It should contain complete and up-to-date information on practically all materials used in the company. For each material standardized, a material standard is written out, embodying the following information (according to requirements), company identification name (trade name), colour, and code number, approved sources of supply and complete purchase information; chemical composition, physical, mechanical, and electrical properties, notes on application, characteristics, fabrication, heat-treatment, and corrosion resistance, method of specifying the material on drawings, available commercial forms and sizes; and dimensional tolerances These material standards should be assembled in loose-leaf binders forming the standards book and distributed to all senior engineers, designers, and draftsmen, and to personnel in inspection, purchasing, planning, manufacturing, and stores The manuals are kept up to date as new standards are added and old ones revised by a standards supervisor, who is responsible for bringing changes to the attention of all holders of standards books

The standards department maintains files of Government specifications and other recognized standards and specifications, commercial catalogues, and technical literature It should maintain sample cabinets containing collections of materials and surface finishes

3 *Purchase Specifications* The purchase specification is a commercial version of the relevant section of the Standards Book and is the medium used for expressing a particular material standard so that it may be clearly understood by the vendor, the buyer, the inspector, and the user The specification comprises the name of the material, the symbol of the material, and a statement of the use for which it is intended It also contains carefully prepared and concise statements in measurable terms of chemical analysis, physical properties, and dimensions, as well as methods of testing and sampling, together with details of other qualities such as form, finish, methods of manufacture, and, where necessary, reference to samples

There are three main classes of materials·

1 Basic raw materials
2 Materials of secondary importance, but required in quantities directly proportional to the rate of production of some product or products
3 Materials required at practically a constant rate, irrespective of output

1. *Basic raw materials* All manufacture requires some materials which are of exceptional importance, because they comprise the principal elements entering the product, and usually no substitutes are permissible The requirements are relatively large and at a rate which closely approximates to the rate of manufacture of the products of which they form a part For example· the steel, cast iron, and bronze used by a machine

tool maker, the coal used by the gas or coke manufacturer; the ores used by a brass or steel mill, the fats and oils required by manufacturers of soap and lubricants, the cotton or wool purchases of the textile factory, and the wheat required by the miller each in its way illustrates the type of materials included in this group. The inventory budget for goods of this general type involves two main considerations

(*a*) Estimating the probable requirements for a season's contracts.

(*b*) Timing deliveries to avoid interruption of manufacturing operations

2 *Materials of secondary importance* but required in quantities directly proportional to the rate of production of some product or products, e g ball bearings, sheet iron for safety covers, chains, belts for driving mechanisms, oilers for bearings, tubes and pipes, etc The dividing line between this group and the one just considered may in some respects seem somewhat arbitrary, for the difference is one of degree It is an important one, however, for the investment in materials of this type is much less This has some bearing upon the methods used for planning and controlling inventories

3 *Materials required at practically a constant rate.* Waste, wipers, files, abrasives, lubricating oils and compounds, building and equipment maintenance materials, stationery, and the like are examples of this kind of materials

Use of Standardization in Engineering **(*See p. 134*)**

The complete and accurate information made available in the standards book is of great value to the designer, planner, buyer, and workshop, enabling all to apply the materials more effectively

With this as a guide, anyone requiring, for example, a steel for a certain purpose can readily determine the most suitable material by consulting the standards book The designer or engineer is encouraged to consider what is offered, and if necessary to vary his design slightly to permit the purchase and utilization of one of the standard materials listed. The requisitioner, with the aid of ordering data also provided in the standards book, simply copies on to the requisition the name of the materials, the company's specification number, and the form, size and quality required

Standardization of this kind eliminates much doubt and controversy and reduces the work of the draftsman in deciding what material and size to use, as his choice is limited to those specified.

In addition, the establishment of standardization simplifies and reduces the cost of instructing new employees, for there are fewer varieties with which to become acquainted and because it is no longer necessary to learn by trial and error what is in stock and what is standard.

Further, one can be sure that the grade and quality of materials purchased are precisely those required for the job

Standardization is one of the principal means of getting the results of research and development into actual use in industry

Manufacturing

Standards of achievement are dependent upon standards of materials, as well as equipment methods, and products

A programme of material standardization *will reduce the total number of tools and of types or cycles of manufacturing processes required*, and this will naturally result in higher labour efficiency due to increased skill arising out of repetitive processes Also, time and materials will be saved by using the correct cutting angles appropriate to groups of standardized materials (see Table XVIIIA) and increased tool life will ensue by reducing the material allowance of bars, etc

With one single standard specification instead of many, quantity production is possible, thus bringing about a reduction in overhead charges, particularly those arising from the duplication of machinery, the cost of testing, and the rent of storage space This all results in increased economy. When the manufacturer is operating at capacity, simplification will permit the machines to turn out products without being handicapped by the delays incidental to processing small batches of material to suit superfluous specifications

Material Inspection

Purchasing specifications equip the *inspector of incoming purchased material* with definite test criteria by which to determine whether the correct quality and quantity of material is being received, and on which to reject inferior goods, thus avoiding inspection which is either too lax or too stringent. Unless definite standards and specifications are established setting out these limits, it is obvious that there can be *no intelligent inspection.* Standardization simplifies inspection of materials and cuts down the cost of this work to a minimum, since the inspection follows a definite routine.

Standard methods of sampling and testing, outlined in the purchase specifications, enable both producer and consumer to test the material in the same manner and obtain comparative results. By providing a workable basis of acceptance and rejection there is a consequent reduction in the number of disputes with suppliers over rejected material

From the standpoint of reducing manufacturing costs, it is more important for the buyer to help in developing standardization within his plant than it is for him to attempt to cut the unit price of any article on his list of purchases Care should be taken to make *all purchases on detailed specifications* The importance of using the materials best suited to the work, uniform in quality, and of the least range in variety, is often not sufficiently appreciated even by the buyer in the most systematized works

Where the material requirements are fully standardized, *a small purchasing force* can turn out more work then a staff twice its size working under the handicaps of non-standardization

Standardization of nomenclature simplifies the details of purchasing, eliminates superfluous effort, and avoids unnecessary 'phone calls or correspondence with requisitioners It simplifies the problem of requisitioning, since standard materials need not be described in detail, but may be referred to by a recognized name and a generally accepted capacity or size designation or number

Whenever possible, purchasing executives should follow the policy of purchasing from two or more sellers of a given material.

Only by the use of standard specifications is it possible to bring about a condition of truly competitive bidding and ensure that quotations are really comparative this is one of the fundamental objects of preparing specifications

Furthermore, the continual quarrel between quality and price, which is one of the most difficult problems of purchasing, is resolved only by proper and adequate specifications.

A full, precise specification assures the supplier that a scientific basis for fair dealing has been furnished, and that he is not bidding against some other manufacturer supplying an inferior material.

It is advisable to combine buying on specifications with an *approved list of manufacturers* who have proved their ability to furnish uniformly good material to the specification and to produce the quantity required with efficient service and at the right price

Such an accredited list which should be authorized by the management, is most essential in respect of materials which would require elaborate or expensive tests, involving complicated testing equipment, in order to determine its suitability for its intended purpose In such a case it would be most unwise to purchase from unproved vendors

The Standards Engineer should work closely with the purchasing department in compiling the list of approved sources of supply When a material is standardized, the lists of prospective manufacturers are submitted to the purchasing department for comment

Delivery

It is evident that with standard raw materials there will be *greater ease in securing supplies.* By the use of a comparatively small number of materials, which can be carried in stock, a supply is always available for fabrication

Inventory simplification also permits of the placing of large orders, which in turn are productive of better delivery service from the suppliers.

The use of nationally-recognized standard materials reduces costs, because these materials can be manufactured in the largest quantities, thus bringing about a decreased unit cost and an increased uniformity in output.

Stores

Reduction in the variety of qualities, forms, and sizes of materials employed, enables the sizes of bins to be standardized and their variety also reduced. This reduction in the variety of materials to be kept in stock, and the simplification of their manner of storage conduces to quicker turnover, and aids still further in reducing inventory Another advantage of standardization is an increase in the ability to secure materials in the local market Simplification also reduces the number of records necessary for stocking materials and produces more effective stock control

Examples of Practical Application of Standardization in General Engineering

A big British works, making special types of machine tools and their necessary equipment is using—

9 kinds of mild steel bars from 0 1/0·18 per cent to 0·75/0 85 per cent carbon

4 kinds of nickel-chrome steel bars.

4 kinds of special tool steel bars

(Carbon steel—high-carbon tool steel—special tool steel—high-speed steel 18–4–1*.)

1 kind of brass bar

1 kind of grey iron casting

1 kind of steel casting.

1 kind of malleable casting

2 kinds of aluminium castings

1 kind of phosphor bronze casting

1 kind of gun metal casting

1 kind of babbitt metal for bearing lining

This is a total of twenty-six different kinds of metals, which is very moderate, for there are many manufacturers who consider it necessary at least to have 120 different types of material (See page 134, Alloy-steels for Motor-cars.) As the drawing office must allow for the use of several sizes of each of the above-mentioned thirteen types of steels the standardization of diameters and their tolerances is a matter of vital importance to ensure the minimum amount of stock being carried

Series				Series				Series				Exact Values	Mantissa
40	20	10	5	40	20	10	5	40	20	10	5		
1	1	1	1	10	10	10	10	100	100	100	100	10000	000
1,06				10,8				106				10593	025
1,12	1,12			11,2	11,2			112	112			11 220	050
1 18				11,8				118				11 885	075
1 25	1,25	1,25		12,5	12,5	12,5		125	125	125		12 589	100
1,32				13,2				132				13 335	125
1,4	1,4			14	14			140	140			14 125	150
1,5				15				150				14 962	175
1,6	1,6	1,6	1,6	18	18	16	16	160	160	160	160	15 849	200
1,7				17				170				16 788	225
1,8	1,8			18	16			180	180			17 783	250
1,9				19				190				18 836	275
2	2	2		20	20	20		200	200	200		19 953	300
2,12				21,2				212				21 135	325
2,24	2,24			22,4	22,4			224	224			22 387	350
2,36				23,6				236				23 714	375
2 5	2,5	2,5	2,5	25	25	25	25	250	250	250	250	25 119	400
2,65				26,5				265				26 607	425
2,8	2,8			28	28			280	280			28 184	450
3				30				300				29 854	475
3,15	3,15	3,15		31,5	31,5	31,5		315	315	315		31 623	500
3 35				33 5				335				33 497	525
3,55	3,55			35,5	35,5			355	355			35 481	550
3 75				37 5				375				37 584	575
4	4	4	4	40	40	40	40	400	400	400	400	39 811	600
4 25				42,5				425				42 170	625
4,5	4,5			45	45			450	450			44 668	650
4,75				47 5				475				47 315	675
5	5	5		50	50	50		500	500	500		50 119	700
5,3				53				530				53 088	725
5,8	5,6			56	56			560	560			56 234	750
6				60				600				59 566	775
6,3	6,3	6,3	6,3	63	63	63	63	630	630	630	630	63 096	800
6,7				67				870				66 834	825
7,1	7,1			71	71			710	710			70 795	850
7 5				75				750				74 989	875
8	8	8		80	80	80		800	800	800		79 433	900
8,5				85				850				84 140	925
9	9			90	90			900	900			89 125	950
9,5				95				950				94 406	975

TABLE V
PREFERRED NUMBERS

Preferred Numbers

A widespread use of the system of "Preferred Numbers" for the economic choice of standardized diameters squares, and hexagons, etc, is recommended Table V shows the section from 1 to 100 in the list of preferred numbers with four different common ratios as used in the U S A and on the whole of the European continent (I S.A Standardization), and might well form a basis for all manufacturers, steel makers, and users.

There is not the slightest reason why one designer should feel thwarted in the exercise of his art if the permissible diameters are not stepped by $\frac{1}{64}$ in., while another is satisfied with steps of $\frac{1}{16}$ in. or $\frac{1}{8}$ in., and for the bigger diameters with $\frac{1}{4}$ in. to $\frac{1}{2}$ in. A good British example is the

* 18 per cent W (Tungsten), 4 per cent Cr (Chromium), 1 per cent V (Vanadium)

diameters of bolts and nuts for B S F, B S W. and B S.P threads, by which the steps are $\frac{1}{32}$ in., $\frac{1}{16}$ in, and $\frac{1}{8}$ in for fine threads, $\frac{1}{16}$ in., $\frac{1}{8}$ in., and $\frac{1}{4}$ in. for standard B S W, and $\frac{1}{8}$ in., $\frac{1}{4}$ in., and $\frac{1}{2}$ in. for pipe threads of the same dimension ranges, e g. $\frac{1}{8}$ in to 2 in diameters As the drawing office provides the basis for the work of the purchaser, these two departments should collaborate to establish the best and most economic design. Often designers need to have their attention forcefully drawn to the necessity of economy

The following guide is suggested for the tolerances (margins) of bar material wrought, free-cutting, and rapid-machining steels

(*a*) Bright Steel Bars for Automatic Semi-Automatic and Turret Lathes (Table VI)—

TABLE VI

TOLERANCES OF BRIGHT BARS

Round		Square		Hexagon	
Standard Dia in in	Tolerance − 0 000	Width across Flats in in	Tolerance + 0 000	Max Width across Flats in in	Tolerance + 0 000
$\frac{1}{4}$ to $\frac{9}{16}$	0 002	$\frac{1}{4}$ to $\frac{1}{2}$	0 003	0 193 to 0 525	0 003
$\frac{5}{8}$ to $\frac{7}{8}$	0 003	$\frac{9}{16}$ to $\frac{7}{8}$	0 004	0 6 to 0 92	0 004
1 to 2	0 004	1 to 2	0 005	1 01 to 2 05	0 005
$2\frac{1}{8}$ to 4	0 005	$2\frac{1}{8}$ to 5	0 006	2 22 to 4 530	0 006
$4\frac{1}{8}$ to 5	0 006	Above 5	0 007		
Above 5	0 007				

(*b*) Tolerances for blue and black bars are not specified in the British Standards The American Society of Automotive Engineers, New York, published on 5th Jan, 1945, Standards AMS 2231 which are similar to the British margins, but vary with the contents of carbon

STRAIGHTNESS (AMS 2231)

(*a*) Cold-finished, heat-treated or machine-straightened bars shall be of such straightness that the maximum curvature (depth of arc) shall not exceed 0·125 inch in any 5 feet of length, or 0·025 inch × length in feet for other length.

(*b*) Hot-finished bars (unless otherwise ordered) shall be of such straightness that the maximum curvature (depth of arc) shall not exceed 0·25 inch in any 5 feet of length or 0 05 inch × length in feet for other length

These fine tolerances are necessary because of the spring collets of the turret lathes and automatics, which are easily damaged if the diameter or the thickness of the bar varies by more than the permitted tolerance, this is a point which must be carefully watched by the technical control Curved or crooked bars are worse than those which are not round or have excessive tolerances, they cannot be safely clamped either by collets or by ordinary chucks, although compressed-air chucks allow for larger deviations The British Standard Specifications Nos 970 and 971* deal with—

Carbon steels,
Carbon manganese steels,
Carbon manganese silicon steels
Carbon manganese molybdenum steels
Carbon nickel steels
Carbon chromium steels
Carbon nickel chromium steels
Carbon chromium molybdenum steels
Carbon nickel chromium molybdenum steels
Carbon nickel chromium tungsten steels
Carbon nickel chromium titanium steels
Carbon chromium vanadium steels
Carbon chromium silicon steels
Carbon chromium aluminium steels
Carbon managanese nickel chromium steels

The selection of the type of steel for a given application should be based on consideration of the particular conditions of service to which the steel and the component part into which it is made are to be subjected The conditions of service involve many varying features Those which usually receive first consideration are the nature and intensity of stress to which the part is to be subjected, the conditions with regard to structural rigidity (or alternatively with regards to the flexibility or resilience), conditions as regards abrasion from various causes, including sliding contacts, necessitating consideration of surface pressure, lubrication and the relative importance of resisting changes of dimensions by wear, conditions with regard to shock and other causes of accidental or abnormal over-stressing, the importance in certain cases of minimizing the weight of the particular component, the relationship and importance of the component to the complete unit of which it forms a part

* B S. Schedule, 970 and 971, 1942 (cf. T A C I 33)

Apart from mechanical features, other conditions of service need consideration, such as temperature and variations in temperature to which the part is to be subjected, the importance in special cases of controlling the amount of thermal expansion and contraction which such changes of temperature involve, and the conditions of exposure of the part to corrosive and/or oxidizing influence, and whether the resistance to such influence is of fundamental importance for the part concerned. Other not less important factors in the selection of material for a particular part are those which affect the fabrication of that part. Such features are, for example, machineability, forgeability, weldability, response to heat-treatment, response to various forming operations cold or hot, and response to cleaning, grinding, polishing, and other finishing operations.

It is the duty of the designer to have sufficient appreciation of the properties of the various materials available to enable him not only to select the material most suitable for any particular part, but also to arrive at such a disposition, shape and proportioning of the part as to make good economic use of the material employed.

Almost the same margins* of manufacture are applied to aluminium alloy bars, extruded sections, and forgings for aircraft purposes

Length Margins

If pieces are parted singly in the stores by sawing machines, considerable savings can be made by parting with as little allowance in length as possible A condition is that the parting machine delivers surfaces which deviate from the plane by not more than 0·004 in. on bars up to 6 in dia The turner can then work on the basis of the following tolerances—

TABLE VII

LENGTH MARGINS

Length Tolerance	Length of Piece
Inches	Inches
0 04	20
0 06	40
0 08	60
0 12	Over 60

* B.S.I Specifications: 2 L.40 and 6 L 1, January, 1940

For pieces which are case-hardened but must remain soft at the ends, a length addition up to ⅜ in. is necessary to remove the carburized ends.

Swarf and Stock Removal

It is important to remember that only part of the raw material entering the shop emerges in the form of the finished product some is transformed into swarf, and the question of swarf disposal must sometimes be prominent in considering the arrangement of the shop. However, in modern manufacture there is a determined trend to reduce the amount of stock removal to the utmost minimum The examples already discussed (see Figs 3 to 18) illustrate the very wide differences prevailing in various industries

The brass ingot transformed to sheets or strips loses by trimming and finishing about 6 to 8 per cent as scrap The green, unseasoned, wooden stock of the rifle is reduced to about 60 per cent of its original weight (not volume) by the process of purifying and drying the wood without producing any swarf at all; the shape is not changed. The telephone and instrument works produce in the turning and punching departments from 10 to 25 per cent swarf Machine tools lose about 25 per cent by stock removal The weaving mill keeps the swarf from yarn to piece goods to between 1 to 2 per cent The oil refinery has an overall loss of 2 to 3 per cent

In the ordinary metal machining shops, the kind of material used, i e. whether black, blue, bright-drawn, or pre-ground, bars, or castings or forgings, is a decisive factor in determining material and labour costs

Drop-forgings

Two drop-forgings for a motor-car (Fig. 22) will illustrate how it depends on the size of the batch as to whether it would pay to use expensive finishing dies instead of roughing dies The steel cup for the brake drum weighed 76 lb rough-stamped and 45 lb fine-stamped. As the weight of the finished piece was 29 lb, this meant a reduction in swarf removal from 47 lb to 16 lb by a change-over to finishing dies.

The other example shows a rough body of 26·5 lb, a fine-stamped piece of 13·7 lb, and the finished piece of 5·3 lb The swarf removal from the rough piece is 21·2 lb, and from the stamped part 8·4 lb; the relation is 1 . 2·6 5. Hence, the following material allowances are obtainable—

Rough forging, 65–50 per cent

Rough and second forging, 25–15 per cent

Fine forging, 12–8 per cent

In a rifle factory, for instance, which produced up to 2000 rifles per day, the scrap losses were reduced from 11 to 6 per cent by the continuous mass production of rifle parts with finishing dies

Cast-iron Parts

The stock removal from cast pieces varies between 30 per cent and 10 per cent in the usual moulding process, in the Holley process (Ford), where only very large quantities come into consideration, stock removal is reduced to 3 per cent

Non-ferrous Castings

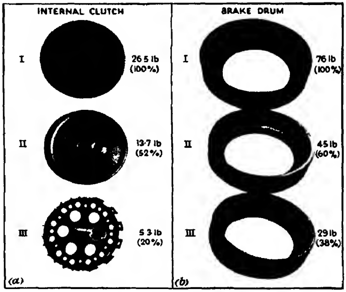
In the case of aluminium, elektron and also brass castings, which to-day are largely produced in metal moulds, the difference between rough and finished weights might vary between 6 per cent and 1 per cent In pressure die-castings the difference is well under 0·5 per cent, because after removal of gates and risers only a very fine burr remains to be cleaned off. The parts come out of the mould finished and interchangeable and can be assembled immediately with a minimum of preliminary hand fitting (See page 275)

Close collaboration between purchase department and management is needed to find the most economic solution, which depends upon both the price of the unit of rough or semi-finished material and the savings in costs of labour, tools, and machines. If stock removal can be kept to a minimum and if the swarf can be made to consist entirely of uniform, small chips (by using correct chip breakers), then it can easily be shovelled away and disposed of, thus avoiding the necessity of expensive and awkward conveying plant, even in factories producing large amounts of scrap It is no longer considered praiseworthy to produce giant chips of say 1·5 sq in cross section (see Fig. 51) instead of machining a well prepared forging with 0·15 in × 0·5 in , i e. a relation of cross section of chips of about 10 1, and correspondingly higher cutting speed and longer tool life.

Summary

The advantages of material standardization are—

1 It confines the range of materials used to as few kinds as possible, based on functional requirements rather than individual preferences.



	I Rough Forged		II Fine Forged		III Finished Turned to Size		Scrap Loss	
	weight lb	per cent	weight lb	per cent	weight lb	per cent	weight lb	per cent
(a) Internal Clutch	26 5	100	13 7	52	5 3	20	21 2	80
(b) Brake Drum	76	100	45	60	29	38	47	62

Fig. 22

2 It sets up a uniform system for everybody to follow

3 It simplifies records kept throughout the company as there are fewer types, sizes, etc , to be recorded

4 It permits the specification of materials on drawings in such a manner that they can be altered without requiring changes in the drawings

5. It guides those concerned with specifying, requisitioning, purchasing, stocking, and inspecting of materials.

6. It establishes standards of quality and effectiveness of the finished product

7. It permits the exercise of proper control over the quality of materials.

8. It permits the purchasing of fewer items and in greater quantities for maximum economy

9. It avoids superfluous effort and confusion in requisitioning and purchasing materials.

10. It reduces the amount of capital tied up in stocks

11 It simplifies storage

12 It reduces manufacturing costs

13 It shortens fabrication time.

14. It facilitates design and development work.

15. It stimulates research and makes for the elimination of antiquated methods and materials.

16. It reduces the period of instruction of new employees, and the cost thereof.

(III) Cost and Accounts Department

Let us again consider the essential sequence of planning, purchasing, supplier, stores, works production department, manufacture, work-in-progress, stores, finished products, shipping, pricing, and costing It is apparent that a large proportion of the work involved is of a mental rather than a physical nature.

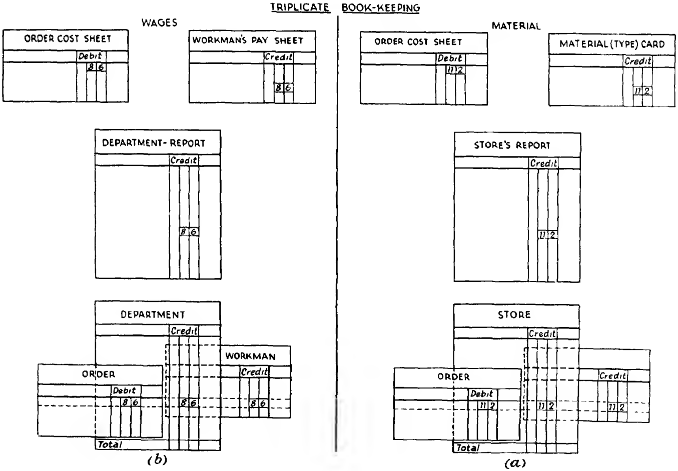


FIG. 23

As the material, unlike labour, cannot speak for itself it is essential that a close and accurate control be exercised over it so as to ensure that the valuation is properly and correctly carried out, and that the cost of material consumed is debited to the right job This is facilitated when the material accounts departments keep their records on the double-entry system Not a single piece of material is allowed to leave the store without its being valued and assigned against a particular order In the case of half-finished products, a special stock-taking is sometimes necessary to arrive at an intermediate valuation

This is made clear, theoretically, by a system introducing debit and credit balances (Fig 23(*a*)), where the department receiving material is debited and at the same time the department from which the material comes is credited, the cycle starting with the supplier of the raw material and ending with the prospective customer The money value of the raw material for each article is debited only once to the order, i e at the time that the raw material enters the workshop for the first operation, and whatever other workshops may machine the piece subsequently they need no material book-keeping as between each other The workshop which performs the last operation, finishing the piece, delivers it to the finished goods stores Each machining operation diminishes the weight of the piece, the difference between the weight of raw material and the finished piece being the amount of stock removal or scrap, the value of which has to be credited to the order The scrap-control balances the total weight of the raw material issued against that of the finished pieces It should be between 15 to 25 per cent of the gross weight for metal machining There are cases in stocktaking where the products have to be valued at intermediate stages, as they lie in sub-stores in a half-finished or unassembled state A special account must then be made for these goods, so as not to interfere with the general book-keeping, but which will meet the needs of the stocktaking.

The amount of cash in hand is, of course, decreased by the money paid to the supplier, but this is returned when the customer pays for the finished article. To balance the inventory account, issues of material should be entered at the purchase price

The pricing of material is a special problem with which we shall deal later (See page 58)

The most important function of the purchaser, as a part of the material management, is clearly explained Each order from a customer reduces the amount of material in stock as soon as the order is acknowledged. The purchaser is able to start buying as soon as he receives a copy of the acknowledgment

If the execution of the order requires little or no work by the drawing office (e.g in the case of repetition orders), then the purchaser is able to ascertain on the same day, by means of his allocation card file (stores ledger card),* what materials are *missing* which are needed to complete the order (Table VIII). On this chart the customer's order is entered under the column demanded ("out") and the new order to the supplier under the column on order ("in") From these two columns the buyer can always ascertain automatically the *balance available* The available stock is diminished by the "outs," and increased by a purchasing order, even if the supplies are not received Should the available balance be nil, or if it falls below the "level" (e g 100) at which the careful purchaser fixes his minimum, then a new order must be placed This happens long before the storekeeper has any idea that a new order has been received It is fundamentally wrong to combine the functions of buyer and storekeeper, thus allowing the storekeeper to exert any influence on purchase queries other than to raise the alarm when the minimum effective limits in the storeroom are approached

As soon as the buyer knows what is needed, he will refer to his files in order to ascertain the right suppliers, ask for quotations, compare same, raise orders, and send those passed by the management to the suppliers Then comes the follow-up, checking of incoming materials (from stores reports), and instructions for payment.

In principle, the buyer has nothing to do with the factory workshop.

* *The Control and Handling of Material in a General Engineering Works*, by J M Newton, Manchester Association of Engineers, 28th October, 1938.

TABLE VIII

SAMPLE STORES LEDGER CARD

Ordering Quantity	200	Ordering Level	100	Card No 7	Location JS14

On Order (In)			Received		Demanded (Out)			Issued		Actual Stock		Available Stock	
Date	Order No	Quantity	Date	Quantity	Date	Order No	Quantity	Date	Quantity	Date	Quantity	Date	Quantity
					—	—				10/2/48	132	10/2/48	132
					15/2/48	116329	8	18/3/48	8	18/3/48	102	15/2/48	124
					16/2/48	116538	6	23/3/48	6	23/3/48	96	16/2/48	118
					21/2/48	116477	2	24/2/48	2	24/2/48	130	21/2/48	116
					21/2/48	109326	12	5/3/48	12	5/3/48	110	21/2/48	104
					28/2/48	116495	8	4/3/48	8	4/3/48	122	28/2/48	96
28/2/48	108312	200	5/4/48	200								28/2/48	296
					3/3/48	116461	20	21/3/48	20	24/3/48	76	3/3/48	276
					9/3/48	116543	6					9/3/48	270
					15/3/48	116704	24	—	—			15/3/48	246
					30/3/48	116648	2	31/3/48	2	31/3/48	74	30/3/48	244
					—			—		5/4/48	274		
					11/4/48	116703	12					11/4/48	232

Catalogue No	Drawing No	Description		To order	On order	Over-due	Slow moving
990	25124	½ Brazing Collars	Item 10				

Function of Stores

The function of the stores, on the other hand, is quite different It receives the quantity of material ordered, ascertains with expert (laboratory) assistance that it is of prescribed quality; sends the report of defects or acknowledgment of correct quality, type, and quantity, to the purchasing department; sorts, stores, and issues the material, sends the receipted slips to the account's department, and enters receipts and withdrawals on bin-cards where such records are considered necessary Immediately on receipt of a consignment, the storekeeper should inform the works production department (planning department—production control), giving details, so that the material can be reserved against the correct orders in accordance with the instructions of the production control. The material can then be sent to the workshop at the correct time by whatever system of transport is in use

It is immaterial whether transport is performed by a man from the stores (delivery system) or by a man sent by the foreman (fetch system)

The "delivery" system is theoretically more economical because fewer carriers are needed and better use is made of stores' employees, it requires careful organization throughout the factory from the outset, proper preparation in the stores and punctual deliveries of materials to the respective shops

The works production department, when preparing the requisition slips for "first operation," must confirm that the necessary material is in stores, and must indicate when it ought to be delivered to the respective foremen according to the loading bulletin board This is a very responsible task In a well-organized factory, the foreman does not have messengers or porters to collect the goods from the stores he relies on the stores "delivery" system. This effects a considerable saving in personnel Furthermore, it should not be permissible for the foreman, or even for a workman, to waste his time running around to the stores repeatedly when material or goods fail to arrive at the right time The object of a materials supply system, as discussed herein, is to manage with as little raw material as possible, and yet never to experience difficulties owing to lack of material

Material Accountancy

The final problem is that of *costing the material* as the order progresses, and to do this in such a way that this most important item should be correctly recorded amongst the assets of the enterprise

The first step of the works production department is to reproduce the parts list and the requisition slips for the raw material Then follows the necessary number of wages dockets The works production department should never put through an order to start work until it knows that the material is in the stores for the first operating stage It is advisable to raise the question of allocation of material-in-store not earlier than two days prior to starting work This short period of time between inquiry regarding stock and the beginning of work helps to prevent the storekeeper (who does not know and does not need to know the urgency and relative importance of orders) from issuing the material on other orders, such as e g an urgent internal order (for, say, new factory plant or equipment). Much confusion and disturbance can arise in a works due to identical material being required for both customers' orders and for internal jobs, thus giving rise to double application for the same stock, and this can be largely avoided by making the works production department the only authority with the power to issue requisitions and by not issuing them too much in advance of actual needs

The works production department should route the requisition slips to the stores for work to be started in two days and send to the first foreman the wages dockets, to which a label is attached marked "material in store" Only those slips for which the material is definitely on hand can be used by the planner for compiling the departmental loading charts

The requisition slips and the first operation dockets go either together to the foreman who has the material fetched from the store ("fetch" system) or they are separated, the requisition slip going to the store and the wages dockets to the foreman ("delivery" system) The foreman can distribute the dockets amongst the operators, as he knows that the material is definitely in the shop, in fact he himself assigned it to the particular operators that very morning when the stores labourer gave him the requisition slips to sign and deposited the material itself in the work-in-progress dump near the foreman's desk or took it directly to the machine designated by the foreman When the requisition slip is receipted by the foreman it goes back to the store and from there to the costing department where evaluation begins

This evaluation has two stages—

1 The control of the slips and their pricing (price register)

2 Book-keeping, i e crediting the stores and debiting the order.

It is advisable to check that all the slips which were made out by the works production department have been received, or whether too many or too few have been made out A simple visual check can be done by comparing and ticking them in a copy of the parts list The parts list is made out so that each horizontal line represents one piece (See Fig 21)

The cause of having too many slips might be due to an error on the part of the works production department or it might be that an additional slip has been written out by the foreman for additional or different material from that which was specified by the designer.

If there are too few slips, it indicates that for some unknown reason there was, wrongly, sufficient material in the workshop to cover the work.

After this preliminary check the accounts department works as follows—

1 Prices the slip

2 Books the withdrawal on stores file cards as a record of stock available

3 Debits the order (material cost sheet)

4 Credits the corresponding stores (stores report).

It is clear that the materials received into stores (new supplies, returns, etc) must be entered up as charges against the stores and that receipts, with the equivalent values shown, should appear as debits on the stores report

Type cards and material cost sheets for the orders form part of the double-entry system as it affects the stores

In small factories the manual triplicate system (see Fig. 23(*a*) and (*b*)) may be used, in which type card, store report, and cost sheet are made out at the same time in one writing

Manual book-keeping may, of course, be replaced by accounting machines or punched card systems (See Figs 47 and 48.)

The cost of materials used for the order is summarized from the material cost sheets, thus providing one of the most important items in the calculation of manufacturing cost.

Finally, the question of methods of pricing has to be considered. There are four methods—

1 First in, first out, or oldest material on hand at its original cost

2 Average method: averaging total quantity and total value of material on hand

3. Cost or market price, whichever is the lower

4. Standard prices.

Of these possibilities the first and fourth are most frequently used (1) "Original cost" includes purchase price, freight and certain administration expenses inside the factory (stores expenses, stationery, book-keeping) The "costs" are ascertained for each lot, and are used consecutively, thus permitting the price per unit to vary continuously

(2) As the purchase price alters (and it can happen that several purchase prices are shown on the same type card), the average price must be computed by dividing total quantity into total value at each new purchase In this way the material account may be kept as a pure stock account as in case (1) the stores being debited or credited with the real cost price This procedure entails a lot of work, and requires great attention and, when invoices from various suppliers are being awaited, delays occur in the monthly balancing of orders as well as accounts

(3) Companies using this method actually use "cost" prices during the year and adjust to "market" prices at the close of the year.

(4) Standard prices are somewhat arbitrarily fixed They are based on statistics over a rather long period during which the works have been operating at standard capacity (see pp. 85–88) and the fluctuating purchase prices have been carefully recorded Here the quality of purchased goods is of greater influence than the stores overhead expenses (See page 77) By introducing fixed standard prices for costing purposes, as most large factories are now doing, one becomes independent of fluctuating figures from suppliers Pricing and balancing can be done without any loss of time But as the standard prices will rarely agree with the purchase prices really paid, there are inevitable discrepancies in the accounts If the standard prices are higher than the purchase prices, there is a profit in the stores account, if they are lower, there is a loss Under this system the stock accounts would not be simple credit accounts but mixed accounts of a type which are now chiefly avoided If it is desired to combine true price and standard price accounts then it is necessary to insert a "proceeds" account between the proper financial accounts and the stores accounts This account takes up temporarily the profits and losses of this type of pricing.

The procedure is the same whether it is a raw material store or a store of semi-finished or finished goods which is involved.

For semi-finished and finished parts, accounts should be used which combine the values of raw materials, wages and overhead as manufacturing cost In introducing standard prices for materials and, if necessary, for the stages of operation, they should be so fixed that a small profit results, then the stores accounts will never show a loss However, the introduction of standard prices for manufacturing cost of work-in-progress makes it necessary to consider very carefully the degree of factory activity, because labour and overhead costs are influenced considerably by the kind of manufacture and the size of production batches

CHAPTER III

The Labour Problem

THE SECOND element of manufacturing cost is the wages portion This wages portion fluctuates in the different industries, between 8·5 per cent and 28 per cent, as is shown in Table II But it must not be forgotten that a considerable part of factory expenses (overhead) is also wages, such as transport, porters, messengers, janitors, house-carpenters, builders, etc , as well as repairs and inspection and so on Finally, much of the cost of incoming materials covers wages paid elsewhere In the case of raw materials, such as coal and ore, wages must be paid not only to miners, but to various kinds of non-productive labour This accounts for the importance of the wage problem in various industries and the endeavour to reduce labour costs by improving equipment and methods in order to remain in the competitive world market Monopoly industries are no exception, nor are the Government's national and regional services, such as post and telegraph, gas, water, electricity, and in some countries railways and armament factories It is not surprising, therefore, that all factory economists devote much attention to wages questions, and that the negotiations between employers and workers' unions are mainly on wages subjects

The following aspects of the problem will be examined—

1 The social and psychological side of the labour problem. wage systems from the standpoint of

(*a*) the workman,

(*b*) the employer.

2. The economic valuation and control of labour.

3 Labour as the technical basis of the whole manufacturing process

(*a*) planning,

(*b*) ratefixing,

(*c*) tooling and jigging,

(*d*) loading.

(*e*) manufacturing,

(*f*) inspection,

(*g*) production control and progress,

(*h*) statistics and conclusions

The Social and Psychological Side of the Labour Problem

Wages and salaries constitute the purchasing power of most individuals and their correct assessment, therefore, is of great importance to all factories. In working on this vital problem it is not simply a question of wage amount, nor of whether hourly rates, piece rates, bonus or premium wages are paid nor which money factor is used in converting working-minutes into cash. It is much more than this it is a question of great delicacy and tremendous psychological importance, as the specialist well knows when he examines the wages system and introduces seemingly unimportant modifications from time to time. From the great number of existing wages systems it can be seen that the most experienced organizers are constantly trying to win the confidence of the working community by alterations in the wages system

Existing wages systems may be divided into two main groups—

(1) payment by time,

(2) payment by results.

In both cases the workmen are interested in their hourly rates (wages earned) and the employer is interested in the total cost of the work produced (labour cost).

The diagrams (Figs. 24, 25) illustrate the characteristics of the hourly-wages system and the piece-wages system.

The curve of constant hourly wage (Fig. 24) is a parallel to the horizontal, e g. a 2*s*. hourly rate, while that of the labour cost per piece is a straight line rising from zero to 16s for a shift of eight hours. The more hours a workman needs for a particular job, the more expensive is his work If he finishes the piece in eight hours, it costs 16s , if in five hours, 10s , etc There is practically always an understanding that a certain amount of work is to be performed, and workers performing less than this minimum are liable to be dismissed

High time-rates are paid to men such as highly skilled fitters who work on their own responsibility, and also to workers engaged on line assembly work, the speed of which is regulated by the pace of the belt or conveyor (See page 275.) Here high time-rates are obviously coupled with a predetermined result , without this incentive, workers might not be willing to work at the fixed speed desired A guaranteed hourly rate does not involve a very strong incentive for sustained effort, producing good quality work at high speed as is desirable in any successful factory Payment by time (per hour) is therefore replaced, wherever possible, by a system of payment by results An effective incentive can be arranged for any work which is capable of being measured as to quantity, quality and material economy Job standardization, production control, inspection, etc , may be used in support of an incentive plan Not only must the works manager put the emphasis on having the materials in the right place at the right time, and in the right condition, but he must also be determined never to allow a worker to suffer in wages through these fundamental conditions of management being imperfectly realized Not only should the wage incentive be strong when the man is working at above target output, it should be protected by a guaranteed time-rate for output below target This time-rate guarantee might be somewhat below average wages, there is no incentive when it is too high The most commonly used systems will now be explained by diagrams and formulae, in each of which the following key letters are used (Figs. 24 to 29 and Table IX)—

T = Time allowed.

t = Time taken.

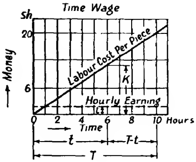


FIG 24

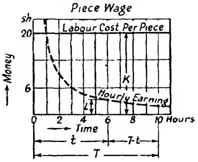


FIG 25

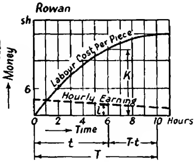


FIG 26 PREMIUM SYSTEM, ROWAN

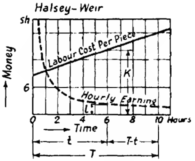


FIG 27 PREMIUM SYSTEM, HALSEY-WEIR

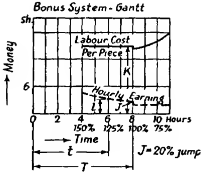


FIG 28 BONUS SYSTEM

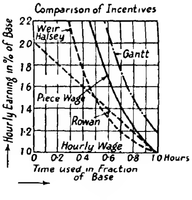


FIG 29 COMPARISON OF INCENTIVES

$T - t$ = Time saved.
L = Basic wage
l = Hourly earning.
$M = l - L$ = Bonus, premium, incentive
K = Labour cost per piece
P = Premium earned
p = Premium percentage

TABLE IX

	K	l	$M = l - L$
Time-wage	$t \times L$	$L = \text{Constant}\left(\frac{K}{t}\right)$	0
Piece-wage	$T \times L = \text{Constant}$	$\frac{T}{t} \times L$	$L\left(\frac{T}{t} - 1\right)$
Rowan	$t \times L + \frac{T - t}{T} \times t \times L$	$L\left(1 + \frac{T - t}{T}\right)$	$\frac{T - t}{T} \times L$
Halsey Weir	$t \times L + (T - t) \times L \times p$	$\frac{K}{t} = L\left(1 + p\frac{T - t}{t}\right)$	$L\, p \times \frac{T - t}{t}$
Gantt	$T \times L + p^* \times T \times L$	$\frac{K}{t} = L \times \frac{T}{t}(1 + p)$	$L\frac{T}{t}(1 + p) - L$

*p from 20% to 100%

A high speed is voluntarily given by the worker on piece-wages (Fig 25) The bold line parallel to the horizontal shows the constant price per piece, e g. 20s , the operator may finish it in eight hours or in one hour. In the first case, he earns $\frac{20}{8}$s = 2s. 6d. an hour, in the second $\frac{20}{1}$s = 20s an hour. The curve of rates/hour is a hyperbola, the system is very easily understood by all workers. They decide on their wages, even if the piece-price is reasonably pre-set by the planning department

With time-wages, the foreman admonishes the workman by saying "You are working too slowly", with piece-wages he says: "You must earn more money" That is an important psychological difference in favour of piece-rates

Even with time-rates individual differences are found between workers, such as those engaged on particularly difficult or highly skilled work, e.g. tool-room workers in an engineering shop, bricklayers on furnace building, etc For high-class production work, wages higher than the usual trade union rates are paid with full trade union approval. In numerous trades, special allowances are paid where the work has exceptional features, e.g. for disagreeable or dirty work (sewer, dyeing, hardening), or for dangerous work, such as that on scaffolding or chimney building, etc.

Conversely, in piece-wage systems there is always a close connexion between wages paid and time worked, because each operation represents a "task." The basis of the system is that the good worker should, with an average effort, be able to earn the average remuneration of his class. The wages are directly related to the output of the worker, since he is paid so much per unit one piece, ten or one hundred pieces, a dozen, or a gross, according to the system adopted.

In "task-wages" a time in minutes is fixed in which a set piece of work must be performed, this is the standard task Time replaces money, and as the time depends mainly upon the nature of the existing equipment, machine, tool, jig, gauge and lifting apparatus, taking either a skilled or a semi-skilled workman as operator, the piece-wage on a fixed time basis is preferable to the piece-wage on a money basis The minutes worked must be changed into cash for the pay-roll by using money-factors which depend upon sex, age, education, knowledge, experience, reliability

Considerable variations in wage rates often occur as between different towns and districts, so that two similar factories owned by the same concern, one situated in a big town and the other in a small village, may use the same basic time for the same piece, but pay different total prices This is particularly obvious in the building industry

Sliding wage scales, varying according to the cost-of-living index, have been adopted in a great variety of industries in order to provide automatic adjustment of wages to changes in the cost of living, and thus prevent continuous friction However, all these objections belong to the social side of the labour problem, while the time of performance, being a technical matter, remains undisturbed

Therefore the whole technical preparation of any job should be based on times, which can be ascertained by time and motion studies and standardized, so as readily to be available for use in any given circumstances (See page 228.)

The principle of straight-line piece-work is the simplest, since the worker is paid at a flat rate for every operation or group of operations performed, and the wages received are strictly proportionate to his output.

In those trades where jobs are not of a repetitive character or where different methods are adopted by firms engaged on similar work, as in the engineering industry, the method of fixing (by mutual agreement) piece-work prices for individual jobs is sometimes used.

"Better a high piece-price than low time-wages" is the slogan, even if the worker's day-rate is guaranteed

Piece-rates are in direct relationship to output, therefore they facilitate the work of the book-keeper in the costing department, and also that of budgeting and of preparing reliable tenders

The two extreme cases of wage payment are—

(*a*) Straight time-wages with a constant hourly rate per operator and strictly proportionate decline of labour costs from the maximum with the slowest worker to the minimum with the fastest operators, and (*b*) straight piece-work with constant labour cost and rapidly increasing labour rates (hyperbolic curve) (See Figs 24 and 25) Time-work includes no other incentive for the worker than the moral obligation to work at a reasonable pace The reward may be an increase of his hourly rate in future Piece-work, however, includes the greatest possible monetary reward for quick performance, closely watched, of course, by a rigid inspection system which allows only good quality pieces to pass

Between these two extreme cases, schemes have been developed which combine payment by time with that by results, using various wage incentive methods Three of these, i.e the premium schemes of Halsey and Weir (Fig 27), and Rowan (Fig 26), and the bonus scheme of Gantt (Fig 28), will now be examined

All these premium and bonus schemes are based on the fundamental idea that both the employer and the employee are concerned with the final aim of high wages combined with low labour cost, and that both must endeavour to help each other to reach that aim and thus ensure the permanent full employment of the factory by their common effort; therefore it is argued that the premium or bonus should be divided between them according to a reasonable ratio.

In Fig. 24, showing straight time-wages, the premium is $P = 0$: in Fig. 25, straight piece-wages, $P = 1$, while Halsey (Fig 27) allows $P = \frac{1}{3}L$, Weir, $P = \frac{1}{2}L$, Rowan (Fig. 26) $P = \frac{T - t}{T} L$ and Gantt (Fig 28) a bonus of $B = 20$ per cent to 35 per cent, becoming suddenly operative when the allowed time for the task is reached

In the Halsey (1891) and Weir (1897) premium schemes, the worker is guaranteed the customary hourly rate Then standard times for each operation are fixed by a special rate-fixing department and inserted on all wages dockets issued to the workers A premium amounting to one-third (Halsey), or one-half (Weir) of the time saved is paid if the job is performed in less than the standard time. If the workman exceeds the standard time by working too slowly, he receives time-wages for all the hours worked by him, for these systems are based on guaranteed time-wages

To take a practical example Suppose the hourly rate is 2s and that eight hours is the standard time allowed for the particular job—the premium being at the rate of one-third of the value of the time saved If the man takes eight hours, he receives $8 \times 2s = 16s$, and no premium, but if he does the job in five hours he gets $5 \times 2s = 10s$ time-wage + one-third of the three hours saved $= \frac{3 \times 2}{3} = 2s$ premium Altogether, he is paid 12s for his five hours' work, that is, about 2s 5d per hour The labour cost is reduced from the standard price of $K_s = 8 \times 2 = 16s$. to $K = 12s$ The savings are 4s against the premium of 2s, which is 2 : 1, the management receiving $\frac{2}{3}$rds and the worker $\frac{1}{3}$rd of the result

The Weir system pays 50/50, so we have again 16s standard price, but divide the saving of $16 - 10 = 6s$, giving $P = 3s$ premium for the worker and $S = 3s$ saving to the employer, which is simpler to understand and more attractive for the worker, but the total labour cost increases to $K = 13s$.

Both for piece-wages (Fig 25) and certain premium-wages (Fig 27) the theoretical possibility of getting an enormous increase in the hourly rate in return for a very high output may induce the ambitious, industrious and skilful worker to over-exert himself. Therefore, J Rowan introduced (1898) a system which increased the wage incentive much more slowly by bringing the rising line of hourly rates closer to the time-wage straight line (Fig 26.) The premium in this case is not a fixed fraction of the value of the time saved, but is calculated by multiplying the time saved by the variable factor $\frac{\text{Time taken}}{\text{Time allowed}} = \frac{t}{T}$, thus the premium is

$$P = \text{time saved} \times \frac{t}{T} = \frac{T-t}{T} \times t \times L$$

EXAMPLE $T = 8$ hours, $t = 5$ hours, $P = \frac{3}{8} \times 5 \times 2s = 3s\ 9d$ premium

The Rowan system pays a higher premium than the Weir system for times between 100 and 50 per cent of the allowed time, below 50 per cent it becomes unfavourable to the worker. In the extreme case, when the time taken (t) becomes (theoretically) nil, the variable factor would be $\frac{T-t}{T} = \frac{T}{T} = 1$, or the maximum premium would be $P = LX$, equal the hourly rate Thus the worker can never earn more than the guaranteed hourly rate, plus another hourly rate as premium, or he can never get double wages Although this limit is not intended to be obvious, the worker soon discovers it, without being a mathematician, and this is one of the reasons why the Rowan system is little used to-day. Besides, it is complicated to understand, and was mostly used in factories where accurate time-setting was difficult to achieve, and where jobbing work of a varied character was undertaken. A wall poster which the author read in 1902 at Rowan's said. "We never cut a fixed rate" That was indeed unnecessary!

The premium systems, which pay a reward only when the operator does the work in less time than the time allowed, are giving place to bonus systems which permit the payment of considerable bonus even before the worker reaches the required standard of output

The Gantt task and bonus plan is a cross between time-wages and piece-wages (Fig. 28).

"Workmen as a whole prefer to sell their time rather than their labour, and to perform in that time the amount of labour they consider proper for the pay received" (H. K. Gantt)

The difference between a premium and a bonus is slight Both are amounts of reward additional to guaranteed time-wages, and may increase directly in some way proportionate to production, or may increase in a variable manner as production increases.

The word "premium" should, however, always be used when the wages saved (time allowed minus time taken) are divided between employee and employer, and the word "bonus" when the wages saved are all paid to the employee making the saving.

Summary

Halsey divided the premium in the ratio 1 : 2, one-third of the savings to the employee, two-thirds to the employer, Weir distributed it 1 : 1, i.e. half to each, and Gantt gave a bonus of 20 to 100 per cent additional to the employee's guaranteed hourly wages, as soon as the "task time" was achieved based on the worker's efficiency, measured by his ability to do the job in from 80 to 100 per cent of the standard time

Bonus can therefore be given at any point of the efficiency scale, and its amount is arbitrarily chosen, premium is paid at a fixed share, using the standard task time as the starting point of the savings.

Historically, the term bonus was restricted to the lump sum given when the task was achieved; this caused a sudden step-up in earnings (shown in Fig 28), then the earnings for work beyond the task continued to incorporate this and any other additions or premiums which had been agreed upon

Fig. 29 compares the effect of incentive on hourly earnings for each of the five systems

All modern rate-fixing methods should be based on a thorough knowledge of the time during which a task can be performed, i e by time-studies of the auxiliary operations, calculation of the machining operations, assuming tool, speed, feed and quality of dimension and surface, and finally on carefully prepared statistics of the time "lost" under prevailing circumstances.

The heritage of F. W. Taylor and F B. Gilbreth on time and motion study is realized to-day: it must be realized before correct task setting in minutes can be undertaken; it is the only reliable basis for piece-work, premium-work, and bonus-work. Unless the employee has not only the full confidence, but the daily proof by his piece-docket that the employer knows what he is ordering, he cannot be expected always to perform his part faithfully towards the common prosperity of his company

Advantages of Hourly Rates are—

(1) Their simplicity

(2) The minimum of pay-roll work although this is not valid as regards costing, as the latter requires more work and greater attention on the part of the book-keeper under the hourly-rate system

(3) The greater internal security, with which the workmen perform their work because their wages are fixed

(4) The higher quality of the work done

(5) Economy in material consumption

(6) Good treatment of tool and machine

(7) The fact that the workmen agree with any changes in methods, and are even collaborating to find them

Disadvantages of Hourly Rates are –

(1) The high production cost, caused by low output, the level of efficiency is reduced, because generally the slowest man is the pace-maker

Low output is particularly disadvantageous with expensive machines

(2) The fact that the only criterion for judgment of the men is their general efficiency, and improvements in their earnings are a matter for decision by the foreman This may not always be quite fair to all workers in a department.

Advantages of Piece-work for the Employee are—

(1) It is the fairest and most reasonable arrangement, because the employee gets 100 per cent of the money he saves Because of the steep increase in earnings, the worker gets a higher reward than he does with any other system. The pace is voluntary, therefore the worker can act independently. The upper limit of his earnings depends on his own decision, and this fosters ambition There must, however, be no rate-cutting.

(2) Piece-rates are very easily understood

(3) If the basic times (standard minutes) are not cut, improved technological conditions increase his earnings

Advantages of Piece-work for the Employer are —

(1) The relations between employer and employee are improved, because the worker feels that he is being treated fairly

(2) Pay-roll and costing, and also budgeting, are simplified, because the piece-rates remain constant The simplification becomes still more evident in the case of group piece-work

(3) The high incentive increases and equalizes the volume of output This decreases the percentage of overhead, and therefore the manufacturing cost of the piece

(4) Machine-loading and planning are facilitated.

(5) Close co-operation of the workers with the management is created All workers become interested in good management, because they need the benefits of correctly planned material supply This effect is still more increased by group piece-work.

(6) There is also good co-operation between foreman and charge-hand, because it is not so necessary to "push"

(7) Progress chasing and the keeping of delivery dates are facilitated

The Classic Objections against Piece-work are the following—

(1) Very high wages incite rate-cutting by the employer This objection is not caused by any defect of piece-work, but is due to a faulty use of the system

(2) Piece-work incites excessive effort by the employee

(3) Piece-work may cause the workman to mishandle an expensive machine and complicated tools in order to increase his earnings

(4) The authority over the worker is lower It is not possible to prescribe the quantity of work, therefore expensive machines may, perhaps, not be used to their full extent

(5) It stimulates an undesirable trend of competition and jealousy among the workers.

(6) It exposes the efficiency of the workers, who often dislike being checked by stopwatch and time studies

(7) It is rather inelastic, because changes in methods, machines, and material demand changes in the basic times

(8) Quality is endangered, consequently keen inspection is necessary

(9) The workers do not care much about economizing material

(10) If the basic times are decreased, the hostility of the worker is increased against the introduction of improved methods and new machines

When the piece minutes, as communicated to the workers, form the basis of the times or prices allowed, the personal element is eliminated by an impartial ratefixing department The same applies to the checking of efficiency if the times fixed are entered on the piece docket or on a parts list Costing is always an effective control of the system's efficiency, operated by comparing the time (or price) fixed against the price paid in the parts list

Changes in the times allowed are admissible only if the method of production is changed The reasonable workman will understand and accept this, because it is far from arbitrary rate-cutting.

Group Payment

Sometimes the nature of a job is such that payment by results is possible only if a number of workers share collectively in the proceeds Examples are · Assembling parts of a machine, loading railway wagons, or ships, dyeing textiles, and working in gangs

For riveting work, for instance, three classes of workers are involved · Riveters, holders-up, and labourers The different classes have different basic wage-rates on which they are given advance payments pending completion of the job. The surplus is finally distributed by forming units of the basic rate multiplied by the time taken for each workman, totalling the units, dividing them into the surplus, and allocating to each man his just share. The essential psychological feature of group payment is to create a team spirit which is indispensable for success.

There are many such jobs which must be done collectively, and it is relatively easy to measure the amount of work done by the group as a whole, whereas it is often impossible to say how much has been done by any individual worker

Similar collective piece-work or bonus-work can be practised by a department or a whole shop, or even by two or three workers only Generally the group bonus or premium does not commence until a certain minimum amount of work is done, but this minimum must not be set too high or the incentive will be lost.

Examples are Loading and unloading railway goods sheds, cargoes of ships, carriage cleaning, work in marshalling yards, and loading of coal.

A bonus is paid to workers not only for time-saving, but also in respect of any other saving which they may effect in, say, materials or maintenance costs over some predetermined average figure For instance, locomotive drivers may receive a bonus on saving effected in the consumption of coal, and in the time they keep the engine in good repair, a bus driver on saving in petrol consumption or tyre maintenance

A decision has sometimes to be made whether individual, group, or departmental piece-work is to be installed The best results of a piece-rate system are obtained from individual operation, owing to the fact that the operator works independently of others and therefore can attain the highest personal efficiency As soon as several operators work together, the average of the group work is lower than the total of possible individual efficiencies. Here the case is the same as in sports In team rowing, and generally in all games depending on team work (e.g football, handball, cricket, hockey), the weakest sets the pace It may be eventually that he will play a stronger game, stimulated by his comrades, but nevertheless he is a burden to his team Only in individual piece-work is the work distributed in the best way; waiting for others is eliminated, and mistakes can be made good by increased effort.

If group work is unavoidable, as with line-production, then a careful choice of operators must be made It is often very difficult to determine the correct group rate, and the correct distribution should be based on figures very carefully compiled by technical experts for the particular case.

The operators on line-production, for instance, which often looks very simple, must get used to the "cycle" time of a large number of different hand or machine operations. Difficulties continuously occur, and, for instance, Charles Bedaux decided that compensation for waiting time caused through no fault of the operators, paid by means of a special "process allowance," was useful for showing up any erratic running of the conveyor For instance, in a big continental rubber factory, the conveyor lines for bicycle tyres were found to be inefficient and were successfully replaced by full-time individual work

Let us now consider the characteristics of the Bedaux (U S A) system for individual and group work, and the "Bata" system (Czechoslovakia) for co-operative work, based on departmental co-operation

The basis of the Bedaux system is—

(1) Very carefully-made time studies, including as a new feature of "rating", the working speed of each operator

(2) The establishment of factors of permissible fatigue, and rewarding efforts above the average

(3) Allowances for unsatisfactory conditions (where these cannot be remedied)

(4) A guaranteed and adequate day-rate

Bedaux associates a "difficulty compensation" with the unavoidable fatigue resulting from each type of occupation, and even relates working speed to what he considers to be the speed of a "standard operator"

Even in Communist Russia, where the supposed "prejudice" of the ruling class is not a factor to be reckoned with, there is a slogan "Equal wages for equal work, so therefore, unequal wages for unequal work" Hence the basic principle of piece-wages based on efficiency exists in Russia, as in all the capitalist countries of the world The writer observed in a large tool works in Moscow in 1936 wage differences of 1 to 5 in several workshops ("Stakhanoff" operator) *

* "Stakhanoff" is the name of the Russian miner who revolutionized the mining methods, speeding up output tenfold. He is called the "Russian Taylor"

Bedaux selects the time results graphically, according to frequency tests For instance, Fig. 30 shows 14 seconds as the most frequent value The speed "rating" of the individual worker is something new, although it is easily learnt by suitable time-study men. The correct choice of "relaxation coefficient" for particular time values can be made only after years of statistics of the particular branch of industry Piece rates are measured in terms of points ("B") Thus Bedaux establishes a value of 60B per hour as a basis for ordinary operators A unit of work 1B is therefore done in one minute. 30B per hour corresponds to 50 per cent of standard effort and, 120B to double performance. Bedaux reckons that the efficiency of a skilled operator is about 75 to 80B, i e 30 per cent higher than that of the average operator

Sec	No of Observations
10	/
11	//
12	////
13	//// ////
14	//// //// //// //
15	//// //// /
16	////
17	////
18	//
19	
20	/

Fig 30 Frequency Graph

One "B" is the output in one minute of a man working at a speed that could be permanently maintained, similar to the arrangement of the piece-rate system. Even when the operator earns less than 60B, he is credited with 60B. It is essential under this system that each operator's efficiency is worked out speedily and the departmental list is hung up in the shop within twenty-four hours for all to see. On this list, all the operators who have earned less than 60B, whether deliberately or not, are marked in red Bedaux pays the operator only 75 per cent of the bonus, the balance of 25 per cent being divided proportionally between inspection, foreman, charge-hands, and other helpers

The relaxation additions are made only by the Bedaux management. For this purpose they utilize their statistical data compiled over decades, over many branches of industry, the additions fluctuate between 5 and 200 per cent according to the nature of the work Contingency additions are not recognized by Bedaux at all, but "lost time" is specially checked and specially paid. Bedaux never overlooks the suitability of any work place or method, nor merely compensates for "difficulties", he continually criticizes the methods, and if, after his investigation, the operator is still unable to make 60 points per hour, he divides payment for work into (1) guaranteed day-rate, and (2) method addition. As this method addition continuously shows up as an error of management, and is even deducted from the bonus of the foremen, charge-hands, and inspectors, every effort is made by operator and manager to eliminate it We have here, therefore, an attempt to use a valuable psychological incentive for the solution of wage problems, and a fair way of penalizing only those who directly or indirectly cause the reduced efficiency. Because the list of efficiencies is openly shown a moral incentive is given to reduce method allowances and time losses

The classification of work is done according to—

(1) Physical requirements of the occupation
(2) Training, skill and experience of the worker.
(3) Responsibility and mental efficiency
(4) Certain risks

These factors decide the length of training time

The Bedaux system is expensive, owing to laborious timing and the amount of personnel needed for making out the daily lists. It has repaid itself in large factories where regular continuous operations are performed, such as rubber tyre manufacture, porcelain, textiles, automobiles, etc

"Bata" Co-operation System (1935)

The wage system of the big shoe manufacturer, Bata, of Zlin (Czechoslovakia), is built up on quite a different psychological basis. Bata places in the foreground, another main object that is "participation of employer and operator in the success of the works." He calls it "Education of Concern-Consciousness." Every employer is, so to speak, a shareholder; if business is good, he makes a profit, if it is not, his bonus is decreased (profit-sharing)

Every active member of each department participates in his department's success Over and above this incentive, about a third of all the employees benefit by means of premiums from the profits of the whole works

This system must be considered in relation to the character of the rural population of Zlin, which is cut off from the rest of the world, with little stimulus to spend money, and needing to be educated on the need for saving for the future. Participation in factory profits inculcates a desire towards economic use of tools and care of machines as well as an urge towards cleanliness and order in every shop A budget is made for all internal issues, checked by a weekly costing (cf. pp 78 and 79), open to a workmen's committee in the same way as that for which we are striving in well-organized factories in this country, but which unfortunately we so seldom find. In the Bata assembly shops, which are uniformly equipped, a sort of collective piece-rate system exists The work is always carried out by a group of assemblers at the conveyor line, with about half as many machine stitchers outside the conveyor By means of carefully prepared statistics, which are easily compiled in a large number of similar shops, one is in a position to check each item and its variations at each stage, and to utilize these figures as an instrument for maintaining a strict control on costing and departmental overhead

The fundamental data on which to build such a group system are—

(1) A certain peak production per day, and a shop budget

(2) The basic hourly-rate per operator according to difficulties of operation

(3) Classification of labour into four groups according to sex and age.

(4) The average wage per group (because the basic wages of the operators are different)

If the output is reduced by half, whether avoidably or not, is immaterial (e g. through decrease in orders), then the earnings of the shops are reduced accordingly From the unit price per shoe the value of the weekly output is obtained. If the total sum of weekly wages is compared with the output produced, then the wages share as the production unit can be ascertained. This valuation is applied, too, when the production fluctuates considerably. A start can then be made on sharing the total money earned among the operators, according to each worker's group. The works manager and the foremen also participate, for a fixed amount of oncost per shoe is allowed to them. Their participation increases when they undercut the agreed costs; when the shop produces at less than the fixed standard price, it shows a profit, and only from this profit can the manager and foreman benefit. As the internal standard prices are not altered, there is an incentive, in spite of continuous control of the quality, to undercut the standard prices, i.e. to increase the profit in all departments. The obvious success of the big Bata enterprise might well be due to the full co-operation of all employees.

Naturally it will be of great interest for the practical engineer to learn how the wage incentive methods have worked in practice, and how much they are used in comparison with payment by time.

The writer through his own experience as works manager and works organizer of more than forty years, has found that straight piece-rate working gives the best results in every respect, for the employee as a wage earner, and for the employer both as a manager and as a business man. Loading, progress, costing, and tendering are all reduced to the clearest and simplest procedure. But let statistics speak. Table X shows two American analyses of wage incentives as published by the National Industries Conference Board of New York. The statistics show the interesting result that in 1928 payment by ordinary time-rates covered 47·2 per cent of the 1,214 engineering works which supplied information, while by 1940, taking 313 companies, there was a decline to 38·3 per cent using time-rates, as against 62 per cent using some type of incentive wage scheme. In both cases individual piece-rates predominated amongst the incentive methods. The writer believes that piece-rates will be accepted more and more as the result of improvements in time-study technique and standardization of jobs.

TABLE X

PRACTICAL APPLICATION OF WAGE INCENTIVES

(*National Industries Conference Board, New York*)

WAGE SYSTEMS	1928 1,214 COMPANIES ANSWERED		1940 313 COMPANIES ANSWERED		REMARKS
	Number of Employees	Per Cent	Number of Employees	Per Cent	
Hourly Time-rates	367,454	47·2	143,993	38·3	
Individual Piece-rates	218,321	28·2	112,977	30·2	Piece-rates
Piece-rates with Guarantees Hourly Basic rate	38,061	4·9	—		Piece-rates
Group Piece-rate	30,164	3·85	27,005	7·2	Piece-rates
Taylor Differential Piece-rate	1,040	0·13	-		Piece-rates
Individual Premium—Halsey	9,953	1·3	41,031	10·8	
Individual Premium—Rowan	226	0·03			
Premium Bonus—Gantt	5,222	0·65			
Efficiency Bonus—Emerson	9,252	1·2	—		
Efficiency Bonus—Parkhurst	1,946	0·25			
Production Bonus	1,093	0·14			
Standard Hours	697	0·08			
Group Bonus	44,896	5·76	30,613	8·1	
Special Incentive—Bedaux	33,177	4·3		–	
Special Incentive—Haynes Manit	551	0·07	20,312	5·2	
Unclassified (Premium or Bonus)	15,323	1·94	902	0·2	
	777,376	100·00	376,833	100·0	

Certain proof of this is already afforded by the experience on the continent of Europe, where piece-rate working predominates, and where premium or bonus systems are only used rarely. There is a tendency to introduce standard supplementary times based on time study of supplementary operations, such as handling, then to calculate accurately the machining times, and to use both together to give the total operating time as a basis, instead of using a fluctuating monetary scale depending on living conditions and unstable currency. The methodical work of the "REFA" (Germany) should be mentioned in this connexion

In the book by Lytle on *Wage Incentive Methods** more than twenty-five different premium and bonus systems are described, and each bears the name of its inventor (they are mostly of American origin). Fig. 31 (*a*) compares the total cost per piece on seventeen of these systems The total cost comprises overhead, material, and wages (cf Table II) The overhead remains approximately constant; it varies very little with increasing output. The material expense is directly proportionate to the size of the batch and the labour is approximately so, the bigger the batches, the smaller the wages per unit. The diagram (Fig 31 (*b*)) in the upper corner shows the cost of material separately and labour and material together, the line of profit, e g 38 per cent, intersects the overhead line in the critical point, when loss begins with decreasing activity

The horizontal axis of Fig 31 (*a*) represents the daily production expressed as a percentage of "standard," i e. the worker's efficiency The vertical ordinate gives the total cost per piece In this particular instance 2s 6d (about half a dollar) may be the total permissible cost per piece This cannot remain constant for every piece-rate, it declines as production increases, but rises if output is small. This is in fact what makes low production so much more expensive : it is not the direct labour cost at piece-rates, for that is constant. We become accustomed to unavoidable conditions, even when they are undesirable. and to pay high wages for low production is often unavoidable

* *Wage Incentive Methods*, by C. W Lytle, Ronald Press, New York, 1929.

Now, if we are paying over the maximum total cost per piece constant at 2s 6d. line in Fig 31 (*a*) owing to inefficient operators, we will certainly welcome a strong incentive to which the usual response is a reduction in total cost per piece to below this maximum Therefore the maximum total cost below the 2s 6d line is the limit which a factory can pay, and the difference between this and the unit selling price is the necessary profit margin

The more slowly the operator works, the higher are the wages and the total cost paid per piece, e g. the 85 per cent efficiency line cuts system 16 (piece-work) and system 17 (Taylor) at 2s 4d, and system 8 (Rowan) at 2s 7d

With 60 per cent efficiency the prices vary between 2s 7d and 3s 3d, i e up to 25 per cent difference With 115 per cent activity the fluctuation is between 2s and 2s 5d All curves show a similar general trend, and it is proved that with increased personal efficiency of the workers, and increased activity of the factory, an hourly rate (10) actually gives a better result than does piece-work with 33⅓ per cent bonus (14) which means that if the average worker would work without incentive at a pace 15 per cent faster than that fixed by the task-time, the total cost of a piece, including wages, material, and overhead, would be at its minimum This would be an ideal state of affairs!

Every wage incentive promotes increase in production speed, and endangers the quality of work and this can be assured only by an organized inspection system The work of the inspector has therefore a continuous influence on the efficiency of the operators, and without adequate inspection the quality and reputation of the factory will suffer. The shop operator always responds very quickly to the peculiarities and standard of efficiency of inspection The methods and tolerances of inspection have therefore a very direct bearing on earning potential on the one hand and costs on the other, controlling as they do the standard of production on which bonus is payable.

All difficulties will be greatly reduced when the employer and employee learn to face their common duty towards the carrying out of their work. The employer has to provide working

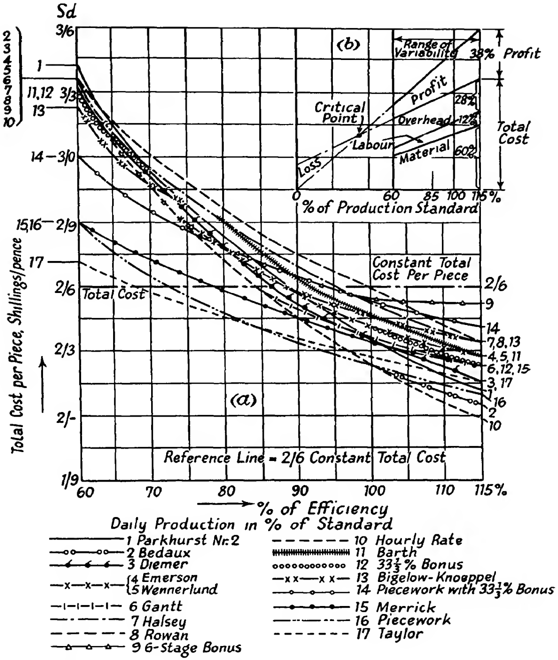


FIG 31 COMPARISON OF INCENTIVE SYSTEMS BASED ON 2s 6d (ABOUT HALF A DOLLAR) TOTAL COST AS REFERENCE LINE (SEE C W LYTLE, NEW YORK)

2s 6d as reference cost is arbitrarily taken as a maximum for total cost per piece and indicated by a heavy line Following across this line we may observe that the Taylor Plan (17) gives this at 68 per cent production, flat piece rate (16) at 73 per cent, Merrick (15) at 78 per cent, Hourly rate (10) and Gantt (6) at 85 per cent

At 100 per cent production all systems are lower than the reference line and Hourly rates (10) together with Bedaux (2) and Piecework (16) give the cheapest total price facilities and to keep them in suitable condition, has to supply the parts to be machined in regular uninterrupted sequence, has to teach correct operating methods, has to specify clearly the correct solution of any problems, has to organize an effective inspection, and has to maintain a fair wage system and make prompt payment for services performed.

The worker, on the other hand, has to practise expert and economical use of manufacturing facilities, and accurate machining of work pieces within the prescribed times, and has to provide such data as the employer may require concerning the time spent on each job, etc

The inspection methods and equipment must be appropriate to the working conditions, and payment must be adequate There should then be no reason for the worker not giving regularly of his best.

The Economical Valuation and Control of Labour

Ultimately the wages problem is settled, as are all the shop problems, in the costing department, which must balance debits and credits on the basis of double entry book-keeping (see Fig 23(*b*)).

The operator is credited weekly for his activity in the shop, the total sum of credits (direct wages) gives the total efficiency of the department, which is later used as the main basis for the distribution of overhead expenses, and the same sums, subdivided into order numbers, are then debited to the orders or the internal (overhead) accounts of the works For debiting and crediting various departments it is necessary that the wages-dockets for each operation (which originate for this purpose in the works production office), or the time-sheets, or the clock-cards, should go in the most economic way through the workshops and back to the costing department. No wages should be paid out in the factory without a voucher, but the number of these vouchers should be reduced to a minimum The total sum paid for direct wages must be balanced by the total debits of all numbered orders.

What do we need now for starting, following through, and valuing the labour output? The starting point is the works production department or factory office (Fig. 32 and Tables I and IV), the heart of the factory management. Here the plans are received and the work is carried out from raw material to finished product, at the correct price and by the due date "Correct price" means at piece price or day-work prices as fixed by the estimating department, the work having been passed by the inspection

The first step in all cases is an order on the stores to issue the material for the first machining operation For this purpose the works production department writes out the material requisition slip. The second step is to give the wages-dockets for the first and subsequent stages to the operators via the foreman The third step is to receive from the operator the finished work (one or more combined operations) and to check the quality; the fourth is to send the wages-docket, duly signed by the inspector, to the pay-roll by way of the progress department, the fifth, pay-roll calculation for paying out weekly amount per operator, and the sixth and last step is for the costing department to use the completed wages-docket for debiting the order, whether customer's order (productive) or repair order (overhead)

In order to ensure that this close sequence is followed the works production department must use the parts list (see Fig 21) received from the drawing office, as the foundation on which to work. Dockets are issued by the works production department for each item, thus forming individual orders which can be handed over to the stores and to individual operators and transporters in such an order as to permit of work being handled in its correct sequence As each shop is advised of the completion date of operations, a copy of the parts list can be used by the progress (due date) department, where all the orders are summarized and placed in numerical order, and dockets issued to the production shop only when materials, tools, and machines are prepared for the respective foremen.

Fig. 32 (1) shows clearly the relationships between all documents used in costing, both for material control and for wages costing. Fig. 32 (2) shows the parts list in connexion with production, stores, transport, and shipping. Each foreman will receive a copy of the parts list, together with the dockets which he has to handle, and which he can put into a box (Fig. 32 (4)) as the orders are given to him two or three days in advance. The total contents of the foreman's box are suitably summarized by the progress department (Fig 32 (3)) or recorded on a distribution or bulletin board (Figs. 44 and 45). The department looks after the foreman's box, giving him more work or cancelling it by withdrawing the documents and finally it receives from him the dockets returned from completed and inspected work Every docket must go through the progress department before going either to pay-roll or costing (See Fig 32 (3)) The recording is done in the costing department by clerks, who, lacking technical knowledge, are not likely to be in a position to falsify their figures to the possible advantage of an unscrupulous colleague in the factory With an efficient duplicating machine in the works production department it is immaterial whether the slips are made out in duplicate or multifold, or whether they are coloured or white The cost of a docket is practically that of the paper only, the cost of printing is negligible.

At the same time it should be noted that although modern duplicating methods facilitate reproduction of slips, every slip more than is absolutely necessary only makes more work for those in the factory who have to fill it in, and for those in the office who have to deal with it when completed It is essential therefore to reduce all paperwork to the absolute minimum.

There is still something to be added on the subject of the pay-roll department and the administration of wages. In every case the value of the task must be fixed, whether in terms of minutes or of cash, and the operator must be informed of the work expected and the amount to be paid.

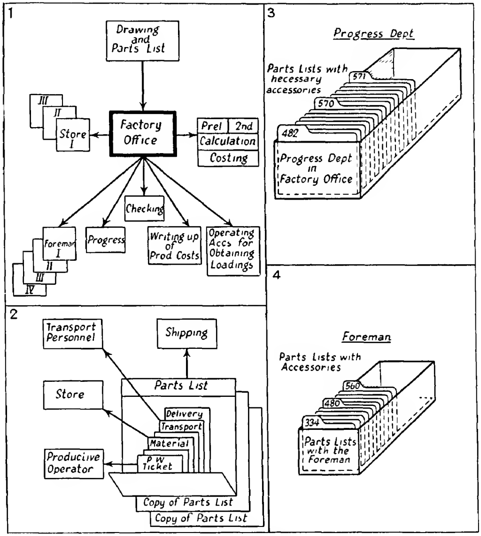


FIG 32 FUNCTIONS OF WORKS PRODUCTION DEPARTMENT (FACTORY OFFICE)

Ratefixing and informing the operator is the work of the works production department and of the foreman calculation of earnings is the work of the pay-roll, and costing (by debiting the orders or overhead account) is the work of the book-keeping department

In the case of day-work, it is sufficient to ascertain the hours of attendance by means of a clock card The scale may be minutes, hours, the day, or the week. Special allowances are generally paid for overtime, night work, holiday hours, or dirty work Output according to quality and efficiency is not taken into consideration in the costing department.

Where a piece-work system is in use, the most important item, apart from type and quantity, is the certification of the quality of the work; hours of attendance do not influence the payment, because payment is made only for the work passed by inspection, and if the piece-rate is based on time units, this is done on the basis of hundredths of hours or minutes. As piece-rates generally carry a guaranteed minimum hourly rate, this fact must be taken into consideration. Since the cash value of a time unit can differ even with the same operator, according to the difficulty of the work or to the time at which it is done (overtime, night shift, or holiday, etc.), the figure of higher value per hour must be shown separately in day-work as well as in piece-work. The pay-roll department has a special file for the different money factors for each category of workers. The allocation to the orders of these differently valued hours is necessary only when the calculation of "special" hours is not entered under overhead. Generally, special hours should be an exception, then the corresponding amount should be shown under the overhead of the department responsible If night shifts became the custom, for example in the case of newspaper printers, then this is simply ordinary payment, but by a different scale In the case of repair work it would be advisable to book these special hours directly to the order number of the job. The calculation of these extra piece-wage earnings is made by comparing the given time allowed with the time inserted by the workman himself. This can usually be done only by comparing the time of attendance (from the clock card) with the total of the piece-wages paid (as debited to the order)

Many kinds of errors arise here, owing to the fact that the operator is able to postpone stamping his card "on and off" the job or to give an incorrect time at which the job was finished, in spite of instructions (theoretical) that a fresh job is to be issued only when the previous one has been delivered. More often than not, such instructions cannot be carried out in practice, as they impede the smooth running of the shop, hence most works have established piece-wage statistics, which make it possible to compare normal earnings with extra and peak earnings. In this way, operators with unusually high or low earnings may be picked out, although it will be impossible to obtain in this way any reliable information of errors in estimating.

The routine for wage computation is as follows: The attendance of the operator is confirmed from his clock card The clock cards serve for a whole week, and are used by the operator for clocking-in or out Late arrival, early leave, etc , are marked in special columns, hence overtime appears automatically on the card Clock cards should moreover be used only to register attendance, and not for any other purpose.

The efficiency record is made by summarizing wages-dockets, recording each individual operation item. With each item the order or oncost number is entered, as well as the name of the operator The order number is indispensable for the costing department According to the type of work done there will be either—

(1) An operation docket for one operation only, or for a combined group of operations, stating the minutes allowed, or

(2) A card or sheet summarizing various kinds of work over a period of (*a*) a day, or (*b*) a week.

The individual operation dockets can be used for any type of work, whereas the summary sheets are suitable only for repairs and group production. If, for instance, the works employs 1000 operators, and each operator does ten items per week, then there would be 10,000 individual operation dockets per week, while with weekly cards there would be only 1000 Nevertheless, the amount of writing and mental work is smaller with individual dockets, because copying and duplicating, etc , is done mechanically, and therefore quickly and cheaply, whilst in the case of weekly sheets progress records must be written out by hand. The individual dockets can be made out in advance by untrained personnel They serve as material slips, process instruction dockets, progress tickets, transport and delivery tickets, and can be distinguished in various ways, i.e. different colours, or thicknesses of paper or card. This paperwork may appear frightening though, actually, when kept down to the practical minimum, it is a very real aid to simplicity.

The weekly sheet for hourly-rates can only be a wages voucher; in order to record the amounts for the different orders the entries have to be allocated according to the various account numbers. It has a relatively small space for operation instructions and is thicker than the ordinary docket, because it remains in the workshop the whole week for operators to handle.

Only in mass-production, where no special instructions need be given (though special preparation is essential), a very simple weekly card is practicable, which resembles the hourly-rate docket described above. The main advantage of the individual weekly docket for each operator is that it is not necessary to sort the separate job dockets in order to prepare the pay-roll; therefore the work of the pay-roll department is facilitated by this presentation of the whole week's work of each worker in summarized form However, the completion of the pay-roll must wait until dockets up to the last working hour have been received. The allocation of wage cost to each separate order is carried out later, after completion of pay-roll The sheet should on no account be withdrawn from the worker for this purpose during the week, as this would deprive him of his most important document

After the operators have been paid, the sorting of single piece-rate dockets can begin according to order or accounts numbers, and the totals per docket can be transferred to the cost sheets. The total wages (pay-roll) and the allocation of wages to each order (costing) must be reconciled weekly. This summarized rough check may raise many queries.

The following mistakes may occur in bookkeeping—

(1) Wage items not booked, then the operators complain.

(2) Wage items booked to the wrong operator; then the operator who is underpaid will complain.

(3) Wage items wrongly carried forward, or wrongly entered. The checker must find the mistake by comparing the dockets with the basic parts list.

(4) Wage items booked twice, this again can be found by comparing with the parts list

In some works the operator is credited and the order debited simultaneously by the use of carbon paper. Experienced clerks are able to make 500 to 600 double entries per day This principle has been carried a stage further and, in addition to the credit entry to the operator and the debit entry to the order, a summarized credit or departmental report for each shop can also be made at the same time. (See Fig 23(*a*) and (*b*))

With this triplicate system, a clerk is able to make 180–200 entries per day From the writer's practical experience it was found that the triplicate system could work only in a small factory. In a large works with many operations, too many highly trained personnel would be required, and the system is not elastic.

Verification by the accountant can be done more quickly by simply extracting and comparing summaries or by the use of accounting machines. For instance, the perforated card systems (Hollerith, Powers, etc (see page 110)), automatically record—

(1) A credit to the operator,

(2) A credit to the department; and

(3) A debit to the order,

simply by passing the same perforated verified cards through the tabulating machines in any order The totals must always agree

With these machines sorting and tabulating take very little time, and results are reliable if the cards are checked before use. Whether their purchase is worth while depends on the number of entries to be made, and the necessity of preparing statistical reviews.

By comparing the totals, the costing department is thus able to confirm that neither too many nor too few slips or wages-dockets have been issued and used. When the totals coincide, the cycle is closed. Operator, order and department have all been credited and/or debited by checked double entries By this system, conformity of preparation, administration and control of all productive work are secured so far as the accounts are concerned.

CHAPTER IV

The Overhead Problem

When direct labour and material costs, i.e. the prime cost, have been recorded, the more difficult item, indirect cost, must be dealt with. This latter is generally known collectively as "oncost," "burden," or "overhead" expenses, but it may be called "works cost," or "factory expense," because it represents the share of the factory itself, personnel and plant, which is included in the total cost of any manufacture.

Unlike the rather simple determination of wages and material costs by dockets and slips works cost is computed from numerous and widely differing elements, peculiar to each factory, and considerable skill and experience are necessary to ensure accurate allocation of overhead to individual orders for varying types and qualities of product.

Faulty allocation may well have serious and far-reaching consequences.

In co-ordinating the functions of technical and commercial management the following principal scheme (Fig 33) may be recommended. It has

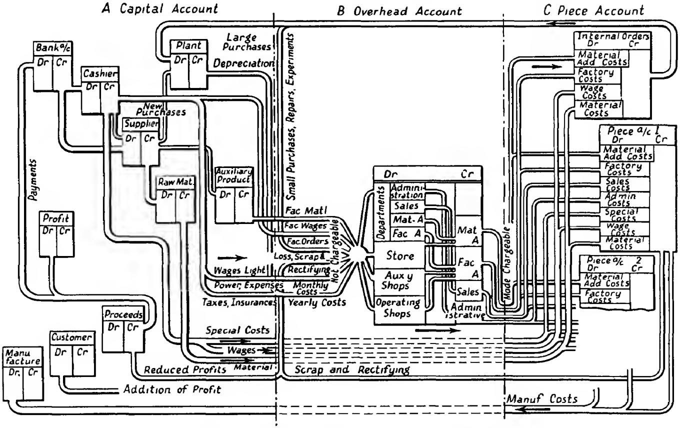


Fig 33 Connexion Between Capital, Overhead, and Piece Account

SHEET 1

TABLE XI

Departmental Oncost (Overhead)

Types of Costs	Total	Sales	Departments: Administration: Commercial	Technical	Stores: Raw Material	Semi-finished Goods	Finished Goods	Auxiliary Material (Chemicals, Tools, etc Building)	Electrical Machinery, Tools, etc	Workshops: Productive	Supplementary	Auxiliary	Additional Costs: Additional Departmental Cost	Dwellings for Staff and Employees	Publicity Department and so on
	£ s d														
(1) Auxiliary Material															
(2) Internal Orders															
(3) Unproductive Wages															
(4) External Invoices (monthly expense)															
(5) Distributable Costs ($\frac{1}{12}$ of yearly amounts)															
(a) Fees															
(b) Insurances															
(c) Rent															
(d) Depreciation															
(e) Interests															
(f) Legal Accounting Charges															
(g) Patents															
(h) Etc															
Total Departmental Costs															

SHEET 2

TABLE XII

Percentage to Productive Wages (or Other Keys of Distribution)

Types of Costs Departmental costs (own costs) from Sheet I	Total	Productive Departments	Additional Costs: Raw Material	Auxiliary Material	Auxiliary Wages	Works Production	Assemblies	Administration	Sales
(1) Sales									
(2) Administration									
(3) Stores									
(4) Supplementary Shops									
(5) Auxiliary Shops									
Total									
Distribution of—									
(1) Works Production									
(2) Assembly									
Total									
Wages of Productive Department (key)									
Wages of Non-productive Departments (key)									
Overhead as Percentage of Wages	%								

TABLE

DEPARTMENTAL OVER

	TYPES OF COSTS		Total		ADMINISTRATION						STORES					
					Administration		Drawing Office		Sales		Magasin		Stores of Finish Goods			
					1		2		3		10		11		12	
			£	s	£	s	£	s	£	s.	£	s	£	s	£	s
	I Auxiliary Material—															
1	Hand Tools (file, hammer, chisel, etc)		9	8												
2.	Mach Tools (cutting tools, abrasives, jigs, test gear)		92	1												
3.	Lubricants (oil, grease)		5	18												
4	Coolants		3	9												
5	Chemicals (potash, sand, paints, hardening material)		4	3												
6	Cleaning (wipers, brooms, soap, etc)		11	19	1	3		15								
7	Belt and Leathers		13	9												
8	Repair Material		3	8												
9	Heat Material (coal, coke, wood, fuel)		43	19												
10	Stationery (incl blankform, wrapping)		13	18	2	13	1	12	5	14						
11	Sundries (limit £5 month)		1	16		1		6								
		Total I	203	8	3	17	2	13	5	14						
	II. Internal Orders—															
1	Standing Orders of Repair		39	9				19								
2	Repair over £2 00		16	6				10								
3	Tests															
4	Scrap		15	14												
5	Re-operation															
6.	Removal		2	6												
7	Exhibition															
8	External Invoices		50	10	16	6										
9	New Plant (machines, equipment)		113	12												
10																
11.																
12																
		Total II	237	17	16	6	1	9								
	III Indirect Labour— (Detailed by special account)															
		Total III	154	2			17	8								
	IV Monthly Distribution Cost (Invoices)															
1	Insurance of Workers		31	9				16								
2	Gas															
3	Water		29	16												
4	Current		32	14												
5	Postage, Telegrams, Telephone (internal)		29	8	7	10			21	18						
6	Long-distance Telephone		11	14	1	19	1	5	8	10						
7	Freight		11	11												
8.	Waiting Times (standstill of machines)															
9	Travelling Expenses (Hotels, etc)		5	19	200				2	14						
10	Support, Presents															
11	Periodicals, Books		3	2	2	14		8								
12																
13																
14.	Sundries		9	3	5	10			3	13						
		Total IV	164	16	19	13	2	9	36	15						
	V Yearly Distribution ($\frac{1}{12}$)— (Detailed by special account)															
		Total V	1401	15	364		57	12	434	19		19	1	16		
		Total I–V	2161	18	403	16	81	11	477	8		19	1	16		

HEAD—SHEET I

PRODUCTIVE DEPARTMENTS

Cutting-off Steel Stores		Smithy		Turnery Capstan		Automatics		Thread Milling		Milling		Backing-off		Circular Grinding		Thread Grinding		Sharp Grinding		Hardening		Assembly Tool Fitting	
20		21		22		23		24		25		26		27		28		29		30		31	
£	s	£	s.	£	s	£	s	£	s	£	s	£	s	£	s	£	s	£	s	£	s	£	s
	1			16							3						1		1	1	2	3	16
1	17			6	19		6						5	10	10	17	11	7	16	37	3		
					9						3				1		3		5		1		
	1			2	11																13		
															10					4	3		
	5			2	2				1		19		3				11		7		13		1
	11														14					9	13		
	3				4						8		4		1	2	6				1		
																				3	19		
					4						1				2		8			5	3		
2	18			13	5		6		1	1	14		12	11	18	21		8	9	62	11	3	17
	12		10	4	11			1	19		5		1			3	19			1	1		
	1				4					3	13	2	14					7	4	1	13		
	1			4	11					4	19			1	12	1	19			3	13		
				2	6																		
																	2						
				4	13			8	13	6	9	1	11		17	11	9						
	14		10	16	5			10	12	15	6	4	6	2	9	16	9	7	4	6	7		
				17	16		2		19	3	6	3	16	7	1	1	6	6	1				3
				5	7		2		8	2	4		19	2	6	3	15	1	11	1	14		17
1																							
																				19	18		
1				5	7		2		8	2	4		19	2	6	3	15	1	11	21	12		17
24	17	6	4	46	2	8	7	8	4	69	17	29	17	26		17	3	18	1	21	3	3	12
29	9	6	14	98	15	8	17	20	4	92	7	39	10	49	14	59	13	41	6	111	13	8	9

SUPPLEMENTARY DEPARTMENTS / **ADDITIONAL COSTS**

Maintenance Repair		Tool-room		Inspection Intermediate Store		Wrapping Dispatch		Tool Distribution		Power Stn Transformer Heating		Transport (Lorry)		Administration		Sales		Material		Workshop	
40		41		42		43		44		45		46		50		51		52		53	
£	s	£	s	£	s	£	s	£	s	£	s	£	s	£	s	£	s	£	s	£	s
	15		13		16								19								
1	18	7	15																		
	5		2							3	13										16
																				2	16
											7										
1	2		11			2	7						1								2
													1								4
										30	10	4	7								
				1	2																3
	3					2	14						12								
4	3	9	1	1	18	5	1			34	10	6								4	1
4	10	1	10		1			13	9	5	11				4						4
			9																		
3	8																				
10	2		3																	23	2
48	5	3	3					18	1			7	14		4						
66	5	5	5		1			31	10	5	11	7	14		8					23	6
		6	13	21	8	40	1	9	5	11	6									7	10
2	11	2	19	1	3	2	1		8		8										17
										9	18										
										32	14										
																11	11				
																				1	5
2	11	2	19	1	3	2	1		8	43						11	11			2	2
77	7	21	9	42	9	6	17	2		18	11		10							63	12
150	6	45	7	67	9	54		43	3	142	18	14	4		8	11	11			100	11

proved useful in a great number of different branches of industry in the last thirty years, including manufacture of machine tools, Diesel engines, locomotives, railway vehicles, fittings, bicycles, agricultural machines, structural erections, motor cars, electrical instruments, and textile fabrics, as well as in copper and brass mills, rifle works, and so on.

The accounts are divided into three main headings, viz —

(*a*) Capital account for "fixed" capital.

(*b*) Overhead or operating account for "circulating" capital

(*c*) Piece account for capital returned by the value of manufactured goods (proceeds)

On this principle, it is possible to arrange the internal administration of a factory in a simple and clear way, using the minimum of personnel, because these three main accounts, or groups of accounts, can be maintained separately at such times as are most convenient

They must, however, be compiled so that on the balancing day, whether monthly or yearly, they are ready to be combined without special effort. The accountants of the capital account, the overhead account, and the piece account, work individually, each delivering his part at the correct time and made up in the correct manner to the chief accounts office to combine on the balancing day

A glance at Table II (page 6) will show the ratio of overhead to wages In one case it reaches 300 per cent, thus proving the importance of works cost in calculating the production cost of parts

The purpose of these accounts is to ascertain the overhead percentages, reckoned on productive wages or quantity (number of automobiles), or weight (tons of coal), etc., as may be convenient. Indirect costs, which cannot be charged directly to orders, are made chargeable to them in this way.

Overhead is classified under type, time, department, and purpose (see Table XI). The type costs are accumulated over a certain period, say one month, per an established classification, based on elements of cost bearers, the total of which gives departmental cost.

The classification of type costs is as follows—

1. Auxiliary material.
2. Internal orders
3. Indirect labour (non-productive wages)
4. Monthly distribution costs (external services).
5. Yearly distributable costs ($\frac{1}{12}$ of yearly amount)

Tables XIIIA and XIIIB show an actual application for a tool works of 100 workmen. For big batches of electric instruments, for line-production of watches, motor cars, etc , every line can easily be controlled by this method

1 *Auxiliary Material* includes fuel, lubricants, cutting oils, chemicals, cleaning material, repair material, hand tools and common tools for machines, implements, instruments, files, belts, electrical material, office appliances, stationery, etc The item "auxiliary material" can be subdivided as desired, though it is not advisable to subdivide it too much. The divisions should be clear enough to enable an intelligent clerk to classify the details correctly after a week's training.

2 *Internal Orders* Under this heading come continual orders for upkeep of buildings, machines, jigs, fixtures and tools, further small repairs, research, removal, erection of new shops, etc. "Standing orders" should be avoided because they degenerate too often in "dumping places" for a variety of expenses

3 *Non-productive Wages* comprise those for foremen, charge-hands, inspectors, setters, helpers of all kinds, such as messengers, janitors, night watchmen, greasers, cleaners, boys, also waiting time, overtime, holidays, and so on

4 *The Monthly Cost* comprises such items as are paid direct by the accounts department, viz invoices for gas, water, electric supply, freight, telegrams, postage, petty cash expenses, fares, telephone, catalogues, advertising, books, gifts, and so on.

5. *Yearly Distributable Cost* $\left(\frac{\text{yearly total}}{12}\right)$ consists of salaries, share of profits, bonuses, commissions, taxes, travelling expenses, depreciation, interests on operating capital, insurances (against fire, etc.), rent, legal expenses, solicitors, patent royalties and licences, employees' insurances, etc , all of which are usually paid in periods

TABLE XIIIB

Distribution Sheet II

Percentages and Statistics

August — Productive Departments

	Total £	Total s	20 Cutting off Steel Stores £	s	21 Smiths £	s	22 Turning Capstans £	s	23 Automatics £	s	24 Thread Milling £	s	25 Milling £	s
Own Costs			29	9	6	14	98	15	8	17	20	4	92	7
Administration														
Drawing Office														
Sales														
Stores														
Magasin														
Intermediate Stores														
Auxiliary Departments—														
Maintenance } Repair }														
Toolroom														
Inspection														
Wrapping and Despatch														
Tool Distribution														
Transformer, Power Station, Heating			10	2		18	27	11	1	17	2	15	29	4
Transport (Lorry)														
Extras														
Total of Addits Workshop Costs	313	6	17	1			76	3	1	19		2	34	12
Total	1022	15	36	12	7	12	202	9	12	13	31	1	156	3
Productive Wages Total	451	6	25	4	2	10	108	10	2	17	11	15	49	9
Percentage %	226		220		338		186		555		278		315	

	26 Backing off £	s	27 Circular Grinding £	s	28 Thread Grinding £	s	29 Sharp Grinding £	s	30 Hardening £	s	31 Assembly Tool Fitting £	s	Administration £	s	Sales £	s	Material £	s	Workshop £	s
Own Costs	39	10	49	14	59	13	41	6	111	13	8	9		8	11	11			100	11
Administration													403	16						
Drawing Office													81	11						
Sales															477	8				
Stores																	1	16		
Magasin																				19
Intermediate Stores																				
Auxiliary Departments—																				
Maintenance } Repair }																				
Toolroom																			45	7
Inspection																			67	9
Wrapping and Despatch																			54	
Tool Distribution																			43	3
Transformer, Power Station, Heating	5	3	8	11	22	2	13	18	18	19	1	18							1	9
Transport (Lorry)															14	4				
Extras																				8
Total of Addits Workshop Costs	15	3	29	12	28	16	63	12	23	1	15	5	485	7	503	3	1	16	313	6
Total	59	16	87	17	110	11	118	16	153	13	25	12								
Productive Wages Total	22	7	43	13	41	13	88	2	33	6	22									
Percentage %	268		203		265		136		465		118									

	£	s	
Overhead (Prod.)	1022	15	
Productive Wages	451	6	
Material	445	11	
Cost of Production	1919	12	100%
Administration	485	7	25.3%
Sales	503	3	26.4%
Monthly Total	2908	2	

Burden	£	s
Workshop	1022	15
Administration	485	7
Sales	503	3
Total	2011	5
Product Wages	451	6
Total Percentage	447%	

longer than a month and must be divided by 3, 6, or 2 to get the monthly amount.

The total of 1 to 5 can be divided into two portions. (1) fixed cost, (2) proportionate cost (see page 85).

The type costs are summarized as departmental costs. All departments of the whole factory are classified into the following main divisions—

(1) General administration.
(2) Stores.
(3) Productive shops.
(4) Supplementary shops.
(5) Auxiliary shops
(6) Generals and extras

(1) *General Administration.* The following departments are included: management, administration, sales, purchases, accounting, cashier, personnel, postage, telephones, telegrams, payroll, costing, material accounting, drawing office, works production department, material control and laboratory, telephone equipment, fire alarm, janitors and watchmen, employees' committee, welfare, apprenticeship scheme, education, and so on

(2) *Stores* items comprise: main material stores (ferrous and non-ferrous metals), coal, ore, electric, plumbing and building materials, paint and varnish, leather, wood, patterns, tools, stationery, etc, other stores of semi-finished and finished goods, standards, sub-assemblies, assemblies, machines.

(3) *Production Shops* are. forge, foundry, and shops engaged on machining such as parting, drilling, milling, planing, grinding, or on hardening, painting, fitting, assembling, etc.

(4) *Supplementary Shops* are those which are *indispensable* for the production, but cannot be charged direct to the job; such as sand blasting, compressed air, water, heating, transport (lorries, cranes, elevators), tool room, hardening, pattern shop, saddlers, painting, internal repair, sick-bay, and so on.

(5) *Auxiliary Shops* are those which could be dispensed with by using external facilities instead, e.g. power station (because we may buy current for power and light from a corporation), carpenters, canteen, laundry, housing for staff and operatives, printing department, fire brigade, and similar items.

(6) *Generals and Extras* receive all accounts, which cannot be allocated to departments 1 to 5 without difficulty, e g. dwellings for workmen or staff members, special festivities, special rewards, gratifications, etc.

The departments must be classified very carefully by the management itself. Large concerns sometimes have over 200 cost bearers, when 40 to 50 types of cost would be sufficient. With 50 types of cost and 20 departments there are 1000 possible combinations, that is a sufficiently detailed classification to suffice for even the most difficult cases. Fortunately 1000 separate accounts are seldom, if ever, all needed in any one month · generally not more than 30 to 50 per cent of them are used. (See Table XIIIA)

Among all factories (about 55) which have been organized according to this scheme and whose personnel fluctuated between 60 and 6000 employees, not a single one was found where this method was not practicable. In most cases it was even possible to reduce the accounting staff by 10 to 30 per cent

It is an advantage for the management to have type costs subdivided thus—

1 Fixed costs which are not dependent upon output

2. Proportionately-variable costs, which vary directly with output

3 Irregularly-variable costs, which fluctuate independently of output and therefore cannot be classified under items 1 or 2

Under ordinary conditions one considers under *fixed cost* Depreciation, interest on loans, rent, salaries, patent royalties, certain taxes, doorkeepers, watchmen, etc

Under the *proportionately-variable costs* come auxiliary material, insurance contributions, power, etc.

Under *irregularly-variable costs* come internal orders such as big repairs, indirect wages, cost of heating, lighting, ventilation, also advertising cost, etc. The classification will vary, and "fixed" costs especially will vary in unusual circumstances. Salaries alter with reduction in staff. Sometimes depreciation is not considered at all. Yet even under the most difficult circumstances a practical solution can always be found.

Fig. 33 shows how the overhead-account is built up, and how additions are transferred to the piece-account, while special costs, wages, and material values flow directly from the capital-account into the piece (or sales) account, either as cash or as priced stores material.

First, individual departmental costs are ascertained (Sheet I, Tables XI and XIIIA): It is quite immaterial whether they concern the cost of a general department, e g. book-keeping department or a store; a productive shop, e g. planing shop, or an auxiliary shop, e g power station With a monthly summary of the overhead in front of him, the works manager can supervise each individual department and is able to budget according to circumstances It is important that he should be able to discuss each department separately with its foreman, and so avoid unnecessary round-table conferences which too often excite ill will and achieve no practical result.

The function of the operating account does not end here, its true purpose is the determination of the overhead percentage on, for instance, productive wages In order to determine this percentage a second step is necessary, enabling the overhead of the supplementary and the auxiliary departments to be related on a suitable scale to the output of the productive shops, because only the productive shops can be recognized as cost-bearers If this be done, it is easy to charge the products themselves correctly (Sheet I, Table XII and Table XIIIB)

The Establishment of the Overhead Account

The first sheet (Table XI) allocates the type costs per department, but there are always general costs which cannot be allocated correctly to any single department because several departments participate in a different percentage, to find which would require great care and intelligence and considerable time Further, the expenses of some supplementary and auxiliary departments have to be allocated to the main cost-bearing department before the final percentage of the departmental cost can be found. These difficulties require much time and consideration and are the reason why departmental costs are not liked and are seldom in actual use. However, there is a very simple method to overcome these seeming difficulties and to charge all general expenses to the right place up to the last penny. For this purpose all "extra" costs which cannot be allocated directly and immediately to a particular department, in whole or in part, are gathered at the end of the department Sheet I under the heading: "Additional Costs"—where they form a series of fictitious departments.

For a certain motor-car works these departments were: toolroom, raw material, pay-roll, repair, dwellings for staff members and employees, sudden changes in design, publicity, and so on.

The correct and simple allocation of these "undistributable" costs to the right cost-bearer is attained by building up Sheet II, the distribution sheet. Here the former general and unproductive departments and stores of Sheet I become types of costs (Tables XII and XIIIB, left vertical column). On top, the productive departments as the single cost-bearers are inserted with their own departmental cost, as already found by Sheet I. The last eleven vertical columns contain the rectified allocations of the "additional costs" and show where they increase the expenses of the unproductive departments, as taken from Sheet I (Table XIIIA), e g. column 45: "*power station*" has a total of £142 18s, which is distributed *pro rata* (based on power consumption as measured by meters or by installed h p) to the consuming departments, thus increasing their departmental direct costs by a justified addition, which enables the complete cost per department to be correctly allocated in each case to the last penny, automatically and without trouble. As the productive wages are the chief yardstick for the distribution of oncost, we get the departmental percentages by dividing the departmental oncost by departmental production wages, thus permitting the real price of a piece or product made in a special department to be accurately determined; or if it was made in several departments, to allocate the right overhead addition to the separate productive wages in respect of drilling, turning, milling, grinding, etc. Several methods exist for the distribution of all factory expenses, the most important of which are—

(1) A percentage on productive wages.

(2) A percentage on productive wages and material.

(3) A percentage on manufacturing costs material plus wages plus factory overhead.

(4) On basis of expense per productive hour.

(5) On basis of machine hour and group machine or department hour

(1) *Productive Wages Method*

By this method (Table XIIIB) the total of factory expenses for a given period in a given department is compared with the total of productive wages paid on all jobs during the period of record, and in this way a factory expense ratio is established. Thus, if the total of factory expenses over a given period was £156 in the milling department and the total productive wages paid during that period was £49 9s, then the factory expense ratio equals 315 per cent. In costing, therefore, a job on which 10s. was paid as direct labour would bear 315 per cent of 10s, i.e £1 11s 6d factory expense.

(2) *Productive Wages and Material Method*

This method is similar to the one considered above with the exception that it takes the total cost of productive labour only, then the material cost is added. The application of this method is confined practically to those cases where the material forms the greater part of the direct cost of the product

(3) *Manufacturing Costs*

In this case the factory expenses are divided up into departmental (workshop) overhead and overhead for administration and sales The idea is that workshop overhead refer to wages, while administration and sales belong to the complete product Table XIIIB shows how the three items of overhead are found and distributed (1) average wages overhead; 226 per cent, (2) administration overhead, 25·3 per cent: (3) sales overhead, 26·4 per cent. The additional work of the accountant is very small, but the results are evident.

(4) *Productive Hour Method*

This method is based on the amount of the workman's *time* instead of *productive wages*. The factory expenses are distributed according to the hours worked instead of the wages the employees receive

(5) *Machine-hour Method*

According to this method, the factory expenses are distributed so as to show the total cost per hour of operating the machine or the department, for instance, a hardening department, where the distribution of hours per piece is impossible.

Sheet II (Table XIIIB) bottom column proves that department 31 (assembly), for example, has a percentage of 118, whereas department 25 (milling) has 315 per cent Table XIV compares the usual but faulty calculation using average factory percentage against departmental overhead For the sales of spare parts of motor cars such a wrong average calculation might well prove disastrous The "cheap" pieces are sold in quantities causing constant losses, while the "expensive" pieces are not sold at all, thus unduly reducing the efficiency of the respective productive department

TABLE XIV

AVERAGE VERSUS DEPARTMENTAL OVERHEAD PERCENTAGES

SURVEY OF THE ONCOST OF THE SINGLE DEPARTMENTS OF AN ELECTRICAL MACHINERY FACTORY

(1) Departmental. correct

(2) Average wrong and detrimental

No	Department	Productive Wages Total Shillings	Oncost Total Shillings	Percentage
1	Heavy Turnery			200
2	Light Turnery			130
3	Big-plano-miller (1)			400
4	Big Horizontal-boring Mill(1)			400
5	Big Punching and Drawing			150
6	Small Punching, Drawing, Forming			100
7	Assembly			20
8	Armature-winding			25
9	Smithy			50
10	Fitting of Arc Lights			25
11	Fitting of Switch-gears			25
12	Fitting of Resistances			25
13	Repair-shop			90
14	Carpenter			50
		429,579 s	261,371 s	About 60

This factory got regular orders from the whole neighbourhood which over-occupied the heavy turnery (1), the plano-miller (3), and the horizontal-borer (4) for months, because the tenders made with 60 per cent average instead of the correct figure of 200 per cent and 400 per cent were amazingly cheap; while departments 7 to 12 got no external orders at all, because 60 per cent oncost made the estimates too high with the exception of the repair shop.

Generally speaking, the summary of departmental costs shows the complete disposition of each department. The departmental percentages show the economy of the individual workshop as well as of the factory. The question is often discussed as to whether it is necessary to establish individual departmental overhead, or whether it is sufficient to use an average percentage for the whole factory. Only if all products pass through all departments and are handled in them in a uniform way, is an average percentage justifiable in all other cases (and these are the great majority) separate percentages are essential. Two factors are important, i e —

1 The amount of work done and the expense to be charged to each department

2 The technical use and importance of departmental overhead

From the departmental summary (see Table XIIIB) a characteristic inclined curve can be plotted for each department (Fig 34), which separates *automatically* the fixed and proportionate costs, intersecting the ordinate through zero and thus determining the level of fixed overhead The departmental summary is therefore the best and simplest means of inducing the works manager and foreman to economize by budgeting the various type costs

The total of the types of cost per department gives the departmental cost and with the aid of a simple table, suitably compiled, one can grant a bonus to the foremen and the works manager, which can be invaluable as an effective incentive to reasonable economy.

A second way of reducing the overhead and establishing a sound budgetary basis without granting a special bonus, is to make a systematic monthly check For this purpose it is necessary for the figures of the type cost sheet I (see Table XIIIA) to be statistically elaborated over six to twelve months, so that one is certain to have reliable data for each cost-bearer. From this we obtain a definite relation between the degree of activity and the percentage of overhead in each respective department—it may be rising or falling —and this can be used to build up a correct budget corresponding to the activity of the works This basis may be used to determine an incentive for

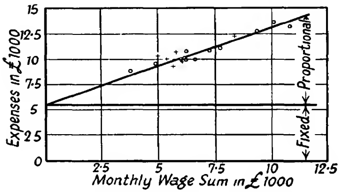


FIG 34 SEPARATION OF FIXED AND PROPORTIONAL OVERHEAD

the responsible executives, to find the causes of irregularities and to analyse and eliminate them Fig 35 shows the budgeting line for the intaglio printing department of a big newspaper and book publishing company and the results obtained for two subsequent years compared with the (bold) budget line To assist the manager, the data of the diagram were also set out in tabular form, one column showing the assumed productive wages in shillings, and the other the total permissible amounts of budgeted overhead. This budgetary table did not show single types of cost separately, such as auxiliary wages and material, internal orders, etc, but gave the manager a fixed maximum sum for the month—of course, based on the detailed figures of departmental overhead—not to be exceeded in total but which could be varied in its composition. He therefore had freedom to vary individual accounts, but was limited to the total budgeted expenditure That was reasonable, for he knew best the weak spots of his realm. An important point was that he was not allowed to raise the productive wages without special consent by the management, because raising the wages would have changed the percentage of overhead in his favour.

The individual dots 1 to 12 correspond to the

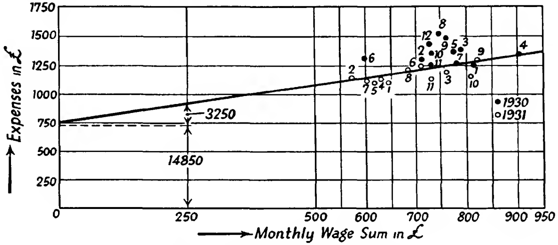
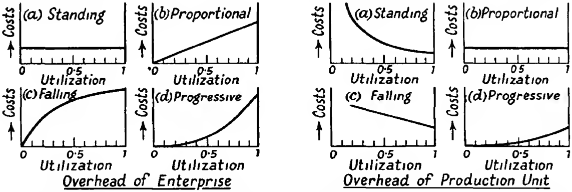


FIG 35 DIAGRAM OF AN INTAGLIO PRINTING DEPARTMENT OF A NEWSPAPER (FOR THE 12 MONTHS (1 TO 12) OF TWO SUBSEQUENT YEARS)

actual monthly expense figure for the two years 1930 and 1931. 1930 results appeared too high and were reduced by well-based budgeting Then in 1931 this capable works manager was able to reduce them still further.



FIGS 36/37. OVERHEAD OF ENTERPRISE DEPENDING ON DEGREE OF UTILIZATION (a) STANDING COSTS; (b) PROPORTIONAL COSTS, (c) FALLING, (d) PROGRESSIVE COSTS RELATED TO (1) ENTERPRISE, (2) PRODUCTION UNIT

This example shows that budgeting of overhead and its control can be carried through in every department of the factory, and it acts as a very effective means of educating the foremen in economic thinking. It is more difficult to make a satisfactory budget for seasonal occupations and for changing degrees of activity. When labour is reduced, only that part of overhead which is proportionate to labour declines, while fixed overhead remains static (See Fig. 35.) It is, therefore, necessary to explain in some detail the nature of fixed, proportionate, decreasing, and progressive costs and the part they bear in (1) total cost (Fig. 36) and (2) cost per manufactured unit (Fig. 37), depending upon the degree of activity or utilization.

The above-mentioned "fixed" or "standing" costs are clearly shown in the yearly distribution account (see Table XIIIA, item V). Materials and wages are the principal "proportionate" manufacturing costs in a steady manufacturing plant, but there are also certain costs of auxiliary materials and continuous internal orders, certain monthly expenses such as gas, water, current, etc., which increase or decrease in proportion to productive activity. Most items of overhead decrease proportionately with increased activity, especially when they relate to plant and equipment, because the production of power, and utilization of transport vehicles and equipment and of manufacturing plant, become more efficient and cost proportionately less, hence the percentage of overhead charges declines as production increases

With increasing output most of the overhead charges decrease considerably per production unit These are shown as "standing and falling" in Figs 36 and 37 Only a small part of the overhead expenses increases more than proportionately with increased activity (i.e. those shown as "progressive" and these mostly under special conditions only, which are generally abnormal), e.g power consumption may be increased by night shift or overtime working of a few big machines, thus needing the power station and perhaps the whole transmission line, or by overloading the transport plant costly emergency transport might become necessary

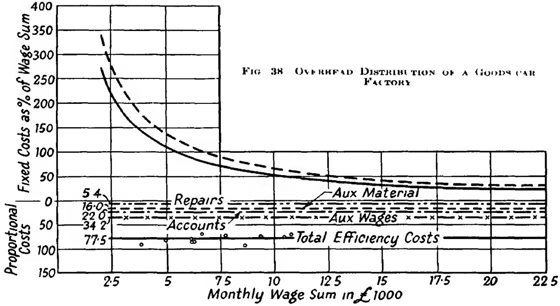


Fig 38 Overhead Distribution of a Goods-car Factory

The character of the curves is changed fundamentally when overhead is related to the cost of the production unit. The fixed cost per unit decreases with increasing output while "proportionate" costs become constant per unit (Fig 37).

"Falling" and "progressive" costs arrange themselves differently according to the law of their increase and decrease It is particularly difficult to comprehend these distinctions in the abstract and it is almost impossible to grasp the figures numerically. The graphical solution, Fig 34, however, illustrates the possibility of satisfactory analysis, and at the same time facilitates permanent control if the departments achieve their work according to the stipulated budgets Fig 38 shows the dependency of the overhead on the degree of productive activity in a goods-car factory, taking into consideration an unavoidable (in this case) heavy variation of the monthly output and the variable overhead belonging to it Fig 39 shows similar results for two machine-tool factories, one of which employed between 50 and 125 workers and the other between 100 and 350 men. These are variations from 40 to 100 per cent and 28 to 100 per cent activity respectively, reckoning the higher figure as 100 per cent in each case In the top right-hand corner of

Fig 39(*a*) the departmental costs are plotted against the activity for one to two years. The diagrams at the left below (Fig. 39(*b*)), present them in the form of departmental cost per unit as total and subdivided sums with "proportionate" expenses horizontal and "fixed" or "standing" decreasing portion of the fixed cost as shown by the hyperbola plotted over the zero line Practical experience has shown that the limits of activity sometimes fluctuate between 20 and 100 per cent, e g. in the case of agricultural machines. Operating below 20 per cent activity is not profit-

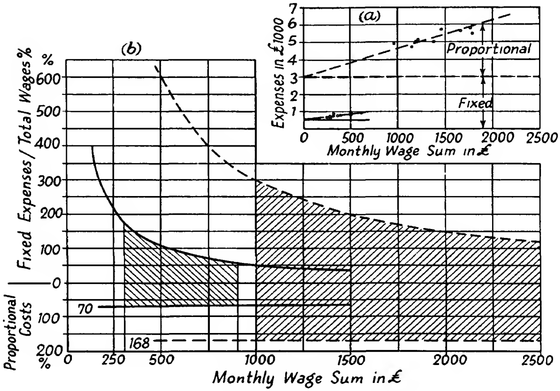


FIG 39 OVERHEAD DIAGRAMS OF TWO MACHINE TOOL FACTORIES
SMALL FACTORY LARGE FACTORY

expenses in the form of a hyperbola above the zero line.

In all cases which have been investigated by the writer, the total of the increasing, decreasing, and proportionate cost has had the approximate shape of an inclined straight line (top right-hand corner), rising with increased activity, hence the possibility of separating fixed cost from proportional cost by prolonging the inclined top line of the total cost to cut the vertical ordinate (at £3000 in the figure). It is therefore admissible to represent the proportionate cost by a constant addition running parallel to the X-axis (Fig. 39(*b*), zero line) and to combine it with a able and, on economic considerations alone, it would be advisable to close down the factory if the activity dropped below 20 per cent

When making quotations this knowledge is of great importance, because it allows the management to take into consideration not only the existing degree of activity but also the future increase, in case orders are received In preparing the tender the question of decreasing overhead can be taken into consideration and a lower tender issued. This procedure is therefore of importance and is perhaps the simplest practical and effective solution of a very difficult question. Even in planning to combine several factories, where a certain amount of new plant (increase of fixed cost) is unavoidable, the hyperbolic curve (see Fig. 38, dotted line) shows whether the planned fusion will be economic or not in that the expected greater activity may bring about reduced fixed overhead The future degree of activity (probably increased) might be compared with the present state The management may supervise the expenses of the workshop and the competitive power of the whole factory with these three summaries—

1 Departmental overhead review
2. Overhead percentages (key figures)
3 Operating characteristic

It must be emphasized that the overhead percentages and the works characteristics are based on the departmental overhead review which is, therefore, the basis He who does not possess these three basic surveys must not be astonished if all the advantages of technical efficiency and rationalization are absorbed by the expenses arising therefrom The ideal solution would be to organize the actual work of a well-equipped factory so that the cost of production figures is available as soon as or very shortly after completion of each order

It is always difficult to adapt the overhead expenses to the varying degrees of production activity, because the actual overhead percentage figure for any month (see Sheet I) is seldom available before the 15th or 20th of the month following Likewise, when a big order is finished at the beginning of a month, it must be decided whether to charge it with the low overhead of the previous month of high activity or with the high percentage of the current month of low activity. It is advisable, therefore, to leave an average overhead percentage figure unchanged for at least six months, but to check it each month—the cost of the clerical work would not be high—and then to decide after a certain period, in the light of the trends thus revealed, if and when the percentage figure should be increased or decreased

Simultaneous costing is only possible in works of a fairly constant degree of activity or with large quantity production over fairly long periods. However, the flexibility of the overhead control system described above is effective in applying the effects of fluctuations of productive effort quickly and easily Furthermore, it is so simple and cheap that one intelligent book-keeper, male or female, can complete the monthly departmental review for 600 to 800 workmen, while two intelligent girls can deal with 1500 to 1800 workers if the accounting methods are correctly applied The chief accountant himself, with, say, two confidential clerks, need spend only about two days per month working out the actual overhead percentages (see Sheet II)

The overhead characteristics should be checked every three to six months to ascertain the bonus, if any, for the works manager (where such is payable) for reducing the budget It is not usually necessary to make a complete costing of each repetition order, but it is advisable to check such operations as deviate from the estimated wage figure and those materials where the quantities consumed differ from those given in the parts lists This requires little clerical work However, a method should be established to provide, if required by the management, an exact costing on any product or on any important internal order (such as a big repair job)

Table XV and Fig 40 show for a motor-car factory how the essential figures on material, wages, and overhead, completed by a reasonable margin of profit, are used to determine the critical

TABLE XV

EFFECTS OF QUANTITY PRODUCED ON COSTS

Costing	Number of Finished Cars per Month: 140		45		Remarks
	Per Cent	£	Per Cent	£	
Material per one car	68	306	63	306	Same material cost per car, but reduced percentage in manufacturing costs
Wages per one car	10	45	11	54	Approx the same percentage, but more money on behalf of smaller batches
Overhead	22	99	26	126	Higher percentage and higher money, decreased activity
Manufacturing cost	100	450	100	486	
Profit	10	45	1 8	9	
Selling price	—	495	—	495	The same

point of the whole works when the activity varies with the seasons

The factory made 140 complete eight-cylinder cars per month—engine, chassis, and body—with a maximum labour force of 1600 workers

The management tried to adapt the manufacturing cost (depending upon the degree of activity)

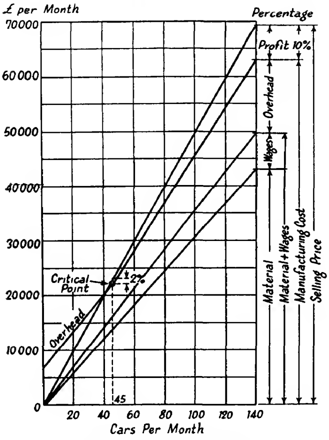


Fig 40 Cost Diagram of a Motor Car Factory Showing that the Profit Decreases to 2% at 45 Cars Output per Month

to the sales in such a way that a fluctuation of between 45 and 140 completed cars should leave a minimum profit varying from about 2 per cent for 45 cars to 10 per cent for 140 cars. To ensure that the factory was operating at a profit, the critical point was carefully watched and the total overhead expenses were adapted to the needs of sales.

The book-keeper supplied each week a report of the departmental fluctuations in material and labour costs, as well as the departmental overhead figure monthly. The value per unit of overhead cost showed a considerable increase as productive activity declined as a result of seasonal drop in trade (See Table XV and Fig. 40)

When the quantity produced fell to 45 the cash value of wages increased from £45 to £54, the percentage of manufacturing cost remaining about the same (11 per cent) the overhead per car was naturally increased, here from £99 to £126 per car, while the total overhead of the factory (not per car unit) was considerably diminished The efficient works manager succeeded in adapting the total factory overhead fairly well to the decrease in output from 140 to 45 cars per month, i e a drop in the proportion of 3 1 Material cost per car remains, of course, the same Regarding wages, the reduction from six to two cars per day required a certain compensation by making pieces for stock, to which was linked the indispensable manufacture of spare parts The reduction of the total amount of overhead (see diagram) which remains constant when output is below 45 cars per month is explained by keeping the fixed portion of overhead as small as possible Buildings and equipment already had a low depreciation rate and interests, power consumption, helpers, transporters, auxiliary materials, small tools, and internal orders were all reduced to the minimum permissible By diminishing the net profit from 10 to 1·8 per cent during the period of depressions one can see from the diagram and the table that with an output of 45 (eight-cylinder) cars per month the factory was able to continue its work with a small profit after paying its actual manufacturing cost

With such a diagram it is possible to ascertain the critical point of production and to be able to decide whether to carry on or to close down before the losses become disastrous

The works overhead accounts thus become the measure of each department's expenditure, because the output of each workshop—represented by the direct wages shown on its own pay-roll—is compared with its cost as recorded in the works accounts Further, each movement of material (receipt into or issue from stores, etc.) can be balanced by the expenditure on wages, rent (proportion for storerooms), crane service, power consumption, and other details

The works manager can control, continually, and automatically, every month, the work and the expenditure of each department, and the monthly statement compels him to consider whether or not they are justified If there is any disparity—for which he must know the reason—the mistakes can be found at once and adjusted In this way the works overhead account becomes not only a true mirror of the monthly activities in the workshop but also an indispensable and infallible measurement and, therefore, a tool, which remains continually sharp, made by the process of calculation adapted to the activity of the works

Those who are accustomed to work with a well-designed departmental overhead system will confirm that no better and quicker source of information is obtainable than the works accountant's figures which are produced usually about the 15th to 20th of the following month The rise or fall of these figures is a much better criterion than the finest personal judgment of any works manager

The best works manager is he whose monthly departmental cost curves fall continuously whilst output remains steady When this can be achieved he may be sure he is using the plant in the most economic way Furthermore the intelligent engineer who constantly follows up the figures from the overhead accounts will be forced automatically to look into the inferior and weak places of his works, nor will he cease his efforts till they are eliminated. The whole economy of the technical processes in the workshop must be surveyed on the basis of the factory costs

The work accounts, arriving automatically on his desk each month, act as a strong and continual stimulus towards improved efficiency

A complete knowledge of factory costs, together with a systematic production and progress control, provides the means of effective utilization of machines and labour and enables "chasing" of delayed delivery dates to be eliminated, thus avoiding unnecessary running about and inter-departmental memo-writing This system or presentation of departmental expenses makes the works accounts invaluable to all responsible executives from the foreman upwards

It seems a small difference and yet it is a fundamental one in its effect on the whole works, and is especially revolutionizing on the mental attitude of the works foremen, who can easily read and understand the departmental factory costs if they are rightly made up The supervision of the works expenses in their most essential form with a minimum of figures, auxiliary materials, auxiliary wages, internal orders, external invoices, monthly and yearly distribution costs, etc (see Tables XIIIA and XIIIB), makes the overhead account a sharp and highly effective instrument in the hands of the works manager who is responsible for the production and its economic success

CHAPTER V

Shop Management and Production Control*

The organization of production has two aspects.

(1) The preparation of a plan

(2) The control of men and equipment to achieve this plan.

When a machine is designed, then it must be built. Manufacture consists of making designs work. If planning and operation control are well co-ordinated we get the best results with the minimum of cost.

The final object of all organization is the smooth and effective co-ordination of effort. It is useless to assign duties to foremen and then to trust in their devotion to carry them out. If there is a need for co-ordination (which no one would deny) then proper machinery must be provided to look after that need Thus every function in every organization should be laid down precisely in writing, including both the duties involved and their relationships with other functions

Most engineering industries are operated on the functional principle, where the superior is held responsible for all work of a particular kind within a department, as in the case of a chief engineer, purchasing manager, or accountant. It may be noted that there is a most important distinction between administration and management.

Administration is concerned with the determination of policy and the final control of the executive; it is essentially legislative in character.

Management is concerned with giving effect to policy within the limits determined by administration; it is essentially executive in character

Execution postulates continuous application Supervision of operation involves the manifestation of two diverse degrees of responsibility, i.e. (I) supervision exercised by the superior, and (II) the amount of responsibility for results left to the subordinates

Taking the production activities in their logical order there are eight fundamental factors—

(1) The general management of manufacturing.

(2) The objects of manufacture

(3) The methods of manufacture

(4) The provision of buildings and equipment necessary to carry out the manufacturing methods decided upon

(5) The provision of the main and secondary materials necessary for the manufacture of the product

(6) The storing of materials until they are required for use

(7) The provision and replacement of the necessary working personnel, staff members and employees

(8) The economic *control* by costing and records.

The practical details affecting these activities are—

(1) Planning of manufacture—

(*a*) Operation schedules

(*b*) Ratefixing

(*c*) Machine loading.

(*d*) Routing materials and products from process to process

(*e*) Issue of instructions to workers.

(*f*) Following up of orders in process by production control

(2) Internal transport, conveying materials or

* Sources of information on Production Control—

(1) *The Gantt Chart*, by W. Clark, New York.

(2) "Production Control," by R Appleby, London, *Institution of Production Engineers' Journal*, May, 1943

(3) *Production Control in the Small Factory*, B S. 1100, Part 2, 1944

(4) *Application of Production Control*, B S 1100, Part 3, 1945.

(5) *Production Control*, by J Ayres and H F Webb (Simms Motor Units, London), Adrema Ltd., London

(6) *Production Control*, by Addressograph - Multigraph, London.

(7) *Production Control (Ticketograph Method)*, by International Time Recorder Co., London.

work-in-process to the points at which they are needed.

(3) Inspection of operations to ensure quality.

(4) Stores for semi-finished or finished goods

(5) Packing and dispatch

(6) External transport

(7) Maintenance of buildings and equipment

These activities are all essential, irrespective of the size of the undertaking Even in the smallest factory they have to be done by someone at some time

Of the three main headings production, sales, and finance, we are dealing here with production only. The connexion between production, finance, and sales is through costing and the accounting departments by methods which will be laid down by the financial controller in close collaboration with the works director as the responsible engineer.

It will be the duty of the financial controller to see that the production manager obtains promptly such figures and records as he requires to do his job properly.

If full preparations have been made for manufacture of a particular product or range of products the foremost and continuous duty of the manager is planning production control, i e to lay out a schedule according to the facilities and labour available and to ensure that the scheme is fulfilled according to plan as regards time, quantity and quality

Planning

Planning is done in the factory office or the works production department (W P D) and begins as soon as the design of the article is complete, i.e. when the assembly and detail drawings are checked and the parts list is made out

The planner commences to make a schedule of operations, allocating them to certain machine-tools, decides if jigs, tools and gauges are necessary and to what extent (see Figs. 41*a* and *b*), and delivers the sheets thus prepared to the ratefixers, who complete the documents by inserting the working times either from their experience of similar pieces or from existing standard data supplemented by time studies for special cases For quantity production and difficult new operations even motion studies may be advantageous (See page 228.)

Production Control

In view of their detailed knowledge of processes, machines, tools, and working times for the various jobs, the production control, which is the executive section for performing the preparatory work of the planning department, can plan the loading of machine groups, and in some cases even of individual machines, according to the capacity of the department It can also initiate routing and processing. An indispensable condition for the maintenance of delivery promises is that the necessary material is at the right place in the right condition at the right time Production control, as with any control, becomes operative as soon as all preparations for the job are finished, both in the office (preparation of parts lists, requisition slips, wages dockets, operation schedules, etc) and in the factory (provision of materials, machines, tools, jigs, test gear, etc.). The production controller has the difficult and onerous task of trying to carry his plans through all their stages This is a very different type of work from that of the inspector, who examines the specimen after each operation, or when it is finished. The inspector passes the good pieces, he returns some for rectification and scraps the bad ones, but he is not involved in the making of parts His advice is, of course, very valuable for finding the best schedule of operations. The production controller is the works manager's right-hand man and has the task of eliminating all difficulties which may occur, with a view to securing that delivery promises are kept, that all machines are occupied to the highest degree of capacity, and that no workman stands idle because materials or tools or labour is missing It is important that all functions of the W P.D should be clearly defined. It is evident that full co-operation must prevail between the technicians (designer, process planner, ratefixer, toolmaker, etc.) and the production controller who is responsible for the successful completion of the work.

According to the writer's experience, the most effective way to achieve this end is to separate the following aspects of the task.

(1) Preparation of work (planning),
(2) Management and production control,
(3) Manufacture,
(4) Costing,

and to combine the control of material issue, processing, and costing into one integral system. (See Fig. 21.)

The completed documents, i.e. requisition slips receipted by the storekeeper and wages-dockets passed by the inspector, are used as the basis of the progress records kept by the production control and these are evaluated by the costing section, i.e. the material prices and wages paid are both checked against the parts list.

(1) *Preparation of Work*

This deals with—

(*a*) Sales or contract programme.

(*b*) Approval of sample or design for manufacture, or modification of existing drawings.

(*c*) Parts lists of materials, schedules of processes and specifications.

(*d*) Jigs, tools and test-gear design and manufacture.

(*e*) Ratefixing and time study.

(*f*) Stock control: making available the necessary quantity and correct quality of material and components according to plan.

(2) *Management and Production Control*—

(*a*) Establishment of manufacture.

(*b*) Routing and processing.

(*c*) Following-up the progress to due date, eliminating deviations from plan.

(*d*) Work-in-progress stores.

(*e*) Stores of finished goods.

(*f*) Dispatch.

(3) *Manufacture*—

(*a*) Feeding of material to the working places.

(*b*) Machining of parts.

(*c*) Fitting of sub-assemblies and final assembly.

(*d*) Final test.

(*e*) Inspection of items *b*, *c*, and *d*.

(4) *Costing*. (*See page* 113.)

(*a*) Passing wages dockets without delay from the progress control to the pay-roll and instructing foremen and storekeeper to dispatch the receipted requisition slips to costing.

(*b*) Comparison of estimates and pre-set rates with records of actual payments.

The work of the production control, being executive, is to ensure that the planning of the administration (or legislature) is carried out as fully as possible. The controller's duty is to prevent machine tools or labour standing idle for any reason whatsoever, e.g. lack of material, tools, help, power, light, etc.

The task of maintaining uninterrupted manufacture is often further complicated by frequent and unexpected developments. Any factory, which has more than one product, has to overcome the difficulties of change-over without suffering drop in output. The inability in such cases of keeping promised delivery dates is mostly due to inadequate preparation. One of the main duties of production control is to see that such preparations are made and thus to avoid overlapping of efforts by other executives on the same problems.

PREPARATION

After the orders are typed out, they are checked with the material control slips, two to six days in advance of shop requirements. Material is reserved and slips are stamped and returned to the production control, where they are filed with the corresponding part orders ready for release to the proper workshop. The material is then definitely known to be on hand when the shop orders are issued to the production release booth. On the proper scheduled day, the order is released, and requisition slip and tag are sent to the stores, who issue the material to the accumulation areas with the tags and return the receipted slip to the production control (release booth). Now the job remains in the hands of the progress section, until finally accepted by the inspection as a finished part. The course of its path is indicated on the label, which should be used for no other major purpose and certainly never for costing purposes.

Each job operation or assignment docket must show the order number, part name, part number, kind of material and specification, size to be cut, operation number, department number, where work is to be performed, kind of tool or tool number required for each operation. Each booth has its incoming receiving area. Hand truckers deposit the stillages with the material in the area and hand the shop paper to the dispatch clerk, obtaining his initials on their dispatch ticket, this being their receipt showing that material was moved correctly and the proper shop paper delivered. The receiving clerk may either dispatch the material to a station or, if no space is available, may place the material in a work dump When the work called for by operation planning is ready in his area, he forwards the material and papers to the next booth and returns to the tool store the tools used on the previous operation

Plant Layout

To permit of a successful dispatch system careful consideration of plant layout is essential

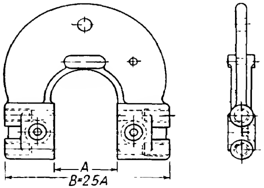
The arrangement and placing of machinery, work benches, ovens and the like ought to provide for routing work through the workshops, so that it will flow from one station to another without retracing its tracks (See Figs 1 to 10) Every work station has its designating number whether a machine, furnace or a bench It is necessary to have provision for a "working" and "next" job at every station

As all work-in-process cannot be stored at a work station, work dumps for accumulation of material between operations should be provided, they are as essential to good plant layout as in machine placement For inspection and control in the manufacturing departments they are vital Each accumulation area should be identified by a clearly visible number and letter, dispatchers will then know by the label exactly where every job is to be located for the next stage

The last operation having been performed, the parts are cleared through the inspection department and receive the specified finish, such as painting.

Interdepartmental Transport

Internal transport as well as intermediate stockrooms are also vital functions under the jurisdiction of the production control. The transport department is charged with the responsibility for movement of all material or parts between departments, and the care and operation of all handling equipment, including hand trucks, power trucks, containers, stillages, stacking pans, flat trucks, and specially built equipment (See Figs 4c and 6) The central dispatch station (usually the main storeroom) is the clearing centre for delivery, where all transporters receive orders and are sent out on their various missions

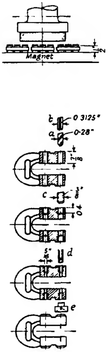


Denomination of Instrument	Snap Gauge
Denomination of Part	Body
Drawing Number	83651
Parts per Unit	1
Yearly Production	0 to 6 mm 1600 6 to 12 mm. 2000 12 to 18 mm 10000
Batch of Pieces	0 to 6 mm. 200 6 to 12 mm 250 12 to 18 mm. 1000
Material	Perlite Cast-iron

Fig 41a Body of Tolerance Snap Gauge

Regular routes on fixed schedules are laid out for ordinary and for "express" service, the material or parts for interdepartmental transport being concentrated in the department depots, where they are picked up and moved according to planning instructions as shown on the label.

Fig 32 illustrates a similar system for a machine-tool factory of 200 to 250 workers but based on the extensive use of the printed parts list (Fig. 21), the right page of which is specially modified according to requirements for. (1) purchase, (2) stores control. (3) machining departments,



Working Sketch	Position No	Position Op	Machining	Machine Tool Kind	Machine Tool Size	Machine Tool Power h p	Jigs and Fixtures	Tools	Gauges	Data of Calculation r p m	f p m	Feed per Rev Min	Feed per Min	Depth in
	1		Supplied as casting											
	1		*Grinding* of marked surfaces and side faces	Vertical surface grinder	No 1	3	1 circular magnetic chuck	Arbor P 36	Caliper	50	25	0 0008		0 015
		a	1 Side											
		b	2 Side clamp 10 pieces at once											
	2		*Drilling*	Vertical drilling m/c	B 44E	1	1 drilling jig							
		a	Drill 4 pin hole					1 twist drill		600	45	0 004	2 4	
		b	Counterbore 4 holes					1 counter bore m/c	1 thread limit gauge	600	45	0 008	4 8	
		c	Tapping 4 holes					1 tap		200	15	25T		
		d	Reaming of 4 pin holes							125	10	p i 0 02	2 5	
		e	External chamfering of 4 pin holes							420	50	0 004	1 68	each 0 1
		—	—											
		—	—											
		—	—											
		k	*Deburring* all holes											

FIG. 41*b*. PLANNING,
(Tooling Jigging—

suring Instruments

(Snap) Gauges

Machining Time for 1 Piece									274 Working Days per 1 m/c	
Setting Min	Machining Min	Auxiliary Min	Allowance Min	Total Min	Pieces per 1 Hour	Occupied Hours per 1 Year	Qualif of Operator	m/c per 1 Operator	Loaded Days	No of m/cs Wanted
						480 min per 1 day of 8 hrs nominal time				
(10 pieces) 0 2 0 2	0 5 0 5	0 25 0 25				10,000 pieces per year	Semi-skilled	1		
Total of grinding 0 4	1	0 5	0 5	2 4	25	400			50	1
(100 pieces) 0 15	1 8	1 8								
	1 4	0 6								
	0 7	0 6								
	2	0 6								
	0 4	0 6								
		—	—							
	—		—							
	—	—	—							
	0 5	0 5	—				Female	1		
Total of drilling 0 15	8 2	6 4	3 25	18 00	3 3	3000			375	2

Ratefixing, Loading

Machine Tools)

(4) inspection, (5) intermediate stores of finished parts, (6) assembly

The co-operation between drawing office, factory office (W.P D), stores, workers, transporters, foremen, progress, and costing is self-explanatory Such lists in book form give rise to the same objection as do ledgers, i.e they do not possess the elasticity of slips, dockets, etc , as derived from the more rigid list, but the lists are very valuable for the final control, for verifying that all dockets have been used, that the correct number were issued, and that all pieces left the stores, passed the inspection and reached the assembly and the costing department

Capacity of Departments

The capacity of the factory should be known in terms of labour and equipment The methods herein described ensure that this information is available.

Figs 41*a* and *b* show a section of a layout showing how this was achieved in a factory manufacturing snap gauges and other measuring instruments in large batches The plan follows closely the system given above, and has been in use since 1930

In old factories, particularly those which are no longer engaged on the work for which they were built, the task is much more difficult, but it can always be solved if the problem is entrusted to a person possessing the requisite experience. (See Fig 16*a* and *b*.) Such reorganization is, however, a highly-specialized task, calling for qualities, knowledge, and experience quite different from those needed for the normal successful running of a factory already being operated on a well-established basis.

Production must be so co-ordinated that the maximum output is obtained from all productive resources, such as material, equipment, and labour. In order to achieve this aim, the management must have specific information relating to these factors, the four main aspects of which have already been described. Production control includes the exertion of planned pressure, ever seeking to overcome all resistance in the form of difficulties connected with materials, equipment, and labour

Typical examples known to the author are factories for making crucibles and rifles and also for oil refining. (See Figs. 5, 19, and 49.)

The main duty of production control is the minimization of—

(1) Hold-ups by lack of materials, tool, help, etc. (leading to items (2) and (3)).

(2) Wasting of workers' time

(3) Idling time of machines

(4) Time spent by the foremen on clerical, planning, and chasing work of all kinds

Paperwork should be reduced to an absolute minimum . this can be attained if the indispensable clerical work is duplicated or printed by any of the well-known methods as above mentioned, and if the receipted requisition slips and passed wages dockets are recognized as the principal documents on their way from the stores through progress to costing and from the inspector through progress to the pay-roll In most cases a visual comparison of the completed parts list with material prices and wages will provide an adequate check It is important that the wages documents shall not be retained more than one day in the progress section of the production control, where they are checked by an intelligent girl clerk (See Fig 45)

Assessment of Capacity

To measure performance and efficiency in the shops the effective capacity of (*a*) machines, and (*b*) labour must be known There may be a great difference between eight machine-hours and the output of eight man-hours with the same machine during the ordinary eight-hours shift, because age, skill, training, etc., may enable the skilled worker to produce, say, treble the output on an ordinary centre lathe as compared with that of a semi-skilled girl, whereas the same girl, well trained, may surpass the craftsman by her patience and perseverance in operating a good capstan lathe

In the case of the mental work done in the drawing office and other engineering departments, it is very difficult to estimate or to measure the time needed to design a tool, or to prepare a drawing, or to form even an approximate idea of the amount of preparatory work required to be done in connexion with an inquiry, order, contract, and so on, before any work can be done in the factory. An average figure would be of little value. This is the great difference between the staff work done in the office and the well-defined labour of the workshop, where all working conditions are well known, e g material, dimension, tolerance, finish, machine, tool, test gear, speed, feed, depth, average times for auxiliary operations, etc All these details are checked so often that work can be measured in fractions of minutes as a basis for piece-wages Those who plead for hourly or yearly rates in the workshop without a well-designed bonus or premium system for keeping the pre-set time properly established *by measurement*, neglect the retarding factor of boredom from which repetition work would suffer, if some adequate stimulus to keep to the pre-set time were lacking

The jig and tool design office can overload the toolroom, unless some effective method exists of measuring the amount of toolroom work created by each tool drawing The chief of the drawing office can only estimate the time for a jig or tool from his own experience and try to obtain completion accordingly, but he will soon be able to distinguish the quick, intelligent draughtsman from the slow, dull one However, a slow but intelligent designer is always preferable to a quick draughtsman, each belongs to a totally different mental category from the other The only means the chief has at his disposal to stimulate the zeal of his staff is the prospect of a future raise of salary

A fully mechanized power-driven assembly line is geared to minutes or seconds (see Fig 151) At the point where the works production department releases operation planning, the production control as its executive assumes responsibility for obtaining material from stores, movement of material throughout manufacture and assembly, movement of tools, supply of all blank forms and records of work-in-process, finished parts and assemblies, the control of all sub-stores, and interdepartmental transport. In other words, all parts are the property and responsibility of the works production department, which assigns them for fabrication or assembly, and this responsibility continues to operate until delivery is made to the customer.

Schedule

A sufficiently detailed schedule is most important, covering not only the parts manufactured in the factory, but also those items bought from sub-contractors or suppliers, or even from the final customer for assembly in the completed product

The works production department is responsible for the preparation of such a schedule. The schedule must include the requirements of final assembly, sub-assembly, and component manufacture, and must take into account the working times involved at each stage For instance, in making a lathe, the headstock, tailstock, carriage, toolpost, apron, and gear box are all major assemblies which are finished separately, sometimes in special departments, while the bed is being levelled, so that the main assembly of this machine tool and sub-assembly of its major parts is proceeding simultaneously, according to a proper plan

Every single item must be available at the right time and at the place where the work is to be performed on it

Order Release

The dates that the respective parts are required having been determined, the order is divided into release batches so as to meet schedule requirements (see page 252), special consideration being given to the question of the most economic size of batch for manufacture

The schedules of detail parts which have been compiled from specification cards and which show the number of days prior to final delivery when each lot of parts must be started, are then coordinated with the release schedule and the shop orders are written out

The complete shop order is reproduced by a suitable process direct from the master specification prepared by the planning department Shop orders for each detailed part are printed and grouped into packets for all operations The printed forms include · progress card, material requisitions, material label, wages-dockets, final inspection report, tool voucher and so on.

The printing department facilitates the work of the clerical preparation for the regular manufacture of a repetition article When the blank forms are released from the release booth (see Figs. 32 and 45) the progress card is detached, and the packet remains in the production control file until the parts reach the finished goods stores. When that time arrives the tag is detached from the material and returned to the office, officially closing the order. The progress card is then cleared from the active file, date-stamped, and forwarded to the cost accounting department, where it meets the requisition slip and all passed wages-dockets, thus closing the circle of indispensable paperwork.

The quantity of satisfactory parts accepted by the inspection department is checked, e.g on a copy of the parts list.

To avoid the very disturbing replacement of scrapped parts during running production it is recommended that the batch quantity should be increased by an amount which corresponds to the usual scrap percentage as shown by careful statistics. For instance, 110 pieces might be ordered to give a batch of 100, leaving 10 per cent scrap allowance, then it is immaterial if 110 or 100 finally reach the assembly bay. If all 110 pieces pass, then 10 are stored as spare parts or available stock, and the next new order can be reduced accordingly.

Fig 42 illustrates a planning and production schedule for the manufacture of locomotives The type is the British engine with outside cylinders and piston valves. Ten of these machines were made simultaneously. The differently cross-hatched columns refer always to the same combination of details, so that it is easy to follow up the manufacturing process from the date of receipt of order to the dispatch of the finished machines. The longest time is consumed by the preparation of drawings and parts list (including design), i e nine months. Production is commenced at the beginning of the second month; production, layout and ratefixing take nine months in all, and the ordering and delivery of material a total of seven months. Design and manufacture of patterns, jigs, and tools begin at the end of the second month and end with the eighth month. All the times shown on the schedule run concurrently.

The first parts to be completed are the castings for the heavy boiler fittings and accessories, beginning in the last part of the ninth month. The schedule is divided into the following main parts—

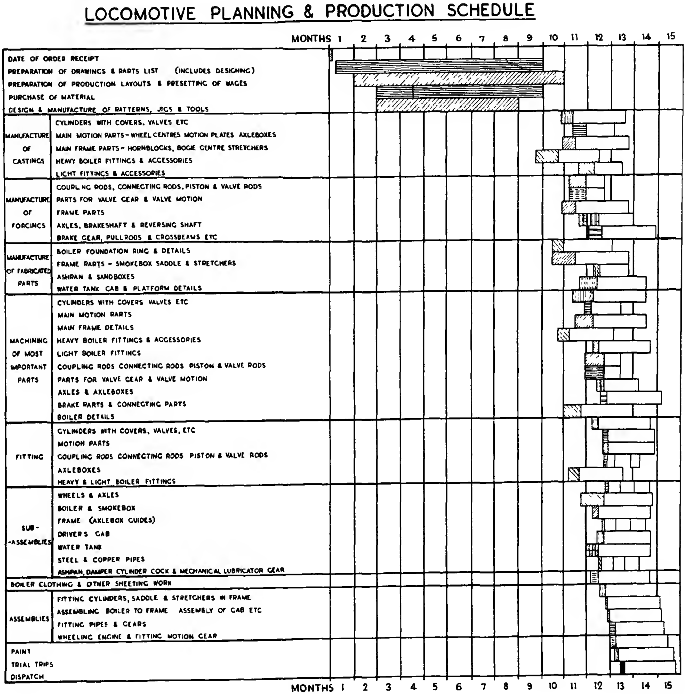
1 Manufacture of castings
2 Manufacture of forgings.
3. Manufacture of fabricated parts.
4 Machining of most important parts.
5 Fittings.
6. Sub-assemblies
7. Boiler plating and other sheeting work.
8. Assemblies

At the end of the twelfth month ten machines are practically finished and the first machine is ready for painting. After fourteen and three-quarter months the tenth machine is finished, then follow the trial trips and finally the dispatch, one engine after the other

The shaded portions of the diagram refer to the time required for the details of one locomotive only The total manufacturing period is controlled by the requirement of one locomotive per week, the staff being adjusted accordingly to give this output The non-shaded parts of each block indicate when the last unit of each batch or sub-assembly is finished, so that the manufacturing period begins in the middle of the tenth month for the first engine and is finished approximately by the end of the fourteenth month. The production control must direct the output of the workshop so that sub-assemblies and assemblies are never disturbed by missing parts

Loading and Progress

There are many useful systems of controlling shop loading For small shops of 50 to 150 workers with medium-sized quantities of, say, small tools of limited types, the production manager himself or his assistant can manage the whole loading plan with a well-arranged pocket book, spending about two hours every day in the workshop, checking actual production against target figures, writing the results in his book, and smoothing out disturbing variations. Much better, and suited to any workshop, is the use of



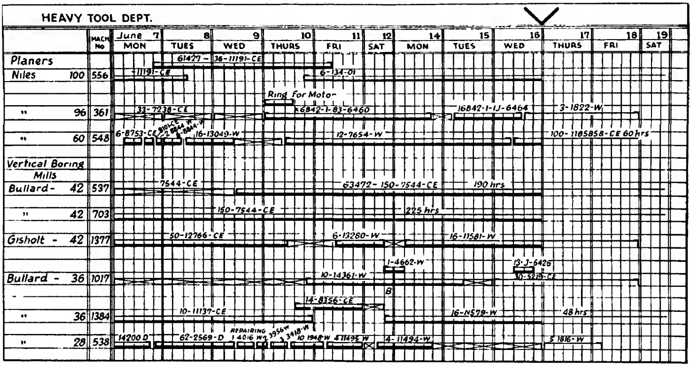
British Railways

FIG 42

the "Gantt" charts (Fig. 43). The writer has used them successfully in small and medium factories employing from 50 to 800 workers and manufacturing batches from upwards of five pieces. In order to attempt to predict future performance it is necessary to use more elaborate statistics, both by the production controller and by the foremen, whose co-operation is, of course, essential in any method of shop loading. The record or chart should compare results with the target, it must keep the executive advised as to the progress made in the execution of his plan, and if the progress is not satisfactory, it must tell him the reason why

The plan is the basis by which the manager works. It shows him what figures will be satisfactory and these are recorded on his chart

All causes tending to influence the success or failure of the plan must be clearly shown, with details of their estimated effect, so that the executive can foresee future happenings with considerable accuracy



Gantt Control

Fig 43 Loading a Machine Shop of Heavy Machines

Gantt charts embody only straight lines, which do not cross each other; all records move from left to right; therefore they are easy to draw and easy to read by the average foreman.

Loading and progress charts must show the passing of time in an obvious manner and thereby help to reduce idleness and waste of time The vertical line of the chart represents both an amount of time and an amount of work to be done in that time. Equal divisions of space on a single horizontal line represent at the same time—

1. Equal divisions of time.
2. Varying amounts of work scheduled (light line)
3. Varying amounts of work done (heavy line).

The chart indicates · on *top*, the month, date, day, *left*, machine tool, firm, inventory number, *below*, percentage per day in light lines, cumulative effect in heavy lines. Each space represents a fifth or 20 per cent of the day's work Instead of writing reports and figures the lines are drawn on the progress department's charts or on those of the foremen, when the wages-dockets, signed by the inspector as to number of pieces accepted, are received before being sent to the pay-roll. The chart shows the relationship of the schedule to time, the work done each day in relation both to time and to schedule, and finally the cumulative work done and its relation to time and schedule

In general use there are charts of 11 in. × 17 in., which have proved satisfactory for records of days, weeks, and months up to a complete year The spaces can be arranged to meet individual needs, i e days, weeks, months, or percentages, they can be drawn on ordinary paper, card, or on tracing paper for duplication The horizontal lines should correspond to double typewriter spacing.

The chart (Fig. 43) shows a sheet ruled for a record covering two weeks of six days each This layout chart was drawn in a department equipped with large machine tools On such machines only one job can be done at a time On the first machine No. 556, part No 1191-CE was to have been finished by Tuesday noon, according to the foreman's estimate, but had actually been completed on Monday and another order begun (No 61427). That job was also finished ahead of estimate and the third order was begun on Thursday afternoon instead of Friday When the chart was checked (**V**) on Wednesday, the 16th, the work was just on schedule.

On the second machine (No 361), the work was already three days behind schedule when it was carried over from a previous sheet At that time, order No. X6842 was scheduled to be begun on Thursday morning and completed Monday afternoon, but it was necessary to run-in a repair job, a ring for a motor, so that four hours had to be allowed for the delay (indicated by crossed lines) before No X6842 could be begun When the chart was checked (**V**), on Wednesday night, the 16th, the work on this machine was four hours behind schedule.

For industrial production, three general classes of charts are in use—

(1) Labour and machine record charts (production control).

(2) Layout and load charts (production control).

(3) Progress charts (production control and foreman).

Labour and Machine Record Charts provide a means of showing the relationship between what is done and what could be done by a worker or a machine. The machine record chart shows when a machine is not being used and the reason why. The labour record chart shows whether or not a man makes proper use of his working hours, and if not, it indicates the reason why.

The gap between actual and possible accomplishment is idleness. The reasons indicate what steps must be taken in order to avoid it

The Layout Chart presents a means of planning work and equipment some time in advance in order to get work done in its order of importance

The Load Chart of a machine shop must show—

(1) The machine hours available

(2) The machine hours reserved for programme

(3) The hours actually used

First of all we must analyse our products. The most suitable type of machines for each operation is known from the time of their last manufacture Setting and machining times can be obtained from existing job cards or must be estimated Then for each machine and machine group we can produce a diagram showing the three characteristic columns

It may be interesting to learn that the average engineering works utilizes between 60 and 70 per cent of its total machine hours capacity and that only in very rare cases of regular quantity production is a percentage of up to 80 per cent obtained

The Progress Chart is the means of getting work done by showing a comparison of the actual achievement with the target and the reasons for failure to meet requirements "Legends" should be embodied in charts the first two or three times they are issued

The charts ought to be sent only to persons having the authority to act on them. If the machines have been waiting to be set-up the foreman must plan the work of his setters more carefully, and if necessary train more setters. If machines are idle for "repairs," steps must be taken to get the repairs completed. If the trouble is "lack of material," the storekeeper or the buyer must take action

As much of the idleness of machines appears to be due to causes over which the foreman has no control, the superintendent, or the production manager, or the works manager, must take such action as is needed. Lack of labourers and operators, lack of tools, of power, and of orders belong to this category.

A similar chart can be made to show whether or not a man does a day's work and, if not, the reason why. The stamped clock card shows each workman's eight hours per day, but is no proof of his actual efficiency.

This system of illustrating machine-loading by clear charts makes it possible to group orders and to allocate them over the available machines in a carefully planned manner. When a machine breaks down, it is easy to transfer its work to other machines without disturbing the proper sequence of work When it is desirable to rush a certain order through ahead of other work, the use of a layout chart makes it possible to do so with maximum speed, because the chart clearly indicates not only the time required to do the rush order but also the time needed to get the other work out of the way Furthermore, any interference with work already in operation is detected at once

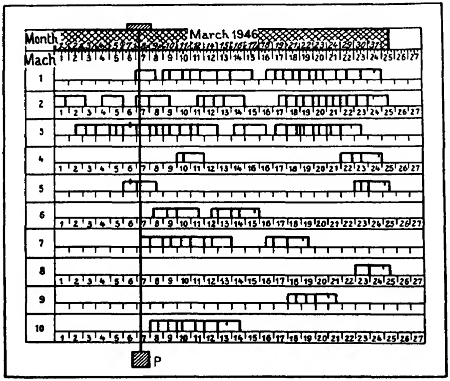


FIG 44 HOME MADE SCHEDULE BOARD

A more detailed kind of visual production control for medium and large factories is the control board (Figs 44 and 45), which is a fairly large piece of apparatus requiring more personnel If care has been taken to ensure adequate shop capacity to meet the orders, and provided that the workshop is correctly balanced, thus eliminating bottlenecks, the control should have no difficulty in keeping the shop-loading running smoothly, while putting jobs through in the correct order of priority The progress control knows the batch route for each part number in each batch It is good policy to have the progress chaser on the spot in the shop near the control board, because the personal contact of the controller with the progressing work can never be satisfactorily replaced by even the most elaborate systems or by masses of paperwork However, the filling-in of superfluous forms by foremen should be either avoided completely or reduced to the absolute minimum The Gantt charts represent such a minimum, and the boards (Figs 44 and 45) eliminate all clerical work by foremen or their shop executives

All effective management records must give a reasonable forecast of the future position To make decisions which affect the future, one must know when those events take place or the rate at which the work is done; the relation of facts to time must be clear

The simple board (Fig. 44) made in each department gives a complete list of assembly numbers and parts required for a given period The board is divided vertically into days, and quantities are posted from agreed wages-dockets for each day. The left vertical column of the table contains the numbers of the work benches or machines In the horizontal direction a time division according to working days per month is provided, the day period may be subdivided into hours if necessary On top of the table a slide is moved with a vertical strip of iron or wood (P), which is advanced every day or half-day until the end of the months. For every workplace of the department a horizontal cardboard strip is fastened across the table, behind which all wages-dockets can be placed. If it is necessary to distribute orders for several weeks or months it is possible to provide two cardboard strips for each machine, the upper strip is used for the current month and the lower one for the next month. The wages-dockets* must be arranged in such a manner that the description of the order is on the bottom left-hand corner and the order number in the upper right-hand corner. Below the order number is the name

International Time Recorder Ltd

FIG 45 CONTROL BOARD

At the left Filing Progress Coupons At the right Sorting Coupons
The Chart above the desk at the right shows cumulative Production Control under Type, Size, and Colour

* Reproduction of the wages-dockets should be done by quick, reliable machines, such as those supplied by Addressograph, Multigraph, Adrema, International Time Recorder, Ticketograph, etc. This is essential because worker, foreman, production control, and costing must all have dockets with identical data, clearly printed and quickly reproduced.

of the department, and also the running number of the wages-docket, and particularly (the most important item) the time allowed for the job. On top of the wages-docket the time allowed is marked by a horizontal line, the length of which corresponds to the time scale of the distribution table. For example: if the scale is 1 hour = 0·2 in., then the line on the wages-docket would cover a distance of 2 in. from the left corner for a work which may take ten hours. If the time allowed is so long that there is not room to represent it on the wages-docket (say a 36-hour job and a scale of 10 hours = 2 in.) then the works production department must state how many full lengths of wages-dockets must be counted and the remainder is shown as a line. Take, for example, a job requiring three wages-dockets and a time allowed of six hours, then the last docket has to be marked with the time of six hours and the delivery date shown According to the delivery dates, period of delay (if any), or other information sent to the foreman by the production control, the foreman arranges the wages-dockets behind the strip of that machine or bench on which the work ought to be performed

The following points must be taken into consideration. The sections provided for each day must be equal in length In arranging the wages-dockets the foreman has to take care that there is a certain freedom of movement, especially for inserting rush orders. It may suffice to have a tolerance of half a day for each week of full occupation of the respective workplace. Further allowance must be made for distinguishing ordinary days of eight hours from Saturdays with five hours. The possibility must not be forgotten that there may in some sections be two or three shifts per day, in this case the wages-dockets are not put side by side, but one above or behind the other so that the bulletin board shows at a glance that special measures must be taken. The arrangement of all wages-dockets according to schedule shows which work has still to be done and how long the machine or bench will be occupied. The position of the vertical strip shows which work is in arrears, represented by all those wages-dockets which are on the left side of the vertical line With this arrangement all clerical work by the workshop executives is eliminated, and the serious disadvantage is avoided of an unforeseen change of dates requiring alterations to delivery dates for other orders in progress. With this board only the wages-dockets have to be rearranged

Some of the above-mentioned systems print duplicate wages-dockets, and use them directly on the distribution board (see Fig. 45). As many orders may be in arrears, because materials are missing, the respective cards on the board may be marked, e g. by coloured riders The use of a threefold pocket made of sheet iron allows the work laid out for a machine to be separated thus—

(1) At work

(2) Ready for machining

(3) In preparation (material, tools, etc, still missing)

All these devices are useful, as far as they serve the purpose, to visualize the result of progress from preparation of work up to costing. The production controller now has the means of obtaining a loading review for the whole works by combining the information shown on the individual departmental distribution boards The summary board can be made on the same basis as the departmental boards This requires personal attention by the production controller himself The daily control of the various departments, with the aid of the charted information, gives the necessary personal contact with all responsible executives this can never be satisfactorily replaced by reports written by the foremen or their assistants Such reports are often of dubious value and require much time which should not be taken up by clerical work Moreover, they still require comprehensive treatment by the production control

Every day receipted requisition slips and agreed wages-dockets return to the control booth, where they are checked on the control board (production control) and sent without delay to the costing department. This is the correct basis for integral accounting Here they are collected until the last operation per piece is finished and the total of wages payments or material prices is checked with the corresponding parts list. If there is no deviation from the pre-set rate it suffices to tick the item. This saves considerable time and clerical work

The parts finished in any workshop are moved to the dispatch section. The foreman, or his clerk, may then either dispatch the material to the next station or, if no room is available there. he may place the material in a finished work dump for movement later. In small works the label is sufficient to show the movement, in bigger works a dispatch ticket is filled in, which identifies the part.

CHAPTER VI

Administration by Economic Control

THE FIRST six of the basic factors of organization (see page 4) are determined by the type of product and the size of batches to be manufactured It is obvious that types of plant and equipment (general or specialized) differ as widely as does a crucible from a copper bar, or a rifle from a machine tool, etc. However, the economic control of production of any of these diverse products (by costing) is in essence the same, therefore, the methods of integral accountancy, adapted as necessary to meet individual needs can be applied to any of them by an intelligent accountant, without requiring a thorough knowledge of the different technical details

The clerical work of costing is, as already mentioned, always based on the recording of the three items (1) material, (2) labour, and (3) overhead, and because overhead consists again, to a considerable extent, of material (indirect) and labour (indirect) (see page 77) the flow of slips and dockets through the works always ends in the costing department, passing via control boards, or booths or parts lists (production control) after the last accepted operation Indirect material and wages, which represent a considerable part of departmental overhead, can be collected weekly, sorted according to type and department, and entered on the collecting sheets for each department with only four totalled entries per month

If it is desired to know the total cost of a big internal order, for instance the reconditioning of a big planing machine or the repair of the Diesel engine belonging to the firm's own power station, such jobs may get a special internal order number (general standing repair orders should be avoided, they are too often misused and allowed to become dumping grounds for miscellaneous expenses), material and wages are debited as a monthly total, perhaps during the three months of repair work, sorted out at the end of each month, collected in a special envelope, and added separately when the order is finished The routine work of departmental overhead accounting must not therefore be disturbed by big internal orders, particularly in view of the facility with which their individual costs can be extracted with any desired accuracy and speed, and under the close control of the manager

Fundamental Practical Solution of the Problem

There are three different solutions of the problem of keeping costing integral with production—

(1) By manual book-keeping

(2) By semi- or full-automatic accounting machines

(3) By a suitable combination of solution 1 and 2

The correct solution must be suited to individual requirements Small batches and uniform production in a small factory can be handled by manual book-keeping

Big batches or mass production with a wide variety of products requiring simultaneously a number of quick and reliable statistical reviews, based on reliable accounts, would call for an automatic punched-card system

Medium-sized factories requiring the ordinary handling of wages, materials, overhead and costing, with all their numerous ramifications, would need modern accounting machines.

But in all three cases the fundamental bases are the verified documents, issued by the planning department for—

(1) Direct material—requisition slip

(2) Direct labour—wages-dockets or job cards.

(3) Overhead·

(a) indirect material—requisition slip.

(b) indirect labour—job card or wages-docket.

(4) Accountancy control—invoices, approved allocation and so on.

In all three cases the accountant follows the same routine, e g. for material and labour, as given below—

MATERIAL—

(*a*) Debit the order from the priced requisition slip (direct or indirect material)

(*b*) Credit the stores material account

(*c*) Credit the material account of the individual item.

LABOUR—

(*a*) Debit the order with the amount of wages paid

(*b*) Credit the department with the total wages.

(*c*) Credit the worker with his wages earned for the order

Overhead again contains material and labour, as well as purchased goods, cash, and other items requiring the same treatment

(1) *Manual Book-keeping*

See Fig 23 (*a*) and (*b*), page 54 To write out three forms in one operation, two sheets of ordinary carbon paper can be used or the Hinz triplicate plate, which uses one sheet of double-faced carbon paper Using the latter method there would be (1) the stores report on transparent paper, firmly clamped in the fixture, together with the double-faced carbon paper, (2) the order sheet, for showing the material issues per order no aligned on top, and (3) the type card for showing material issue and receipt per type underneath The entries are made simultaneously in triplicate, clean and orderly, giving at one writing an identical entry for each of the three different purposes, and, of course, each entry on the last free line of each form

The threefold recording of labour expenses is done in a similar way, i e the debit to the order number and the credits to the worker and to his department (Fig 46). In this way an automatic and self-checking control system is established over the costing of wages and materials, providing the essential information required in all well-organized factories. The principle of the double entry, i.e. that nothing is to be debited without being credited at the same time and to the right account, has been fully achieved.

The necessity for a final adjustment is superfluous, because coincidence is secured from the first by the procedure itself

This system is useful for up to 200 triple entries per book-keeper per day It requires very accurately-spaced horizontal lines on the printed forms

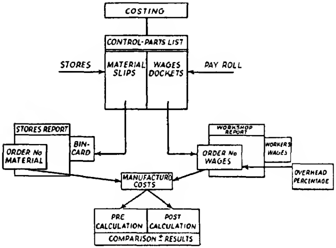


FIG 46 PRINCIPLE OF TRIPLICATE BOOK KEEPING

which become, in fact, a kind of precision tool. This kind of three-fold booking is correct in theory but is very rigid and is not always adaptable to the changing requirements of, for instance, the pay-roll office. It is not necessary, nor even advisable, to cost up each order in detail, particularly repetition orders (see Parts List, Fig. 21) and the triplicate system demands this to be done with every single wages-docket, including those containing only one operation Too much time and work has to be spent to achieve this, and separate entries and their careful checking afterwards will lead to a cheaper and quicker result, secured by systematic reconciliation of the totals with a moderate use of accounting machines.

(2) *Punched-card System*

Punched cards, as supplied by Powers or Hollerith (see Fig. 47), are well-known instruments for all purposes of accountancy and statistics. They fulfil the requirements of material labour, and production control excellently, because the *same verified* punched card, containing in the case of material, for example, the order number, the type code number, the stores number, the weight, quantity and dimensions, etc , can be sorted in very short time (24,000 sortings per column per hour or about 5000 of four columns, as, say, for material to code No. "2345") and then tabulated, i.e rewritten by automatic printing; thus giving the theoretical results not only of a threefold but of a multifold controlled entry, fully and in much less time. Of course, the volume of bookings must justify the outlay of equipment

It is difficult to lay down any hard and fast rule regarding the minimum number of bookings per month necessary to make punched card machines an economic proposition Everything depends on whether the machines are used for only one section of the accounting work or whether they are used for pay-roll, material, costing, general accounting, and statistics However, there exist to-day commercial firms which provide a punched-card statistical service for small factories, thus distributing the cost of their expensive machinery over a number of users (see page 109).

The chart (Fig. 47) indicates a system of material and labour control in broadest outline The method portrayed is being followed, in its basic principles, by many users, but the individual applications differ in detail according to the special conditions obtaining within each organization

The system is especially applicable in the case of factories where the greater part of the manufacture is of a repetitive nature and where, as a consequence, standard material requisitions and operation lists can be established for the manufacture of batches of the various goods produced.

Material (A)

From these lists standards sets of cards (*C*) are punched and filed (*A*). In the case of materials, the data punched into the cards for each order would always include such constant information as material code number, storeroom account number and abbreviated description of material quantity. The cards would also have spaces to accommodate such variable details as works order number, unit value and total value, etc.

Labour (B)

In the case of labour or job cards, the punched information would include such constant details as part number, operation number, batch number, abbreviated description of operation, quantity required, and time allowed each. Provision would also have to be made for accommodating works order number, machine number, clock number, hourly rate, total time, quantity accepted, quantity scrap, total wages, etc.

As manufacturing orders are placed on the factory, the appropriate standard sets of material costs (*C*) and labour costs (*D*) are extracted from the files (*A* and *B*) and, by means of a reproducing punch (*E*), are mechanically punched into the new set of cards, together with the works order number which is included automatically in the punching The verification of all cards (*F*) by a conscientious clerk is essential These new cards are what is known as *dual purpose cards* (*C* and *D*), in other words, the information which is punched into them is also written on them, and the interpreting of the punched information in this manner can be done in a variety of ways Mechanically it can be performed by an "Interpreter," a machine which automatically translates the punched holes into typed characters which are printed on the face of the card, or it can be done by duplicating equipment or addressing machines. Alternatively the information can be written on the cards by hand

Thus interpreted, these cards not only can be rapidly tabulated to provide advice notes to stores, etc., but can themselves be used as actual material requisitions or job cards

After the cards have been prepared in this manner, they are sent to the planning and progress department, where they are filed in an "uncommenced orders" file (*J*) until the department decides that operations are to commence The appropriate cards are then extracted from the file and sent to their respective destinations with appropriate covering instructions.

Note that by sorting (*G*) and tabulating (*H*) the "uncommenced orders" file, one can obtain particulars of materials and machine hours required for uncommenced orders for the purpose of ascertaining loading.

The material requisition cards are sent to the stores (K), together with a suitable job label The storekeeper then gets together and issues the various materials and having indicated on the materials requisition cards all the required information, signatures, etc , sends them to the costs office (M) where all necessary extensions are made (i.e quantity of materials × unit price = total value), and entered on them, and this information is thereupon punched into the cards.

The material requisition cards are now completely punched and can be sorted and tabulated to give quantities and value of materials issued from stores, materials costs per job, department, etc

Like the material requisition cards, the labour cards (B) are not issued by the planning and progress department (J) until the actual work is planned to commence, when they are duly passed to the shop foreman (L) After the work is completed, the necessary information is entered on the card (time on, time off, quantity scrap, etc.), which is then transmitted to the costs office (M) Provision is made for issuing "waiting for work" tickets as and when necessary The costs office then calculate and enter on the cards the time taken, wages, bonus, etc , and these details are thereupon punched into them, thus completing the punched information they are to contain

The cards can now be sorted (G) and tabulated (H) to provide important production records (O) and costing records (P) such as—

Output and production hours per machine, operator, department, etc

Efficiency of operators, machines and department.

Idle time per man, machine, etc

Scrap analysis by operator, machine, cause, etc

Bonus earnings per employee.

Direct labour cost per job, department.

Indirect labour cost per machine, department, etc.

It will be seen that this system is simple to operate and for a great volume of work involves the minimum of skilled or unskilled labour. It places the control of production where it should be—in the planning and progress department—and it enables vital production information to be available on an almost hour-to-hour basis. Moreover, by the adoption of suitable card forms, the equipment can also be used for the preparation of the pay-roll, for materials and purchase control, and for the provision of much information vital to efficient factory management.

(3) *Use of Accounting Machines for the Mechanization of the Wages, Stores and Costing Records of Medium-sized Engineering Firms*

With accounting machines (Fig. 48) both the original material requisition and the job card or piece docket must be transferred by the mental attention and digital skill of the operator to the keys of the machine Therefore, a tally roll is indispensable and cross-checking of totals to check the insertions for correctness, the results can then compete both with the triplicate entries and the verified punched card. The chart (Fig 48) illustrates the general principles on which these tasks can usually be mechanized on efficient and economical lines However, the great applicational flexibility of the modern accounting machine makes it possible for any desired modifications to be made and, in practice, considerable variations do take place to meet individual requirements

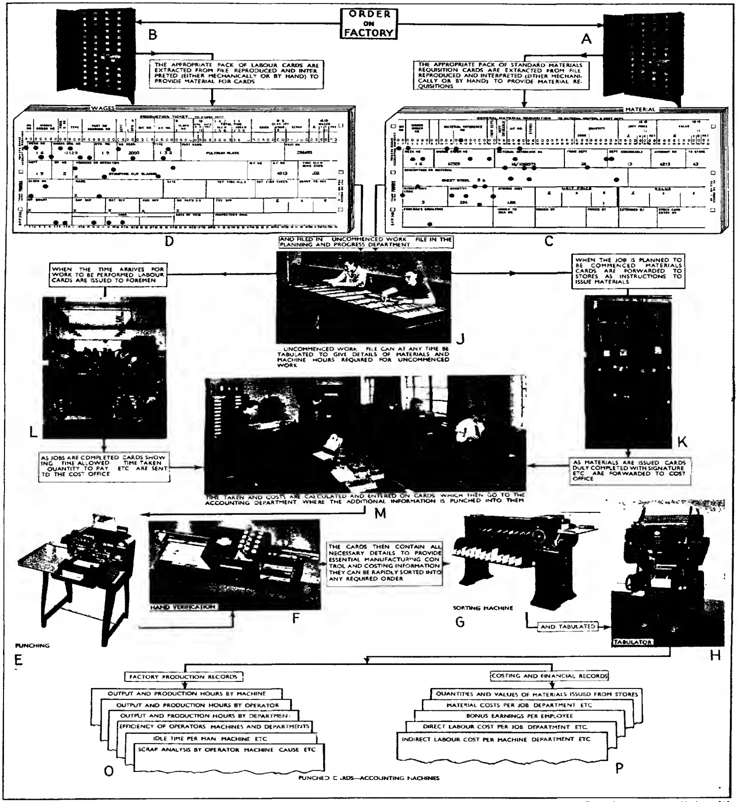
Wages

It is presumed that time clocks are in use At the end of the pay week clock cards (A) are totalled for hours worked and all necessary closing information entered in order to compute the gross pay. Piece-work earnings may be computed from piece tickets (B) or, according to circumstances, from data recorded on the backs of the clock cards (C).

Alternatively, the latter may be utilized for such purposes as recording bonus earnings

Various means have been devised to ascertain income-tax deductions (or refunds) under the Pay as You Earn scheme, and in the chart it is assumed that the computation is made on the clock card, so that after this and other deductions have been made and net pay computed, they have become a complete medium for the preparation on the accounting machines of—

D Wages sheet.

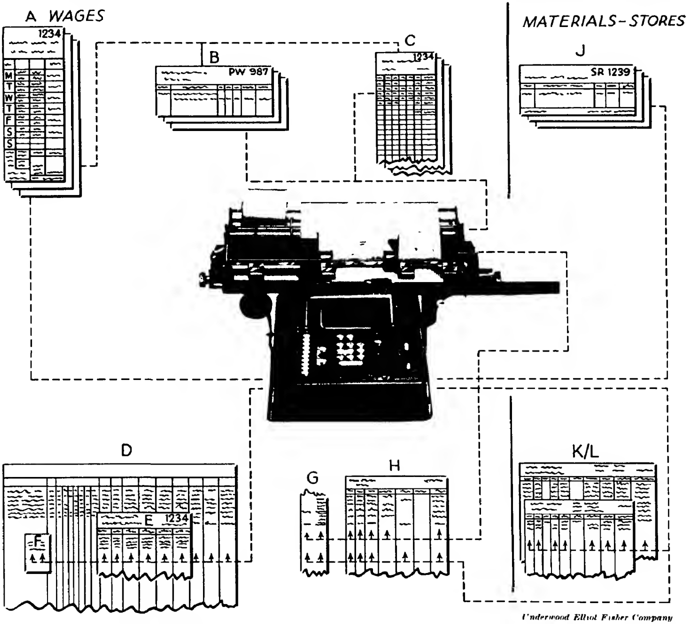


(B 402)

FIG 47

Powers Samas Accounting Machines, Ltd

E Individual employee's earnings and income-tax record (not shown) which can embody holiday pay, credits or any other required information.



Underwood Elliot Fisher Company

FIG 48 WAGES AND MATERIAL SLIPS EVALUATED BY AN ACCOUNTING MACHINE

F Pay slip (not illustrated) and pay envelope *All in one simple and speedy operation*

The machine computes the net pay for the employee and prints this automatically on the wages sheet, and on the pay envelope Comparison of this figure with that shown on the clock card gives an immediate visual check on the accuracy of the work, line by line. The machine also provides an automatic total, either per department or of all net pay at the end of the run. By listing the net pay figures on the clock cards, and agreeing the total so obtained with that provided by the machine, proof is obtained that all the computations on the clock cards and entries on the wages records are correct.

As previously mentioned, the layout of the forms would be decided by individual requirements, but a typical wages sheet might consist of the following columns—

1 Name
2 Clock-card number
3 Details of standard deductions and total thereof
4 Hourly rate
5 Hours worked.
6 Gross pay for week, possibly broken down into the various elements such as day-work, piece-work, overtime, bonus, etc
7 Total gross pay to date
8 Income tax due to date
9 Income tax for current week.
10 Standard deductions
11 Other deductions
12 Net pay

Multi-register models, more comprehensive than that illustrated in the chart would provide automatic totals of all columns on the wages sheet

Employee's earnings and income-tax record cards cover only such columns as are required

Columns 1 to 4 would be pre-entered, generally by some form of addressing machine, which can also be used for pre-entering constant information on pay envelopes and for many other purposes

Costing

LABOUR

Clock cards, piece-work tickets, or other forms, as the case may be, are then sorted into job or order number sequence All items for the first account affected are listed on the tally roll (*G*) and after the last item a sub-total is thrown out automatically by the machine This figure is automatically repeated on the cost account (*H*) by the machine, which then goes on to compute and print the new cumulative balances to date of labour cost and total cost before finally throwing out a proof figure on the tally roll, alongside the original figure, for visual proof of correct entry line by line

On completion of the postings to all accounts affected, the machine provides an automatic total. By comparison of this figure with a predetermined total proof is obtained that all items have been included, all entries made accurately, and previous balances picked up correctly

MATERIALS

In this case the posting medium would probably consist of stores requisitions (*J*), and after pricing, extending and sorting in order of accounts, a similar procedure is adopted The machine automatically computes and prints the new cumulative balances to date of material cost and total cost on each account, any altered requirement having been catered for by the special automatic column feature of the machine Similar proof of accuracy is obtained

Stores

ISSUES

Stores requisitions are sorted into stock order and passed to the accounting machine which in one simple operation posts the respective issues to the stock account (*K*) automatically computes and prints the new (reduced) balance in stock (quantity and or value), and provides an automatic audit sheet (*L*) of all work done daily, weekly or monthly, as desired thus permitting complete control of accuracy

OVERHEAD

It is immaterial whether these are determined as—

(1) A departmental percentage, to add to the share of productive wages, per department, or

(2) A percentage of aggregate cost, on completion of the job

In both cases the overhead consists of—

(*a*) Material,
(*b*) Wages,
(*c*) Cash, and
(*d*) Other fixed standard costs, of the kind generally called non-productive (see page 78)

These are therefore dealt with in the same way as the productive cost but, if desired, provision can be made for separate posting with a separate cumulative balance to date

RECEIPTS

Using goods received notes, inspection notes, vendor's invoices, or other suitable documents (not illustrated), the procedure is similar except that in this case the machine automatically computes and prints the increased balance now available The necessary change in set up of machine is again obtained automatically. Similar proof of accuracy is provided.

Application of Integral Accounting to Typical Factories

Let us now illustrate how typical factories have made use of the systems described, commencing with a small and simple factory making crucibles, to show at a glance the inseparable connexion which exists between manufacture and costing

If integral accountancy can be achieved by the manual book-keeping in a small factory, there is no doubt that the more difficult problems in big factories can be solved by the proper use of suitable accounting machines

Crucible Factory

The factory (Fig 49 (*a*)) produced crucibles for melting all kinds of valuable ferrous and non-ferrous alloys, as well as dipping vessels, brazing pans, refractory tubes, etc (Fig 49(*b*)) About 100 workmen were occupied manufacturing these simple products from a limited range of ingredients, using certain standardized preparatory processes The manufacture involved no assembly or fitting operations, and the items were generally made in rather big batches and were sometimes mass-produced. Layout, buildings, and equipment were based on over 50 years' experience from an old, small, crucible department of a big brass foundry and rolling mill (Fig. 3), which had been transformed into

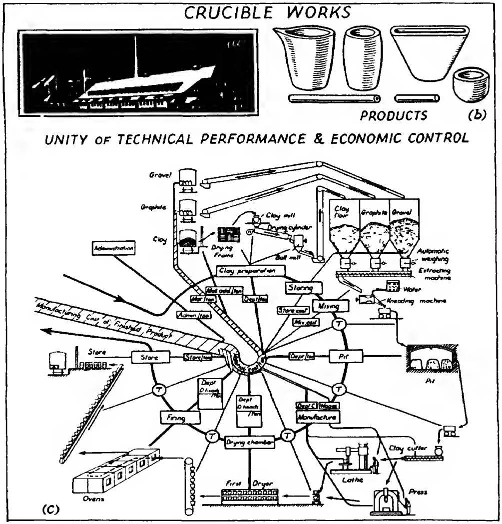


FIG 49 THE FACTORY AS A LIVING BEING
Unity of Technical Performance and Economic Control shown at the Simple Process of Crucibles as Finished Units

an independent factory, to guarantee a quick and cheap supply of crucibles

The crucibles, etc., were made in different sizes and of different material composition, but the constituents of the various mixtures were generally composed of gravel, graphite, and clay

About 80 workers were on piece-work The others were paid at hourly rates, using weekly wages sheets, these included helpers, transporters, messengers, etc

The processes were largely standardized On an average, the 80 *piece-workers* did two different jobs per day, thus requiring about 200 entries per day ($2 \times 80 = 160$, plus 40 at hourly rates, $= 200$) As this number could be done with one book-keeper by the *triplicate handwriting system*, the use of this system was justified

In this case the men on *hourly* rates generally had only two to four entries per week on their wages sheets and many of these entries belonged to the overhead account The overhead accountant was therefore also available for general assistance The material entries were still less than 200 per day, sometimes less than half of that The whole problem was therefore adequately solved by using the triplicate cost recording system for wages, material, and overhead, and employing minimum of clerical personnel

Fig 49 (*c*) shows the intimate connexion between actual production and its economic control The outer black circle shows how the raw materials—gravel, graphite clay, etc—arrive by train and are transported by conveyor bands to the bunkers

Only the clay needs a special preparation It is transported to its bunker, passing drying frames, crushing mill, drying-drum, and ball-mill, and is finally transformed into a clay flour Every bunker exit is controlled by an automatic weighing machine which weighs material issued, books the weight on a tally-band, and prints a copy-slip for each withdrawal This machine transports (*T*) the prescribed components of the mixture to the kneading machines after the necessary moisture has been added from the water tank. The kneaded plastic mass is now transported to the "sump" by lorries where it remains two to three weeks to become "ripe." Then the mixture is sent to the press-cutting machine which squeezes it out to the shape of a cylinder of standard diameter, the length of which depends on the size of the various crucibles. The raw material is then sent either to a special lathe, where the crucibles are shaped singly by using templates, or to the hydraulic press, where the crucibles are made in big batches or in quantity production Suitable transport cars carry the very fragile shaped products to a pre-drying oven From there the pre-dried vessels are taken by an elevator to a continuous chamber-furnace where the final vitrifying is done at high temperature The crucibles are transported by conveyor to the finished goods storeroom, from whence they are dispatched by train

In this factory the actual operations are accompanied daily from stage to stage by their monetary valuation as calculated by the book-keeper The increasing direct expenditure corresponds to increasing wages plus the known value of the weighed material This is illustrated by the shaded inner circle The manufacturing cost consists of material plus additional cost of freight plus preparation of clay (before the clay bunker), transport (*T*) from one department to the next, production wages, and departmental overhead (power, steam, water, rent, depreciation of machines, salaries or wages of foremen, inspectors, messengers, cleaners, etc) Finally the expenses of the finished goods store and a percentage for scrap, inevitable with these fragile articles, have to be added and the costing formula is complete

It was stated above that this crucible factory was established after more than fifty years of hard experience, gained in dark, old and badly-equipped workshops, with financial results more or less dependent on guesswork But the crucibles were indispensable "tools" in the brass foundry, they had to be made, as auxiliary products, and the whole expense was calculated as an overhead of the existing brass, bronze, and copper rolling mill and foundry employing up to 3000 workmen

The new factory was established with the help of competent technical guidance for erecting and equipping the plant, the object being to learn by proper administration the actual manufacturing cost, and thus to sell the surplus production, using the proceeds to offset against the expenses of the main works. An experienced production engineer was entrusted with the layout of the works, i e the provision of plant, erection of suitably designed and equipped buildings (in close co-operation with an experienced factory architect), and the designing of special machines and means of transport, in short, with the complete creation of an efficiently working unit with administration and integral accountancy established in accordance with the leading law—

The work of the shop and the plant as a totality cannot be better organized than by arranging both in such a way that they furnish the whole costing simultaneously with the manufacturing operations

The costing (or recording of costs paid) must be created as a by-product of the mechanical activity Acknowledging this rule, the costing assumes an importance which is not always realized Thus the manager is forced by circumstance to make claims on the accountant which are not easily achieved.

His first demand is that the costing be finished (1) punctually, (2) correctly, and (3) automatically with the finished products. This requires that the manufacturing process be arranged suitably, without detour, and without interruptions

"Suitably" means with the best equipment, machine tools, tools, jigs, etc

"Without detour" means in correctly arranged workshops with shortest routes, using suitable means of transport

"Without interruption" demands perfect pre-production arrangements, planning, ratefixing, material supply, and absolute readiness of machines and workmen leading to a natural production control

In short, we demand unity between management, manufacturing, production, and costing

This enumeration proves that there must be no separate technical and commercial departments, but instead a uniform organism, since management and manufacture are technical, costing is commercial, while material determination, purchasing, and controlling are partly technical, partly commercial. The technical control is insufficient unless it is accompanied by the commercial one

Fig 49 (c) shows that in the present example the technical part, i e equipment and buildings, is fairly simple The same applies to the manufacturing process, for the products, i e crucibles, brazing pans, and refractory tubes, etc., vary considerably in shape and size (Fig 49 (b)), but little in the mixture and composition of their constituents

The cost of the material in each bunker is calculated from the purchase price as delivered, plus cost of transport from lorry to bunker, plus cost of drying the clay Then the subsequent procedure is simple The production manager has only to keep an eye on the correct mixture of the material from bunker to the sump, to the template turning machine or the hydraulic press, and to the drying furnaces He is only designing, mixing, manufacturing, costing is not generally his concern.

The commercial manager, however, provides the money, buys the raw material, pays the salaries of staff and employees and the other factory expenses (overhead), finds the manufacturing cost for the finished goods, and sells them His concern is how his money is converted into goods how goods become invoices for clients, how the invoices become credit at the bank, and how the credit is again converted into cash He is completely satisfied if the balance shows a reasonable profit Design and manufacture are not his province However, in this small simple factory the technical and the commercial director was *one* person There was thus a minimum of managerial staff The managing director himself must always succeed in uniting the physical movements of labour, material, and machinery with its clerical reflexion The commercial staff purchaser, accountant, and book-keeper, must help, otherwise the undertaking will become a failure whether the manager is an engineer, a designer and manufacturer, or a merchant interested mainly in buying and selling

The diagram (Fig 49 (c)) represents a perfect solution, as viewed from the outside The technical arrangements of the outer circle (black) are good and make success inevitable The administrative arrangements of the inner circle (shaded) are equally good

The costing could be done daily but it was controlled weekly, checking deviations by visual comparison of requisition slips, and wages-dockets with the specification card of each product (See Parts List, Fig 21) The salesmen could then be informed at once if a decrease of selling prices was possible so as to beat competition

Temporary deferments of costing and incorrect distribution of material or labour to the orders were taken into account weekly

We have, therefore, found that correct costing is the measure of the efficiency of any organization, verifying and supporting the experience and technical judgment of the capable works manager The two laws which we develop from the simple example of the crucible factory are –

(1) The law of the technical management of the order (manufacturing)

(2) The law of its economic administration (costing)

Law (2) contains the measure for law (1) and at the same time embraces the major aim of running the factory with profit, this being based not merely on the elements of scientific management, but also on every aspect of its technical performance and administration It will be evident that this provides the whole key to the *raison d'être* of the factory, envisaging not only every single operation, but also at the same time, the whole gamut of operations, practical, technical and commercial

It is essential that all parts of the undertaking are equally strong, permitting of no bottlenecks and ensuring full occupation by correct loading It is uneconomic to attach importance to one special function Each department is best fitted to perform a certain selected activity, as determined by the management just as in the case of the human body the brain controls every organ, and each organ is intended for the performance of one specific function The eye, ear, hand or foot never perform any function other than that for which Nature has created them In the same way the parts or organs of a factory as created by men ought to be made and used for their single specific functions only. The blind man tries to "see with his hands," the deaf man to "hear with his eyes," but only because one of his organs is disturbed or prevented from doing the function for which it was made But these organs communicate the smallest disturbance to the brain in a sharp and energetic way and demand immediate relief Think of a dust grain in the eye!

The works manager, too, must have an indicating mechanism which works automatically If a disturbance occurs he must get the necessary information from all his organs at once and by one unquestionable indication, so that his immediate intervention is possible The shop should run like clockwork without serious troubles

This automatically indicating central organ can only be a correctly designed integral costing system It has been compared to a *mirror*, but a mirror is a passive instrument, which is useful only if you look into it It might better be compared with a *shadow*, which is thrown by the object and is inseparable from it, which exists always but must be caught up in such a way that it does not give a distorted silhouette The silhouette must be characteristic, it must return the main features of the original, appropriate and in the most condensed form Then we can make this clerical reflexion of physical movement a real *tool* which replaces the "passive and tardy judge of the past by an active leader of the present and a superior guide for the future " Thus vital costing becomes a work of art, which is produced at the same time as the work, correctly, reliably, and self-checking, with the cheapest apparatus

The many sheets of paper and forms of control, which are established in many modern workshops according to a ' system " may be compared to single pointers (Fig 50 (*a*)) which must be checked individually because they do not have that connexion among themselves which exists in a clock and which is necessary in an integrated mechanism

Even a complete stoppage of such a single pointer does not alter the course of the undertaking because it is not integral with the organization, but is only loosely attached Of course, the management of such a works is driving the clock centrally, but the rigid connexion between the various dials is replaced by the more or less arbitrary reports of the statisticians These have not the same convincing effect as the double-entry control of the accountant

All special indicators and dials should be combined in one single common dial, which should show output figures, just as a clock shows hours, minutes, and seconds, i.e by a fixed interconnexion

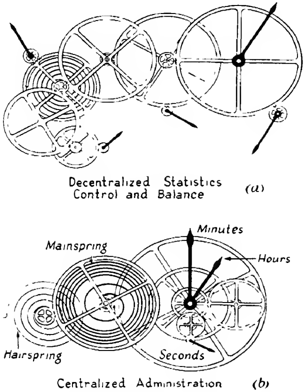


Fig 50 Decentralized and Centralized Administration

between the various details of its mechanism, and should be driven by the leader as the mainspring (Fig 50 (*b*)) The breakage of one single gear tooth then causes the whole clock to go wrong, which is felt and shown by the continual comparison of the physical position and its clerical record, while the stoppage of an essential part stops the whole mechanism.

Organisms or machines created by man must be clear and simple in their operation. Undue bias in one direction causes distortion Too much "system" causes unrest and at the same time needs too much personnel and paperwork.

Only the real organizer succeeds in combining the highest economy with the best technical performance Such a person will find in every case the natural solution of the various problems of shop organization

Examples

With the exception of the crucible factory, all the factories mentioned (see page 14) used either the punched-card accounting or an adequate combination of accounting machines, as may be seen below —

1 Brass, bronze and copper products 2 Machine tools of medium size, but with about 5000 workmen 3 Big steel works	Punched-card Accounting
4 Machine tools small and medium-size moderate number of workmen 5 Rifles 6 Motor-car works 7 Electrical instruments 8 Cloth manufacture 9 Oil refinery	Accounting Machines

(1) *Brass, Bronze, and Copper Mill*

The brass, bronze, and copper mill employed 3000 people with an output of 1 ton per head per month, or 36,000 tons per year The mill was making plates, sheets, strips, bars of different section (hexagon, round, square, etc), wires of all diameters, tubes extruded profiles, stampings, pressings, etc The finished products were of a wide range of dimensions, and of material compositions (See Fig 3) There were de-oxidized and tough-pitch coppers, brasses from 52 to 78 per cent copper content alloyed with zinc, tin, aluminium, and iron, some aluminium alloys, copper-plated steel sheets for bullets, and brass cartridges for small ammunition In short, this factory had a vast programme typical of non-ferrous rolling mills The operators on the machines worked on between one to three different orders per day thus necessitating up to 40,000 wages entries per week for the 2500 productive operators

Similar problems were caused by the purchase of the different materials If we consider only the three basic materials -copper, tin, and zinc—we have to bear in mind that their prices vary considerably, sometimes from week to week, and that therefore the purchasing manager must watch the external markets very carefully, and must select just the right moment for buying in order to catch a low price level

It was consequently of the greatest importance that the purchasing department be given a clear review, if possible daily, of the materials necessary for future orders to enable the buying programme to be maintained Accurate statistics on material movements by weight and value were required daily

Here was a need for the best automatic accounting machines which could also be used for general statistical purposes In this case the punched-card system was selected It reduced the staff for wages, materials, overhead, and statistics from 45 to about 15, serving the punching, controlling, sorting, and tabulating machines all records being based on the use of the punched and verified dual card (see Fig 47) In particular the statistical data concerning materials for purchase and sales, were delivered from the tabulating machines very reliably, quickly and cheaply Any required statistics could be compiled merely by sorting the cards, this being done automatically by the machine and in very short time

(2) *Machine Tools*

A big machine-tool factory occupying about 4000 workers and manufacturing capstan and combination turret lathes, automatic screw machines, and vertical milling machines, in big batches also used the punched-card system

(3) *The Steel Works*

With more than 6000 workers this works had about the same enormous variety of products as had the brass and copper mill and therefore also used the punched-card system

Between the two extremes, triplicate handwriting and the use of mechanically punched cards, we have the systems used by the bulk of medium-size factories Examples are—

(4) Two medium machine-tool factories with 200 and 450 workers

(5) The rifle factory with 1200 workers

(6) The engine works of a motor-car factory with about 4000 men

(7) The factory producing telephones, wireless, and switchboard apparatus of all kinds, with 2500 men

(8) The cloth manufacturer with 800 operators

(9) The oil refinery with 500 men

(4) The two medium-size machine-tool factories used accounting machines with some handwriting for the control of their fairly big programme

(5) *Rifle Factory*

This factory was making 400 rifles per day in two shifts of eleven hours It was a small factory for this kind of work, there are factories making up to 6000 rifles per day The rifle is a complicated and accurate piece of mechanism It has about fifty to sixty-five different parts according to the design, say a Mauser or an Enfield rifle The most difficult part is the body which requires more than 100 operations Altogether there are about 900 operations on the whole instrument including the wooden stock Most operations were made on single-purpose machines, equipped with special jigs and tools The operators (mostly female) were doing the same movements all day long clamping and unclamping the finished piece, putting it on the counting board for finished pieces on the right-hand side of the machine and taking another partly finished piece from another counting board on the left-hand side of her machine

The counting boards were square wooden fixtures, with a certain number of holes or openings, e g 10, 20, 50 or 100, varying according to the size and weight of the components for which they were intended. There were as many counting boards as necessary to keep the factory in full production at 400 rifles per day and to facilitate the control of the quantity of inspected pieces when changing the shift. An interval of one hour between the two shifts was sufficient to rest the machines, to complete the inspection of quantity and quality and to put down on the operator's piece slip the number of inspected and accepted parts The floor inspectors were at work all day long They did not inspect every operation but only the "danger spots" which were carefully laid out and reduced to a minimum In such a quantity production the batch number is kept constant The operation is always the same for the same person and is done on the same familiar single-purpose machine

Consequently the "loading" of all machine tools was well planned, and production control was done by the daily report of the piece dockets signed by the inspector. Together with the scrap report, showing which parts could be repaired and which must really be scrapped, there was a perfect production control which was practically automatic and rigidly controlled by the output of 400 checked rifles per day Allowance was made for the replacement of excess scrap at the end of the week by increasing or decreasing the order from the usual 412 (3 per cent scrap allowance) to a higher or lower figure as necessary

This was an unusually simple works to administer in spite of the complicated nature of the product. There were always big batches of the same quantity and type of part for each machine, controlled by the daily output of finished parts and the number of complete rifles assembled and accepted A permanent running order for rifles was in uninterrupted production and the piece dockets showed the same time per piece for slightly varying quantities, requiring a minimum of writing and permitting control by weekly reports containing major deviations

Because all departments deliver their products for the sub-assembly or first assembly with slight unavoidable dimensional variation, a certain amount of fitting was necessary on many parts, i e selective assembly The work of all departments had, of course, to be balanced so that 400 complete rifles could be tested every day.

No bottleneck was possible Some parts were hardened, some of them were browned by a chemical process, and the seat of the sight was soft-soldered to the barrel. The whole manufacturing process was not a simple one, yet it had to run like clockwork because the products were required for immediate use by the Forces who could not accept delay nor go to a competitor But the problem of administration and management was, in this case, particularly simple It was simpler than in the crucible factory, for instance, where the main products varied in shape, size, and mixture of constituents Simple accounting machines in this case performed the whole of the weekly costing.

(6) *Motor Cars*

Motor cars, both engines and assembly represent typical mass production, which maintains the same uninterrupted flow for months at a time It is generally sufficient to issue a running order for several months' output, say up to 50,000 engines, but to watch weekly deviations up or down by comparing the actual weight of materials used with the parts list and actual wages paid with the fixed rates allowed, output being controlled in batches of between 3000 and 3500 engines Such a quantity-order may be stopped any day if circumstances require it, without interfering with the supply of correct information by the costing office

In a continental car factory the batch quantities per part or sub-assembly or assembly are taken and priced with the average earnings per department, because the single piece-prices vary according to the variable bonus of different workers Suitable accounting machines solve the costing problem in this case

(7) *Telephone, Telegraph, Wireless, and Switchboard Apparatus*

These components of motor cars, aeroplanes, and submarines are complicated items the design of which suffers frequent modification to-day owing to the rapid technical development in this field, but the designer tries to use as many standardized units as possible If essential changes are made, all tooling and jigging must, of course, be changed too, whereas the same machine tools remain in use with the changed jigs

In the factory in question the costing was done in the following way—

The planning department furnished the specification charts which were based on long experience of similar parts. The ratefixer knew by experience and statistics how many parts could be punched, drawn, turned, drilled, milled, etc , in a certain time He also knew, by time studies, the time permissible in minutes for fitting the sub-assemblies, so that a good basis was available for planning and loading Most of the work was done on piece-rates, quoted in minutes

The total sum paid to the workers as gross wages must coincide with the total sum allocated to the orders each week This is the accountant's balance, but before the wages were paid there was a visual control of the piece dockets signed by the inspector against the ratefixer's assembly parts list The comparison of the price paid per the dockets had to coincide with the price allowed on the ratefixer's parts list This is a fairly heavy task, therefore it was done only once per month for all important products, using accounting machines

(8) *Textile Works*

These were mixing their cotton and wool in different quantities, qualities, and colours, according to fluctuating public taste Here the designer needed special skill, experience, and acumen in order to meet the demands of the individualistic market with the smallest possible number of mixtures Remember the report of the British committee of 1944 on the competition of American standardized cloth made on automatic looms as against the Lancashire hand looms individually operated, and fulfilling special demands Quality was the same, though the price of the American product was much lower

The buyers of wool and cotton (which is expensive and mainly bought from outside), and the sales staff must work together to guarantee the success of the business The manufacturing process of weaving (see Fig. 17) was invariably flyer, mule, ringspin, warping, weaving, dying, dressing, and finishing machines—the same for any quality of cloth Therefore, the recording by the book-keeper of the internal prime cost on the system of hourly rates plus a bonus was selected and proved satisfactory Manual book-keeping plus a moderate addition of accounting machines was sufficient to solve the problems of costing in this factory

(9) *Oil Refinery*

The activities of an oil refinery represent automatically controlled high-standard production on predetermined specifications according to tested chemical processes The crude oil is the only direct material and this is processed chemically by contact with various solvents, extractors, and bleachers which do not remain in the finished product but are removed during the process after having completed their desired effects. Economic control is based on automatically written records, using accounting machines and handwriting, providing automatic comparison with predetermined standards The control of stocks, production, etc , is balanced daily by automatic systems and running costs are compared with predetermined standard costs

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PART TWO

THE PROBLEMS OF MANUFACTURE

CHAPTER VII

Machinability

MUCH HAS been written and said about the word "Machinability" and about its variation in meaning according to the type of machining operations involved The American practice intends to cover by machinability at least three different material properties * (1) the true machinability, i e the ease with which a chip may be removed, (2) the tendency of the material to wear the tool, which is called "Abrasiveness", (3) the ease with which a good finish may be obtained, "Finishability" We propose to consider each property separately in selecting the material for a given operation, and to evaluate the ratings in accordance with their importance in each particular case

Machinability as a Reciprocal Effect of Material and Tool; and its Measurement

For our purpose we will define the true machinability of a material as its conduct, while being cut with a standard cross-section of chip using a standardized kind and shape of cutting tool, which must remain sharp during its action Therefore true machinability depends on the resistance which the correctly shaped sharp cutting edge of the tool encounters in penetrating the material Since the load which is applied is referred to as a force, machinability should be measured as a force (specific force per sq in) in pounds independent of other cutting conditions particularly cutting speed, cross-section of chip, material of tool This independence has been proved by many investigators The surface finish is irrelevant for rough-turning (machining tests) and generally obtained by some subsequent grinding method

As the measured tangential cutting force (T) is the power component of the main cutting force (F) (Fig 57a), it can be used directly to calculate the cub in. per horse power and minute as basis of comparison This kind of machinability of materials (cutting resistance) is the only variable of the machining test, and has nothing to do with tool life, since the tool must be kept sharp always during the short machining test

* *Physics of Metal Cutting*, H Ernst, Cincinnati, pp 31, 32

Tool Life

Tool life, however, depends on the economic cutting speed, the cross-section of chip, the dulling properties (abrasiveness) of the material, the dimensional accuracy and the surface quality required from the specimen It is generally measured by the cutting speed which allows an hour's tool life (v_{60}) between grindings

Machining metals by cutting covers the great majority of workshop processes, i e turning, drilling, boring, reaming, thread-cutting, planing, shaping, milling, gear-cutting, grinding, honing, lapping, super-finishing The problems which are dealt with in this book, are restricted to the ordinary methods of metal cutting However, it is not overlooked that whenever "chipless forming" can be used instead, i e in the different processes of forging, punching, pressing, drawing, coining, powder metallurgy, etc , they usually beat the chip-producing machine tools for mass-production work, both economically and in keeping a very high degree of accuracy up to full interchangeability, e g tin cans and their tight fitting lids.

The production engineer wants to use machine tools and cutting tools which will last a long time without perceptible wear At the same time the labour spent to finish a specimen is to be as cheap as possible To fulfil these conditions, the material of the parts must be sufficiently strong but easily machinable.

The type (e g steel) and quality (e g tons per sq in tensile strength, elongation, etc) of material is determined only by the designer The old saying that "manufacturing commences at the designing board" obtains here its strongest and most evident confirmation

The designer will always endeavour to create a component which maintains its shape a long time without deformation arising by tension, compression, bending, torsion, or collapse, while being exposed to the highest stress it is likely to bear in actual use. Furthermore, the part must not undergo any change of geometrical shape (flat surface, cylinder, taper, ball, etc) by molecules being rubbed off in consequence of wear.

The choice of the right material as to (*a*) resistance to stress and, (*b*) resistance to wear, is one of the most important tasks of the designer He makes the main spindle of a lathe of carburizing steel, because it will be bent, pressed, pulled, and generally submitted to distorting forces and must be resistant in every respect He has its journal surfaces case-hardened and ground in order that they may keep their cylindrical or conical shape for a long period without wear The spindle bearing is made of high-quality bronze, the lower stress resistance of which is compensated for by the stiffness of the housing, and because its qualities against wear are very favourable If the main bearing of the machine tool is well made, the whole machine will produce good work

Typical examples of the fact that resistance to stress and to wear are the decisive factors for different designs, are the soft piston of light metal with cast-iron expanding rings in the hard cast-iron or heat-treated steel liner of the automobile cylinder, the hardened gears of the headstock of a high-speed lathe made of nickel chrome steel, the hardened steel balls or rollers in the hardened races of anti-friction bearings, and so on The production engineer has to execute what the designer dictates, and he will do so as long as the growing difficulties of machinability do not militate against output.

Let us now consider the question of admissible abrasion in connexion with the hardness of the material, and with its resistance in general; the importance of the point being demonstrated by the simple observation of (*a*) hardened cutting tools which are worn out in a few hours by machining steel, (*b*) the cast-iron slide ways of machine tools, which become inaccurate and make accurate manufacturing impossible, though only after some years of use

Of all the materials which have to be machined, iron and steel are still by far the most important, so that in most cases the requirements for machining these materials must receive first consideration when selecting machines and tools

The cutting action creates heat at the working tip of the tool Temperatures of chips vary from 300° C. for turning ferrous metals with high-speed steel tools up to 1600° C (burning steel chips in spite of copious water supply) in the case of grinding These temperatures are created by shearing, compressing and curling or burning the chip from the piece and by friction between the flowing chip and tool surface At the moment of shearing the piece, tool edge and chip element must obviously all have the same high temperature The cleaner the tool surface and the better the cutting action, the lower the temperature, therefore we must try to avoid building-up of the tool edge, which is always detrimental as it clogs the sharp edge and spoils the cutting action and the surface quality When using cemented carbides and high cutting speeds the temperature at the tool nose rises very quickly to between 400° to 700° C (red hot) Such a heat would soften ordinary high-speed steel tools (18–4–1), which cannot stand more than about 300° C, and might deteriorate the surface of the work-piece. For example, by grinding thin-hardened or case-hardened surfaces hair cracks are sometimes produced (gear-grinding) when the abrasive is clogged The removal of the hot chip from the moving piece is always quick (cutting speed), but the contact with the stationary tool is never interrupted Heat and dry-friction combined crater the tool and eventually cause collapse of the cutting edge, therefore the speed must be increased to the permissible maximum The superiority of cemented carbide tipped tools over high-speed tools is founded on this fact For this reason the question of lubricant-coolants for high-speed tools is of considerable importance if the unfavourable influence of these high temperatures caused by friction is to be reduced to a minimum, but the effect of such coolants on cemented carbides in the zone of 350° to 900° C. is not yet fully clarified. Cemented carbides easily withstand higher temperatures up to 900° C., hence the application of a suitable coolant must be made very amply and carefully before the cut commences, or the hard and brittle tool will crack by the belated supply of coolants. Unless the supply of coolant is certain, it is preferable to cut dry with carbides. More than 90 per cent of the heat produced is carried away by the flowing chips.

The machinability of standard steels and especially of alloy steels exerts a great influence upon the production economy in all workshops. In general, as the physical properties of materials are increased continuously in order to make more resistant components, so the difficulty of machining those components increases, because the machinability of the material becomes poorer. A considerable improvement in production efficiency would be achieved if constructional steels were produced which could be easily machined (machinability) and which nevertheless had chemical constituents and physical properties which would withstand working conditions (tensile strength, stress and wear) present in many parts of automobiles, aeroplanes, machine tools, etc.

Nowadays, designers are frequently compelled to design components in which weight-reduction is an important factor, e.g. for the aeroplane engine. To facilitate the production of these components, materials are continually being developed with improved physical properties, such as higher tensile strength (120 tons per sq. in.) resistance to fatigue, etc. So far as alloy steels are concerned these physical improvements are usually accompanied by a considerable worsening in machinability, so that production cost (stress on machine tools, power consumption, wear of tools, etc.) becomes so high that it creates serious limitations to the economic manufacture of the parts of such high-class engines. It is further desirable that producers and users of these superior steels should co-operate to restrict the number of different specifications of such materials as much as possible. Such a restriction would lead to greater uniformity of composition and physical properties of steels supplied at different times and in different places, and would also reduce the cost of production. Another aim of such standardization should be to select steels which have the required physical properties combined with a machining factor within the economic limits of production. It is encouraging to note that in America and in Great Britain in recent years steels of high physical properties have been made which seem much easier and therefore cheaper to machine than the steels of similar physical properties which have hitherto been commonly used (free-cutting steels).

The American Standards Association together with the Society of Automobile Engineers standardized about 290 kinds of steel, and in 1939 published a manual* giving feeds, speeds, etc., for the machining of these materials under various conditions. These data should be modernized to-day because the present tools allow higher cutting speeds combined with longer tool life.

The increasingly exacting requirements of the designer must be recognized, nevertheless the difficulties of quantity production of steel by the the steel maker and of components by the manufacturer must also be considered. In most cases some reduction in the number of specifications might be effected by eliminating unnecessary overlapping, although the steel maker needs some tolerances to facilitate both manufacturing and sales.

It is desirable to know the speeds for a tool life of eight-hours (shift = V_{480}, see page 142) under various conditions of cutting, because by working at this lower speed it is possible to arrange for the replacement of tools and the grinding without interruption during working shifts. These economic cutting speeds for hard and tough materials are also the basis for accurate ratefixing as applied to heavily stressed parts.

Deep roughing cuts, as those shown in Fig. 51 where the chip area was 1·5 sq. in. (1¾ in. deep by 0·85 in. feed), are undesirable. Such a heavy chip taken from steel of 18 to 20 tons sq. in. tensile strength (150 tons pressure) required at a speed of 15 ft./min. a drive of about 150 h.p. This chip was actually produced on a giant vertical boring mill. Although such chips are possible, the modern

* *Manual on Cutting Metals (Single-point Lathe Tools)*, published by the American Society of Mechanical Engineers, New York, 1939.

trend is to reduce the material allowance for machining (Fig 52) to the absolute minimum, so that the chip depths are as small as possible Where deep cuts have to be taken it is desirable to adjust the feed in order to give a "depth to feed" ratio of between 4 1 and 10 1 Such thin, flat chips bend easily, the friction on the tool face, causing heat, is reduced, thus requiring smaller power consumption and ensuring increased tool life It is important that the designer should

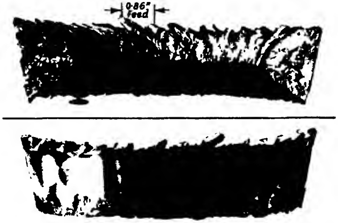
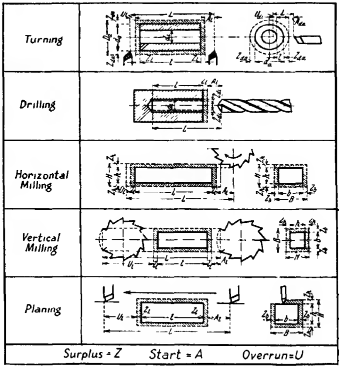


FIG 51 GIANT CHIP, 1 5 IN.^{2} ≏ 1000 MM^2 (1¾" DEPTH 0 86" FEED)

arrange for castings and stampings to have the minimum machining allowances (see Fig 22) Some parts, such as the main shaft of a steam turbine or a Diesel engine, may have large steps which call for heavy roughing cuts in the machining process, but this must be the exception and not the rule

The three demands on modern tools are (1) high speed, (2) long life, (3) accuracy and good quality of surface All three mean economy for the user Achievement of these three conditions depends not only upon the tool but also on the cutting resistance of the material to be machined, its tensile strength, hardness and toughness, and its wearing properties Increase in resistance of the material is finally reflected back on to the machine tool, which must be designed for greater power and speed and made more rigid The surface finish is generally produced by grinding operations. (See page 221)

Attempts to speed up old machines to exploit high-speed tools must be made carefully as many breakdowns are probable and these may outweigh the benefit It is necessary to balance all rotating parts dynamically if they turn at more than 2000 r p m , especially the main spindle together with the parts fitted thereto. (See Fig 105)



Calculation Scale	Abbreviation	Drawing Size	Machining Allowance	Start	Overrun
		Dimensions contain following values			
Length	L	l	$2 Z_l$	A_l	U'_l
Width	B	b	$2 Z_b$	A_b	U'_b
Height	H	h	$2 Z_h$	A_h	U_h
Outside φ	D_a	d_a	$2 Z_{da}$	A_{da}	U'_{da}
Bore φ	D_i	d_i	$2 Z_{di}$	A_{di}	U_{di}

FIG 52 MACHINING ALLOWANCES

The cutting speed depends on the endurance of the tools against continual wear by abrasion. That is the criterion for the whole machine shop. Output is always dependent on the influence of hard and soft constructional materials on the wear of tools

In this connexion life tests of tools are of real importance as their results can be translated directly into shop practice.

The endurance of the tool must be considered in the ratefixing department in the fixing of correct cutting speeds. The operator can work directly at the prescribed cutting speed only if the machine tool has a cutting-speed indicator, or indirectly if the number of revolutions (n) is made plain by a table (see later, Table XLII) fixed to the machines, calculated from $n = \frac{12 \times v}{\pi d}$ in connexion with the gear drive (v = peripheral speed in feet per minute, d = external or internal diameter of piece in inches). The speeds in r.p.m. of this Table must correspond to those on the plate of the machine. It must be stated that this is only to be taken literally for the standard qualities of materials, for the cutting edge can be worn by other influences than those of cutting forces. Carbide crystals in soft steel or crystals of chrome, manganese, etc., cause considerable abrasion, while very soft material such as pure copper, dulls the tool with a small cutting force. Yet even for soft copper the rule is valid: the better the shape of the tool, the smaller the cutting force, for a rapid increase of the cutting force signifies the end of tool by excessive wear.

The economic tool life differs greatly from the tool life determined by the wearing out of the cutter. The *economic tool life* of a given tool is the number of hours it can continue to be used for the manufacture of a certain number of pieces at minimum cost. These expenses are composed of: (1) cost of making the tool, (2) cost of setting up the tool, (3) power consumption, (4) depreciation of the machine (see Fig. 61).

The total of these expenses will differ according to the management of the shop, the equipment of machines, shape of tools, nature of the toolmaking department, etc. These are very complicated economic questions, which should be considered by the planning department in addition to the purely machining items. (See page 141, Tool Life.)

Material Being Machined

What has been said of the tool also applies to the material to be cut. It is necessary to know its resistance against cutting, otherwise it is impossible to give the right cutting speed. The

TABLE XVI

COMPARISON OF BRINELL HARDNESS AND CUTTING SPEED

(*Merchant & Zlatin, Cincinnati, U.S.A.*)

		Nominal Physical Properties			Practical Machining Properties		
No.	Material	Condition	Brinell Hardness	Workhardenability Meyer n	Cutting Speed-s.f.p.m. (Relative Tool Life)	H.p. cu.in. min. (Relative Power Cons.) K	Surface Finish
1	Type 303 (sulphur) (stainless steel)	Annealed	162	2.37	100–130	0.94	20–30
2	Type 304 (stainless steel)	Annealed	139	2.39	70–90	1.24	6–9
3	A 8640 steels (sulphite treated)	Annealed and cold-finished	187	2.30	111 (5 hrs. per grind)	1.11	65–85
4	Plain	Annealed and cold-finished	191	2.30	88 ($2\frac{1}{2}$ hrs.)	1.16	65–85
5	C-1022 leaded	Hot-rolled	121	2.29	160–190	0.60	30–40
6	C-1019 (low-carbon mild steel) plain	Hot-rolled	147	2.20	120–140	0.90	60–70
7	SAE 52100 (steel tubing)	Cold-drawn	235	2.12	95	1.08	6–7
8	SAE 52100	Cold-drawn and annealed	190	2.33	85	1.15	6–7

Brinell tests and the carbon content are simple to derive and are often used to give an idea of the machinability of mild, semi-hard, and hard steels. The Brinell (Rockwell, Vickers) impression can usually be made on a very small part of the surface, and where it does not affect the appearance The chemical analysis can be made with chips or with a small part of the bar or spectroscopically It is a far spread error to identify the Brinell hardness or the tensile strength derived from Brinell hardness (about 4·5 · 1) with the machinability of materials. There are some investigators, who believe that machining tests are unnecessary in the workshop, because all information required could be done with the Brinell hardness as well Table XVI contains tests with new types of special steels.* A sintered carbide tool was used, the side rake angle was +10° The data proved that of the eight types of steel investigated—

(1) Type 304, with low Brinell hardness of 139, allowed less speed (70–90 f.p.m.) than the harder type 303 with B.H 162, allowing 100–130 f p m.

(2) That the two steels, A–8640 with approximately the same B.H. (187 and 191), required 20 per cent difference in the cutting speeds, a difference which is still accentuated because the hours of tool life for the softer material were double as long as those with the harder material

(3) That SAE 52100 cold-drawn, much used for ball-bearing races, with B H. 235, which was considerably harder than SAE 52100, cold-drawn and annealed with B H 190, allowed again a higher speed of 95 against 85 f p m Only for the steels C–1022 and C–1019, the B.H. corresponded to the speed variations

Particularly interesting data on chrome-nickel alloy steels are compiled in Table XVIIA.

* Paper read in New York on 2nd December, 1946, on "Correlation of the Machining Properties of Several Representatives of Steel, with the Mechanics of Cutting," by E Merchant and N Zlatin, Cincinnati Milling Machine Co

TABLE XVIIA

BRINELL HARDNESS—TYPES OF TOOL—MACHINING INDEX—RELATIVE TOOL LIFE—METAL REMOVING FACTOR

Type of Material	Mark of Material	Brinell Hardness No of External Diameter		Types of Tool	Machining Index Tangential Force lb per 0·001 sq in		Relative Tool Life for a Chip Area of 0·0062 sq in Cutting Speed v_{60} f p m	Metal Removing Factor $S = \frac{396}{T'}$ cub in
Carburizing Soft Steels	En 15	124		B	225		156	1·76
	En 15	124		S	199		182	1·98
	ECN 35	155		B	277		99	1·43
	ECN 35	155		S	267		102	1·48
	SAE 4615	122		B	238		141	1·66
	SAE 2512	159		S	263		122	1·51
	SAE 2315	161		S	264		105	1·50
	SAE 3312	276		B	321		41·5	1·24
		Annealed	*Normalized*		*Annealed*	*Normalized*		
	VCN 15	—	237	B		305	55	1·47
	VCN 35	—	293	B	—	318	45	1·25
Heat-treated Steels	SAE 3130	155	– –	B	263	—	97	1·51
	SAE 3130	—	205	S	—	270	—	1·47
	SAE 3240	182	—	B	288	—	74	1·38
	SAE 3240	–	250	S		305	61	1·30
	SAE 5130	143		S	246	—	130	1·62
	SAE 5130	—	205	S	—	267	105	1·48
	SAE 5150	177	—	S	282	—	89	1·41
	SAE 5150	—	248	S	-	310	59	1·28
	SAE 6130	156	—	S	252	–	117	1·57
	SAE 6130	—	208	S	—	276	102	1·44
	SAE 6150	168	—	S	278	—	93	1·43
	SAE 6150	—	244	S	—	302	62	1·31

Research Department, Berlin, 1933

B–Tool Side Rake, 12°
S–Tool. Side Rake, 20°

They contain ten American and four German chrome-nickel steels, mostly used for motor cars and aeroplanes. The cross-section of chips used were about 0 003 sq in , 0·006, 0 009 and 0·0125 sq in. (2–4–6–8 mm²) The Table gives the according to the constant slope of the characteristic lines (Fig. 53). Table XVIIA shows in the lower part that all Brinell hardnesses of the annealed materials are between 25 to 35 per cent lower than those of the normalized pieces of the

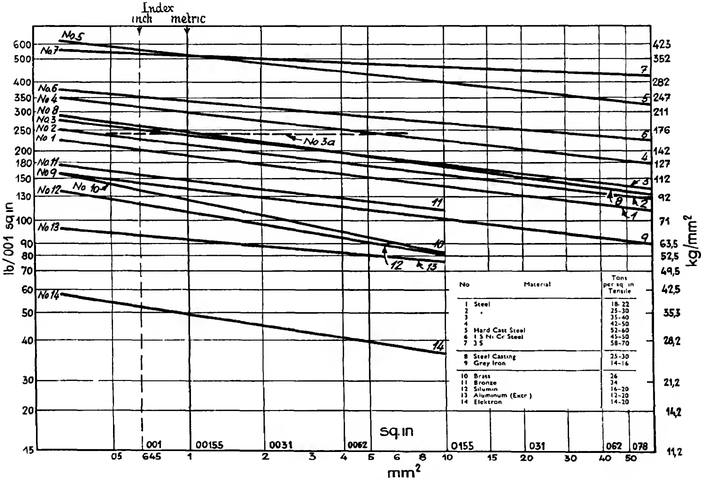


FIG 53 SPECIFIC CUTTING RESISTANCE

Interdependence of specific forces per material (Nos 1 to 14), and cross-sectional areas of chip (1000 lb per in ²) and Machinability Index tangential force = lb/ 001 per in ² (and Kg/mm²)

Brinell hardness, the heat-treatment, the shape of tool, the machining index in pounds per 0 001 sq in. (specific cutting force), and the measured cutting speed v_{60} for a tool life of 60 minutes But the tangential back and feed forces were measured with a chip of 0·0062 sq in. only. The machining index was derived by measuring the total tangential force by a three-component dynamometer extrapolating from 0·006 sq in. to 0·001 sq in. same analysis, but the measured cutting speed for v_{60} (tool life) remained about the same for both cases, because the machining indices vary only little from 2 to 8 per cent. These life tests were particularly made (in 1934) as check tests, published already in 1928* and made on the same materials but using partly another shape

* *Stahl und Eisen*, 1928, G Schlesinger ('Machinability of Construction Steels for Motor Cars.")

of tool These two shapes, tool S with 20° side rake against tool B with 12° caused considerably different machining indices which proved the necessity to standardize the shape of the tool according to the material (See Fig 55 and Table XVIIIA)

In Fig 54 the cutting speed is plotted both against the Brinell hardness and the machining

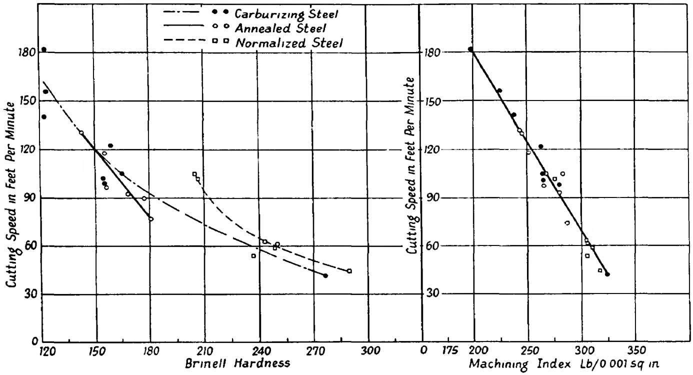


Fig 54 Machining Index = Correct Basis of Cutting Speed
(Graphs plotted from Table XVIIIB)

index The Brinell diagram is clearly divided in three groups · (1) for six soft-carburizing, not heat-treated alloy steels, (2) for six different soft-annealed American alloy steels, (3) for the same six American steels, but normalized and for two normalized hard German steels. The machining-index diagram shows a clear straight line for all twenty investigated steels The Brinell hardness diagram visualizes the striking difference between Brinell hardness and machining index as basis Obviously the tool life is allocated from 50 ft/min for the hard material SAE 3312 up to 180 ft/min for the soft steel EN 15 to the machining index and not to Brinell hardness. The cutting tool was made of 5 per cent cobalt + (18–4–1) high-speed steel, its hardness was 60 to 62 Rockwell C These misleading results based on the wrong use of Brinell hardness for cutting properties are particularly annoying for the rate-fixer and the workshop in setting and using the correct cutting speed to get a reasonable tool life.

We have learned in recent decades that neither the chemical analysis nor the physical properties of the material to be machined suffice as data from which to draw reliable conclusions on its machinability But it is certain that the progressive use of standardized types of steels and ferrous castings and of all non-ferrous materials (such as copper, aluminium, and magnesium alloys) and the consistent reduction of the number of available types by the steel, copper, brass, aluminium and elektron mills and foundries will create an increasing command over the preliminary processes, particularly of the heat-treatment, with the aim of securing for each material uniform machining conditions. The *machining index* will then need to be determined only once for any new material.

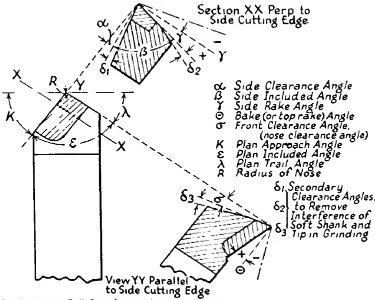
B S I. Standards Nos 1, 2, 11, 15, 21, 28, 32, etc, 65 to 82, etc, 970, and 971 still contain about 170 different types of steels alone for general engineering, electricity, shipbuilding, aeroplanes, etc As mentioned above, the *Manual of the American Society of Mechanical Engineers* even mentions 290 types of steels However, there is a tendency to standardize, i e to reduce the numbers of types and, therefore to give a chance to the production engineer who has to machine them to define the most economic procedure by selecting the best shape and kind of tools for machining

As it is not possible to adapt the tool angles even approximately to the best working conditions of, say, 170 different types, an average selection must be improvised to solve an almost desperate problem

Table XVIIIB shows how on the Continent the motor-car industry and the steel mills by their close co-operation reduced a range of sixty different quality alloy steels (Ni and Ni-Cr), used in the highest stressed parts of the engine and driving gear, to one of 11 to their mutual advantage This made it possible to make machinability and tool life tests in the reasonable time of 1½ years * Besides these eleven alloy-steels, a factory making the complete car (engine, chassis, body) might need, perhaps, a hundred different materials

Table XVIIIA gives a review of eight different well-proven combinations of tool angles and shapes, as applied to large general groups of the principal materials ordinarily used in a factory, ferrous and non-ferrous, and enumerated in the second column of the Table As the limits for the grouping are very wide it is quite natural that for special cases, e g for a shipyard, which has also to use many anti-corrosive metals (e g stainless steels, Tobin bronze, etc), additional or substitute tool contours must be inserted to solve the specific machining problem correctly, but it should not be left in the hands of the foreman alone, as he cannot possibly be expected to follow the rapid development of tools and materials Fig 55 gives the proposed nomenclature for the cutting angles of single-point tools, much used in Great Britain

Considering the fact that about sixteen (nine



*Angles γ and Θ are in Full Development They are named -
1 Positive Rake Angles, if Sloping is below the Centre Line (Usual Shape)
2 Negative Pake Angle, if Sloping is above the Centre Line (New Development)

FIG 55 NOMENCLATURE OF SINGLE-POINT TOOLS

normal, seven special) different tool shapes are necessary (see Table XXVI) for at least four groups of material (Nos 2 to 5 of Table XVIIIA), we already have 4 × 9 — 36 (eventually 4 × 16 — 64) different tools, which must be at the personal disposal of a skilled turner at his lathe, he cannot borrow the ordinary tools from the toolroom for every job "The dividends of the factory are sitting at the edge of the cutting tools," is an unalterable truth, just as much as, ' Give us the tools, and we will finish the job "

As most workshops possess old, more modern, and quite modern machine tools the prescriptions for the use of high-speed (18–4–1), super-high-speed (cobalt-tungsten 10–18–5–1·5), stellite 80/100, and cemented carbide-tipped tools (see Table XX) must be adapted to the different

* (1) *Stahl und Eisen*, 1928, Nos 10–11, pp 1–13, G Schlesinger, "Machinability of Construction Steels of Automobiles" (Bearbeitbarkeit der Konstruktionstahle im Automobilbau) (2) *Archiv f d Eisenhüttenwesen*, February, 1934, No 8, Plingens

the Brinell hardness number is not so, especially in the case of all cast materials. It is, of course, easy to make Brinell tests and very difficult, if not impossible, to make tensile test bars of a particular piece of material All production research engineers are looking for a factor which

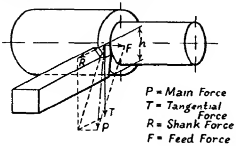


FIG 57a

similar to the tensile resistance of a material, characterizes its resistance to the cutting action of tools

Resistance is measured as a force In calculations on beams, girders, stands, etc the force of resistance to rupture is generally combined with a safety factor of about 1 10, because the beam should not be destroyed or even distorted It seems plausible to try to find a machining factor which represents the resistance of material against separation by real cutting action. The cutting procedure is complex (there are nineteen variables), but we must try to see the problem as a whole, and not be deterred by the complexity of its details *

When we take a lathe, we have as a formula for the power of the motor driving the machine

$$P = \frac{F \times V}{C \times E} \text{ h p}$$

where P = horse power (h p)
F = cutting force (lb)
V = cutting speed (feet/min)
C = constant factor = 33,000 (lb feet/min)
E = total efficiency of machine tool (idle + load influence on the driving gear).

Abrasiveness requires a special test, but one which can be connected with the Tester (Fig 56)

* "Determination of Machinability," *Tool Life and Machine Tool—Machinery*, London, 3rd and 10th October, 1946 "How to Measure Machinability," *American Machinist*, New York, 21st November, 1946

Because the radial (R) and axial (F) components of the main cutting force (P) (Fig 57*a*) do not perceptibly affect the horse-power, as they produce only additional friction in the slideways, it is permissible for our purpose to replace the resultant force (P) by the tangential force T which simplifies measurement by enabling the usual complicated and expensive 3-component dynamometer to be replaced by the simple and robust single-component instrument (see Fig 56), which works without chatter and vibration The three-component instrument is, however, necessary for tool research to investigate the influence of the tool angles separately To secure a fixed basis of comparison, the eight standardized shapes of cutting tools used for finding the machining index must be kept identical for the eight basic classes of material, as per Table XVIIIA

The regrinding of the standard test tool must therefore be performed by using simple hand-operated fixtures which guarantee identical angles and contours without having to check them by a tool protractor (Fig 57*b*) However, a check test from time to time is advisable to prevent mistakes by careless grinding

If we assume the efficiency factor for an average well-maintained and normally loaded machine

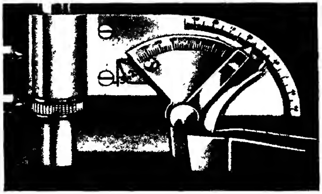


FIG 57b TOOL-ANGLE PROTRACTOR

tool (motor included) about five years old, to be $E = 0{\cdot}67$, we have $C \times E = 33{,}000 \times 0{\cdot}67 = 22{,}000$ and the simplified formula becomes.

$$P = \frac{T \times V}{22{,}000} \text{ lb ft/min}$$

The total tangential cutting force divided by the cross-sectional area of chip is the specific pressure in pounds per sq inch If the chip area is standardized for these machining tests to 0 001 sq in., we read instead of 1000 lb/sq in directly the index in pounds on the dial To avoid non-permissible residue the ratio of depth to feed should be not less than 4 1 A section of $\frac{1}{16}$ in depth × $\frac{1}{64}$ in feed, or, more accurately, 0·0625 in × 0 0156 in , meets both requirements, that of the area — 0 001 sq in , and that of the ratio 4 1 *

The graphs (see Fig 53) show that the indices decrease with increasing chip area, 0·001 sq in gives the largest indices, but the slope for larger areas can be ignored for this kind of defining true machinability on the basis of the standardized unit of chip area, using standardized tools

Now, using the same or a stronger testing instrument for heavier chips, a speed should be chosen for the tool to be tested which will allow of a tool life of 60 minutes — v_{60} This speed depends both upon the material of the cutting tool and the material of the specimen to be machined, but

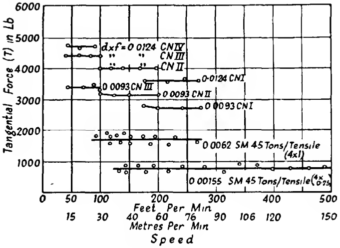


FIG 58 NO INFLUENCE OF CUTTING SPEED ON TANGENTIAL FORCE WITHIN 50 TO 500 F P M

in practical limits (from 30 f p m to 500 f p m) the speed *does not affect the tangential force T* (Fig 58)

* O W Boston proposes for *Tool Life Tests*, Paper No 84 January, 1944 (1) $\frac{1}{8}$ in by 0 020 in feed (6 1), (2) $\frac{3}{16}$ in by 0 010 in feed (18 1), (3) $\frac{1}{4}$ in by 0 050 in feed (5 1)

TABLE XVIIIB

No	Material	Tensile Strength tons per sq in	Brinell Hardness	Machining Index related to 0 001 sq in	Recommended Cutting Speeds Feet per Minute for v_{60} Tool Life: High speed Steel (18 4 1)	Super High Speed 10%Co + (18 5 1 5)	Cemented Carbides
1	Steel (screw stock)	18–22	80 100	205	70–85	100 120	400–600
2	Steel	25 30	120 140	230	40–60	60–90	250 400
3	Steel (semi-hard)	35–40	150 180	250	35 55	50 80	220 275
4	Steel (hard)	42 50	180 220	270	35–50	45 70	175–250
5	Steel (cast steel)	52–60	230 270	440	25 45	35–60	150 200
6	1 5 Ni-Cr steel	45–55	200 230	300	40 60	60–80	190 300
7	3 5 Ni Cr steel	58 70	250 310	430	30–40	50 70	175 250
8	Steel casting	25 30	135–160	252	35–70	80 100	150 300
9	Grey casting	14 16	170 190	145	40–60	85 120	180 300
10	Brass	26	115	110	100–140	150–280	400 800
11	Bronze	34	140	140	70–100	120 170	300 500
12	Silumin	16 20	70 90	122	100 140	150–200	500 800
13	Aluminium (extr)	12–20	30 70	58	180 250	250–400	750–1500
14	Elektron	14 20	40 60	42	200–350	400 600	1400 2500
		Strength		Machinability	Tool Life		

for different Materials and Tools

As the machining index (I) refers to the machined material only, a type of tool should be used which is uniform as to material, contour, cutting angles, and quality of grinding, and is insensible within wide limits against the cutting heat, e g. cemented carbide-tipped tools (with honed cutting edges)

The basis is now defined All variables are eliminated but one, i.e the resistance of the

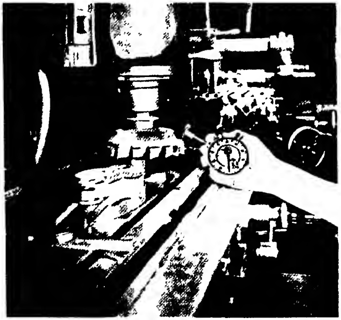


FIG 59 SPEEDOMETER DIRECTLY ON TOOL (Hasler-Bern)

material against machining by turning = its machining index (including abrasiveness)

Table XVIIIB shows for fourteen ferrous and non-ferrous materials used in ordinary workshops tensile strength in tons sq in calculated from an average Brinell hardness by dividing B.H. by 4·5, the machining index for the standard cross-section of 0·001 sq in. It is proposed to use an average figure so as to provide a single reliable machining index for use by the ratefixer and the workshop and thus to prevent confusion The ratings of cutting speeds are given for high-speed (18–5–1·5), Cobalt high-speed 5 to 10 per cent Co + (18–4–1), and cemented carbides, for v_{60} as basis for tool life.

The "feed-and-speed" man (see page 232) should have a speedometer* (Fig. 59) in his pocket to enable him to check at once the speed of any rotating part or tool. The cutting forces can only be measured by a correctly designed strong tool dynamometer, some tests are published in Table XIX

They prove in the case of a lathe and a shaper, that index I remained practically constant for very uniform annealed material with only ± 2 to 3 per cent variation in spite of changing the cross-section of chip from 0·035 in. × 0·076 in. = 0·0027 sq in to 0 035 in × 0·307 in = 0·0107 sq in, while the tangential force increased from 660 lb to 2520 lb and the speed varied between 64 and 85 f p.m (Fig 53) Hundreds of tests have been made for roughing cuts which have confirmed this result Only such a figure can be chosen as an "Index" for practical use, as will remain fairly constant under varying working conditions

As tangential force (T) times cutting speed (V) represents the power consumption of the machine tool, i e. $T \times V =$ h p, a wattmeter for A C current or an ammeter for D C current shows the power consumption of the machine directly and convincingly as a check test and a red mark on the dial should indicate the permissible maximum

A lathe and capstan department of thirty-five machines was equipped with simple ammeters (D.C) and has worked satisfactorily for years, the expenses for damage of machines due to overloading being reduced to a minimum, and at the same time the operators' bonus considerably increased The advantages of using a practical and simple dynamometer and a current consumption meter both by the user of machine tools and by the steel mills are fully proved as a method of confirming that the material used has the prescribed strength and is at the same time easily machinable

Cast-iron

From the standpoint of machinability cast-iron is simpler to control than the many variations of steel, because there are generally only one or two grades in use in the same shop. The iron casting arrives in the shop in a shape which is practically

* "Practical Research of a Dockyard (Wilton Fyjnoit-Rotterdam)" by G. Schlesinger, *Proc. of Inst. of Mech. Engs*, 1937

ready for use and after having the skin taken off from some surfaces, and sensitive castings being seasoned, there will seldom be any additional heat-treatment, refining, or hardening required. In most cases one intentionally avoids any additional heating of castings, so as to prevent the formation of new strains (warping) which might disturb the state of rest of the cast piece

It is, therefore, understandable why up to now research on cutting metals deals mostly with steel. The majority of machine parts which are highly stressed by tension, bending, buckling, or torsion, are nearly always made of steel and machined all over. Consider the development of highly-stressed gears Cast-iron has been superseded, in spite of its good running qualities, by steel gears made of hardened and ground nickel-chrome steel, which allows of much smaller

TABLE XIX

MACHINING INDEX LATHE TESTS (A), SHAPER-TESTS (B) (MADE BY G SCHLESINGER, 1935 TO 1937 IN BRUSSELS WITH SCHIESS-WALLICHS-SIEMENS-DYNAMOMETER)

(A) LATHE

Number of Test	f Constant Feed in	d Depth of Cut in	A Area of Chip sq in	T Tangent Force lb	V Peripheral Speed f p m	I Index 1000 lb/sq in
1	0.035	0.076	0.0027	660	72	241
2	0.035	0.076	0.0027	645	64	239
3	0.035	0.114	0.0041	1002	82	245
4	0.035	0.117	0.0041	1002	73	245
5	0.035	0.158	0.0056	1370	85	244
6	0.035	0.168	0.0059	1470	64	250
7	0.035	0.189	0.0068	1650	72	240
8	0.035	0.267	0.0095	2250	74	236
9	0.035	0.265	0.0095	2250	66	236
10	0.035	0.307	0.0107	2520	65	237
				Average		241 ± 3%

(B) SHAPER

Number of Test	Number of Strokes per min	Length of Stroke in	V (Mean) Cutting Speed f p m	$(d \times f)$ Depth in $\times$ Feed in (Approx)	Chip Section sq in	T Tangent Force lb	I Index 1000 lb/sq in
1	12	21.65	33	—		—	—
2		..	.	0.04 × 0.04	0.00155	373	232
3	,	..	..	0.08 × 0.04	0.0031	755	242
4	.	.	..	0.12 × 0.04	0.0047	1145	244
5	..	.	.	0.158 × 0.04	0.0063	1540	245
6	..	..	..	0.158 × 0.05	0.0075	1800	240
7	.		..	0.158 × 0.06	0.0093	2250	238
8	.	..	..	0.158 × 0.08	0.0125	3020	242
9	.	..		0.195 × 0.08	0.0155	3770	241
10	.	..	.	0.235 × 0.08	0.0186	4480	238
					Average		241 ± 2%

Machinability tests on steel of 32 tons/sq in tensile strength were made on—

(A) Lathe with constant feed (f) and variable depth (d), keeping the cutting speed (v) fairly constant (between 64 and 85 f p m.)

(B) A crank shaper with constant maximum speed (v) (calculated from 12 strokes per min, the crank motion and the length of stroke) and variable chip section ($d \times f$)

The last column of each Table contains for the lathe and shaper the machining index $I = \frac{T}{d \times f}$ which is very constant ($\pm$ 2 to 3 per cent) for all cross section of chips used dimensions and has a much longer life. The successful efforts of foundrymen in the past twenty years have been mainly to create high-quality cast-iron (Meehanite process), to increase its resistance against tension and bending, to decrease weight by diminishing the thickness of the walls, and above all to combine a sufficient hardness and resistance to abrasion with easy machinability.

Flat surfaces of castings can be easily checked for machinability by clamping the tester (Fig. 56) into the tool post of a shaper or planer, thus avoiding the necessity of casting small test bars with the casting, the structure of which differs always, sometimes considerably, from the main piece. Porous spots or hard inclusions may make Brinell tests very doubtful.

The excellent qualities of cast-iron slideways on machine tool beds have not been replaced until recently by the occasional introduction of hardened and ground steel slides, and the secure fastening of these on to the bed casting has led to new difficulties.

The composition of cast-iron should be such that its resistance and hardness allow easy machining and, while hardness is here of some importance, high Brinell hardness (H $= 200 \pm 15$ per cent) can be combined with good machinability. Chilled and flame-hardened cast-iron slideways must be finished by grinding, the same as all hardened steel parts.

Sufficient data on the machining index found for existing materials as ordinary steel, alloy steels, cast-iron, and steel castings are not yet available. A systematic investigation of the "true machinability" is still in its infancy. Therefore in the following chapters on cutting tools, the tensile strength is given in tons per sq in. for steel, and the Brinell hardness for cast-iron. It must be hoped that in the course of the next few years all important machining data will be elaborated.

CHAPTER VIII

Tool Life and Coolants

Tool Life

With regard to roughing cuts, tool life depends on—

1. Machinability of the material.
2. Shape and material of tool.
3. Cutting speed.
4. Cross-section of chip.
5. Coolant (dry-cutting included).

If it is the tool material which is under consideration, then all other items (1, 3, 4, 5) and the shape (cutting angles) of the tool (2) should be kept constant. Tool-life tests concern either a change of the cutting angles or the tool material, but there should be only one variable in each test.

The cutting edges of the tool are finally destroyed by—

(*a*) The mechanical effort of the cutting action (friction).

(*b*) The heat created by severing the chip.

(*c*) The dulling effect of some constituents of the material to be cut (abrasiveness).

For the commonly used materials, items (*a*) and (*b*) are decisive. Item (*c*) arises mainly in exceptional cases and must be dealt with separately. The influence of the so-called work-hardening effect of the cutting action itself is, for all common steels and alloy steels, steel and malleable castings, grey-iron castings, and red and white alloys, always included in the machining index as a matter of course. It is, in the majority of cases, irrelevant, as proved by thousands of tests made on all kinds of steels turning test bars from 14 in. diameter down to 4 in. In all cases observed, the material became between 1 and 10 per cent softer (Brinell and tensile tests) when approaching the core, so that the resistance to cutting decreased considerably. This fact must be taken into consideration when drawing conclusions from the results.

Regarding tool life, for finishing tests with very small cross-sectional areas of chip, e.g. for steel 0·002 in. × 0·004 in. = 0·000008 sq in. (= 0·005 mm²) or for aluminium castings, 0·001 in. × 0·0025 in. = 0·0000025 sq in., another unit of measurement must be chosen, which should be the area of surface finished with a predetermined quality of surface. Here the dulling effect on the tool edges is best measured by surface analysers. (See page 216.)

Cutting speeds and tool angles are interdependent, and the best angles and speeds for a given material can be specified only when the machinability of that material is known. This can be obtained by multiplying the cutting speed (feet per min) by the cross-section of chip (sq in.) by 12 to give the volume of material removed in cub in. per min. This can easily be calculated. If the cross-section is standardized as proposed above, the tool life depends directly on the cutting speed and the tool life in minutes can be plotted against speed (Fig. 60). This has been done during the past forty years. F. W. Taylor in 1902, chose that speed which dulled the tool in 20 min. Most subsequent serious investigators have chosen 60 min tool life and some have made check tests with 400 min or a "shift life," deducting a reasonable figure of about 20 per cent from 480 min (an 8 hours gross shift) to give the actual cutting time per shift after taking into consideration the usual stoppages.

The results of such tests are condensed in Fig. 60 in cartesian co-ordinates. They were made with high-speed steels [18(*W*) — 4(Cr) — 1(Va)]. The speed line v_{60} cuts the different alloy-diagrams at the corresponding permissible cutting speeds for one hour and the asymptotic lines (dash and dot—marked *a* and *b*) at the speeds for a shift v_{400} and longer. The speeds v_{400} were at that time for a cross-section of chip, 0·32 in. × 0·04 in. = 8 mm², for the hard material VCN 35 (see Table XVI)

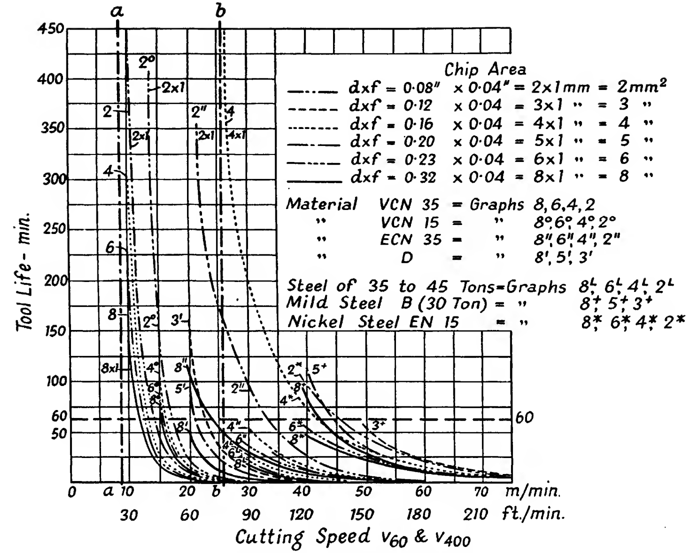


FIG. 60. TOOL LIFE DEPENDING ON CUTTING SPEED (DRY-TOOL 18–4–1)

about 28 ft/min $V(a)$ and for soft material (D) with cross-section = 0·16 in. × 0·04 in. = 4 mm² about 80 f.p.m. (tangent (b)).

These tool-life diagrams contain the five essential characteristics—

1. Material machined.
2. Material of tool (18–4–1).
3. Cross-section of chip.
4. Permissible cutting speed.
5. Resulting tool life, both for v_{60} and v_{400}.

They are basic machinability tests of direct practical use to the workshop.

A graph (Fig. 61) had been developed to combine the conditions of economic life; however, it applies only to the special case and most works managers prefer to have a definite figure representing the cutting speed and the time in hours per grind or the number of finished pieces per grind as a criterion understood by everybody.

The total cost T to produce a certain volume of chips consists of—

(1) Part A = Wages for operator + overhead expense of turning department.

(2) Part B = Cost of regrinding tool + cost of tool itself.

$$(1)\quad A = \frac{10{,}000}{V_0} \times 8 \times L\,(1 + B)$$

V_0 = chip volume in in.^{3} or cm^3 produced in eight hours or 400 min (1 shift).
L = hourly rate of operator in s./hour.
B = overhead percentage of turnery.
10,000 cm^3 = 610 in.^{3}

$$(2)\ B = n \times S$$

n = number of tool regrinds per 610 in.^{3} = 10,000 cm^3 chip volume.
S = cost of regrinding and resetting the tool each time = material + wages + overhead of the toolroom.

Part B is very high for short tool life, i.e. less than 50 min, whilst it decreases very much with long tool life.

Part A has a minimum at about 90 min, at which point it is only slowly increasing.

It is a rather complicated task to calculate the economic tool life, but it is a simple measure and takes little time and trouble to take short machinability tests. Every workshop should therefore reserve a little of the time of an existing lathe of about 5 to 10 h.p., allowing a speed range of between 20 and 1000 revs. per min and using tools of standard shape to carry out the following tests—

(1) To check the machinability index of materials.

(2) To take from an approved table the approximate speed for v_{60}.

(3) To verify that the 60 minutes test is carried out without dulling the tool.

(4) To reduce the hourly speed (v_{60}) between 20 per cent and 50 per cent to cover either the whole shift (v_{400}) or less for, say, 2 to 4 hours' tool life.

(5) To test whether the tool would stand the whole shift with v_{400} on practical workshop use and to keep careful records of the results (ratefixing department).

As these practical tests seldom take more than half a day for a new material, it is quicker and very reliable and convincing for the ratefixer and foreman to make these tests once and finally for all new materials which arrive, than to use a long and uncertain formula composed of the six to eight conditions (see page 154), particularly when the calculations would still have to be verified by such tests in the case of all doubtful materials.

The cutting speed is definitely the most important factor for the ratefixer to know. He knows the cutting angles and tool materials which ought to be standardized in his works, and if he knows the machining index of the materials his computations will correspond with the actual work which is subsequently performed in the workshop. Furthermore, when the workman and foreman

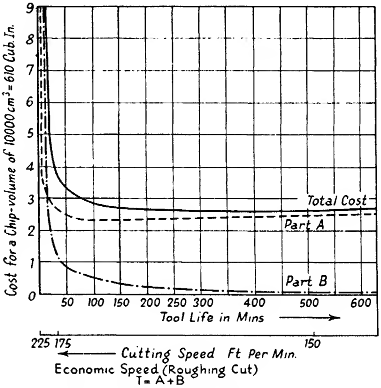


FIG. 61. ELEMENTS OF ECONOMIC TOOL LIFE

attempt to carry out the work at prescribed feeds, speeds, etc., soundly computed from reliable evidence, they will find that they can do so without trouble and that the work is within the capacity of the machine tool. (See Tables XX and XXVI.)

The life of a tool with the usual positive rake angles increases rapidly as cutting speed is decreased within the practical working range (see Fig. 60 (a), but the output is decreased also.

The Most Efficient Method of Removing Metal

In rough-machining operations the maximum volume of chips ought to be removed per minute for minimum cost consistent with good workmanship. This can be done only with the best combination of tool contour, depth of cut, feed, cutting speed, long tool life and rigid tool support.

Tool contour is usually a compromise between a shape that will permit maximum cutting speed at a given cross-sectional area of chip and the shape that prevents excessive chatter. A tool with a nose radius of at least 0·06 in. to 0·15 in., for deep cuts, a plan angle of approach of about 75° (Fig. 62*a*) and not less than 45° and side and

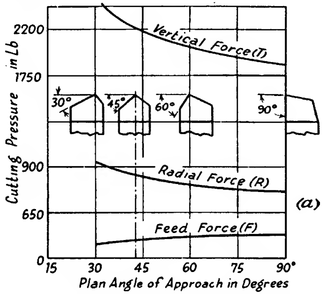


FIG. 62*a*. INFLUENCE OF APPROACH ANGLE ON CHATTER

back rakes according to Table XVIIIA, is an efficient tool that can be used without serious chatter.

Fig. 62*b* shows some examples of correctly supported tipped tools. For ideal conditions (*N*) overhang (*D*) should be less than three-quarters of height (*H*) of the shank. If that is impossible special projections to support the tool should be used. B_1 shows the tool supported on the front. In the case B_2 the tool is held by a special projection at the bottom, whereas *Bt* shows that the tool is supported at the side and front.

Depth of Cut

It is good practice to use the maximum depth of cut that is permissible by the stiffness of work, the rigidity of the machine tool and the power available. Increase in depth of cut affects the maximum cutting speed but little, if the motor is strong enough, but reduces the specific pressure and machinability index (see Fig. 57); therefore the total cutting pressure does not increase in direct proportion to the depth of cut.

Present-day casting and forging practice leaves a relatively small amount of stock removal; and cuts deeper than 0·15 in. to 0·25 in. are seldom necessary. For most work it should be possible to finish a surface with one roughing cut and one

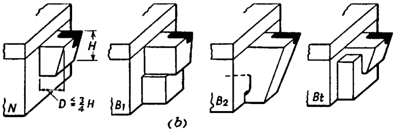


FIG. 62*b*. MINIMUM OVERHANG AND RIGID TOOL SUPPORTS

to two finishing cuts. The material allowance on forgings frequently depends on the batch to be machined (see Fig. 22), whether from roughing or finishing dies.

Economic Feed

The cutting efficiency of a given tool and for a given tool life, measured in cubic inches removed per minute, increases with the feed, other factors remaining constant. Feeds below 0·030 in. per rev. should be avoided for roughing cuts.

There is a limit for the size of chip which may be cut from a given piece without causing excessive deformation of the work. Deformation results from the pressure (tangential force mainly) created between tool and work by the chip action or the heat produced by its removal. Chatter is less likely to occur, however, with heavy cuts at the proper speed than with lighter cuts at high speed.

Materials Cut

As already mentioned, most workshop performance consists of cutting steel or cast-iron. Many steels in common use differ not only in carbon contents but also in the percentages of nickel, chromium, vanadium, molybdenum, lead, manganese, silicon, phosphorus, and sulphur which they contain. These steels also differ widely in their heat treatment and therefore in their physical characteristics.

Cast-iron ranges from soft alloys, used where hardness and strength figures are of little importance, e.g. foundation plates of steam turbines, Diesel engines, radial drills, etc., to high-grade irons used in the manufacture of quality machinery such as machine tool beds, columns, uprights, cylinders of internal combustion engines, etc.

Table XX covers the cutting speeds of ferrous and non-ferrous metals for a modern workshop equipped with fairly strong and fast machine tools using high-speed steels (HS) and super-high-speed steels (SHS) and stellites 80 and particularly cemented carbide-tipped tools (Tu-Carb) for roughing (about 0·006 sq. in. area) and ordinary finishing cuts and for cast-iron. The tool life is supposed to be at least three hours, up to eight hours.

All Tables of tool speed are based on stiff, well-supported workpieces. In the case of lathe work between centres or unsupported chucked length of more than 12 × the diameter, the tool action tends to cause chatter and makes necessary the use of lighter cuts.

The tangential forces for roughing-cuts are considerable and deflect the piece. Table XXI, shown on page 148, gives an idea of the tangential forces on a lathe for three different materials and cross-sections.

Power Available

In using cemented carbides it is important that the machine should never be allowed to stall owing to an excessive power consumption arising through an increase in the cutting speed, otherwise the tools are destroyed. The permissible limit should be watched. The consequences to the machine tool and tool itself will be discussed in the chapter on "Effective Use of Machine Tools" (see page 192).

Coolants

Cutting Fluids

Cutting fluids correctly selected, have a great influence on the tool life and the quality of the finished piece, especially in cutting steels of all kinds. But just as when grinding the tool edges ready for use, the coolant must be supplied constantly; any interruption endangers the tool. The inconvenience of coolants must be overcome by the correct design of the machine tool and the supply (without splashing) and good drainage of the coolant. The best example is the grinding machine; it produces the finest surface with the highest cutting speeds (3000 to 6000 f.p.m.) and has a good efficiency of emery wear against swarf produced (1 : 30, see page 186). Nobody thinks of grinding dry because of the unavoidable heat. It may be that tools with negative rake angles will soon reach the limit of high speed and then correct coolants will be indispensable. (See pp. 152 and 181.)

Every cutting action causes considerable heat by shearing the chips from the basic material and by simultaneous friction to remove the parted, bent, and curled chip from the top of the tool. The correct adaptation of the tool contour to the material to be cut reduces the power consumption, improves the tool life, increases the output and produces a smoother surface from the roughing operation and a more accurate and finer surface when finishing.

The modern trend is to reduce or even to avoid the detrimental "built-up" edge by the four available means, i.e.—

(1) Highest possible cutting speed.
(2) Well-chosen coolant.
(3) Hard tool material.
(4) Honed cutting surfaces and edges.

The favourable effect of very high speeds, combined with negative rake angles for rotating tools, e.g. milling-cutters, is discussed in Chapter IX but it requires a very strong motor, very rigidly built machines, and very small clearances in all bearings and slideways and therefore a reconstruction of the machine tools, as desirable aim of the future.

The well-chosen coolant, however, can be used at once with the existing plant, applying a few changes to transform a "dry" machine into a cooled one. A good coolant must have the properties necessary—

(1) To cool tool, specimen, and chips.
(2) To reduce the friction or adhesion between shorn chips and tool surface.

Data for Rate

Cutting Speeds for the present modern workshop using simultaneously: HS (18–4–1)

Adaptation of speeds and feeds

Operations		Tools Speed V Feed a	Carbon, Nickel, and Nickel-chromium Steels 22–30 tons/sq in	32–40 tons/sq in	42–60 tons/sq in	65–80 tons/sq in	Stainless 32–42 tons/sq in	Steel Castings *Soft* 22–30 tons/sq in	*Hard* 32–45 tons/sq in	Cast-iron *Soft* Brinell Hardness < 180	*Hard* Brinell Hardness > 220
Turning	Roughing	HS V a	80 0 04–0 3	60 0 04–0 2	40 0 04–0 08	30 0 02–0 06	40 0 02–0 06	60 0 015–0 15	40 0 015–0 15	60 0 04–0 1	40 0 04–0 1
Turning	Roughing	SHS V a	100 0 02–0 15	80 0 02–0 1	60 0 02–0 08	50 0 02–0 06	50 0 02–0 08	100 0 02–0 08	60 0 04–0 1	100 0 04–0 1	60 0 04–0 1
Turning	Roughing	Tu-Carb V a	250 0 010–0 08	200 0 010–0 08	150 0 010–0 06	125 0 010–0 06	125 0 010–0 06	175 0 05	125 0 05	175 0 05–0 10	125 0 05–0 10
Turning	Finishing	HS V a	75 0 01–0 015	60 0 01–0 015	50 0 01–0 015	30 0 01–0 015	30 0 01–0 015	60 0 01	40 0 01	60 0 01–0 015	40 0 01–0 015
Turning	Finishing	SHS V a	150 0 01–0 015	120 0 01–0 015	100 0 01–0 015	75 0 01–0 015	75 0 01–0 015	125 0 01	75 0 01	100 0 01–0 015	60 0 01–0 015
Turning	Finishing	Tu-Carb V a	500 0 01–0 015	300 0 01–0 015	200 0 01–0 015	150 0 01–0 015	150 0 01	250 0 01	150 0 01	200 0 01	120 0 01
Turning	Thread Cutting	HS V	60	50	30	20	20	50	20	50	20
Turning	Thread Cutting	SHS V	80	70	60	30	30	60	40	60	30
Grinding		Speed roughing of workpiece V_r = 40 to 50 ft/min, Feed$_r$ = [illegible] to [illegible] of width of abrasive									
Grinding		Speed finishing of workpiece V_f = 50 to 80 ft/min, Feed$_f$ = 0 3 to 0 4 width of abrasive									
Boring	Twist Drill	HS V a	80	65	55	40 a = 0 1 to 0 015d (→ across columns)	45	65	45	70 0 02d	45 0 02d
Boring	Twist Drill	SHS V a	120	100	80	65 a = 0 01 to 0 015d (→ across columns)	65			0 02d	0 02d
Boring	Boring Bar	HS V a	60 0 01–0 04	50 0 01–0 04	45 0 01–0 03	35 0 01–0 03	35 0 01–0 03	45 0 01–0 1	25 0 01–0 1	50 0 01–0 2	25 0 01–0 2
Boring	Boring Bar	SHS V a	90 0 01–0 04	75 0 01–0 04	65 0 01–0 03	50 0 01–0 03	50 0 01–0 03	50 0 01–0 03	35 0 01–0 2	60 0 01–0 2	40 0 01–0 2
Boring	Boring Bar	Tu-Carb V a	200 0 01–0 04	150 0 01–0 04	130 0 01–0 03	100 0 01–0 03	100 0 01–0 03	130 0 01–0 1	80 0 01–0 1	150 0 01–0 2	80 0 01–0 2
Boring	Reamer	SHS V a	60 0 04–0 3	45 0 04–0 2	35 0 04–0 15	25 0 04–0 1	30 0 04–0 1	40 0 04–0 1	25 0 04–0 2	40 0 04–0 2	25 0 04–0 2
Boring	Reamer	Tu-Carb V a	120	90	70	60	60	80	50	80	50
Milling	Slab- and Facing-Milling	HS V a	90 up to 12″	65 up to 10″	50 up to 8″	35 up to 4″	35 up to 4″	65 up to 6″	40 up to 3″	80 up to 8″	40 up to 3″
Milling	Slab- and Facing-Milling	SHS V a	120 up to 16″	90 up to 12″	65 up to 10″	45 up to 6″	45 up to 6″	90 up to 8″	50 up to 4″	100 up to 12″	50 up to 5″
Milling	Slab- and Facing-Milling	Tu-Carb V a	300	250	175	120	120	175	60	175	60
Planing (shaping)	Roughing	HS V a	80 0 04–0 4	65 0 04–0 25	50 0 04–0 12	35 0 03–0 06	35 0 03–0 06	55 0 04–0 12	40 0 03–0 08	80 0 02–0 45	55 0 02–0 45
Planing (shaping)	Roughing	SHS V a	100 0 04–0 4	80 0 04–0 25	60 0 04–0 12	50 0 03–0 06	50 0 03–0 06	80 0 04–0 12	40 0 03–0 08	80 0 02–0 45	40 0 02–0 45
Planing (shaping)	Finishing	SHS V a	100 0 04–0 4	80 0 04–0 3	60 0 04–0 25	40 0 03–0 12	40 0 03–0 12	60 0 04–0 5	30 0 04–0 2	60 0 04–0 5	30 0 04–0 2
Planing (shaping)	Finishing	Tu-Carb V a	200	180	120	100	100	180	60	200	60
Horizontal Boring Mill		The operations are: 1 Boring, 2 Turning, 3 Milling — Take values from data in corresponding operation above and below									

Steel—SHS (5/10 Co–18/20 W–4/5 Cr–1/2 Va) Steel or Stellite—T.C. (Tungsten Carbides).

to material of parts and tools

BRONZE		BRASS		LIGHT METALS		HS = High Speed 18% W SHS = Super High Speed 5% Co + 15% W Tu-Carb = Tungsten Carbide
Soft	*Hard*	*Soft*	*Hard*	*Soft*	*Hard*	
200 0 03–0 1	100 0 02 0 06	250 0 015–0 12	100 0 012 0 1	600 0 015–0 12	400 0 012 0 01	Instead of SHS-tools Stellite 100 can be used successfully for machining cast-iron and for roughing cuts in general
300 0 025–0 08	150 0 02–0 06	400 0 012 -0 1	150 0 012 -0 06	800 0 012–0 08	500 0 012–0 06	
750 0 04–0 1	350 0 04	1000 0 04–0 1	500 0 04	1500 0 04 0 08	800 0 04–0 08	
250 0 008–0 012	150 0 008–0 012	500 0 008	200 0 008	800 0 004–0 008	400 0 004 -0 008	For the last finish to guarantee the dimensional accuracy according to limit gauges, the finest feeds are to be chosen
300 0 008–0 012	200 0 008–0 012	650 0 008	300 0 008	1000 0 004 -0 008	600 0 004–0 008	
1000 0 008	400 0 008	1300 0 008 0 005	600 0 002–0 004	2000 0 002–0 006	1200 0 002–0 006	
50	35	80	40	110	75	Feed = pitch Cemented carbide-tipped die-heads exist
80	50	130	50	200	150	

V wheel–r = 3000 to 5000 ft/min

V wheel–f = 5000 to 7000 ft/min

Rigid workpieces allow larger travel and deeper cross feed

100 0 015d	50 0 015d	400 0 015d to 0 01d	75 0 015d to 0 01d	800 0 01d	500 0 01d	The feeds for twist drills are in a certain relation to the diameter of the drill
150 0 015d	75 0 01d	600	150	1000	600	
130 0 01–0 03	65 0 01–0 03	220 0 01–0 04	100 0 01–0 04	600 0 005–0 03	400 0 005 0 03	
160 0 01–0 03	100 0 01–0 03	300 0 01–0 03	160 0 01-0 04	1000 0 005–0 03	600	
250 0 01-0 03	125 0 01-0 03	500 0 01–0 03	250 0 01–0 03	2000 0 01–0 03	1000 0 01 0 03	
40 0 04–0 02	25 0 04–0 2	90 0 04–0 4	60 0 04-0 4	130 0 04–0 4	100 0 04–0 4	Cemented carbide-tipped reamers have two to three times the tool life.
80	50	150	75	250	200	
100 up to 6"	50 up to 3"	160 up to 8"	100 up to 4"	600 up to 16"	350 up to 16"	
160 up to 8"	80 up to 5"	220 up to 12"	130 up to 6"	700 up to 24"	500 up to 24"	
400	300	500	300	1500	1000	
80 0 02–0 2	50 0 02 0 2	130 0 01–0 15	80 0 01 0 15	160 0 01–0 15	120 0 01 -0 15	
100 0 02–0 2	80 0 02–0 2	200 0 01–0 15	150 0 01–0 15	260 0 01 -0 15	200 0 01-0 15	
110 from 0 008 to 0 5 in	80 from 0 008 to 0 5 in	170 from 0 008 to 0 5 in	100 from 0 008 to 0 5 in	300 from 0 008 to 0 5 in	200 from 0 008 to 0 5 in	
200	100	270	160	400	250	

TABLE XXI

TANGENTIAL FORCES (LB.) OF HEAVY ROUGHING CUTS ON A LATHE

d (Depth)	f (Feed)	Mild Steel, 30 tons/sq in	Cast-iron, 12 tons/sq in	Chrome Ni (3.5%) Steel, 50 tons/sq in
in	in	lb	lb	lb
0.125	0.04	1,100	350	1580
0.15	0.04	1,450	570	2200
0.20	0.04	1,700	700	2400
0.15	0.008	2,570	1120	3450
0.20	0.008	3,250	1450	4100
0.28	0.008	3,750	1630	4500
0.20	0.125	4,050	1980	5600
0.40	0.125	6,500	3600	—
0.40	0.15	9,000	4350	—
0.40	0.2	11,300	5100	—

Naturally, the maximum speed should be used, which can be sustained on the same specimen by the different types of tools necessary. There are various theories of cutting fluid action, but none is convincing, for no theory can be correct unless it can be used to bring about practical success in ordinary machining work. When the "built-up" edge* is eliminated, we have the right combination of—

(1) Tool sharpness (honed edges)
(2) Correct rake angles.
(3) Optimum cutting speed.
(4) Well-dimensioned cross-section of chip (thin feed).
(5) Minimum adhesion between the relatively moving surfaces of chip and tool.

The attainment of this result can be confirmed by proving that the minimum cutting forces and power were at work, measuring them by, say, a cutting tool dynamometer and a wattmeter, and that the quality of surface produced was acceptable, as measured by a reliable surface-analyser.

* (1) *Chip Formation, Friction, and Finish*, by H Ernst and M. E. Merchant, American Society for Metals, New York, 1940 (2) "Neue Untersuchungen zur Schnitt-Theorie und Bearbeitbarkeit" (New Investigations of the Theory of Cutting and Machinability), by F. Schwerd, *Stahl und Eisen*, 1931, pp. 481–491. (3) *Über die Spanbildung bei der Metallbearbeitung* (Chip Formation in Cutting Metals), by A. Raupp, 1937, Thesis, Techn. University in Hanover. (4) "Final Operations," by G. Schlesinger, *Aircraft Production*, 1945, June–July.

A good cutting fluid is characterized by—

A. Chemical Properties

(1) No skin troubles for operators
(2) No bad smell.
(3) No deterioration in stores
(4) No corrosion and rust of machine, work, tools.

B Cooling Abilities

(1) Good heat absorption
(2) Low viscosity.
(3) Reduction of adhesion

The fulfilment of the four chemical conditions, despite their negative nature, is the essential natural foundation of all cutting oils, but the positive effects of the coolant are concentrated in its heat absorption and viscosity

Take the much-used lard oil as an example Lard oil becomes rancid and develops disagreeable odours in use. Rancidity thickens the oil, resulting in gumming and choking of feed pipes. Bacterial growth in rancid oil may cause skin disease It congeals in cold weather. As heat has a tendency to thicken it, it cannot be used in high-speed work Its cost is high. It should, therefore, be replaced by a more suitable coolant whenever possible.

Heat Absorption and Viscosity

Both high specific heat and low viscosity improve the cooling action. The specific heat of a liquid is its ability to absorb heat

Pure water has a very high specific heat, it cools very intensely, and as it has a very low viscosity and no clinging consistency, it flows easily to the spot to be cooled It is the cheapest coolant, but it causes rust and corrosion, vaporizes by great heat, and congeals in cold weather.

Cutting emulsions having a high specific heat and low viscosity are ideal coolants, avoiding rust and corrosion, but they do not reduce the friction between chip and tool.

Low-viscosity mineral oils are the next best coolants, decreasing in their cooling ability with increase in viscosity. Compound of mineral oils with animal and vegetable oils may have an indirect effect through reduction of adhesion between chip and tool surface.

Reduction of Adhesion

To secure a good finish and a long tool-life the wear on the lip surface of the tool must be reduced. Approved means employed for increasing this property are—

(1) Sulphur.

(2) Chlorine.

(3) Animal or vegetable compounds.

The practical results secured by sulphurizing or chlorination of fats are extraordinary. The method by which these results are achieved, i.e whether by chemical reactivity, the greater load-carrying capacity, increased metal-wetting properties, greater oiliness, or a combination of several factors, need not be analysed here

Numerous shop tests made on automatic screwing machines, capstan lathes, and milling machines,* which the writer has observed, have shown that the addition of sulphur has increased the tool life between 30 to 50 per cent

To shear the chip from the material and then to tear it off from the piece obviously requires close contact between tool and piece, whether the tool edge be clean or whether the chip removal be by the hard "built-up" edge pressed to the tool lip and therefore performed much less efficiently than with a clean tool (Fig 62c).

There is no advance gap or vacuum formed for the cutting fluid to occupy, it is not conceivable that a vacuum can exist even for a split-second in the middle of the atmosphere in a red-hot chamber of 300° to 600° C., one side of which must be open The problem is—

(1) To keep the tool and the work cool by copious coolant, flooding the always red-hot point of action, carrying off by the chips as much as possible of the heat that is generated

(2) Make the tool's task easier by reducing friction or adhesion between the contacting surfaces

It is possible to cut some metals dry because of an inherently low tendency to adhesion, brass and cast-iron being typical examples, but in general practice the lower the cutting speed and the deeper the cut, the greater the need for a cutting fluid that will reduce friction

* "Die Bearbeitbarkeit der Konstruktionstähle im Automobilbau" (The Machinability of Construction Steels in the Motor-car Industry), by G. Schlesinger, *Stahl und Eisen*, 1928

The usual conditions are—

(1) Low speed, shallow cut, therefore little need for coolant.

(2) Low speed, heavy cut; great need for reducing friction, particularly if material is tough.

(3) High speed, shallow cut, great need for cooling properties and still greater need for reducing adhesion, i.e. built-up edge, which destroys good finish

(4) High speed, heavy cut, great need for both cooling and reducing friction

Tear Chip *A* in the act of being removed from Workpiece *B* which is badly deformed by the tearing effect of the large built-up edge at *C* and *D* and the nose

Flow Chip Clean surface of tool real shearing without deformation of workpiece

FIG 62c DETRIMENTAL EFFECT OF BUILT-UP EDGE CLEAN CUTTING TOOL SURFACE

The cutting speed exerts an overwhelming influence, because it decides the length of tool-life, which is the fundamental factor of all production methods The life of a tool used for rough turning obviously differs from that of one used on finishing operations In roughing, a tool may be used until its cutting edge is so damaged that it refuses to cut (see Fig 63b). For finishing operations, one can consider the tool to have failed when either the nose of the tool, which in this case does the whole work, is so worn that there is an appreciable loss in depth of cut (dimensional deviation), or when by tool wear or particles adhering to the tool the quality of the surface is not acceptable

To obtain the best results in the use of cutting fluids it is necessary that a copious stream be directed so that it flows over the piece, the chips and the tool, because the hot point of contact between the cutter and the work cannot be reached.

Ideal conditions exist for grinding operations. Nobody tries to grind dry. The steel chips are burnt in the midst of the coolant to FeO (or FeO_2, or Fe_2O_3) with temperatures between 1500° to 1800° C. The cut is extremely shallow (0·0005 in) and very wide (½ in. to 4 in.) but distributed over

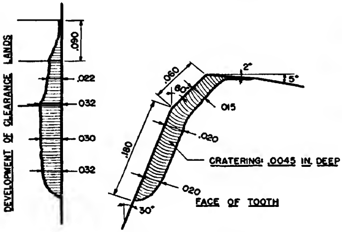


Fig 63a Face of Dulled Tooth (Development of Clearance Lands)

a great many cutting edges of positive and negative rake angles. The vitrified porous grinding wheel is filled with coolant, which is in continuous contact with tool and piece, and is centrifuged at 4000 to 7000 feet/min peripheral speed, and at the same time the piece and the rotating tool work in a stream of soluble oil (1 . 40 to 1 : 80 emulsion), tangentially directed, which washes away the swarf and keeps its temperature constant by the circulation of the purified coolant.

Dimensional accuracy and surface quality again depend on the correct choice of abrasive, on keeping it sharp by timely dressing, and on the coolant and its adequate dilution.

With lathes, capstans, etc., the use of special coolant tanks to promote good housekeeping has made cleaner departments and more economic machine operation. There is usually a small chip container tank in the main tank. The chip container is screened at the bottom so that. as the shavings and the coolant flow into it, the chips are arrested and the coolant passes through.

When the chip tank is full the machine is shut down, the coolant is allowed to drain through for some minutes, and the chip tank is then replaced by an empty one. This arrangement is easy and quick to clean, and not only saves much space but also reduces considerably the amount of coolant necessary to perform the work on such machines

The use of the hand oil-can and hand brush, and the makeshift water pots, should be restricted to low-speed work. The best means of application

Fig 63b. Tool Wear of Cutting Edge (Cemented Carbide-tipped Tool)

for all conditions is the circulating system, which supplies a large volume of fluid at low velocity over the tool and over the point of contact between cutter and work. Splashing of the cutting fluid should be avoided as it impairs cooling and is wasteful. By proper arrangement of tank and guards the cutting fluids can be kept off the floor and the amount required over a period of time reduced to a minimum.

A rotary gear pump is less likely to jam than a centrifugal or vane type pump. A plunger type pump is considered less desirable because of pulsation

Means of separating fluid from chips and abrasive contamination are—

(1) By strainers

(2) By settling, for example, flowing the mixture over dams or weirs.

(3) By filtration.

(4) By centrifugal separators.

(5) By magnetic extraction of ferrous chips.

Lathes, capstans, drilling and milling machines mainly use strainers because the chips are heavy; grinding machines require careful combinations of items (1) and (2), and sometimes for the separation of fine suspended steel chips the magnetic extraction method (5) must be added

An effective separation of the fluid from the chips requires first, filtration by weight difference and then, a powerful centrifuging in a special plant.

As for cooling effect and price the soluble oils are superior. Soluble oil of the best type possesses the following qualities—

(1) It emulsifies readily with all waters.

(2) It forms a stable emulsion

(3) It does not turn rancid.

(4) It is not injurious to men, machine, or work.

(5) It prevents rusting of work and machines.

(6) It does not form gum on the machines

(7) It is economic by meeting requirements with relatively low concentrations.

(8) It gives good tool life.

Soluble oils of proper quality can be used in complicated machines, such as screw machines, automatic turret lathes, etc, without detrimental results on machine bearings, spindles, slideways, and gears

The mixture proportions to be used are not sufficiently definite to permit of hard rules and must usually be worked out by actual trial and experience in each individual situation. The degree of solubility in water is perhaps the most important factor for determining both the most economic and most effective utilization of a cutting oil. The limiting value is a mixture so weak (1 80) as just to prevent rusting of the work or the machine.

Steel is the least troublesome of the metals likely to become rusted Malleable and annealed cast-iron are the most sensitive metals in this respect.

For most roughing operations by turning, drilling, and milling, cooling is the prime requisite For grinding, both cooling action and surface finish are required.

For thread-grinding and gear-grinding, aqueous emulsions cannot be used satisfactorily, because of their tendency to form minute surface cracks due to too rapid cooling of the metal, particularly on hardened surfaces Grinding oils for this purpose must be of proper viscosity and give maximum efficiency together with good chip-settling characteristics. Speed, type of steel, and amount of material to be removed, must all be taken into consideration in the choice of the particular oil to use for the best results.

Honing operations, where true cutting action is performed, require a light mineral oil as a coolant and to wash loose chips and abrasive away from the work

Lapping requires an oil in which the loose abrasive can mix and be circulated. The lapping mixture depends upon the metal being lapped and the severity of the operation.

Metal-working fluids should be selected primarily for the work they will do, they are not costly in themselves but they can increase the costs of production considerably if poorly chosen or improperly handled and controlled.

The workshop should have some practical recommendation (Table XXII), but it is almost impossible to give more than a rough review of the two main factors—

(1) machining operations,

(2) material to be cut,

which are decisive for the choice of the coolant.

It must be remembered that there are many other important considerations apart from the "machining index," based on the machining of some selected standard soft material. These include speed, depth of cut and feed, size and shape of specimens, contour of tool, tool life, chip formation, and surface finish.

It is no real help to the production engineer to propose a "machining index," based on a particular kind of steel, e.g AISI–B 1112,* without stating the exact reference conditions (speed, depth, feed, shape of tool, tool life, etc, and the heat-treatment of the steel) For example, drilling deep holes in soft steel of 110 Brinell is much more difficult than in hard chrome-nickel steel of 330 Brinell, which requires quite another shape of drill and a coolant which reduces adhesion so that the chips can escape from the bottom of the drilled hole to the face of the piece without

* *Cutting, Grinding, and Forming Fluids*, Standard Oil Co, Chicago, 1943

TABLE XXII

Coolants—Materials—Operations

No	Operation	Ferrous Metals: SM-Steel	Ferrous Metals: Alloy Steel	Ferrous Metals: Carbon Tool Steel	Ferrous Metals: Steel Casting Malleable	Ferrous Metals: Cast-iron	Red Metals: Brass	Red Metals: Bronze	Red Metals: Copper	White Metals: Aluminium Alloy	White Metals: Duralumin	White Metals: Electron
1	Turning (rough)	S ML E (1 25)	S E Dry (1 10)	S E Dry (1 15)	S E Dry	Dry S E	SO E Compr air	SO E Compr air	E (1 25)	E Dry	E Dry	Dry 4% Natr fluor
2	Turning (finish)	S SO E	S SO E	S SO E	Dry	Dry	Dry	Dry	Dry	E (1 10) Dry	E SO L	Dry 4% Natr fluor emuls.
3	Threading	S L	S L	S L	S	S Dry	E S	E SO S	S Dry	E S	SO L E	" " " "
4	Drilling (deep hole)	E SO	E S	E S	E SO	E S	Dry SO E	E SO	E SO	E SO	E SO	" " " " E
5	Reaming	S SO L L E	S SO L E	S SO L E	S SO	Dry SO	SO E	SO S	E SO S S	SO S E	SO S E	" " " "
6	Broaching	S R E	S R E	S R E	Dry S	Dry ES	E SO	E SO R	E S	E SO	S SO E	" " " "
7	Milling (rough)	S SO	S E Dry	S SO Dry	E SO Dry	S SO Compr Air	E Dry	E Dry	S E	E Dry	S E	" " " "
8	Gear cutting	S SO	S SO	S SO	S SO	Dry SO	Dry E	Dry E SO SO	S SO	S SO E	S SO	" " "
9	Milling (finish)	E SO	E	E	E Dry	Dry SO	E Dry	E Dry	E S	E Dry	SO E	Dry
10	Sawing	E S	E S	E S	E S	Dry SO	Dry E	E S	E S	E	E S SO	Dry 4% Natr fluor emuls
11	Planing, shaping	E SO Dry	E S Dry	E S Dry	Dry E	Dry SO	E Dry	E Dry	E Dry	E S Dry	Dry E	" " " "
12	Grinding	E (1 40)	E (1 60)	E (1 60)	E (1 50)	E (1 40) Dry	E	E	E	E S	E S	" " " "
13	Drawing (power press)	E R Ta	E R	E R	—	—	E	E	E	Grease	Grease	Tallow and grease

Abbreviations of Coolants

E = Emulsion, soluble oils and compounds
S = Sulphurized oils, or oils containing both sulphur and chlorine
SO = Straight cutting oil
L = Lard oil
M = Mineral oils
ML = Mixture of mineral and lard oil
R = Rape oil

Ta = Tallow
Tu = Turpentine or Carbon-tetrachloride
K = Kerosene
W = Wool grease
NF = Natron fluoride solution
D = Dry

If two or more symbols are inserted, the first should be preferred
Lard and rape oil are very expensive
Turpentine and kerosene attack the skin

causing a built-up edge. Still worse are the working conditions for drilling deep holes in soft non-ferrous metals. (See page 164.) Therefore any reference for machinability in the ordinary sense and to Brinell hardness was dropped in Table

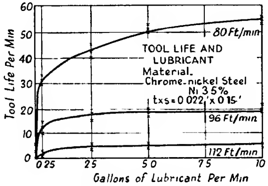


FIG 64a INFLUENCE OF COOLANT AND CUTTING SPEED ON TOOL LIFE

XXII which gives only a loose indication which kind of coolant might be used for a certain operation on different kinds of material. The best fluid dilution must be found separately for each case.

A series of cutting tests were made to determine the general effect of coolants (Fig 64) The material machined was VCN 35 (see Table XVIIB), which is very hard (235 Brinell) heat-treated material, the depth of cut was 0·15 in. and the feed per rev. 0·022 in (4 mm × 0·55 mm) The super-high-speed (10Co–18–5–1) tool was used (1) dry with a cutting speed of 112 ft/min, giving a tool life of only a few seconds, (2) with a speed reduced to 96 ft/min when the tool life rose to 3 min; and (3) with a speed reduced further to 80 ft/min when the tool life rose to 6 min. Emulsion was then applied at the rate of 0·25 gal/min and the tool life for the three speeds mentioned above rose to 2 min, 10 min, and 30 min respectively. When the coolant supply was increased to 2·5 gal/min, there were further increases of tool life to 4 min, 17 min, and 43 min respectively. Finally, with a coolant supply of 5 gal/min, the tool lasted 4½ min, 18 min, and 50 min. The graphs show that further increases in coolant supply did not have any marked effect upon tool life, for with a cutting speed of 80 ft/min the tool life, using 7½ gal of coolant per minute, was 53 min, and that using 10 gal of coolant per minute was 54 min. These tests show conclusively that coolant should be used for all roughing cuts and that the quantity of fluid should increase with the size of chip. It does not appear economic to use less than 5 gal/min for roughing cuts and it would seem advisable to use not more than 10 gal/min even if very heavy cuts are made

It is desirable to protect small diameter specimens from deformation and tool points from softening by the use of ample coolants, but it is essential that the coolant flow shall commence *before* the cutting action begins When a cemented carbide tool commences cutting at, say 200 ft/min, the tool tip is red hot in a few seconds and, if it then comes into contact with cold-cutting fluids, cracking will occur.

A similar series of tests were made in 1944 by O. W. Boston (Fig. 64b)* in turning cylindrical test bars. Again tool life in minutes is plotted against cutting speed in f p.m. as the decisive factor for the workshop. The formula expressing the relation between cutting speed and tool life between grindings for a given tool, material, feed. and depth of cut, is $VT^n = C$, in which V is

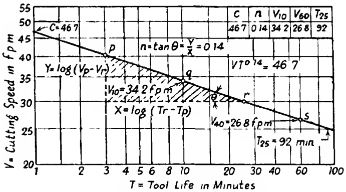


FIG 64b TOOL LIFE AND CUTTING SPEED OF NON-SINTERED TOOLS (*O. W. Boston*)

the cutting speed in ft/min, T is the tool life or duration of cut between grindings in minutes, C is a constant depending on the conditions and

* *Tool-life Tests*, by O W Boston The American Society of Mechanical Engineers, New York, proposed standards of tool-life tests for evaluating the machinability of single-point tools, cutting fluids, or materials cut Contributed by the Special Research Committee on Cutting of Metals

equals the cutting speed for a tool life of 1 min, and n is the slope of the straight line on log-log paper. If three or more turning tests were run on a metal in which all factors were kept constant except the cutting speed V, a definite value of tool life T would be obtained for each cutting speed, as indicated by points p, q, and r, on the lowest curve in Fig. 64*b* These and more points plotted on cartesian co-ordinates would produce a hyperbolic curve. On log paper they produce a straight line. When $T = 1$, then $C = V_1$ (in ft/min for a one-minute tool life) V_{10} (the cutting speed in ft/min for a ten-minute tool life) as read from the curve, is 34·2, V_{60} is 26·8, and T_{25} (the tool life for the cutting speed of 25 f.p.m.) is 92 min.

As the cross-section of chip depends upon the required material removal rate, and as the chip size is reduced to a minimum in modern manufacturing, the tool life should be measured not against the volume or weight of swarf produced, but against the output of satisfactory finished workpieces per tool grind. (See Fig 52) The units of cub in./min or cub in./h.p. and hour may be useful to the machine designer for research comparisons, but they are meaningless to the workshop executives, foremen, operators, and inspectors.

It is generally believed that a relatively long interval between grinds is desirable. This false belief causes tools to be used which perform unsatisfactory work at the end of their cutting period

Minimum machining cost for *economic tool life* depends on—

(1) The time required to change and grind the tool

(2) The cost per grind of the tool material.

(3) The wages of the operator of the machine tool

(4) The wages of the tool setter

(5) The wages of the tool grinder

(6) The indirect rates chargeable against the machine operator, setter and tool grinder

(7) The indirect rates chargeable against the machine tool and the tool-grinding machine.

(8) The number of machines operated by a single worker. (See Fig 61.)

CHAPTER IX

Cutting Tools

THE CUTTING tools, to which this chapter is restricted, are—

A Single-point tools

Lathe and planer tools

B Multiple-point tools

1 Twist drills, taps, and reamers
2 Milling cutters
3 Abrasives.

Single-point Tools

The single-point tools were detailed in the foregoing chapters as being fundamental The same contour as for single-point tools is employed for the inserted blades of the multiple-point cutting tools, and their cutting action is very similar, the abrasives, of course, form a special class Fig 55 shows that six angles are necessary to determine the shape of a single-point tool, i.e. two rake angles (γ and θ), two relief angles (α and σ), and two plan (contour) angles (κ and λ). furthermore the radius of nose (R) must be correctly ground If the brazed tip is of cemented carbide the soft material of the shank must clear the hard tip in grinding it, therefore relief angles (δ_1, δ_2, δ_3) must be ground beforehand to avoid the grinding wheel removing hard and soft material simultaneously, this being detrimental to the abrasive The same thing applies to the grinding of the correct radius and clearance of the nose of the tip, this being particularly essential for finishing cuts, as these are done entirely by the nose of the tool. Freehand grinding of the nose produces tool contours which are irregular and which usually have insufficient clearance.

As the correct shape and practical use of single-point tools is defined in detail (see page 133), it will be sufficient here to give speed Tables XXIII and XXIV of the latest practice with stellite 80 and cemented carbide-tipped tools The carbides have different grades for roughing and finishing and for different materials, information on which is obtainable from the suppliers. Because the figures vary considerably according to the physical properties, heat-treatment, and chemical analysis of the materials to be machined, the tables are intended only as a guide. Such factors as condition of machine, rigidity of work-piece in chuck, etc, must be taken into account and these factors may affect the performance of the tool.

Table XXV shows the conversion factors (see the A S.M.E Handbook) between high-speed tools stellite, and cemented carbides

Types of Single-point Tools

(1) *Solid Single-point Tools.* The point and the shank is in one solid piece of tool steel, formed—

(*a*) by roughly forging the point on the shank and by subsequent grinding, or

(*b*) by grinding the point on a piece of bar forming the shank

Solid tools are restricted to the ordinary high-speed (18–4–1) tools and sometimes to stellite In rare cases solid cemented carbides are used as tool bits, e.g. in boring bars.

(2) *Butt-welded Single-point Tools*, made by fabrication; the point is of a suitable alloy steel butt-welded to a shank of a different quality material.

This method is used for high-speed and super-high-speed steels.

(3) *Tipped Single-point Tools*, made by "tipping," that is brazing or welding a suitable cutting alloy-steel tip of super-high-speed stellite or cemented carbide into a seat formed on the point end of the shank. The shank should be considerably stronger than that of a solid or

TABLE XXIII

MODERN RECOMMENDATIONS FOR SPEEDS OF CEMENTED CARBIDE-TIPPED TOOLS FOR RIGID HIGH-SPEED MACHINE TOOLS

Material	Roughing	Finishing
	Speed in ft/min	Speed in ft/min
Steel		
Free-cutting steel	600–900	800–1200
Up to 50 tons/sq in tensile—		
Black bar, rough stampings, forgings	200–600	700–900
Clean material, free from scale and blowholes	600–800	800–1200
Over 50 tons/sq in tensile—		
Black bar, rough stampings, forgings	200–350	400–750
Clean material, free from scale and blowholes	400–600	600–1000
Cast-steel—		
30–45 tons/sq in tensile	200–300	600–800
45–65 tons/sq in. tensile	150–250	300–500
High-speed steel, annealed	100–250	250–400
Manganese steel, 12%	10–20	25–50
Nickel-chrome steel, 65–90 tons—		
Black bars, stampings, forgings	120–250	250–400
Clean metal	250–450	350–500
Non-corroding steel	75–150	200–350
Stainless steel—		
Forgings	60–100	100–200
Bar	150–300	250–350
Cast-iron and Wrought Iron		
Cast-iron—		
200 Brinell	180–300	350–500
200–400 Brinell	120–250	250–350
Chilled iron	15–25	20–40
Malleable iron	150–250	350–450
Wrought iron	300–400	400–700
Non-ferrous Metals		
Aluminium	1000–2000	1000–3000
Aluminium alloys	600–1000	750–1000
Duralumin	600–800	750–1000
Silicon aluminium	400–600	500–750
Brass, soft	700–1000	750–1200
Brass, hard	400–600	500–800
Bronze	400–600	500–800
Gunmetal	400–600	400–800
Aluminium bronze	300–500	400–700
Manganese bronze	300–500	400–700
Copper	500–800	750–1200
Cupro nickel	350–600	400–700
Zinc-base alloys	400–600	600–1000
Non-metallic Materials		
Glass	60–90	80–100
Granite	15–30	15–40
Marble	80–120	100–150
Plastic materials	400–800	800–1000
Porcelain	20–30	30–50
Rubber, hard	600–1000	800–1500

It will be found that these figures vary according to individual conditions, but they are higher than those of the present ordinary practice (see Table XX)

TABLE XXIV

MACHINING WITH STELLITE GRADE 80

Material	Speed		Feed		Depth of Cut	
	Rough	Finish	Rough	Finish	Rough	Finish
	ft	ft	in	in	in	in
Cast-iron (below 200 Brinell)	120	180	0.062	0.030	0.375	0.031
Cast-iron (above 200 Brinell)	100	150	0.040	0.020	0.375	0.031
Brass and phosphor-bronze	120	180	0.040	0.020	0.25	0.031
Aluminium alloys	400	800	0.050	0.020	0.25	0.031
Steel (below 50 tons tensile)	150	220	0.040	0.015	0.375	0.031
Steel (above 50 tons tensile)	100	150	0.030	0.015	0.375	0.031
Steel (above 75 tons tensile)	60	90	0.020	0.010	0.375	0.031
Steel castings	100	150	0.030	0.015	0.375	0.031

TABLE XXV

CONVERSION FACTORS OF AMERICAN SOCIETY OF MECHANICAL ENGINEERS

CHANGES OF TOOL LIFE BY CHANGING THE TOOL MATERIAL

	K (Efficiency Factor)	Basis
High-speed Steel		
18–4–1 (v_{60})	1.00	v_{60} = 1 hr life
18–4–1 + 5% (cobalt)	1.07	
18–4–1 + 12% (cobalt)	1.12	
Stellite		
No 80	3.0	
Tungsten Carbide		
On steel	2.9	
,, cast-iron	4.00	
Tantalum Carbide	4.00	

The factor K indicates relative tool life, e.g. if a high-speed tool has a life of one hour (1.00) the stellite tool has a life of three hours, and the carbides of between 2.9 and four hours

butt-welded high-speed steel tool for the following reasons—

(1) The cutting of the recess to receive the tip weakens the shank.

(2) The cutting temperatures are higher, when cutting dry

(3) The cutting pressures are greater, since the top rakes are generally less on account of the design of the tool

(4) Vibrations and deflections, caused by too weak a shank, must be kept at a minimum

The contours of the single-point tools are often standardized as shown in the Table XXVI. they have straight, bent, off-set (right and left), swan-necked, raised, parting, threading, profiling, and other shapes

The maintenance of standardized cutting angles is best done by a rigid template gauge (Fig 65) which contains all necessary rake, shape, and clearance angles. Such a gauge is cheap so that every tool-grinder or setter can have one at his work-place so as to ensure that the same angles are employed all over the workshop

For checking purposes the cutting tool protractor (see Fig 56) with two independent pointers is useful, it enables the rake angle and the clearance angle to be read from one setting. A very good scheme is to develop a set of grinding fixtures for hand-grinding, which guarantee identical cutting angles for the standardized values of Table XVIIIA, so that the template need only be used to confirm that the angles produced by the fixtures are correct

RULES FOR THE HANDLING OF CEMENTED CARBIDE-TIPPED TOOLS

(1) No irregularity of feed is permissible The ordinary rack and pinion drives usually have some play, therefore screw and nut feed mechanisms are preferable, particularly for finishing cuts.

(2) There must be no end movement or upward lift in the main spindle bearings.

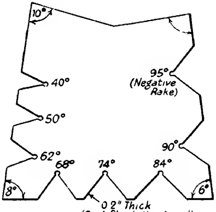
(3) The tool must be firmly supported as near to the cutting edge as is conveniently possible

(4) There must be no chatter or vibration in either the machine itself or the shape of the piece being machined.

(5) The driving belt or motor must provide sufficient power without any slipping of the belt or clutch. The least stoppage of the work-piece suffices to break the brittle cemented carbide-tipped tool.

The cutting surface of the tool must be kept clean Avoid the built-up edge, which is always "tearing" and a good result should be obtained. In cutting steel, high speed and good adhesive lubricants are the two best remedies against rough surface finish. From 300 up to 3000 f.p m. the built-up edge generally disappears even on tough chromium-nickel steel with 3·5 per cent Ni and 60 to 75 tons/sq in tensile strength (for case-hardening purposes).

There is an old Krupp-patent D R P No. 523594/1931, which states that at over 600 m/min



ANGLE GAUGE

FIG 65

(2000 ft/min), the structure of the chip is mainly changed to a flow-type and that with the same type of tool the specific cutting power is considerably reduced. (See Negative Rake Angles, pp. 177 and 181.)

High Speed

There is a continuous trend toward improved machining methods, which in all cases have the effect of increasing production by increasing the cutting speeds, at the same time improving the surface quality of work and the tool life. This is illustrated by the development between 1902 and 1940 of Taylor-White high-speed tools with 8 per cent tungsten; 1910–1912, of cobalt-alloy steels and stellite; and 1923–1940 of cemented carbide-tipped tools with tantalum and titanium. With this increase of the cutting speed of tools has come a general increase in the working pace of all manufacturing processes.

TABLE XXVI

Table of Order for a Small Shop of 20 Lathes to Change from HS Steels to Tungsten Carbides where Useful

	Turning Operation	Shape	Section of Shank In	Number of Tools Service and Stock: For Soft and Semi-hard Steel Tensile Strength 20–32 tons p s i			For Hard Steel Tensile Strength 35–40 tons p s i		For Cast Iron Brinell 160	For Bronze and Yellow Brass			Total Number of Tools		
				SHS Tools "Tough" Roughing	SHS Tools "Hard" Finishing	Tungsten Carbide Tools	SHS Tools "Tough" Roughing	SHS Tools "Hard" Finishing	Tungsten Carbide Tools	HS Tools "Tough" Roughing	HS Tools "Hard" Finishing	Tungsten Carbide Tools	In Use	Stock	Total
Tools of Personal Use	Roughing, r h		⅝-1 ¾-1 1/16 1-1½	28—14 8—4 4—2			28—14 8—4 4—2	14—7 4—2 2—1	14 7 4—2 2—1	4—2	4—2		84 32 12	42 16 6	126 48 18
	Roughing, l h		⅝-1 ¾ 1 1/16 1-1½	14—7 4 2 2—1			14—7 4 2 2—1	14—7 4—2 2—1	14—7 4 -2 2—1	4—2	4—2		56 24 8	28 12 4	84 36 12
	Finishing		⅝ 1 ¾-1 1/16 1—1½						14 -7 4 -2 2—1				14 4 2	7 2 1	21 6 3
	Facing r h		⅝-1 ¾-1 1/16 1-1½	28—14 8—4 2—1			28—14 8—4 4 2	14 7 4—2 2—1	14—7 4 2 2—1	4 -2	4—2		84 32 12	42 16 6	126 48 18
	Facing, l h		⅝-1 ¾-1 1/16 1-1½	14—7 4—2 2—1			14—7 4—2 2 1	14 -7 4—2 2—1	14—7 4—2 2—1	4 -2	2—1		56 24 8	28 12 4	84 36 12
	Boring		φ 10 mm 14 ⅜ ½ ¾ 1 1 1/16						12—6 12—6 12—6 12—6 2 2 2—2		4—2 4—2 4—2		12 12 12 16 6	6 6 6 8 4	18 18 18 24 10
	Boring Facing		⅜ 7/16 ½ ¾ 1					12 6 12—6 12—6 12—6 2 2			4 2 4—2		12 12 12 16 6	6 6 6 8 4	18 18 18 24 10
Tools for Common Use	Round Nose		r = ⅛ = 3/16 3/16 = ¼					10—5 10—5 10—5 5 3					10 10 10 10	5 5 5 3	15 15 15 8
	Grooving, Offset r h		l = 1/16 = ⅛ = 3/16 = ¼ Shank ⅝ × 1					10 —5 20—10 10 —5			4—2		10 20 4 10	5 10 2 5	15 30 6 15
	Grooving, Offset l h		l = ⅛ = ¼ Shank ⅝ × 1					20—10 10—5					20 10	10 5	30 15
	Radius Form		r = ⅛ = 3/16 Shank ⅝ × 1					10—5 6—3					10 6	5 3	15 9
	Grooving, Internal		l = ⅛ = 3/16 = 3/16 Shank φ = ¾					6—3 6 3 6 3					6 6 6	3 3 3	9 9 9
	Grooving, Radius Form		r = ⅛ = 3/16 Shank φ = ¾								4—2 4—2		4 4	2 2	6 6
	Threading, Whitworth		φ = ½					20—10					20	10	30
	Threading, Square		φ = ½					8—4			4—2		12	6	18
	Threading, Acme		l = 0 082 = 0 087 = 0 163 = 0 165 Shank φ = ½					2—2 2—2 2—2 2—2					2 2 2 2	2 2 2 2	4 4 4 4
												Total	765	390	1155

For the high-speed and super-high-speed tools made with iron (Fe) as a basis, the positive rake-angles with average cutting speeds proved best because they were well adapted to the usual peripheral speeds of journals and the normal design of machine-tool bearings.

For the alloy tools and particularly the hard metals which contain very little or no iron at all, such as stellite and cemented carbides, the fact that they have no elasticity and are therefore brittle, forced an increase in cutting speed and the use of negative rakes (since 1928, see Fig 89) so as to secure compression strain at the tool edge and a decrease in the cross-sectional area of chip, i.e. the cutting pressure, to the necessary minimum according to the available motor drive.

In order to secure the essential small depth of cut it is necessary to produce forgings, stampings, and castings leaving the smallest amount of material for removal This is also a good feature as regards material economy, but depends, of course, upon the shape of the piece, thus again emphasizing the saying that "manufacturing commences on the drawing board."

If the shoulders of the main shaft of a steam turbine, a Diesel engine, or electric generator, have big differences of diameter, the redundant material must be removed, either with a very heavy cut and slow speed using a high-speed steel tool, or with several rather shallow cuts and high-cutting speed using a hard-metal tipped tool. A comparison will show which is the best solution economically. From the standpoint of the user of existing machine tools, the power drive available will always decide.

Take as an example a 12 in. diameter steel shaft of 40 tons/sq in tensile strength, for a large combustion engine which is to be reduced at one end to 8·5 in. dia by 24 in long This can be done (1) With a solid high-speed steel tool in one cut, 1·75 in deep and 0·4 in feed, taking a 0·7 sq in cross-section with a single cut, a cutting speed of 18 f.p.m., and needing the full motor capacity of about 70 h p. of a heavy-engine lathe, the number of revs /min were 6, the cutting time for the 24 in. length would be 10 min plus 1·5 min to withdraw and return the tool, i e. 11·5 min total time (2) With a cemented carbide-tipped tool by four cuts of 0·44 in deep and 0·1 in feed, taking a chip section of 0·044 sq in., but increasing the speed to 200 f p.m., this would again need about 70 h.p with 63 r.p.m and 6·3 in. feed per minute, or 3·8 minutes per run, i e. 4 runs = 15 min, plus 4 returns plus adjustments at, say, 8 min, gives a total of 23 min, or twice as long as with the "old-fashioned" tool, and with considerably more work and careful attention.

In this case the ordinary high-speed steel tool is economically superior to the cemented carbide-tipped tool, in many other cases the cemented carbides or stellite 80 and 100 are preferable. It is the task of the planning department to select the most suitable tools, and of the foreman to see that they are correctly applied according to Table XXVI

Negative Rake Angles If the machine tool has not only a powerful drive but also very high speeds, and the piece does not require much material removal, then the best working method is to use cemented carbide-tipped tools but ground with negative rake angles *

Chip thickness is not quite the same as feed However, if the depth of cut is at least 4 × feed and the feed is small, say 0·04 in (= 1 mm), the calculation of speed and chip volume may be based on the feed without substantial error (residue of material) As the cross-section of chip remains the same, if calculating feed × depth (= thickness) or length of tool engagement, the power basis remains the same and the residue for small feeds is negligible (See page 128)

As regards size of the tool shank for big sections, it is recommended that the height should be twice the width, e g. $1\frac{1}{2}$ in. × $\frac{3}{4}$ in , 1 in × $\frac{1}{2}$ in , but $1\frac{1}{2}$ in. × 1 in and 1 in. × $\frac{5}{8}$ in are also obtainable and much used because they give a broader support to a carbide tip.

Rake and Relief There seems to be little necessity for making any considerable variation in rake and relief for similar materials, therefore the range of useful roughing tool shapes for iron and steel might be reduced to three contours (Nos. 2, 3, 4). (See Table XVIIIA.) While cutting

* (1) *Bearbeitbarkeit und Werkstaettenausnutzung* (Machinability and Exploitation of Workshops), by G Schlesinger, Z.V D.I , 1928 (2) "Cutting with Carbides," *Machine-Tool Review* (Alfred Herbert, Coventry), pp 51–56, May–June, 1945.

pressure decreases with increased positive rake, cutting speed is not, in general, greatly affected by such changes. The chip is removed with less energy by the tool having the greater rake, but the greater positive rake weakens the tool edge and failure occurs sooner than it would with a smaller rake. This is important, hence, the introduction of negative rake angles for the brittle carbide tips, which are weakened by progressive cratering when used with positive rake angles.

Effect of Tool Set-ups on the Rate of Metal Removal. Tools should be clamped in the tool-post

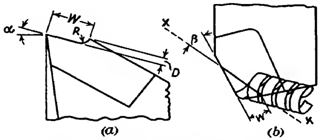


FIG 66 CORRECT CHIP BREAKER GROOVES
Front width (W), depth (D), radius (R) inclination of bottom (X) of groove (ρ)

so as to have support as close as possible to a point directly under the active cutting edge. Excessive overhang will cause chatter and necessitate an appreciable reduction in speed or feed or both. (See Fig. 62*b*.)

Work should be clamped in a machine tool so that the maximum rate of production is possible. Work should be supported as close as possible to the cutting edge (by a following rest) to prevent the springing of the part under the pressure of the tool. If accurate surfaces are to be produced, work should not be supported on rough surfaces. This is particularly true when machining castings Clamping strains tend to distort the work, while the release of casting strains by removal of a portion of the skin tends to cause a permanent deformation of the casting. When accurate surfaces must be machined on rough parts, they should first be set up as rigidly as possible for the roughing cuts but avoiding warping. Then the clamps should be loosened to release the clamping strains, and should be clamped no tighter than is necessary to hold it firmly against the finishing cut It may then be finished with fair assurance that deformations caused by the release of casting strains will be eliminated and that no new deformations will be introduced by strains set up by the method of clamping It is advisable to let castings rest after roughing and do the finishing some days later. For very accurate parts artificial seasoning of castings is the quickest, safest, and cheapest method For instance, the very sensitive stands and beds of jig borers of the best makes are heated in a special chamber for about six to eight hours up to 550° C , soaked for another four hours, then slowly cooled down at about 5° C. per hour under thermostatic control. $\frac{550}{5} = 110$ hours and $\frac{110}{24} = 4{\cdot}5$ to 5 days are required to remove any further movement from the castings, this being indispensable for the lasting accuracy of such machines

Chip Breakers. Straight chips and chips of large radius helix made by cemented carbide-tipped tools are difficult to handle and dangerous to the operator. A chip which curls into a tight spiral, breaking up into short sections against the unfinished surface of the work, is much to be preferred This is particularly true when soft but very tough materials, such as some of the low-carbon alloy steels or monel metals, are being machined. The best chip breakers are ground directly into the face of the tool, fulfilling the following conditions (Fig. 66)—

1 Contour of chip control groove must be made so as easily to deflect the steel chip into a coil of small diameter The groove contour consists of a flat, blending into a radius. The flat is diamond-ground at an angle α corresponding to the top side rake or slope best suited for the steel to be cut

The width of the groove W (flat + radius) determines the diameter of the coiled chip. This groove width is affected by the feed per revolution and the type of steel being cut.

The radius R effectively deflects the chip into a coil. This radius varies chiefly with the feed per revolution. Usually, for best results the following radii are recommended: up to 0·010 in. feed, $\frac{1}{16}$ in. radius; from 0·010 in to 0·030 in. feed, $\frac{3}{32}$ in. radius; from 0·030 in. to 0·050 in.

feed, $\frac{1}{8}$ in radius; above 0·050 in. feed, $\frac{3}{16}$ in radius.

The depth of groove D must be sufficient to deflect the chip into a coil. Usually a 0·015 in. depth is sufficient for feeds up to 0·010 in, 0·025 in depth for feeds up to 0·030 in, and 0·04 in to 0·05 in. depth for feeds above 0·030 in. It is recommended that D should not be allowed to exceed 0·06 in depth.

2. Generally the chip control groove should not be parallel to the cutting edge. The top view of the chip control groove should be in the shape of a flat triangle, the radiused side of the groove forming an angle β to the cutting edge The amount of this angle determines the direction of chip flow This type of groove usually throws the coiled chip in the direction shown in Fig 66. When chips are directed as shown, the chip does not injure the cutting edge, nor can the chip gouge out the shank directly under the tip. This type of groove usually directs the coiled chip into the unmachined part of the work, and this action breaks up the chip into coils of short manageable length.

3. Once the end contour and top shape of the groove have been determined they must be duplicated exactly to maintain efficient operation This cannot be done by freehand grinding The chip control groove should be reproduced on a universal tool-grinder, producing a straight (xy) and not a curved back, which is ground by the cylindrical external surface of the abrasive When the chip-breaker groove is ground "all in one" a double bending of the chip coil is caused, which is detrimental to the chip-breaker back and to the tool surface.

Grinding of Tools

Individual grinding of tools on floor or bench stands by the machinist cannot be recommended, because it seldom produces correct angles or contours. If the most suitable tool angles are selected and standardized the adjustable protractor should be replaced by suitable fixtures to guarantee correct grinding results and by simple templates (see Fig. 65) to check the correct angles and contours.

The best practice in tool-grinding requires the use of a semi-automatic tool-grinder with all grinding centralized in the toolroom and done correctly and in a fraction of the time by a trained operator. Then tools are always available at the machines from stock, ready ground to the angles and shapes best suited for maximum production Cutting speeds and feeds can be specified by the ratefixer with the certainty that they can be achieved, and production rates and costs are under control (see Table XX).

Wet-grinding is recommended and should be carried out with extreme care. Coolant must be supplied copiously and constantly by a pump and not by a pot If dry-grinding is unavoidable, the operator must make perfectly sure that the tip does not become too hot, and above all he must avoid cooling it suddenly with water. This is the most frequent cause of cracks, which will immediately lead to a breakdown of the tool. A water-pot should not be allowed near the dry tool-grinder.

Ordinary emery grinding-wheels with peripheral speeds of from 4000 to 6000 ft/min are used for wet-grinding high-speed and cobalt-tungsten tools. To grind cemented carbide-tipped tools two operations are generally used, i e. (1) roughing with a carborundum wheel, and (2) finishing with a diamond-impregnated wheel.

For roughing the tip a soft carborundum wheel (green crystolon) is generally used either dry or with copious water. Final finishing should be effected with diamond-impregnated wheels, using a straight oil as lubricant No other method but diamond honing* will produce a perfect cutting edge. Diamond-grinding of the cutting edge is absolutely essential for finishing tools. Diamond wheels are made in a variety of cup and disc wheel shapes, with different diamond concentrations and bonds, either of a bakelite or a metallic base such as steel or copper Peripheral speeds of between 3600 and 5500 ft/min are employed

Care should be taken to avoid the soft shank material being removed by the sensitive carborundum wheel. A secondary angle of relief (δ_1, δ_2, δ_3, (see Fig 55) for the shank should therefore

* Honing is a method using a fine-grain *bonded* abrasive, whereas for lapping a *loose* abrasive is used As tools are always finished with bonded discs or sticks, the correct denotation "honing" ought to be used for this final operation

be provided, using an ordinary emery wheel on a tool-grinder as a preliminary operation.

To minimize the risk of chipping, the tool should be ground from the tip to the body of the tool, the front and side faces being ground first and the top lastly. Only moderate pressures should be used in grinding. The application of undue

FIG 67 ONE-FACET DIAMOND TOOL WITH BLENDED CORNERS

force results in rapid wheel wear with the possible cracking and chipping of the cutting edge of the tool. Hand-grinding is therefore recommended but with the use of rest and angle fixtures. As mentioned above the shank should be considerably stronger than that of a solid or butt-welded high-speed steel tool.

Rockwell-hardness of tools. Well-hardened high-speed steel and cobalt-tungsten tools ought to show a hardness of about 62 to 65 on the Rockwell C-scale and tungsten carbide tips about 85 to 92

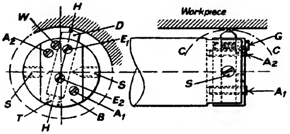


FIG 68. DIAMOND BORING-BAR

Rockwell C. Cobalt-tungsten tools reach maximum hardness only by reheating at least once, between 560° and 620° C, and in some cases twice. A means of measuring tool hardness with the Vickers or Rockwell hardness tester is an excellent investment and education for any toolroom, and it always pays.

It is remarkable how correct ratefixing, leaving a good bonus for the intelligent and skilful operator, reduces the number of tools destroyed. Tool destruction means a stoppage of the machine and therefore loss of time, and the operator finds out very soon that his earnings are dependent on sharp cutting edges and high-speed tools. However, the worker must have full confidence in the uniform reliability of the tools supplied by the toolroom.

*Diamond Tools**

The single-point diamond tool has been used for more than forty years for machining non-ferrous metals and alloys such as copper, brass, bronze, white metals, aluminium, duralumin, elektron, silumin, silver, gold, platinum, as well as vulcanite, ebonite, and various synthetic products. For steel and cast-iron the working conditions must be exceptionally good for diamond tools to be used to advantage.

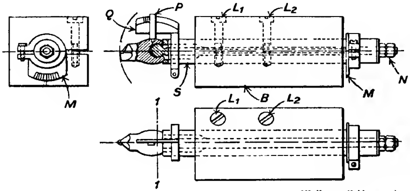
Only fine finishing work can be carried out with diamond tools, and feeds may be between 0·00004 to 0·004 in./rev. and the cutting depth not more than 0·008 to 0·03 in. Both depend upon the cutting resistance of the material to be machined. The surface speed ought to be not less than 600 ft/min. On large diameters, i.e. copper slip-rings, commutators, etc., speeds over 10,000 ft/min have been employed.

The life of the diamond tool may be between 100 and 500 working hours if the machine is very rigid and speed, feed, and depth of cut are correctly selected and the tool is well treated. Whether diamond tools can be economically employed, however, can be decided only on the facts of each particular case, their closest competitor being the cemented-carbide tool with well-honed cutting edges.

Aircraft and motor-car manufacturers especially have used diamonds with great success for external and internal manufacturing purposes. For the ordinary diamond-tipped boring tool the B.S.I. edited a standard specification, B.S. 1120–1943. The external tool gives excellent surfaces, especially if it has one facet with blended corners (Fig. 67). A surface finish of 1 to 4 μ-in.

* D. F. Galloway and G. Schlesinger. *Journal of I P E.*, August, 1944, No. 9, London.

average can be guaranteed for months on aluminium alloys. There must be a micrometer adjustment (Fig. 68 and 69) to adjust the facet almost parallel to the axis of the piece and also to the correct inclination *



(Galloway-Schlesinger)

Fig 69 Adjustable Diamond Tool-holder

Good working conditions are

1 Cold-set rigid diamond tool

2 Micrometer means of adjustment

3 Easily readable graduated dials, indicating the extent of adjustment (0·00005 in to 0 0005 in)

4 Means for securely retaining the diamond tool when performing heavy cutting operations.

5. Provision for the ready removal and replacement of the diamond tool without disturbing the adjustment

6. A very rigid machine tool

7 Very rigid tool-holder and secure clamping in the tool-post

Every trace of vibration must be avoided Working tolerances of 0·00008 in may be maintained with a very fine surface finish surpassing that of a fine-grinding action The built-in micrometer adjustment of the cutting facet reads directly to 0 0001 in (0·0025 mm)

Multiple-point Tools

1. Twist Drills

The most commonly used tool with two edges cutting simultaneously is the twist drill. Because the drilling machine is usually operated by unskilled labour the point of the drill should be accurately shaped in the toolroom by a very skilled operator.

No tool is so difficult to grind without the proper equipment and therefore hand-grinding should be eliminated since it is never uniform even though it seems quicker. A comparison of results produced by properly ground drills with those ground in a haphazard manner often reveals a tremendous loss of efficiency Tool life measured by the number of holes per sharp drill may differ in the ratio 10 · 1 merely by regrinding the point with suitable relief

There are four conditions for a perfect working drill, lack of any one of which will result in imperfect holes and high drilling expense. They are (*a*) equal length of the cutting lips, (*b*) correct and equal angle of the cutting lips, (*c*) correct clearance behind the cutting edges, (*d*) correct thickness of the web or chisel point. (Fig 70.)

(*a*) If the tool lips are not exactly of the same length ($A = B$) the drill will produce oversize holes and bad internal surfaces One lip does all the cutting, frequent sharpening is necessary,

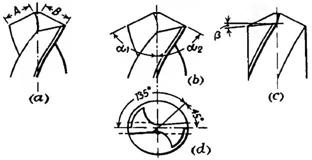


Fig 70 Correct Shape of Twist Drill Point

(*a*) Tool lips of same length, $A = B$ (*c*) Suitable relief, β
(*b*) Angle of lips, $\alpha_1 = \alpha_2$ (*d*) Position of chisel edge

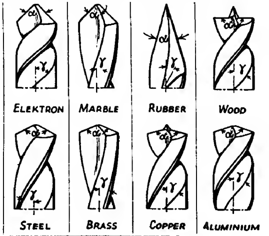
and the drilling machine is eccentrically loaded These deficiencies result in high drill costs, since much metal is wasted during the frequent sharpening.

(*b*) The angles ($\alpha_1 = \alpha_2$) of the cutting lips must be exactly the same for each lip. These angles must be adapted to suit different materials.

* P. Grodzinski: *Diamond Tools*, N.A G. Press, Ltd , 1944, London.

they vary from 30° for rubber to 180° for wood (Fig. 71).

(*c*) Clearance is the relief (β) behind the cutting edges. Without clearance the drill will not cut



Angle α of point	E 80° St 118°	M 80° B 130°	R 30° C 150°	W 180° A 140°
Angle γ of flute (helix)	E 45° St 28°	M 12° B 15°	R 15° C 30°	W 36° A 36°

FIG 71. ANGLES OF POINT AND ANGLES OF HELIX SUITABLE FOR VARIOUS MATERIALS

and with too much clearance the drill will dig in and break. The clearance should increase gradually from the periphery to the centre of the drill. The clearance usually accepted as standard is $\beta = 8°$ at the periphery for hard materials, up to 15° for soft materials. The clearance increases towards the centre to such an extent that the angle of the web intersection on the lips will be 130° to 135° to the cutting edge.

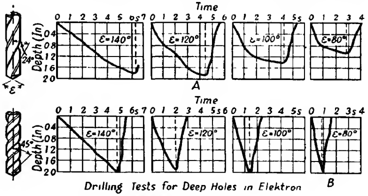
(*d*) The chisel edge is the edge at the end of the web formed by the intersection of the flanks. The chisel edge angle is determined by the point angle and the relief near the chisel edge; it is generally 45° to the axis.

The web is a metal column which separates the flutes. It runs the entire length of the drill between the flutes. This web is the supporting section of the drill, the backbone of the drill in fact.

If the web is too thick, excessive power by increased thrust is required in drilling; if too thin the point is weakened so that it cannot withstand the thrust of drilling and the drill will fail. Since the web increases usually in thickness as the shank is approached and as this central web does no cutting, it is important that the point is thin to reduce the thickness of web. For all tough materials the thinning of the chisel point is necessary, i.e. for steel, while for most cast materials, such as cast-iron, brass, and aluminium castings, etc , which are brittle, thinning is not necessary. In general the thickness of web at the point should be about one-eighth of the thickness of the drill. Drills with a cylindrical web are also manufactured.

There are two steps in the sharpening of the drill: (1) to grind the cutting edge which develops the angle and clearance correctly, (2) to thin the point by a drill grinder having fixtures for holding the drill properly. The inclination of the helical flute and smooth surfaces of the grooves are essential for a quick removal of the chips, eliminating clogging or the forming of a built-up edge behind the cutting edges Figs. 72 (*a*) and (*b*) show helix angles between 12° for brass and 45° for elektron. The correct inclination of the helix is essential for drilling deep holes.

An example may illustrate how the right shape of the tool point, helix, and relief, decreased the



A Failure using the ordinary drill with 24° helix.
B Success using special drill with 45° helix

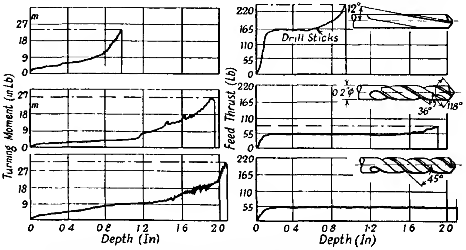
FIG 72*a*

cutting time from 5 sec to 1·8 sec for drilling deep holes of small diameter, e.g. 0·2 in. dia × 2 in. deep in elektron. Instead of using the usual twist drill of 24° helix and 120° point angle

(Fig. 72 (*a*)) a special drill of 45° helix and 80° point (Fig. 72 (*b*)) was used, which allowed the drilling of 3000 holes for one grind, whilst the drill of ordinary shape only produced 200 holes per grind and resulted in many broken drills at the end of the day.

Most workshops use the same twist drill shape for cast-iron, mild steel, hard steel, brass, and light metals, which is not at all economic. It is advisable to have at least three different clearance angles even for the same flute and point inclination for (1) steel, between 8° for hard and 12° for tough grades, (2) cast-iron, about 10° to 12°, and (3) non-ferrous metals, about 12° to 15°, and to have all drills ground by the same operator in a central grinding department Coolant should always be used for drilling any material.

Correct cutting angles diminish thrust and torque in drilling Excessive torque dulls the external edges; excessive thrust breaks the drill, even if the tool is drilling soft elektron. Fig. 72*b* shows how the more suitable drill with 45° helix and 80° point angles reduced the dangerous increasing thrust from the breaking point of



(1) 12° Helix excessive thrust Drill sticks and breaks
(2) 36 Helix great improvement Thrust increases not before reaching 1 6 in depth
(3) 45° Helix ideal conditions, constant (low) thrust for any depth
Turning moment about the same for all three cases

FIG 72*b* SPECIALLY DESIGNED DRILL FOR DEEP HOLES IN ELEKTRON

TABLE XXVII

SPEEDS AND FEEDS OF HIGH-SPEED STEEL DRILLS FOR DIFFERENT KINDS OF MATERIALS

Dia of Drill in	Steel of 35 tons Tensile		Steel of 40–50 tons Tensile		Steel of 50–60 tons Tensile		Steel of 60–75 tons Tensile	
	Speed ft/min	Feed in /rev	Speed ft/min	Feed in /rev	Speed ft/min	Feed in /rev	Speed ft/min	Feed in /rev
0·08–0·20	60 80	0·004	60–80	0·004	50–60	0·002	30–45	0·002
0·21–0·40	,,	0·008	,,	0·008	,,	0·004	,,	0·004
0·41–0·70	90–110	0·010	,,	0·010	,,	0·008	40–60	0·006
0·71–1·00	,,	0·012	80–100	0·012	60–70	0·012	50 65	0·008
1·01–2·00	80 100	0·016	80	0·016	50–60	0·014	45–55	0·012

Dia of Drill in	Cast-iron, 8–10 tons Tensile		Cast-iron, 12–20 tons Tensile		Brass (soft)		Brass (hard)	
	Speed ft/min	Feed in /rev	Speed ft/min	Feed in /rev	Speed ft/min	Feed in./rev	Speed ft/min	Feed in./rev.
0·08–0·20	80–100	0·004	40–60	0·004		0·004		0·002
0·21–0·40	100–130	0·008	,,	0·006	= 600	0·008	≤ 150	0·004
0·41–0·70	80–100	0·014	50–65	0·008		0·016		0·008
0·71–1·00	65	0·025	,,	0·012		0·025		0·012
1·01–2·00	65	0·040	45–60	0·016				

247 lb (12° helix) to a uniform load of 55 lb (45° helix), whilst the torque remained about 27 in./lb. in all three cases even at the bottom of the 2 in deep hole, where the torque is naturally increased by the friction of chips against cutting edges and walls of flutes.

Table XXVII gives suitable speeds and feeds for drills of different diameters made of ordinary high-speed steel, when used on different kinds of steel, cast-iron, and brass.

Table XXVIII gives the feed thrust and the torques for different diameters, materials and feeds in inches per revolution

TABLE XXVIII

DRILLING THRUSTS AND TORQUES FOR DIFFERENT DIAMETERS, FEEDS, AND MATERIALS

Dia of Drill in	Material to be Drilled	Feeds in In /rev: 0.004 in	0.008 in	0.012 in	0.016 in	0.02 in	0.024 in	
		lb	lb	lb	lb	lb	lb	
0.4	Cast-iron	200	285	375	440	500	570	Feed Thrust (lb)
	Steel (35 tons)	350	530	700	850	960	1100	
	Cr-Ni steel	440	790	1100	1420	1720	2050	
1.0	Cast-iron	370	620	850	1080	1300	1500	
	Steel (35 tons)	800	1260	1750	2200	2650	3100	
	Cr-Ni steel	1000	1900	2800	3650	4450	5200	
1.6	Cast-iron	600	1000	1300	1650	2000	2300	
	Steel (35 tons)	1300	2100	2800	3700	4000	4500	
	Cr-Ni steel	1750	3100	4400	5400	6600	7300	
2.0	Cast-iron	900	1400	1850	2300	2700	3100	
	Steel (35 tons)	1900	2850	3620	4400	5100	5620	
	Cr-Ni steel	2200	3950	5600	7000	8600	9850	
0.4	Cast-iron	35	53	70	88	98	106	Torque (in /lb)
	Steel (35 tons)	70	140	158	176	195	215	
	Cr-Ni steel	70	106	142	176	195	220	
1.0	Cast-iron	178	265	344	425	495	562	
	Steel (35 tons)	356	530	750	930	1110	1300	
	Cr-Ni steel	282	530	705	920	1100	1300	
1.6	Cast-iron	365	545	740	925	1090	1270	
	Steel (35 tons)	800	1240	1675	2120	2570	2900	
	Cr-Ni steel	670	1240	1760	2290	2820	3350	
2.0	Cast-iron	615	920	1200	1480	760	1950	
	Steel (35 tons)	1130	1760	2380	3080	3600	4250	
	Cr-Ni steel	—	—	—	—	—	—	

If cobalt tungsten super-high-speed drills are used, speeds should be increased 25 to 30 per cent but feeds kept as specified.

2. Threading Tools: Taps and Dies

When machining internal and external threads which call for the use of taps and dies, accuracy of shape is demanded within fine tolerances, together with smoothly finished surfaces. In most cases it is not possible for reasons of economy to perform a second operation to finish a thread made by a tap or die.

Fig 73 shows a standard tap and indicates the various terms used. The feed is given by the pitch of the thread. The shape of the thread (B S W, U.S S., S I, etc.) is fixed and determines the depth of cut, the only variable is the cutting speed (Table XXIX) Cutting angles must be

TABLE XXIX

MATERIALS AND CUTTING SPEEDS FOR TAPPING

Material	Tensile Strength	Cutting Speed: High-speed tap ft/min	Cast Steel tap ft/min
Ordinary mild steel	35–40 tons/sq in	60–80	25–35
Steel with 0 4–0 5 C	40 50 ,,	30–50	12–25
Cr-Ni steels	60-70 ,,	20 25	6-12
Heat-treated Cr-Ni steels	80 90 ,,	6-12	3 6
Cast-iron Brinell hardness	110 (soft)	45–55	25 35
	150 (medium)	40–45	20–30
	180 (fairly hard, machine tools)	30–40	12 20
Brass	12–16 tons/sq in	80–100	40-50
Bronze	16-25 ,,	65–80	25 40
Aluminium and its alloys	10–16 ,,	150-200	100-150
Elektron	10–18 ,,	150–200	100 150

adapted to the material being threaded (p 170) but this adaptability is much more limited than with ordinary single- or multi-point cutting tools. With a tap or die all the work is done in one single pass as the tool contains all the necessary dimensions. Indeed, the whole work of the tap or die is done by the chamfer (or taper lead) at the front and the first or second threads following this chamfer, these threads being in effect the finishing part of the tool. Because the feed is controlled by the pitch of the thread and the section of the chip by its profile, the stress on the cutting edges of the chamfer can only be regulated by varying the length of this chamfer or by changing the cutting speed. Another method of reducing the tool stress is by distributing the work between two, three or more taps in a set.

The Selection of the Correct Type of Tap

It is usual for reasons of economy to finish a thread, where possible, in one operation. This being so, the chamfer (taper lead) on the tap should be made long enough to ensure a good distribution of the cutting forces. The machine nut tap or tapper tap embodies this feature. The possibility of using this tap is limited by the fact that the run-out of the thread is often limited, as in blind holes, and is therefore smaller than the chamfer on the tap.

As stated above, the load ought to be well distributed. The work done in one turn of the tap produces one finished thread. With a long chamfer, each cutting edge is lightly loaded and the tap will have longer life In most cases it is necessary to shorten the chamfer. The machine nut tap with the shortened chamfer becomes the so-called machine tap Its usefulness is limited by the machinability of the material and it may be necessary to subdivide the operation between a set of taps

For through holes, taps with longer chamfers can be used than for blind holes. Consequently, the subdivision into two taps is often sufficient, while for blind holes three or more taps may be necessary The bottom tap should have only one thread chamfered Thus, for ordinary machine taps we have the following divisions—

1. *Nut taps* for short through holes, the lengths of which are not greater than those of standard nuts.

2. *Machine taps* for long through holes in a material which is easily cut, or where a long run-out is not permissible

3 *Set of two taps* for through holes especially for materials difficult to machine

4 *Set of three or more taps* for materials difficult to machine or for holes with short run-out.

Ground Thread Taps

By grinding all essential parts of the taps on their own centres after hardening, ground taps are accurately made straight and concentric. They have correctly shaped flutes to give the best cutting action, and power consumption is reduced. In addition, the largest possible chip chamber is obtained without weakening the tap to any appreciable extent

The British Standard Institution has published in B S. No 949 (temporary issue) of April, 1941, new tolerances for the diameters, pitches, and angles of screwing taps.

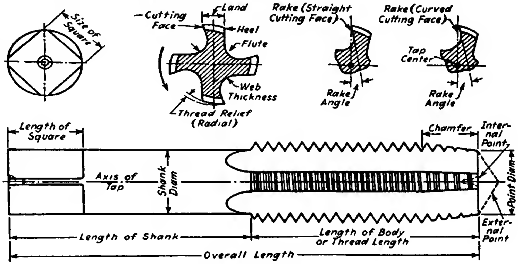


FIG 73 NOMENCLATURE OF STANDARD TAP

The tolerances allowed on the cumulative pitch errors of taps are based on a length of thread of 1 in. The tolerances for the four grades of taps are—

	Over a 1-in. Length
Ground threads, Grade 1	0.0003 in
„ „ „ 2	0 0006 in
Cut threads, Grade 1	0 0015 in.
„ „ „ 2	0 0030 in

Tolerances The B S I Standards for B.S W , B.S.F and B S.P. bolts and nuts distinguish between close, medium, and free fits and give the tolerances to which the work-pieces must be finished But in the latest preliminary issue, tolerance tables are given for the manufacturing accuracy of the taps themselves It seems to be more practical (see also the American Standards for taps) to distinguish the taps by their method of manufacture, i.e. whether cut or ground because the accuracy of the tap has a decisive effect upon the quality of the fit (close, medium, or free)

For high-class work (e.g aircraft and aero engines), where a bolt which becomes loose may be a source of danger, close fits are used, while medium fits suffice for ordinary good machinery.

The three grades of tolerance correspond to the following definitions—

CLOSE FIT. This includes screw-thread work requiring a fine snug fit. It is only obtainable by the use of the highest quality screwing tools, supported by a very efficient system of gauging and inspection This grade of fit is recommended only for special work, where refined accuracy of pitch and thread form are particularly required

MEDIUM FIT. This includes the better grade of interchangeable screw-thread work

FREE FIT. This includes the great bulk of screw-thread work of ordinary quality.

An accurate tap must possess the following features—

1 The tap must be straight and concentric

2. The shape of the flutes must be correct and suitable for the material being cut.

3. The following important dimensions must be accurate · (*a*) effective diameter, (*b*) pitch, (*c*) angle of thread, and (*d*) flank angle in relation to tap axis.

4. Correct cutting angles.

5 The material of the tap must be of high-quality steel properly treated throughout manufacture up to the final grinding.

The high-speed steel used should have usually the following analysis—

	W	Cr	Va	Co
Ordinary	18	4	1	—
Superior .	18	5	1 5	5 to 12

Numbers of Flutes. The number of flutes is not standardized, it being usual to find one, two, three, five, six, or eight flutes. Single-flute taps are sometimes used for aluminium. A two-fluted tap is only used for soft material and short holes, the cutting action being similar to that of a twist drill. Two cutting edges are sufficient for soft material and will stand up to the tapping of thousands of work-pieces. The two flutes provide maximum chip space. Three-fluted taps are said to cut more easily and with fewer shocks than those with four flutes, because three flutes give a good balance between number of cutting edges and chip clearance. The four-fluted tap, however, has better guidance on the chamfer Moreover, and this is an important point, it can be measured more easily using ordinary micrometers or gauges. Correctly ground three-flute taps have fewer edges, and consequently friction is reduced.

Materials to be Machined

The selection of an appropriate cutting speed, cutting angles, and chamfer relief depend on the material For taps to cut semi-hard, hard, and tough steels up to 50 tons/sq in a definite chamfer relief should be carefully ground *

Materials may be divided into the following groups—

1. Steels up to 50 tons/sq in
2. Tough and hard materials chrome steels, Ni-Cr and nickel steels, stainless steels and tool steels.
3 Cast-iron
4 Brass and bronze
5 Light metals.
6. Plastic and resins.

Group 1 . *Steels from* 25 *to* 50 *tons/sq in*. Threads in these materials can easily be cut. Through-holes from ¼ in up can be tapped by machine taps or single taps. It is advisable to give them a shaving chamfer to remove the chips more easily. The chips are continuous, remain together, and are pushed out in the direction of the cut in front of the tool point. If it is possible, the thread ought to have a sufficient run-out. If the run-out is too short, several taps of a set must be used. The designer should note that for blind holes a run-out or recess of double pitch at least ⅛ in. is necessary. Taps with spiral flutes (the direction of the helix depends on whether the bore is blind or through) facilitate the removal of the chips in such cases. The angle of rake is 5° to 10°, the cutting speed approximately 50 ft/min.

Ample coolant and lubrication with good cutting

* "Taps Their Correct Design and Efficient Use," by G. Schlesinger, *Machinery*, London. July, 1941.

oils are required. (See Table XXIII) The machine tap for these steels ought to be made of high-speed steel with ground flanks. Mild steels below 35 tons/sq in. are generally very tough; they require cutting angles and tools similar to those in Group No. 2 (tough-hard material).

Group 2: Tough-hard Materials. The cutting speed is 3 to 12 ft/min, with ample coolant Cutting angle 5° to 10°

Group 3: Cast-iron For ordinary cast-iron (140 to 160 Brinell hardness), the same taps are used as for ordinary steel. For through holes, machine taps of high-speed steel should be used or a single tap For harder cast-iron (180 to 220 Brinell hardness) use the same taps as for rough hard material The cutting angle is 0° to 5°. Cut dry, or use tallow or a good cutting oil

Group 4 Brass or Bronze give the least difficulties in tapping The thread is generally cut in one operation, using a machine tap or a single tap. Gun-nose taps are very suitable Cutting speed about 80 ft/min, cutting angle 0° to 5°, which can be increased to 10° to 15°, if a gun-nose tap is used. Ample coolant with cutting oils is necessary.

Group 5 · Light Metals frequently cause difficulties in tapping The alloys vary considerably and consequently great differences in machinability are found. The aluminium manganese alloys are tough. They clog easily and give long curls, and for this reason the flutes of the tap must be very wide in order to give ample chip space. Small taps have generally two flutes, otherwise three-fluted taps are used A front rake angle of 15° to 20° is suitable A machine tap, however, must not be used for holes where the tap has to be reversed The magnesium alloys give short broken chips, and their removal is not difficult, but they dull the cutting edges considerably as do the aluminium silicon alloys. The cutting speed should be about 150 ft/min Some alloys ought to be tapped without lubricant, e.g. electron. With others the coolant increases the quality of the finished thread. Fine threads below 0·03 in. pitch ought not to be used at all on these materials. Because great accuracy is usually required with light metals, ground taps are mostly used. The threads can be finished with one single tap and to enable this to be done it is advisable to have a long run-out. A gun-nose tap with six threads chamfer is quite suitable.

Group 6 Plastics and Pressed Materials, e.g. vulcanite, fibre, bakelite, etc., can be cut with the same tools as those for light metals. The chips are generally coherent. The phenol resins behave in a similar way to cast-iron, being brittle and giving short chips The taps should have cutting angles from 0° to 5°. Pressed materials dull the cutting edges considerably. They should be cut dry to avoid spoiling the material, with cutting speeds of about 100 ft/min. The threads can be finished with machine nut taps or single taps

Owing to the wearing qualities of these materials the relief should be kept to a minimum, say 0 0 to 0 0005 in per land The cutting angle must be at a maximum and the tap kept sharp

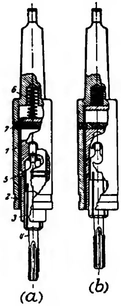
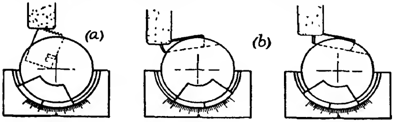


FIG 74 TAP-CHUCK, LENGTHWISE SELF-ADJUSTING, BUT RIGIDLY CENTRED
(a) Starting position
(b) Spring compressed

Chucking the Tap

It is of importance to secure the accurate axial position of the tap with regard to the machine spindle and to direct the chamfer truly in line with the axis of the hole to be tapped A correct chucking device secures not only the correct position of the tap but lengthens its life and produces good threads, avoiding any tendency to "reamer" the first part of the nut.

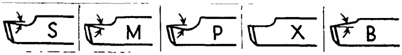
The lengthwise self-adjusting, but rigidly centred, chuck shown in Fig. 74 consists of two main parts which are adjustable, lengthwise relative to one another. An external sleeve (1) with taper shank is used to clamp the chuck in the machine. The sleeve (2) has an internal taper to take an intermediate chuck (3) for the tap (4). To equalize inaccurate alignment of the tool and the bore, the design permits a small floating movement of the sleeve (2) about the ring (5). Further, the design allows considerable axial movement of the parts in relation to one another to the extent of about 1·5 times the diameter of the tap. This axial movement takes place against the tension of a spring (6) The cross pin (7) passing through an elongated hole in the sleeve (2) prevents the sleeve from falling out. The right-hand view indicates



Grinding fixture adjustable for the variable cutting angles of the chasers—

(a) Throat (b) Cutting surfaces

Short throat = 30–40° Normal throat = 20° Long throat = 10–15°



S	M	P	X	B
Soft and forged steel 8–13°	Cast-iron 0–5° (rake angle)	Copper 15°	Steels of more than 55 to sq in 0	Brass 12° (negative rake)
Malleable castings 8°	Bronze 0°	Aluminium 15–20°	Tool steel 0°	Red brass 12°
Chrome-nickel steel 12°				Electron 12°
Rustless steel 12–15°				Delta metal 12°

Fig. 75

the extent of the movement of the internal assembly in relation to the external sleeve when the spring (6) is fully compressed.

The most perfect tap is spoilt unless it runs perfectly true and is truly in line with the bore Firms who excel in tapping operations hold tap shanks within 0·0005 in for size and concentricity with threads, in order that they may run true. A lot of trouble occurs through using inferior tapping devices, chucks, etc., but the worst offender of all is the floating tap-holder. In this device if the tap is out of line with the hole, the only power that can bring it into line is supplied by the resistance that the work offers to the tap entering the hole at an angle. This resistance cannot be effective until the tap has entered to a considerable depth, and even then, when the axis of the tapped portion is at an angle to the hole axis, the tap has continuously to be brought to its new lining-up position, as the revolution of the machine spindle takes it out of line again, under impossible conditions of torque transmission

If instead of one machine tap a set of three hand taps is to be used, the distribution of the cutting action between the three tools of the set should be chosen so that the taper tap does the biggest part of the cutting action. The second (plug) should do approximately half of the work done by the taper and should finish almost the full profile The third tap is for producing the precision dimensions only

External Threading Tools

Die heads are now used even with small batches of parts These tools are of the multiple-cutting type, generally with four chasers cutting simultaneously. The die-head parts are of heat-treated high-carbon steel, hardened and ground where necessary. They are mainly of the pull-off type, operated by arresting the travel of the turret slide.

Micrometer adjustment to 0·001 in. (0·025 mm) is provided and the setting can be repeated by foolproof mechanism at any time This great accuracy demands precise cutting angles, altered to suit the varying materials. Fig 75 gives the angles of throat and the correct cutting angles.

The same brand of steel often varies considerably in machining properties. Experiments are then necessary with different cutting angles, if the one specified does not meet the particular case. For general work a throat angle of 20° is recommended and for tough materials 15°. There are two different methods of cutting threads: (1) without a lead screw (usual way); (2) parallel cuts with a lead screw to control. Concerning (1), the non-cutting portion forms a hardened nut so that the pitch is controlled by its guiding action.

*Milling Cutters**

This tool, with its multiple-cutting edges, is amongst the most difficult in the shop Correct

A C Wickman, Coventry

FIG 76 FLYWHEEL ABOVE FACING CUTTER

milling is dependent on the fulfilment of the following conditions

1 Milled surfaces must be accurate within the prescribed limits according to dimension and form

2 The surface finish must be smooth and uniform

3 The working time ought to be as short as possible (maximum feed and adequate speed)

4 The cutter should nevertheless have the longest possible life

5 No chatter, or vibration, or irregular feeding, is permissible.

6 Power consumption must be the minimum.

Some of these conditions are incompatible with each other, therefore we must skillfully seek the best compromise

The two main classes of milling operations are—

(1) *Face Milling*, in which the finished surface is mainly parallel to the face of the cutter.

(2) *Peripheral Milling* (including slab and form milling), in which the finished surface is mainly parallel to the periphery of the cutter

* *Milling Cutters*, B S. No. 122, 1938.

Face Milling versus Plain Milling. Wherever possible, face mills or straddle mills should always be used in preference to plain mills, because they operate with reduced cutting pressure. This permits the use of increased feeds and results in longer cutter life. A plain mill involves problems in design and manufacture, since it is difficult, for instance, to maintain a uniform rake angle with cemented carbide-tipped cutters because of the cutter width These problems do not exist when considering the face mill or the straddle mill.

The facing cutter can be fastened very rigidly on the front of the spindle, and there is usually sufficient space to use a flywheel or to make the body of the facing cutter sufficiently heavy so that it performs the function of a flywheel (Fig 76)

For peripheral milling an arbor is used, which is fastened to the spindle by a taper, while the cutter is held by the cylindrical part of the arbor and driven by keys (Fig 77) The three kinds of taper are shown in Fig 78 The adapter allows for the comparison (and quick change, if necessary) of (1) Brown and Sharpe Taper 1 24 (central, but abandoned), (2) Morse Taper 1 20 (medium,

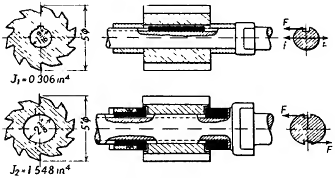


FIG 77

1 Small Diameter, Single Axial Key Groove Torque + Bending Force F, Moment of Inertia $J_1 = 0\ 306\ in^4$
2 Large Diameter, Two Pairs of Radial Driving Dogs Pure Torque Moment of Inertia $J_2 = 1\ 548\ in$ (5 times J_1)

sometimes in use), and (3)* Standardized Modern American and British Taper 1 · 3½ (external). All improvements by higher speeds, cemented carbide-tipped tools, negative rake, etc., are frustrated by the rather weak central part of the cylindrical arbor which carries and drives the milling cutter.

* N M T B A. = National Machine Tool Builders Association (U S.A.)

To adjust the cylindrical cutter in its position to work-piece and table, distance rings are necessary

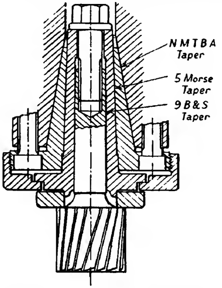


Fig. 78. Adapter to Use B & S or Morse Taper within the Standardized Modern Taper

(Fig. 79). These rings or bushings must have a close running internal fit on the arbor, and the end faces must be perfectly parallel to each other and perpendicular to the axis of the arbor. Any deviation from parallel deflects the arbor by tightening the nut which is pressing the rings against the shoulder of the arbor and the surfaces of the milling cutter. This tightening effect is particularly important. The last ring is knurled and has

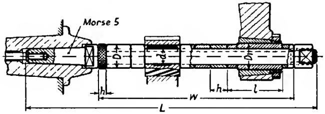


Fig 79 Milling Arbor with Distance Rings

a big internal radius or chamfer to clear the fillet of the arbor against the shoulder. It is a task for the future to standardize the diameters D, d, and D_1 and the heights (h) of the rings corresponding to the lengths w and L The diameter of the bronze bushing (D_1) should be as big as possible to allow the arbor to pass, instead of supporting the arbor by a small pivot at the outer end behind the nut, the latter is still frequently used.

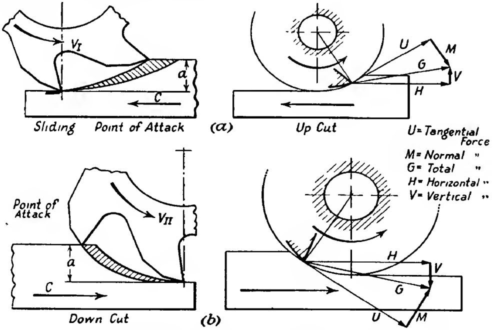


Fig 80 Characteristic Features of (a) Up-milling; (b) Down-milling

Characteristic Form of Milling Chip. Because of the limited period of engagement of each tooth with the work-piece, the removal of metal in milling is accomplished by the separation of small individual chips. The rotary motion of the cutter

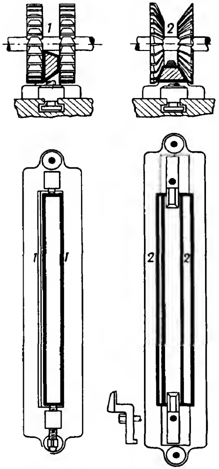


FIG 81 TWO TYPICAL EXAMPLES WHERE DOWN-MILLING IS ADVISABLE
No centre-support for Slender Gibs 20 in long

and the translatory motion of the work-piece combine to produce a chip whose cross-section varies from instant to instant as the direction of motion of a tooth changes with respect to direction of motion of the work-piece Chip thickness is a maximum at the instant that these motions are perpendicular to each other, and substantially zero when they are parallel.

Surface Generated in Milling. In peripheral milling, two distinct methods are used (Fig. 80).

UP-MILLING. The work-pieces advance toward the cutter from the side where the teeth are moving upward. The cutter rotates against the direction of the feed. The chip thickness is a minimum at the beginning of the cut and a maximum at the end (Fig. 80 (*a*)).

DOWN-MILLING. The work-piece advances toward the cutter from the side where the teeth are moving downward The cutter rotates in the

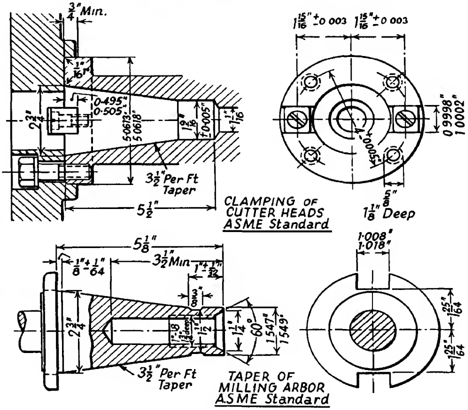


FIG 82 STANDARDIZED TYPE OF SPINDLE NOSE
(A S M E Standard and B S I Specification N 739)

same direction as the feed. The chip thickness is a maximum at the beginning of the cut, and a minimum at the end (Fig 80 (*b*)). Down-milling requires a special driving gear for the table eliminating backlash.

Chip Formation. Up-milling and down-milling produce surfaces of different character, the reason lying in the process of chip formation.

In up-milling, the portion of the finished surface which is produced by a tooth is formed at the beginning of its contact with the work-piece, when the chip thickness is small Hence, the built-up edge itself is small, and the resultant surface is generally smooth, if the machine is rigid.

In down-milling, an element of the finished surface is produced at the end of the tooth engagement with the work. With a ductile material such as a low-carbon steel, where the built-up edge is large, the latter persists to the extreme end of the chip, the escape of fragments likewise persists, and sometimes produces a torn finish.

It depends on the shape of the work-piece and the kind of clamping, which method is best used (Fig. 81). The great majority of existing machines are designed for up-milling.

The drive of the milling arbor and its fastening in the main spindle are greatly improved in the American Standard (A S.M.E) type of spindle nose (Fig 82), accepted by the B S.I. Specification No 739–1937. The three fundamental requirements of milling arbors are well separated. They are (1) centring, (2) clamping, and (3) driving. Centring is done by the short rear cylinder and by the steep taper, which does not seize. Clamping is done by an internal rod and thread, and driving is effected by two dogs situated at the largest diameter of the flange (pure torque) It is unfortunate that this marked improvement of the cutter drive is restricted to the cylindrical parts within the spindle nose, and does not include the exterior cylindrical part of the arbor, its diameter and especially the driving

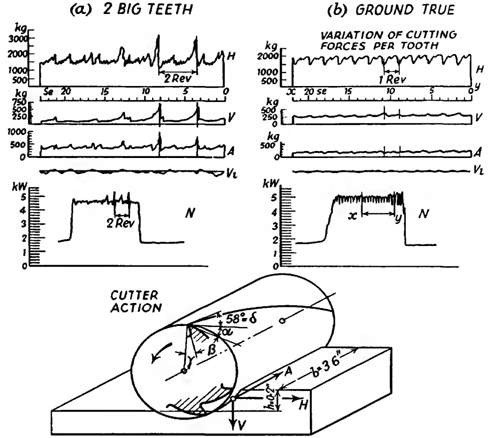


FIG 83 FORCES ACTING AT THE TOOTH OF THE MILLING CUTTER

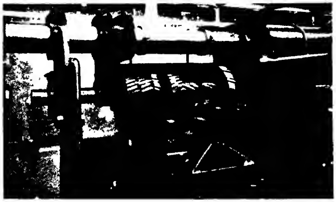
H = Horizontal Force V = Vertical Force A = Axial Force V_t = Vibrogram

(a) Graph of Two "Big" Cutter Teeth (b) Graph of Cutter "Ground True"

(Tests made with special Three-component Dynamometer and Vibrograph) method for the cutter itself. The transfer of the torque to the milling cutter is still as unsatisfactory as it was at the time of the invention of the milling machine (1878), due to the small diameter of the arbor weakened by a single key groove The load-carrying part of the milling arbor still remains weak, and it is this weak part which determines the work done by the machine, both regarding quantity of chips and quality of surface If a strong milling machine is noisy and refuses to perform a reasonable deep and wide cut with a well-ground cutter, it is always the fault of the weak milling arbor

The drive to the cylindrical cutter is effected either by one standardized axial key or by two radial driving dogs (See Fig 77) The cutter arbor, which is often quite long, is supported by the overhanging arm of the machine Three forces act upon the cutter during the milling process (Fig 83) in three mutually perpendicular directions—horizontal H, vertical V, and axial A Other factors, which must be noted, are width and depth of cut, circumferential speed of cutter, angle of helix, number of teeth, the kind of material being machined, and particulars of any coolant or lubricant (see Table XXII) used In Fig 83 is shown the positive angle of rake (γ), which is the angle between the radius of the cutter and the breast of the tooth The four diagrams H, V, A, Vi show the relation between power and depth of cut, power, and feed of table, vibration (Vi), and also the influence of speed and of the use of coolant, in this case emulsion From Fig 84 it is clear that the forces involved may be very great (3 to 5 tons). Both examples refer to gangs of eight cutters (with inserted blades up to 8 in. diameter on the same arbor of $1\frac{1}{2}$ in diameter, all cutting at the same time, but with small feeds of about 2 in and $2\frac{3}{4}$ in /min. In spite of this low feed the gain both in time and interchangeability of components is extraordinary and quite sufficient to offset the cost of such expensive tools

Fig 85 shows the effect of the action of the milling cutter on the arbor itself for a given cutter, diameter 4 in , 8 teeth, 50° angle of helix,



Alfred Herbert, Coventry

FIG 84 GANG CUTTER FOR LATHE HEADSTOCK (LOWER HALF)

Material Cast-iron, Brinell Hardness 212 Spindle Speed 20 25 r p m Feed $2\frac{3}{4}$ in to $3\frac{1}{4}$ in per min Dia of Largest Cutter $12\frac{3}{4}$ in Depth of Cut $\frac{1}{4}$ in to $\frac{5}{8}$ in Total Width of Surface Machined $17\frac{3}{4}$ in

4 in wide, cutting at 33 r p m , 0·2 in. deep, on steel 35 tons/sq in. tensile strength. The diagrams show the influence of different angles of rake (γ) on the power consumed for different feeds C, and also the relation between feed and angle of rake A third diagram shows the relation of torque to feed under given cutting conditions. The two diagrams at the bottom of Fig 85 show the deflections caused by forces from 100 lb up to 4 tons on arbors having three different diameters, $1\frac{1}{8}$ in , $1\frac{9}{16}$ in , and $2\frac{3}{8}$ in , and two lengths, 10 in and 16 in From this information we conclude

TABLE XXX

INFLUENCE OF CUTTER DRIVE TO THE POWER-INPUT OF A MILLING MACHINE

Cutter	Material being Machined	Brinell Hardness	Cut Width in	Depth in	Feed in	Cutting Speed ft/min	Dia of Cutter in	Key	Teeth	Angle of Helix	Power h p	Ratio of Output	Dia of Arbor in	Length of Arbor in	Mean Pressure ton	Deflection Middle of Arbor in
a	Cast-iron	163	3	$\frac{3}{8}$	4 5	50	3	Axial	7	20	4	1 0	$1\frac{9}{16}$	20	1	0 00150
b		163	3	$\frac{3}{8}$	7 5	50	3	Across	8	25	4	1 65	$2\frac{3}{8}$	20	1	0 00033
b	VCN 35 (hard)	288	$2\frac{3}{8}$	$\frac{1}{8}$	3 5	50	3	Axial	8	25	3	1 0	$1\frac{9}{16}$	20	1	0 00150
c	,, ,,	288	$2\frac{3}{8}$	$\frac{1}{8}$	6 6	50	3	Across	10	20	3	1 9	$2\frac{3}{8}$	20	1	0 00033

that it is desirable to have the largest diameter of arbor possible and the shortest length. This requires a large hole in the cutter, which in turn sometimes requires a larger diameter of cutter. It is well known that for economic milling the smallest diameter of cutter is most desirable, so eight to ten teeth, but the diameters of the arbors are $1\frac{9}{16}$ in. and $2\frac{3}{8}$ in. respectively, and the method of driving was changed from the axial drive with one key, which gives an eccentric torque and a single bending force, to the concentric double-sided drive (see Fig. 77), which eliminates single-

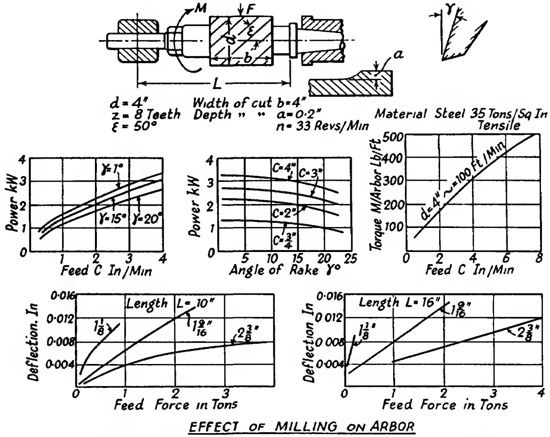


FIG 85 RELATION BETWEEN DIAMETER AND LENGTH OF ARBOR AND DEFLECTION

(1) Working arrangement and dimensions of cutter
(2) Relation of power to feed C if breast rake γ is variable
(3) Relation of power to γ if feed C is variable
(4) Relation of torque to feed if circumferential speed remains constant
Deflection of arbors for—
(5) Three different diameters—length of arbor 10 in
(6) Three different diameters—length of arbor 16 in

that we are faced with the problem of deciding the optimum diameter of arbor to give sufficient rigidity and at the same time economic cutting. When these optimum values corresponding to various cutter diameters have been decided, standardization should follow.

The influence of the method of driving the cutter upon the rate of metal removal is shown in Table XXX. The cutters *a* and *b* differ from seven to eight teeth, and the cutters *b* and *c* from

bending forces. The gain in metal removal is clearly shown by the fact that with a 4-h.p. machine the feed on cast-iron was increased from $4\frac{1}{2}$ in./min to $7\frac{1}{2}$ in./min, which represents a 65 per cent increase, and with a 3-h.p. milling machine the feed on Ni-Cr steel was increased from 3·5 in. to 6·6 in./min, which represents a gain of 90 per cent. Thus it is clear that by replacing an incorrect cutter drive by a correct cutter drive the output is almost doubled.

Furthermore, the surfaces obtained with correct cutter drives are much smoother than those obtained with incorrect cutter drives. This improvement is largely due to the fact that with correct cutter drives the oscillating action of the cutter teeth by twisting and relieving the arbor is practically eliminated, and that the action of the drive is located at a greater radius, so that chatter is reduced and the cutting action is smooth and practically vibrationless.

A flywheel on a spindle head can be considered as only smoothing out the spindle oscillations without influencing the pulsation of the weak arbor itself. The flywheel is therefore very effective for facing cutters on the spindle head correctly fastened and driven, but much less effective for slab-milling with a cutter on the middle of an arbor. Before the angles for milling cutters can be satisfactorily standardized, this problem of cutter drives must be solved and a uniform practice adopted. In Table XXXI six classes of material are given together with their clearance angles α and top-rake angles γ. In practice, the correct angles can be obtained in the case of built-up cutters only with inserted blades, when each blade can be treated as a single-point cutting tool (Fig. 86). In such cases top-rake, side-rake, and clearance can be adapted to suit the material being machined. In addition it is possible, if desired, to replace high-speed blades by cemented carbide-tipped blades, which permit a considerable increase in speed, which incidentally is accompanied by a decrease in cutting forces.

TABLE XXXI

SHAPE OF HIGH-SPEED STEEL CUTTERS WITH POSITIVE RAKE AND SPEEDS BETWEEN 40 TO 80 FT/MIN

Class No	Material	Clearance α	Top-rake Angle γ
1	Hard brass or bronze, hard cast-iron	6°	0°
2	Steel castings and steel above 50 tons/sq in, cast-iron, red brass, bronze brass	6°	8°
3	Steel castings and steel of 35–50 tons/sq in, soft brass	6°	12°
4	Steel castings and steel of 22–35 tons/sq in	6°	15°
5	Tough and soft bronze, very soft steel	6°	15–20°
6	White and light metals	6°	25–30°

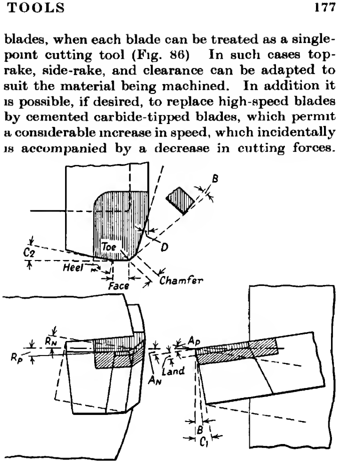


FIG 86 NOMENCLATURE OF MILLING CUTTER

B Relief (peripheral)
D Bevel
C_2 Clearance (heel)
R_N Radial rake (negative)
R_P Radial rake (positive)
A_N Axial rake (negative)
A_P Axial rake (positive)
B' Relief (face)
C_1 Clearance (face)

F W Lucht, A S M E, 1943

Naturally the motor of the machine must be strong enough to permit of the increase of speed. 50 h.p. for the drive and 5 h.p for the feed of ordinary milling machines form an attractive target for the next ten years.

We know that force × speed = power. This is valid for the milling machine, too, so that by doubling the speed we must decrease the force for the same size of motor to half its original value, but also diminish the deflection of the arbor and produce a very good smooth-milled surface. Great care must be taken to avoid vibration at high speed, and this involves accurate balancing and accurate location of every single groove and blade; the flywheel is no full remedy against an unbalanced cutter The required accuracy is, however, well within the economic limits of production, and yields its due reward in increased output

Fig. 87 shows graphs which combine power consumption with—

A. Depths (a) from $\frac{1}{16}$ in to $\frac{3}{4}$ in. with constant feed of 2 in /min

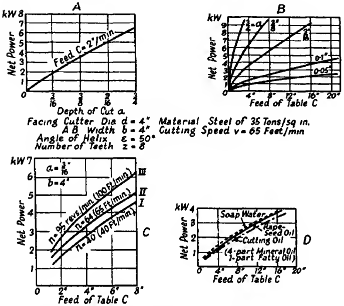


Fig 87 Forces Acting at the Tooth of the Milling Cutter, Relation Between Power and Depth and Power and Feed, and Power and Coolant

Data—

Cutter dia	d = 4 4 in	Depth of cut	a = 08 in
Revs /min	n = 94	Width	b = 4 in
Cutting speed	v = 105 ft /min	Material	Steel of 35 tons/sq in
Number of teeth	z = 12	Angle of helix	= 30°

A = Relation of power to depth of cut for constant feed
B = Relation of power to feed for various depth of cut
C = Relation of power to feed for various speeds
D = Relation of power to feed using various lubricants

B Feeds (c) up to 20 in /min and depths from 0·05 in. to $\frac{3}{4}$ in.

C. Feeds up to 8 in /min and three different speeds 40–65–100 f.p m., with constant depth of $a = \frac{3}{16}$ in. and width $b = 4$ in

D The influence of emulsion, rape-seed oil, and neat cutting oil.

Speeds and Feeds of Milling Cutters. Cutters are made of carbon-steel, high-speed steel, and such hard materials as stellite, or with cemented carbide tips. Carbon-steel, one of the oldest cutting-tool materials, is still used on many light milling operations High-speed steel serves for a great many medium- and heavy-duty jobs. Stellite is particularly good for medium- and heavy-duty work, especially of an interrupted nature and on cast material. Carbide-tipped cutters are used under similar conditions and are suitable for many high-speed jobs

The design as well as the material of the cutter influences the speed and feed Helical teeth have a shearing cut which allows them to cut more freely and with less chatter than straight teeth Also, the fewer teeth there are in contact with the work at any time, the less will be the pressure on the cutter, hence coarse-tooth cutters operate under less stress than fine-tooth cutters They have the added advantage of more space between teeth for chip removal

The nature of the cut is important, since heavy cuts must be run slower than light ones, and deep slots, in which heat accumulates rapidly, must be cut slower than shallow ones Roughing cuts are usually performed with slower speeds and heavier feeds than finishing cuts

The ordinary milling cutter, made of high-speed steel working with average speeds and feeds (see Table XXXII), generates a great deal of heat. This heat must be carried away or the work will be distorted and the tool edge ruined Therefore the work and tool should be flooded with some sort of cutting fluid or coolant This will also prevent undue friction, improve the finish, flush away the chips, prevent corrosion, and permit faster cutting speeds

Suggested coolants for various materials are given in the coolant Table (see page 152). The chief precautions needed in the use of cutting fluids concern cast-iron and magnesium Because of the abrasive action of wet cast-iron chips, this material is always milled dry As magnesium chips and water make an inflammable mixture, only straight cutting oils should be used in milling this metal.

The following precautions should be observed when using cemented carbide-tipped cutters—

1 Never disengage spindle while feed is engaged.

2. Always have the cutter rotating before feeding the work up to the cutter.

3 When using machines with rapid traverse make certain that the rapid traverse is out and the regular feed is in, before the work contacts the rotating cutter

4 When stopping the machine, first throw out the feed and then immediately disengage the spindle clutch.

5. Never allow the cutter to idle in the cut, as the rubbing of the cutting edges against the work has a lapping effect on the cutting edges which dulls the cutter

6 Keep the cutter rotating when returning the table to starting position after a roughing cut

7 After a finish cut, the work should be removed before returning the table

When face-milling on a universal knee-type of milling machine, the table must be set at zero position The table should travel normal to the centre line of the cutter spindle, or be set to travel slightly past at an angle equivalent to 0·002 in to 18 in (1 9000), so that the trailing portion of the cutter will not spoil the work by making criss-cross marks When face-milling on a plain-type milling machine of either the horizontal knee or the vertical type, the angular relation of the milling-machine spindle to the direction of table travel is such that the trailing portion of a cutter which is properly ground will not spoil the finish on the work This also applies to the manufacturing and planer-type of milling machine

The ideal type of cemented carbide cutter set-up is one where either the cutter is automatically moved to clear the work or the work moved to clear the cutter on the return stroke

Chip Removal All cutters must be designed to give the chips unrestricted flow from the cut, otherwise they will develop added heat and become troublesome This may become a real problem and should be given careful consideration when deciding upon the proper number of teeth in the cutter Always provide ample chip space

If proper consideration has been given to chip space, and the chips are inclined to "build-up" or stick to the cutting edge, there is always a danger that they will ruin the cutting edge when they hit the work again. It is suggested that a strong air-blast be directed against the cut, to remove the chips as they form Chips have been removed from face-mill cuts by directing an air-blast through the machine spindle and the centre of the cutter at pressure as high as 150 lb/sq in.

The flying chips which result from the high-speed milling of steel with cemented carbide-tipped cutters can become a danger to the operators in the vicinity of the milling machine where the work is being done These can be easily controlled if simple chip guards are installed on the machine in question.

Cutter Grinding The surface condition of any machined surface depends to a large extent upon the accuracy with which the cutting tool for machining the work has been ground. For this reason, it is essential that the proper technique both for grinding cemented carbide-tipped cutters and solid high-speed steel cutters is followed if the maximum results are to be obtained The relief, clearance, and concave angles should be ground to clear specifications, for all details

Use 60- to 80-grit silicon-carbide wheels for rough-grinding both the carbide and steel Use 180- to 220-grit diamond wheels to finish-grind the carbide tip only, to produce a smooth and keen cutting edge

All multi-tooth cutters should be ground on a tool- and cutter-grinder which is equipped with a suitable rigid fixture The grinding machine must be kept in first-class condition with a free but close running spindle, tight gibs, and straight and true ways Either the cup-wheel or straight-wheel method of grinding is satisfactory

Cutter run-out should always be checked before using any multi-tooth cutter. For best results it should be kept within the value shown in Table XXXII. When inspecting run-out on outside diameter no consecutive tooth should have a variation greater than one-half of the total run-out

According to this Table a good cutter or gang of cutters mounted on the arbor of the machine ought not to be more than 0·001 in = 0·025 mm out of round for 8 in diameter; this eccentricity should be distributed to all teeth. The surfaces produced are rough and torn if, for example, two teeth are "thick," having a run-out of 0·003 in. as shown in Fig. 83

TABLE XXXII

CUTTER RUN-OUT FOR MULTI-TOOTH CUTTERS

Cutter Diameter in.	Permissible Run-out			
	Roughing Cuts		Finishing Cuts	
	Face in.	O D. and Chamfer in	Face in	O D. and Chamfer in
Up to 12	0 001	0 002	0 0005	0 0015
12 to 16	0 0015	0 003	0 00075	0 002
Over 16	0 002	0 004	0 001	0 0025

The permissible working accuracy of flatness of good surfaces is 0·015 mm per 300 mm = 0·0006 in./ft. Oscillographic investigation of milling cutters before and after re-grinding (Fig. 83) proved that the cutter supplied had two "big" teeth which could be rectified by re-grinding (right). After re-grinding all teeth to less than 0·001 in. eccentricity on the arbor the surfaces became smooth, accurate, and free from chatter marks

The undulation per tooth which is very clearly shown in the oscillograms on the left has been rendered uniform in the graphs on the right.

The testing apparatus allowed for the simultaneous measurement of the forces: H = horizontal, V = vertical, A = axial, Vi = vibration of the table surface, P = total power.

Rules for Operators

Use the smallest cutter that will do the job. Time may be wasted in waiting for large cutters to run through the work.

Change cutters when they become dull. The finish may be spoiled, production time wasted, and the cutter damaged by running it dull.

Use arbors that are as short in length and as large in diameter as practicable. The more rigid the set-up the better.

Do not remove shell end mills or face mills from their arbors when they need grinding. It is impossible to remount them just as they were.

Direct the coolant to the point where the cutter enters the work, so that it will be carried by the teeth up to the cutting point.

There are indications, however, that the best cutter life is obtained when milling steel dry, because the chips are thin and the major portion of the heat flows into them until they seem to approach a plastic state. In this condition they seem to wear the cutting edge less than when they are chilled by a coolant.

Rigidity an Important Factor in Milling Operations. The fundamental idea to be kept in mind at all times when considering any milling operation is rigidity. This applies not only to the machine but also to the method of clamping the work.

THE MACHINE Machines should be used which are appropriate to the job and which are rigid enough to withstand all the forces and shocks incidental to the operation. The life and accuracy of the milling machine can be prolonged, the quality of the work can be improved, cost per finished piece can be lowered, and shut down periods of the machine reduced, if these suggestions are followed—

1 All backlash in the feed screw should always be kept at a minimum. Machines with reliable backlash eliminators should be used.

2. Table gibs should be adjusted to give the table a snug sliding fit

3. End-play in the machine spindle should be kept at an absolute minimum

4 Because of the higher speeds and increased feed rates used with cemented carbide-tipped cutters, lubrication should be checked to make certain that it is both adequate and properly applied.

5. Periodic machine inspections mean smooth, accurate, milled surfaces. Machine ways wear at their most commonly-used sections, thereby causing play at those parts only, leading to chatter on cuts longer than usual

6. The knee and saddle should be securely locked before starting a cut.

7. When the tapered hole in the machine spindle is used to centralize a milling cutter, it should be cleaned in order to ensure a uniform metal-to-metal fit for the full length of the shank.

FIXTURE FOR HOLDING WORK The general nature of the work and the proper clamping of it have a direct bearing on the success or failure of any milling operation. (See Fig. 84.) The increased feed rates which are now possible with cemented carbide-tipped cutters reduce the cutting time to such an extent that the time occupied by loading and unloading assumes a major importance. In other words the material handling time becomes more of a problem than the milling time. The only way to correct this situation is to use fixtures with very heavy wall sections and to actuate them rapidly by either air or oil pressure. The best arrangement is to use an automatic-cycle type of milling machine which has a fixture or fixtures which can be unloaded and loaded by the operator during actual cutting time (See Figs 128 and 129.)

*Negative Rake Milling.** Milling is a process involving an interrupted cutting action. The application of cemented carbide-tipped blades to this class of work was formerly very limited because the shock of the blade against the surface of the piece of metal to be machined, unavoidable with an interrupted milling action, very quickly destroyed the cutting edges of tools with normal positive rakes when using the average fairly high cutting speeds.

Recent development in the design of milling cutters using negative rakes both for radial and axial cutting angles, instead of the conventional types employing angles of positive rake, open up ways of considerable advance Furthermore, harder grades of carbide have been developed to decrease cratering on the cutting face and wear on the tool clearance face

Fig 88 (*a*) and (*b*) compare positive and negative radial and axial rake angles. For the ordinary cutting speeds up to 350 f.p m the cutting forces (*F*) for all tools with positive rake angles are considerably smaller (real cutting action) than with negative rake angles (sweeping action), but cemented carbides are brittle, and the stress and strain on carbide tips with positive rakes tend to wear, crater, and finally chip the delicate sharp cutting edges By changing their form to negative rake, their resistance to impact is enormously strengthened To diminish the rising

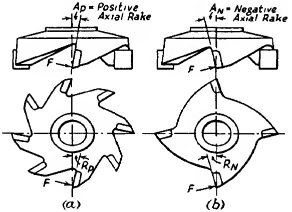


FIG 88

(*a*) A_P = Positive Axial Rake (*b*) A_N = Negative Axial Rake
R_P = Positive Radial Rake R_N = Negative Radial Rake
F = Cutting Force

power consumption caused by the new shape, the peripheral speed must be increased to such an extent that the inertia of the tool hitting the surface of the part overcomes the resistance of the material so quickly that the chip is made red-hot in split seconds, loses its cold resistance, is transformed to a plastic state, and is removed instantaneously from the part to be cut and from the surface of the tool

As investigations into the heat balance of ordinary metal-cutting have shown that more than 90–95 per cent of the heat is carried away with the chips, while the remainder is distributed between tool and work-piece, it is important to remove the hot chips at once and not to risk re-hardening them by coolants The higher the speed and the greater the sweeping action of the few teeth actually engaged on intermittent cutting at any one time (4 to 10 depending on the diameter) the more

* For further information on negative rake milling, the reader is referred to: "High-speed Milling with Negative Rake Angles," by Hans Ernst, *Mechanical Engineering*, May, 1944 "Cemented Carbide-tipped Milling Cutters," by Fred W Lucht, *Mechanical Engineering*, June, 1945 "Radial Rake Angles in Face Milling," by J B Armitage and A O. Schmidt, *Mechanical Engineering*, June, July, August, 1945 "An Analysis of the Milling Process," by M E Martelotti, *Mechanical Engineering*, Dec, 1940, and May, 1945 "Carbide Milling of Steel," by A W Meyer and F R Archibald, *Mechanical Engineering*, Oct, 1945 "Determining Tool Forces in High-speed Milling by Thermoanalysis," by A O Schmidt, *Mechanical Engineering*, July, 1944 "Grinding of Cemented Carbide Milling Cutters," by Hans Ernst and Max Kronenberg, *Mechanical Engineering*, April, 1937. "An Introduction to High-speed Milling," by Paul Duboselard, *Mechanical Engineering*, Dec, 1943 "Milling Cast-iron with Carbides," by Michael Field and W E Bullock, *Mechanical Engineering*, Oct, 1945 "Negative Rake Milling," by H Eckersley (A. C. Wickman), *Journal of the Institution of Production Engineers*, Nov, 1945

favourable is the use of cemented carbide tips. Because the shape of the negative blade counteracts the tendency to form a built-up edge, the cutting edge itself is always clean and therefore giving its most efficient service.

Tests were carried out as far back as 1928 (Fig. 89) with single-point cemented carbide-

FIG. 89. SINGLE-POINT LATHE TOOL WITH NEGATIVE BACK-RAKE (*Widia*, 1928)

tipped tools for lathes, using a suitable combination of positive and negative cutting angles.* The tool had a negative back-rake angle of —15° and a positive side-rake angle +5° turning steel of 45 to 50 tons/sq in. tensile strength, Brinell 190. The cross-section of chip was 0·16 × 0·04 sq in. (4 × 1 mm²), the cutting speed about 350 f.p.m., the—

Tangential force = 1850 lb
Shank force = 750 lb
Feed force = 320 lb
Machining index = 290 lb/0·001 sq in.
Power consumed = 25 h.p.

The life of the tool was only 38·3 min.

A reduction of speed to 200 f.p.m. increased the tool life to more than two hours.

Milling machines need the following conditions to be satisfied if they are to produce vibration-free work, thus increasing the tool-life and producing smooth surfaces, with negative rake tools—

(1) A powerful machine.

(2) A rigid machine.

(3) A heavy cutter body acting as a flywheel or the provision of an external flywheel.

(4) Well-supported work-pieces.

(5) Robust clamping devices.

(6) Heavy feeds per tooth, between 0·008 in. to 0·020 in.

The planning department should easily be able to decide from the cutting conditions which of the existing milling machines is suitable for the job.

The speeds for negative rakes must be very high to get an acceptable result. The power consumption is therefore increased, even if only one tooth (fly-cutter) is cutting, and it is doubled when two are working as is preferable for keeping the main spindle in balance. The bearings should be well adjusted radially, and the axial slip ought to be a minimum.

Kearney and Trecker, Milwawkee, recommend a combination of a negative primary radial rake of — 12° with a + 15° or + 30° positive secondary radial rake for speeds up to 1200 f.p.m. so as to reduce power consumption.

Recommended cutting speeds for face-milling with cemented carbide-tipped cutters of negative rake are given in Table XXXIII.

TABLE XXXIII

Material	Tensile Strength tons/sq in	Cutting Speed (Roughing) ft/min	Feed per Tooth and Rev in
Mild steel	30	800	0·008
Mild steel	35	750	to
Semi-hard steel	40	700	0·020
Hard steel	50	550	0·002
,, ,,	60	500	to
,, ,,	70	400	0·015
Grey cast-iron	15 to 20	250	
Dense cast-iron	20 to 30	200	

For the same maximum speeds of 530, 1400, and 1500 f.p.m., and the same cutting forces of 380, 210, 150 lb, both positive and negative rake naturally require the same power, i.e. 9·2, 12·2,

* "German Practice with Tungsten Carbide Tools (Widia 1928)," G. Schlesinger, *American Machinist*, August, 1929, p. 37. *Zerspanung und Werkstoff* (Machining Material), E. Broedner, 1934, VDI—Publishers, Berlin, p. 131-133. *Negative Rake Cutting* (3rd Edition), Booklet by Alfred Herbert, Coventry, 1948

and 10·2 h.p. As all research engineers confirm that the tool life of the milling cutter with negative rake is much longer than that with positive rake, and that the surface finish is at the same time superior, the future development of *face* milling with hard cemented carbide-tipped blades will probably be in the use of negative rakes. However, a quick and satisfactory solution of the problem must depend solely on the initiative of the machine-tool builders

clamping in use. The design of many present-day milling machines is not yet adapted to the extraordinary increase of cutting speed possible, and therefore of power required, by negative-rake cutters nor to the changed effect of the cutting forces on the main spindle and its bearings.

H. Ernst of Cincinnati Milling Machine Co. gave some elucidating graphs which compared the power and forces of positive and negative rakes under the same working conditions The graphs

TABLE XXXIV

(derived from H Ernst's Tests)

Diagram No.	Feed in./tooth	Speed		Forces		Power	
		Positive Rake ft/min	Negative Rake ft/min	Positive Rake lb	Negative Rake lb	Positive Rake h p	Negative Rake h p
a	0 0036	min 100 max 530	220 530	380 380	450 380	1 6 9 2	5 3 9 2
b	0 0018	min 220 max 1400	480 1400	210 210	260 210	1 9 12 2	5 5 12 2
c	0 0011	min 360 max 1500	460 1500	120 110	170 150	1 9 10 2	3 4 10 2

Eckersley recommends a main-drive motor of 50 h.p. and a feed and rapid traverse motor of 5 h p. for a satisfactory milling machine, suitable for milling ferrous metals He gives as an example the milling of S.A.E. 4640 forgings on an existing Kearney and Trecker machine, diameter of cutter 8 in., 10 teeth, cutting 0·15 in. depth, 5·5 in width, feed 29·25 in./min, speed 429 ft/min, 0·0142 in. chip-load/tooth. The piece was 52 in. long, the cutter performed 13 passes. The machine consumed 28·94 h.p. and made 42·9 cu in. of metal per pass, removed 558 cu in. in total, and had a specific output of 0·85 cu in./h p./min.

As this method of working is now in the course of development it is not possible to give fixed rates, either for the best cutting speed or the permissible maximum feed per tooth. The best combination depends largely upon (1) the rigidity and power of the machine tool; (2) the shape and material of the piece to be milled, and (3) the kind of

confirm that the cutting speed between 100 and 1500 f p.m has no influence on the cutting force with positive rakes, whereas this force decreases considerably for negative rakes.

Table XXXIV compares speed, forces for positive and negative rakes, and power consumption, for three feeds per tooth, using a single tool, but not taking the tool life into consideration. With increasing speed the cutting force for negative rake is relatively decreased, while that for positive rake remains about the same, but decreasing also for very high speeds.

For the future the production engineer should follow these rules—

1. Do not tool up all milling machines at once with carbides

2. Change from positive to negative rake angles only if the machine has·

(*a*) a wide speed range of at least twelve steps; e g. for ferrous metals from 34 to 1200 r.p.m., for non-ferrous metals from 235 to 3000 r.p.m. (speed figures should be "preferred numbers"),

(*b*) a fine feed range of about twelve steps from 1 in. to 40 in. for ferrous and 4 in to 160 in. for non-ferrous metals, or feeds of from 0·002 in. to 0·080 in. per tooth.

3. Use only very rigid machines with a strong motor of at least 12 h.p. up to 50 h p.

4. Train the grinding-room personnel in the proper technique of grinding carbides, according to exact schedules for negative and/or positive rakes More cutters will have to be ground per day, because the rate of production is so much faster than that of high-speed cutters.

The fulfilment of this programme for the ordinary milling department might require years; it means replacing about 90 per cent of the existing milling machines and cutters.

Abrasives

The Grinding Process

Dimensional accuracy and high surface finish are produced in the great majority of cases on external, internal, and surface grinding machines If the pieces are of hardened steel or chilled or flame hardened cast-iron there is no other way of machining them, but even for soft pieces the grinding machine surpasses all other finishing processes, not only for accuracy and finish but also for economy.

A most important point is the convenience of operation of the grinding machine. From the manual point of view its advantages are the automatic action as soon as depth, feed, and length are adjusted, and the high degree of automatic sizing and operation, so that all the operator has to do is to insert the work, to watch, and to remove it when finished. The factors which govern production are: the grinding wheel, its speed, grade, diameter and width, cross-feed, the table travel, speed of work-piece, the material removed, and the coolant.

(1) *Wheel Speed.* The average wheel speed is about 5000 ft/min for external grinding with a variation of between 4000 and 6000 ft/min, but on work of large diameter, which may be equal or even greater than the grinding wheel itself, lower speeds of 3000 to 4000 ft/min are advisable.

The highest wheel speed is used on external grinding of small diameters; lower speeds on large diameters, and lower still on surface grinding with a cylindrical wheel. For surface grinding with cup or segmental wheel and finally for internal grinding, the speed is still further decreased

Wheel speed is limited by danger of bursting, otherwise it depends on area of contact. All reliable suppliers of wheels test them with a considerably higher speed to eliminate the bursting danger, and some mark the test speed on the label

(2) *The Grade of Wheel* The grade depends upon the bond of the wheel and on the type of work for which it is needed It must be selected with regard to the work speed only Generally, soft grades are used for hard material and hard grades for soft material It is difficult to make useful recommendations unless the detailed working conditions are known. Modern grinding wheels, however, possess the property of covering a large range of work without necessitating a change of grades. Table XXXV (*A*) and (*B*) give a general guide, but if by practical use a grinding wheel has been found suitable for a particular work a careful record should be kept of grade and grit of the selected wheel as a guide for subsequent work of a similar nature

(3) *Cross-feed* The cross-feed to the grinding wheel should operate at each reversal of the table, that is at the end of each stroke, and not at one end of stroke only. This is necessary to distribute the work over the whole width of the grinding wheel. Using a traverse of about two-thirds of the width of the wheel per revolution of work, at about 50 to 70 ft/min surface speed, as much cross-speed should be given as the work, the grinding wheel, and the power drive will stand. Useful cross-feeds are from 0·0002 in to 0·0015 in. on the work diameter at each reversal of the table.

(4) *Table Travel.* The oscillating movement of either the rotating work-piece with the table or the rotating abrasive with its carriage is directly

TABLE XXXV

SPEEDS OF WORK-PIECES AND WHEELS

(Example: Norton Specifications)

SPEEDS OF WORK-PIECES, EXTERNAL GRINDING

Material of Work-piece	Kind of Abrasive and Designation	Grain Size	Grade	Kind of Bond and Structure	Peripheral Speed of Work, f p m	
					Roughing	Finishing
Aluminium	Crystolon 37	46	J or K	Vitrified	60	70
Brass and soft bronze	Crystolon 37	36 or 46	K or L	Vit	60	70
Cast-iron	Crystolon 37	36 or 46	J or K	Vit	60	70
Alloy steels heat-treated	Alundum	46 or 50	L or M	Vit 5	75–80	70–75
Soft M steel, 0 2 0 5 C	Alundum	46 or 50	M or N	Vit 5BE	50–60	70–80
Hardened steel, 0 2–0 5 C	Alundum 38	50 or 60	K or L	Vit 5BE	75–80	65–75

(*A*) Wheel speeds 5000 to 6500 S F P M

SPEEDS OF WORK-PIECES, INTERNAL GRINDING

Material of Work-piece	Kind of Abrasive and Designation	Grain Size	Grade	Kind of Bond and Structure	Peripheral Speed of Work f p m
Aluminium	Crystolon 37	46 or 50	K	7	110–140
Brass and soft bronze	Crystolon 37	36 or 46	K or L	7	110–140
Cast-iron	Crystolon 37	36 or 46	J or K	7	110–140
Alloy steels heat-treated	Alundum	46 or 60	K or L	5BE	120–160
Soft M Steel, 0 2–0 5 C	Alundum	46 or 60	K, L, or M	5BE	100–150
Hardened steel, 0 2–0 5 C	Alundum 38	46 or 60	J or K	5BE	100–140

(*B*) Wheel speeds vary from 2000 to 5500 S F P M

connected with the width of the grinding wheel. The modern trend is to use wide wheels with a width of approximately one-tenth to one-eighth of the diameter The traverse per revolution of work ought to be at least one-half and preferably two-thirds of the width of the wheel. This has a direct influence on the output and the table travel must maintain this ratio on wide wheels. If the traverse per revolution of the work is more than half of the width of the wheel, then the wheel will preserve a flat face Modern grinding machines are built with table speeds of 16 ft/min and over, in combination with wide grinding wheels

The main factor leading to increased production on external cylindrical grinders is the combination of wide wheels with fast table speeds, because the machine which possesses these advantages is the most efficient tool.

Fig. 90 shows, by way of example, graphs for steel and cast-iron ground on a heavy machine with 32-h.p. input, for different speeds, cross-feeds up to 0·0056 in. and work travel.

An examination of the three graphs in Fig. 90 shows: (1) F = cutting force in lb, (2) P (gross) = total horse-power of machine, (3) P (net) = horse-power for the cutting action only, (4) S = volume of iron swarf in cu in. per hour, (5) W = wear of abrasive wheel in cu in. (emery). All wheels were of 20 in. dia. × 2 in. width.

The relation $S : W$ gives the cutting efficiency of the grinding wheel measured in pounds of swarf per pound of emery. Fig. 90 shows these that for 1 lb of emery 20 lb swarf were produced. This is a good result.

Fig. 90 (*b*) shows another very good wheel acting on steel of 35 to 40 tons/sq in., 0·3 to 0·35 per cent C, constant speed of 6500 ft/min, constant cross-travel 0·68 in per rev. Maximum results for 0·0056 in depth, force F = 68 lb; P gross = 18 h.p., P net = 13 h.p.; swarf S = 100 cu in.; wear of wheel W = 28 cu in. Relation of S W = 100 28 = 3·6 lb swarf per 1 lb emery

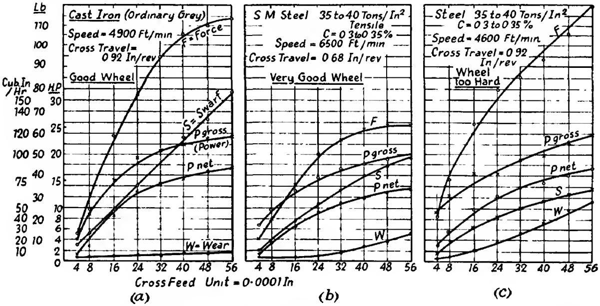


FIG 90. INVESTIGATION OF THE ACTION OF GRINDING WHEELS ON (*a*) CAST IRON, (*b*) AND (*c*) STEEL OF 35 TO 40 TONS P S I

F = Cutting Force P_{gross}, P_{net} = Power Consumption S = Swarf W = Wear of Abrasive

five characteristic measurements for ordinary cast-iron and mild steel ground with vitrified emery wheels, using a ceramic bond well selected for the purpose by the supplier himself who knew the working conditions well.

In Fig. 90 (*a*) the speed for all cross-sections of chip (constant travel × varying depth) was 4900 ft/min. The cross-travel of the table was also constant, at 0·92 in. per rev. The maximum force value was at 0·0056 in. depth (maximum), F = 123 lb; the gross horse-power P gross = 23 h.p.; the net horse-power P net = 17·5 h.p.; the volume of swarf (iron) S = 158 cu in.; the wear of the emery wheel (disintegration) W = 8 cu in.; so

Fig. 90 (*c*) shows the same steel material ground with a wheel that was too hard. The speed had to be reduced to 4600 ft but the cross-travel was increased to 0·9 in. per rev Compare the results with Fig. 90 (*a*), a good wheel for cast-iron with about the same speed and cross-travel; and with Fig. 90 (*b*) for steel with higher speed and smaller travel. The maximum values are: force F = 130 lb; power P gross = 24 h.p.; P net = 18 h.p., steel swarf S = 68 cu in., emery wear W = 56 cu in.; for 1 lb emery only 1·2 lb of swarf, which means a quick disintegration of the badly-selected emery wheel.

A depth of 0·0056 in. is far too much for ordinary use, but a comparison for the usual maximum of 0·0015 in. depth can easily be derived from the diagrams. The tests were made with a heavy cylindrical grinder driven by four separate motors so as to throw the heaviest possible stress on the wheel with the intention of disintegrating the wheel by big cross-feeds—

(1) A motor of 26 h p for the abrasive.
(2) A motor of 5 h p for the work-piece.
(3) A motor of 5 h p for the feed.
(4) A motor of 2 h p for the water pump,

i e a total of 38 h.p.

The pump could supply from 7 to 50 gal/min.

The worn emery wheel revolved even after the heaviest stress and wear

(5) *Speed of Work-piece.* It makes little difference to the finish obtained whether the speed of the work-piece is 30 or 60 ft/min, except that low speeds limit the table travel and consequently the output. For external cylindrical grinding an average surface speed of 60 ft/min can be recommended as a basis. Lower work-speeds, keeping the same table traverse, means a wider area of contact but reduced chip thickness. If for the same table traverse and constant in-feed the work-speed is increased, it means a narrower area of contact but a thicker chip. In both cases heat is generated, which must be distributed as quickly as possible, keeping the area of contact small and the chip thin by a correct combination of high work-speed and adequate table travel, aided by an ample supply of coolant. The limiting factors to a high work-speed are vibrations of the machine and chatter on the work which are detrimental to the abrasive and more difficult to control on heavy work than on light work The speed of work-piece must then be reduced

(6) *Material Removed* Table XXXVI gives the ordinary amount left on for external grinding of different diameters and length When work has to be finished in a soft state, coarse limits can be allowed for the preparation by fairly rough turning, leaving approximately 0·015 in. to 0·03 in. The grinding machine will remove the surplus metal quicker than the turning tool could.

The amount for internal grinding varies with the class of work, but is generally about 0·008 in. to 0·015 in. per diameter.

(7) *Coolant* Because the heat created by the grinding process is very high, an ample supply of coolant is necessary. An investigation of swarf proved that more than 90 per cent of the steel chips consist of iron-oxide (burnt steel). This corresponds to a temperature of about 1600° to 1800° C. generated in water. The grinding wheel is a remarkable tool Its manufacturing process, e g by vitrifying a ceramic bond with the emery or carborundum grit, produces a porous tool which is soaked with water. This coolant is centrifuged by the high speed of 5000 ft and permanently pressed against the grinding spot from within, and at the same time at least five to ten gallons of coolant per minute are flooded over the work-piece and the grinding wheel from outside. This forms an ideal cooling arrangement, which does not exist for any other machining method. The coolant is generally a watery emulsion, diluted from 1 to 50 for finishing and 1 to 80 for roughing cuts 1 to 80 is the limit to prevent rusting for machine and parts, 1 to 50 is sufficiently adherent to give a good surface without glazing the abrasive. The volume of lubricant for a wheel of 16 in. diameter × 2 in width should be between 5 to 10 gallons per minute, on larger wheels of 32 in. diameter × 3 in. to 4 in. width or more, 20 to 50 gallons should be used.

TABLE XXXVI

MATERIAL REMOVAL OF EXTERNAL CYLINDERS GRINDING INCH PER DIAMETER

Dia in	Length of Piece in								
	1	8	16	24	32	40	48	64	80
⅛	0 006	0 010	—	—		—	—	—	—
½	0 008	,,	0 020	—	—	—	—	—	—
1	0 010	0 015	,,	0 020	0 020	0 020	0 010	0 020	0 020
1½	0 010	,,	,,	—	,,	,,	,,	,,	,,
2	0 012	,,	,,	—	,,	,,	,,	,,	,,
3	0 015	0 020	,,	—	,,	,,	,,	,,	,,
4	0 020	,,	,,	0 025	0 025	0 025	0 025	0 025	0 025
5	,,	,,	0 025	,,	,,	,,	—	,,	,,
6	,,	,,	,,	,,	,,	,,	—	,,	,,
8	,,	0 020	,,	,,	,,	,,	—	,,	,,
10	,,	,,	,,	,,	,,	,,	—	,,	,,
12	0 020	,,	,,	,,	,,	,,	—	,,	,,

From 1 in. to 12 in. dia. × 16 in. to 80 in length an allowance of 0 020 in. to 0 025 in. is sufficient

(8) *Grinding Time* The output cannot be calculated for grinding operations on the usual basis of cutting speeds and feed, etc. The Churchill Machine Tool Co., Manchester, developed a method (Table XXXVII) to find external and internal grinding times, based on the fact that a grinding wheel has under normal working conditions a certain capacity for the removal of material according to the area ground. This takes into consideration the fact that the finish-grinding of a given diameter and length is an operation starting at zero, rising quickly to a point at which the maximum cutting capacity of the wheel is demanded, and then falling gradually to the finished size The time in which the final operations can be done depends on the fineness of the limits demanded for the finished diameter.

TABLE XXXVII

TABLE OF CONSTANTS (CHURCHILL MACHINE TOOL CO)

Minimum Diameter of Work in	Size of Wheel		Constant Factor C
	Diameter in.	Width in	
4·0	26	3	1·3
3·0	,,	,,	1·4
2·0	,,	,,	1·8
1·5	,,	,,	2·2
1·0	,,	,,	3·0
3·0	20	2	2·2
2·0	,,	,,	3·0
1·5	,,	,,	3·7
1·0	,,	,,	5·0
3·0	12	1	3·0
2·0	,,	,,	3·8
1·5	,,	,,	4·5
1·0	,,	,,	6·3

The formula is: Time $= C \times D \times L$, where $D =$ diameter of work in inches, $L =$ length in feet, $C =$ a constant factor found by experience. The grinding time is found in minutes for the removal of 0·03 in. $= \frac{1}{32}$ in. from the diameter and finishing to commercial limits.

For the removal of 0·015 in. $= \frac{1}{64}$ in. in diameter, allow two-thirds of the time obtained from the Table. For work below 1 in. diameter the grinding time tends to increase · extra time should also be allowed for special limits.

(9) *Selection of Grinding Wheels.** Decisive factors in the correct choice of an abrasive are: (1) the cutting power, (2) the tool life. The selection is always based on the kind of work to be done, its material, its dimensional accuracy, and its surface finish. The selection of grade and grain is based on the area of surface in contact between the wheel and the work to be ground. The greater the area of contact the softer or coarser must be the wheel The smaller or narrower the contact the harder and finer the wheels are required. In ordinary grinding practice and on the same material the hardest wheels are used for external cylindrical grinding (see graphs of Fig 90), a softer grade for plane surface grinding with a cylinder wheel, a still softer grade for internal grinding, and the softest grade of all for surface grinding with a cup wheel. All wheels should be dressed true with a diamond when truing the wheel some continental manufacturers use a much lower speed (not more than 1000 ft/min) than for grinding together with a very slow traverse, and using an ample supply of water, so as to save diamonds

The design of the grinding machine of whatever type or size should provide a big range of speeds for the work rotation and the table traverse, for the grinding wheel two speeds are generally sufficient, covering about 6000 ft/min for the full diameter of wheel when new and 3500 ft/min for the diameter of the wheel when worn down to its minimum. For the rotation of the work-piece modern machines often use the Ward-Leonard infinitely variable electric drive, whilst the traversing mechanism is often hydraulically driven Both can be varied independently of each other

The drawback of the Ward-Leonard drive is that four rotating mechanisms, i e driving motor, generator, exciter, and work-head motor all have to be carefully balanced as well as three commutators. The latest development therefore is to use A.C. commutator variable speed motors or other drives, such as mercury-arc or similar rectifiers,

* (1) *Facts about Grinding Wheels*, Norton Grinding Wheel Co, Ltd, Welwyn Garden City, Herts, England. (2) *Guide to Grinding-wheel Selection*, The Carborundum Co., Ltd., Trafford Park, Manchester

in conjunction with D.C. motors (electronic control).

(10) *Steadies.* It is fundamental that the design of the grinding machine and its workmanship should prevent vibration from any cause The work-pieces, whether they be large or small in diameter must, therefore, be supported by the intelligent use of as many steadies as possible Further, the abrasive wheel itself must, if possible, be dynamically balanced, therefore all modern machines provide adjustable balance weights in special balance collets of the wheel Static balancing of soaked wheels is difficult, since water tends to run to one side. The wheels are therefore frequently allowed to run the water off after initial truing and before final rebalancing

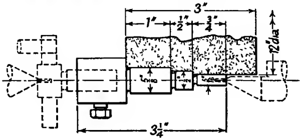


FIG. 91. PLUNGE CUT OF MAGNETO-SHAFT
Material Soft steel 0 2 per cent C Speed 40 s f p m
Average removal 0 012 in
Wheel Norton Alundum, K 38–46. Speed 6000 f p m.
Output 100 pieces in 43 min (two operators)

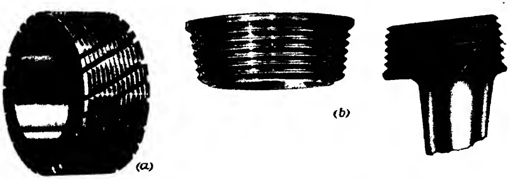
(11) *Kinds of Grinding* 1. External and internal cylindrical grinding. 2. Plunge cuts. 3 Thread grinding. 4. Centreless grinding. 5. Surface grinding.

1 For *external and internal grinding* the necessary data are already given.

2 *Plunge cut or form grinding* is distinct from the standard process of applying a cross-feed to the grinding wheel at each reversal of the table in that it leaves the table stationary and feeds the shaped wheel directly on to the work (Fig. 91). For this process the full width of a wide wheel is used, therefore additional horse-power is required proportional to the width of the wheel. Very careful wheel-truing is required and extra diamond tool cost is incurred. Plunge-cut grinding depends on an exceptional rigidity of the machine It is very quick and economic for big batches and mass-production work

CRUSH DRESSING* is the process of using hardened high-speed steel rolls to form or dress grinding wheels to a wide variety of shapes, which in turn can be transferred to the work-part with plunge cuts (Fig. 92 (*a*) and (*b*))

The same form that is to be crushed into the wheel is ground into a hardened-steel roll of approximately three inches in diameter by the use of a micro-form grinder. The profile is reproduced directly from a drawing. A pantograph positions a microscope to guide the operator in feeding the



The Sheffield Corporation, Dayton, Ohio

FIG. 92 CRUSHER TOOLS

(*a*) Gashed crusher roll (*b*) The crusher roll (*a*) is used in dressing a grinding wheel (1¼ in face) to grind the gas turbine blade root (right) Lead tolerance of grooves is + 0 0001 in to 0 000 in

* (1) "Crush Dressing of Grinding Wheels," by Carl J. Linxweiler, The Sheffield Corporation, Dayton, Ohio, *Steel*, March, 1945. (2) *The Multiple-ribbed Wheel Crusher*, Coventry Gauge & Tool Co , Ltd

grinding wheel into the steel roll to an accuracy of 0·0003 in.

Original crusher rolls for threaded parts are produced on a precision thread and form grinder by using a single-point wheel.

The wheels of surface grinders can be crushed-dressed, too (Fig. 92 (*b*)), the example shows a gas turbine blade root with 0·0001 in. tolerance.

The actual crushing operation is remarkable for its ease and simplicity. The roll is lowered until it makes contact with the grinding wheel, both roll and wheel thus far being at rest. The

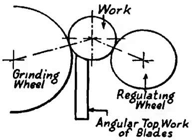


FIG. 93. PRINCIPLE OF CENTRELESS GRINDING

grinding wheel is then rotated slowly under a stream of oil coolant, while the crusher roll is gradually forced into the wheel to the full depth of the form. The pressure required is relatively light, because at this slow rotating speed the wheel acts like a friable object rather than like the hard, abrasive body which it becomes when run at high speed. At the most, this crushing operation requires only a few minutes.

It should be mentioned that only wheels with a vitrified bond can be crush-dressed. Grit selection depends, of course, upon the material to be ground and the finish required. Wheels of 120 and up to 220 grit are those most frequently used.

Crush dressing and diamond dressing are not competitive. Each method has its advantages in form-dressing grinding wheels, and rarely do the applications overlap.

3. *Thread grinding*. Threads can be ground into the solid after the stock is hardened, eliminating the ill-effects of distortion or surface decarburization from heat-treating. This is especially desirable in the case of tubes and other thin-walled components. Critical thread elements are accurately produced and held concentric with other ground diameters and threaded sections.

Threads can be ground most quickly by plunge grinding with a crush-dressed multi-ribbed wheel on the precision thread and form grinder, this is four to five times quicker than thread cutting on a lathe.

Plunge grinding of threads produces a full-threaded section equal to the width of a crush-dressed multi-ribbed wheel in one quick operation of less than two revolutions of the work (Fig. 92 (*a*) and (*b*)).

Plunge grinding takes much less time than required with thread hobbing, is more accurate, and tooling costs are considerably lower.

The wheel is fed to full depth in one-third to one-half revolution of the work, and only one additional revolution is required to complete the threaded part. Sections of threads up to 1¼ in in length can be quickly produced by plunge grinding.

Exceptional uniformity of thread angle, lead, and pitch diameter is commercially possible with the precision thread and form grinder, especially designed for plunge grinding Thick first and last threads are eliminated. Plunge grinding produces commercial work of high-class accuracy

4 *Centreless Grinding* is a method of precision grinding of a circular cross-section without the support of centres. Grinding action, and movement and support of work-piece, are performed with the aid of three contact points between the machine and the work, i e. the grinding wheel, the regulating or control wheel, and the support (Fig. 93). The grinding wheel on a centreless grinder revolves at about 5000 to 6000 ft/min, the speed of the control wheel can be varied between 50 to 200 ft/min. The through-feed travel is very quick, e.g up to 100 ft per hour of 1½-in. dia steel rod, round within 0·0005 in., straight within 0·001 in., which means that the accuracy of this almost automatic machine achieves the most accurate limits (grade B) of the B S.I specifications for cylinders.

5. *Surface Grinding* is being used to an increasing extent for the production of flat surfaces and surfaces with a linear direction, e.g. the slideways of lathes, milling, drilling, and grinding machines.

This process guarantees a greater accuracy of alignment of guiding surfaces and the elimination of hand scraping (Fig 94) Two principal methods of surface grinding are in use: (1) using the periphery of the grinding wheel with the wheel axis parallel with the work surface, (2) using the face of the cup wheel with the wheel axis vertical to the work surface or, better still, with using softer wheels. With a wheel of correct grade the wear of the wheels compared with the metal removed is very small for cup or segmental wheels, i.e. approximately 1 · 20 to 1 : 30 wheel wear against swarf. (See diagrams, Fig. 90.)

Under normal working conditions the actual wheel wear on all cylindrical grinding operations is considerably less than the reduction of the wheel

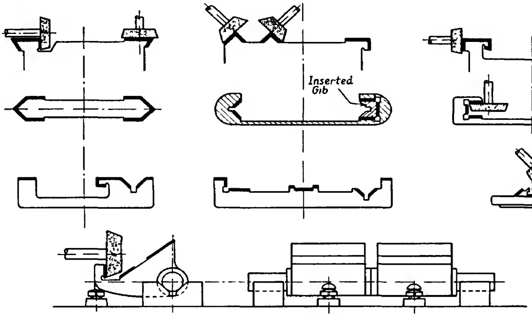


Fig. 94. Application of Surface Grinding to Slideways

a small inclination of 1 : 5000 to 1 . 10,000 to ensure free cutting and to avoid criss-cross appearance. The wheel speed for surface grinding is about 4000 ft/min down to 3500, generally surface grinders have only one speed. Cup wheels, which are used on vertical spindle machines, have, of course, a constant speed throughout their life

The work travels with the table and at the table speed. It is important that the distribution of heat generated by the grinding wheel should be ensured either by an ample supply of coolant, or, if this is not possible, by reducing the travel and diameter through dressing: whereas dressing is measured in thousandths of an inch, wear itself would be measured in ten-thousandths.

The economic results of a grinding machine depend on · (1) the cost of power, (2) the cost of the emery wheel as a tool, (3) the specific cost per cubic inch of swarf. Considering its output in chips, the grinding machine is one of the most economic machine tools. As to its power consumption, it is an expensive machine, but this item is not decisive in the economy of the grinding department. (See Table XI.)

CHAPTER X

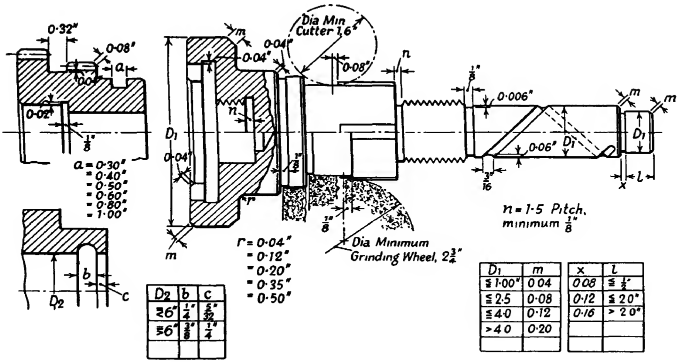
Effective Use of Machine Tools

THE most effective use of machine tools depends upon—

(1) Working accuracy.
(2) Cutting speeds
(3) Cutting forces.
(4) Power available

Working Accuracies

The degree of manufacturing accuracy required is marked on the drawing of each piece in the form of stipulated tolerances· this determines the kind and quality of machine on which the surfaces must be finished. The schematic drawing (Fig. 95 (*a*)) establishes the connexion between the drawing office and the workshop. The machine tools for grinding, milling, threading. gear cutting, etc., allow certain minimum lengths limited by the shoulders of the workpiece. The example shows, e.g that the minimum diameter of cutter is 1·6 in , the minimum diameter of a grinding wheel to rectify splines is 2¾ in. Besides internal grooves, external undercuts, chamfers, and roundings are marked so that all controversy between office and shop is eliminated. Machining to tolerances can only be done on accurate and well-maintained machine tools, capable of working to the limits prescribed by, for instance, the B.S. 164 Standards or of the American Standards Association or by the I S A. Standards, which are practically all in size and types identical



D2	b	c
≥6"	1/4"	5/32"
≤6"	3/8"	1/4"

D1	m	x	l
≤1·00"	0 04	0 08	≤ 1/2"
≤2·5	0·08	0·12	≤2 0"
≤4·0	0·12	0·16	>2 0"
>4 0	0·20		

FIG. 95

Standard instructions on "Testing Machine Tools" have, therefore, been adopted and applied to new machines of good quality, but they are also used to-day in many shops in reconditioning and rebuilding worn machine tools, and for maintenance.

The following thirteen tables (Table XXXVIII, 1–13) give the working accuracies of most types of commonly used high-grade machine tools, i.e. the permissible errors which are allowed in finishing parts on these machines—

1. Lathes up to 15½ in height of centres.
2. Lathes from over 15½ in. to 40 in
3. Toolroom lathes up to 8 in. centres.
4. Turret lathes, and single-spindle automatics up to 12 in. centres.
5. Double-standard vertical turning and boring mills up to 10 ft diameter
6. Cylindrical grinding machines
7. Vertical surface grinders.
8. Milling machines
9. Horizontal boring machines.
10. Planing machines.
11. Shaping machines.
12. Spur, worm and helical gear-hobbing machines
13. Radial drilling machines

The grade of working accuracy, besides depending on the machine itself, depends also upon factors, such as: (1) the type of cutting tool and its condition (cutting angles, hardness, eccentricity of milling cutters, true running of grinding wheel, and so on); (2) cutter arbors, (3) cutting speed, feed, and sectional area of chip; (4) material to be machined; (5) shape and rigidity of work-piece, (6) chucking or holding equipment, (7) certainty that undue vibration will not occur.

Foremen and inspectors should classify and group the existing machines in each department according to accuracy *

* *Testing Machine Tools*, by G Schlesinger, Machinery Publishing Co, Ltd, 4th Edition, 1945

TABLE XXXVIII (NOS. 1 TO 13)

WORKING ACCURACIES OF GOOD QUALITY MACHINE TOOLS

No. 1

Finish-turning Lathes up to 15½ in in Height of Centres	Permissible Error
Lathe turns round within	0 0004 in
Lathe turns cylindrically— (*a*) Work between centres within (*b*) Work held in chuck within For each 1000 mm (40 in), 0 01 mm (0 0004 in) addition up to 0 05 mm max (0 002 in)	 0 0008 in /ft 0 0008 in /8 in
Lathe faces (hollow or concave only) within	0 0008 in /ft
Thread cut on 50 mm (2 in) length	± 0 0008 in /2 in

No 2

Finish-turning Lathes with Height of Centres from over 15½ in to 40 in	Permissible Error
Lathe turns round within	0 0008 in
Lathe turns cylindrically— (*a*) Between centres within (*b*) Work held in chuck within	 0 0008 in /ft 0 0018 in /ft
Lathe faces (concave only) within	0 0008 in /ft dia
Thread cut on 50 mm (2 in) length Thread cut on 300 mm (12 in) length	± 0 0008 in /2 in ± 0 002 in /ft

No. 3

Toolroom Lathes (Highest Degree of Accuracy) up to 8 in Height of Centres	Permissible Error
Lathe turns round within . . .	0 0002 in.
Lathe turns cylindrically— (a) Work between centres within (b) Work held in chuck within . .	 0 0004 in /ft 0 0004 in./6 in. 0 0008 in /total length
Lathe faces (concave only) within . .	0 0006 in./ft dia
Thread cut on 50 mm (2 in) length . . .	+ 0 0004 in./2 in

Dimensions of Test Pieces, Gauges and Methods Applied to All Lathes

Tests to be Applied	Dimensions of Piece	Gauges and Methods
Lathe (a) Round turning (chucking) (b) Parallel turning (chucking)	Diameter = ½ centre height Length = centre height	Made on two bands of cylinder, each 1 in distant from both ends and 1 in wide Standard micrometers, 0 0001 in
(c) Parallel turning between centres	Diameter = ⅛ length Length from ½ to 1 distance between centres	Standard tools
(d) Facing	Diameter = ⅛ centre height Length about centre height	Standard tools (concave only)
(e) Screwing	Diameter = 1 in Length of thread = 2 in Length of thread = 12 in	Standard tools

No. 4

Turret Lathes and Single-spindle Automatic Turret Lathes up to 12 in Height of Centres	Permissible Error
Lathe turns round with turret-head slide within .	0 0004 in.
Ditto, with cutting-off slide within . .	0 0004 in
Lathe turns cylindrically with turret-head slide within (mandrel mounted in bar chuck)	0 0012 in /ft
Ditto, with cutting-off slide within	0 0012 in./ft
Lathe faces with turret-head slide (concave only)	0 0008 in /ft dia.
Ditto, with cutting-off slide (concave only)	0·0008 in /ft dia

No. 5

Double-standard Vertical Turning and Boring Mills	Permissible Error
Machine turns round up to 3 m (10 ft) dia within Over 10 ft dia within	0 0008 in 0 0012 in
Machine turns cylindrically on a length of 300 mm (about 12 in) within Machine turns cylindrically on a length of 1000 mm (about 40 in) within	0 0008 in 0 0012 in
Machine faces (concave only) on 300 mm dia (about 12 in) within Machine faces (concave only) on 1000 mm dia (about 40 in) within	0 0008 in 0 0012 in

N B The movement of the cross-rail should be upwards against the weight The tool-holders should be in the mean position

No 6

Cylindrical Grinding Machines	Permissible Error
Machine grinds round – Up to 80 mm dia ($3\frac{3}{16}$ in) From 80–200 mm dia ($3\frac{3}{16}$–8 in) Over 200 mm dia (8 in)	 0 00012 in 0 0002 in 0 0004 in
Machine grinds cylindrically without applying steady rests (convex only)— Shafts 1000 mm long, 80 mm in dia (about 40 × $3\frac{3}{16}$ in) Shafts 500 mm long, 50 mm in dia (about 20 × 2 in)	 0 0008 in 0 0004 in

Dimensions of Test Piece, Gauges and Methods

Tests to be Applied	Dimensions of Piece	Gauges and Methods
Grinding Machines (*a*) Machine grinds round (1) between centres (2) chucking	 Diameter 3 in $3\frac{1}{8}$–8 in long Over 8 in = centre distance long	Piece either between dead centres or in chuck For long pieces, three strips 2 in long at both ends and at centre Abrasive wheel well dressed, maximum permissible diameter Width 0 1 of diameter of wheel Speed 4000–5000 ft/min Feed half of width of wheel
(*b*) Machine grinds parallel between centres	1. Shafts 40 in long × 3 in dia 2. Shafts 20 in long × 2 in dia 3 Shafts 10 in long × 1 5 in dia	Piece turns round between dead centres without steadies Standard tools
(*c*) Fine in-feed—sensitive	—	Test against abrasive wheel-periphery or diameter of wheel spindle Clock records six repeated movements of the wheel or clock
(*d*) Quick approach (in-feed) to the work repeats accurately to grinding position	—	Ditto

No. 7

Vertical Surface Grinders	Permissible Error
Ground work plane parallel to within	0 0004 in./3 ft

No. 8

Milling Machines	Permissible Error
1 Horizontal and Universal milling machines, knee-type—	
Slab-milling finishing cut* surface is plane	0 001 in /ft
Facing by cutter head or end mill	0 0006 in /ft
For each 500 mm (20 in) more	0 0004 in
2. Surface-milling machine and plano-type milling machine	
Slab-milling finishing cut*	0 0008 in /ft
Facing by cutter head	0 0006 in /ft
3. Vertical milling machine—	
Facing-finishing cut*	0 0006 in /ft
Slab-milling	0 001 in /ft
For all types—	
(a) Facing the two parallel surfaces of a rigid block, deviation from parallelism	0 0008 in /ft
(b) Two surfaces at right angles	0 0012 in /ft
The eccentricity of the milling cutter when in position should not be more than	0 001 in.

* The work piece to be finished should be at least 3 in × 3 in × 16 in. For longer pieces, 4 in × 4 in × 30 in The clamping of the block should permit the test to be completed in one traverse

Dimensions of Test Pieces, Gauges, and Methods for Milling Machines

Tests to be Applied	Dimensions of Piece	Gauges and Methods
Milling Machine (a) Slab-milling finishing cut to mill the top and bottom faces of a block to a uniform thickness	Cast-iron (or mild steel) block of at least 3 in. × 3 in. × 16 in. long. For longer pieces, 4 in. × 4 in × 30 in	Take one finishing cut of approximately 0 004 in. deep over each surface. Micrometer or dial indicator test. The clamping of the block should permit the test to be completed in one traverse. The eccentricity of the milling cutter when in position should not be more than 0 001 in The cutter should be 3½ in. to 4½ in. wide
(b) Facing by cutter head or end mill-mounted on a short arbor in the spindle. Traversing longitudinally. Milling parallel strips one below and one overlapping the other	Cast-iron (or mild-steel) block 6 in × 6 in., shaped for clamping	Take three finishing cuts, 2 in. wide and 0 004 in. deep which overlap ⅜ in. Vertical movement of the knee by hand. Test with a straight-edge and clock

No. 9

Working Accuracy of Horizontal Boring Machines (Three Different Types)	Spindle up to 80 mm ($3\frac{3}{16}$ in.) Permissible Error	Spindle over 80 mm ($3\frac{3}{16}$ in.) Permissible Error	With Adjustable Column Permissible Error
The bores and outside diameters to be round	0·0006 in.	0·0008 in.	0·0008 in.
The bores to be cylindrical	0·0008 in./ft	0·0016 in./ft	0·0016 in./ft
In boring a hole halfway from one end and turning the revolving table through 180° to complete the hole, the bores to be concentric within .	0·0006 in.	0·0010 in.	0·0010 in.
Outside and inside diameters of test piece to be concentric within .	0·001 in.	0·0016 in.	0·0016 in.
Machined surface to be flat (concave only)	0·0006 in./ft	0·001 in./ft	0·001 in./ft
Milled surfaces on opposite sides of work to be parallel within	0·001 in./ft	0·001 in./ft	0·001 in./ft
Surfaces at right angles to be square within . .	0·0006 in./ft	0·0006 in./ft	0·0006 in./ft

No. 10

Planing Machines (Double-standard Machine)	Permissible Error
Test to be performed with a plane-parallel straight-edge representing a work-piece, if cutting tests are not possible, unclamped and free from stresses—	
Work is finished parallel	
On machines up to 6 ft in planing length within	0·0008 in.
On machines with planing length over 6 ft within	0·0004 in./3 ft

No. 11

Shaping Machines	Permissible Error
Finishing test-block: Maximum length of test-block = $\frac{2}{3}$rd of stroke of ram, 4 in.-5 in. wide. Material. Steel of 35–40 tons/sq in., or cast-iron of 12–15 tons/sq in.	
(1) Finishing top surface	
(2) Finishing bottom surface	
The finished surfaces are parallel with each other measured by micrometer with 0·002 mm (0·0001 in.) accuracy . .	0·0008 in./ft

No. 12

Spur, Worm, and Helical Gear-hobbing Machines	Permissible Error
For gears cut on the machine, the following accuracies measured from tooth to tooth are obtainable, in diameters—	
Up to 500 mm (20 in) .	0 0008 in
From 500–1000 mm (20–40 in)	0·0010 in
From 1000 mm and over (40 in)	0 0012 in.
Teeth are parallel to axis	0 0008 in /ft
Eccentricity after cutting up to 300 mm (12 in) dia	0 0006 in
Eccentricity after cutting over 300 mm (12 in) dia	0 0010 in
Shape of tooth up to 300 mm (12 in) dia.	0 0004 in.
Shape of tooth over 300 mm (12 in) dia	0 0006 in.

No. 13

Radial Drilling Machines	Permissible Error
Maximum permissible deflection of arm in the extreme position of saddle, when applying the maximum diameter of drill at the proposed feed, provided that the base-plate is grouted in and bolted to the foundation (arm in the highest position of the column)	Deflection by biggest drill 0 050 in /3 ft

The working tolerance specifications apply to finishing operations only A finishing cut on a lathe, for example, has been defined (I S A , Committee 39, Stockholm, 1937) as a chip of about 0·1 to 0·2 mm depth (0·004 in to 0·008 in) and 0·05 to 0·1 mm (0·002 in. to 0·004 in) feed taken with the highest permissible speed, depending on the material of tool and specimen

Cutting Speeds

The cutting speeds are fundamental for the efficient use of the different types of tools—

(*a*) Carbon cast-steel.
(*b*) High-speed steel.
(*c*) Cobalt-tungsten steel.
(*d*) Stellite.
(*e*) Cemented carbides.
(*f*) Diamonds.

For machining steels the speeds vary from 10 f.p.m. . (*a*) with carbon steel to 1500 f.p.m. with (*e*) cemented carbides with negative rakes and for non-ferrous metals up to 3000 f.p.m. with (*f*) diamonds, and even up to 5000 f.p m. for elektron.

It is therefore impossible to use the same machine for all kinds of materials and all types of tools.

The speed range of ordinary machine tools varies from 1 · 20 to 1 . 50 (e.g. 19 to 375 r.p.m. or 15 to 750 r p m) The range of 1 . 100, e g for high-class radial drills (from 15 to 1500 r p.m) is very rare, but it is necessary because these machines handle drills of small to large diameters, as well as reamers, taps, etc , on jig work for different ferrous and non-ferrous materials Diagram Fig. 96 shows the big variations of cutting forces when machining chrome-nickel steel (60 tons), S.M steel (35 tons), and cast-iron (12 tons) with the same chip area of, e g. 0·015 sq in on a lathe The stress varies from 2·8 tons to 0·8 tons vertical pressure (*D*).

The necessity for using economic speeds and pressures makes it imperative, therefore, that there be a reasonable distribution of work to different machines according to the nature of the material.

There must be at least a separation into ferrous and non-ferrous materials and the non-ferrous parts ought to be separated again according to the actual metal, e g copper, aluminium and magnesium alloys, etc. Obviously, every machine should be cleaned of swarf before a different material is machined, as copper chips would spoil precious nickel-chrome swarf and vice versa. The sale of swarf might not appear very important but it represents an average of 15 to 30 per cent of the gross weight of the machined pieces, with a money value of about 3 to 5 per cent of the total cost of material.

Magnesium alloys belong to a special group because of the inflammability of the chips.

If they are to be of any value at all to the ratefixer, it is essential that the plates affixed to the machine tools and giving their speed ranges should be strictly uniform for all machines of the same type, otherwise the ratefixer will need voluminous records giving the correct feeds and speeds for each individual machine. Ratefixing often remains purely theoretical when, for instance the only machine tool with the correct speed is already occupied or broken down and all others differ by as much as ± 15 per cent from the calculated speed. The time set on the wages-docket has then to be changed.

It is another sad fact that the speed figures on the plate are often nominal and not real, particularly in workshops with belt-driven machines, grouped according to available transmission lines and sometimes connected by incorrect pulleys. Even modern motorized machines differ widely between each other in range and value of speeds, though they may have been produced by the same machine-tool maker, though in different years.

Furthermore, it is regrettable that the speeds given on the plates are different for almost each machine, thus making the correct time setting of the ratefixer very difficult and sometimes impossible. There is an urgent need for the standardization of the numbers of revolutions of the various machine tools of at least the common groups, i.e. lathes, capstans, milling, drilling, grinding machines, shapers, and planers.

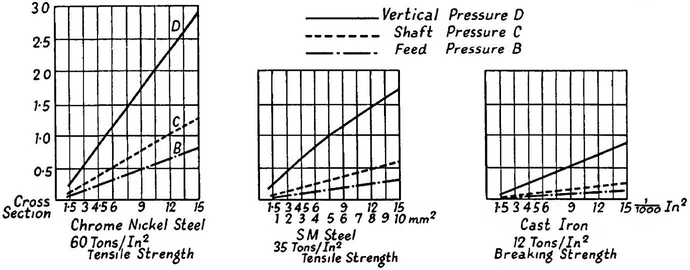


FIG 96 VARIATION OF CUTTING FORCES FOR DIFFERENT MATERIALS

The standardization of speeds by "preferred numbers" has already been accomplished on the Continent by the I S A, including Russia, Italy, France, Germany, Belgium, the Netherlands Scandinavia, Poland, Czechoslovakia, and Austria (Table XXXIX)

This standardization of speeds for machine tools has a greater effect in reducing costs of machining operations than any time studies, including studies of cutting times If the speeds vary ± 15 per cent for two neighbouring capstan lathes, the pre-set time of at least one of them is wrong and the confidence of the operator in the time set on the piece docket is lost even if the time is based on "time studies" Accurate rates cannot, of course, be set unless there are standardized working conditions from the beginning.

TABLE XXXIX

STANDARDIZATION OF SPEEDS (revs/min)

Series 1.06 (R40)	Series 1.12 (R20)	Ser 1.26 (R10)	Ser 1.58 (R5)	Ser 1.19 (∜2)	Ser 1.41 (√2)	Series 2 (2)
0.118	0.118	0.118	0.118			
0.125						
0.132	0.132			0.132	0.132	
0.140						
0.150	0.150	0.160				
0.160				0.16		
0.170	0.17					
0.180						
0.190	0.18	0.19	0.19	0.19	0.19	0.19
0.200						
0.212	0.212					
0.224				0.224		
0.236	0.236	0.236				
0.250						
0.265	0.265			0.265	0.265	
0.280						
0.300	0.30	0.30	0.30			
0.315				0.315		
0.335	0.335					
0.355						
0.375	0.375	0.375		0.375	0.375	0.375
0.400						
0.425	0.425					
0.450				0.45		
0.475	0.475	0.475	0.475			
0.500						
0.530	0.53			0.53	0.53	
0.560						
0.600	0.60	0.60				
0.630				0.63		
0.670	0.67					
0.710						
0.750	0.75	0.76	0.75	0.75	0.75	0.75
0.800						
0.850	0.85					
0.900				0.90		
0.950	0.85	0.95				
1.000						
1.060	1.06			1.06	1.06	
1.120						

Ser 1.06 (R40)	Ser 1.12 (R20)	Ser 1.26 (R10)	Ser 1.58 (R5)	Ser 1.19 (∜2)	Ser 1.41 (√2)	Series 2 (2)
1.18	1.18	1.18	1.18			
1.25				1.25		
1.32	1.32					
1.40						
1.50	1.50	1.50		1.50	1.50	1.50
1.60						
1.70	1.7					
1.80				1.8		
1.90	1.9	1.8	1.9			
2.00						
2.12	2.12			2.12	2.12	
2.24						
2.36	2.36	2.36				
2.50				2.5		
2.65	2.65					
2.80						
3.00	3.0	3.0	3.0	3.0	3.0	3.0
3.15						
3.35	3.35					
3.55				3.55		
3.75	3.75	3.75				
4.00						
4.25	4.25			4.25	4.25	
4.50						
4.75	4.75	4.75	4.75			
5.00				5.0		
5.30	5.3					
5.60						
6.00	6.0	6.0		6.0	6.0	6.0
6.30						
6.70	6.7					
7.10				7.1		
7.50	7.5	7.5	7.5			
8.00						
8.50	8.6			8.5	8.5	
9.00						
9.50	9.5	9.6				
10.00				10.0		
10.60	10.6					
11.20						

Ser 1.06 (R40)	Ser 1.12 (R20)	Ser 1.26 (R10)	Ser 1.58 (R5)	Ser 1.19 (∜2)	Ser 1.41 (√2)	Series 2 (2)
11.8	11.8	11.8	11.8	11.8	11.8	11.8
12.5						
13.2	13.2					
14.0				14.0		
15.0	15.0	15.0				
16.0						
17.0	17			17	17	
18.0						
19.0	19	19	19			
20.0				20		
21.2	21.2					
22.4						
23.6	23.6	23.6		23.6	23.8	23.8
25.0						
26.5	26.5					
28.0				28		
30.0	30	30	30			
31.5						
33.5	33.5			33.5	33.5	
35.5						
37.6	37.5	37.5				
40.0				40		
42.5	42.5					
45.0						
47.5	47.5	47.5	47.5	47.5	47.5	47.5
50.0						
53.0	53					
56.0				56		
60.0	60	60				
63.0						
67.0	67			67	67	
71.0						
75.0	75	75	75			
80.0				80		
85.0	85					
90.0						
95.0	95	95		95	95	95
100.0						
106.0	106					
112.0				112		

Ser 1.06 (R40)	Ser 1.12 (R20)	Ser 1.26 (R10)	Ser 1.58 (R5)	Ser 1.19 (∜2)	Ser 1.41 (√2)	Series 2 (2)
118	118	118	118			
125						
132	132			132	132	
140						
150	150	150				
160				160		
170	170					
180						
190	190	190	190	190	190	190
200						
212	212					
224				224		
236	236	236				
250						
265	265			265	265	
280						
300	300	300	300			
315				315		
335	335					
355						
375	376	375		375	375	375
400						
425	425					
450				450		
475	475	475	475			
500						
530	530			530	530	
560						
600	600	600				
630				630		
670	670					
710						
750	750	750	750	750	750	750
800						
850	850					
900				900		
950	950	950				
1000						
1060	1060			1060	1060	
1120						

Ser 1.06 (R40)	Ser 1.12 (R20)	Ser 1.26 (R10)	Ser 1.58 (R5)	Ser 1.19 (∜2)	Ser 1.41 (√2)	Series 2 (2)
1180	1180	1180	1180			
1250				1250		
1320	1320					
1400						
1500	1500	1500		1500	1500	1500
1600						
1700	1700					
1800				1800		
1900	1900	1900	1900			
2000						
2120	2120			2120	2120	
2240						
2360	2360	2360				
2500				2500		
2650	2650					
2800						
3000	3000	3000	3000	3000	3000	3000
3150						
3350	3350					
3550				3550		
3750	3750	3750				
4000						
4250	4750			4250	4250	
4500						
4750	4760	4750	4750			
5000				5000		
5300	5300					
5600						
6000	6000	6000		6000	6000	6000
6300						
6700	6700					
7100				7100		
7500	7600	7500	7500			
8000						
8500	8500			8500	8500	
9000						
9500	9600	9600				
10000				10000		
10600						
11200						

The table of standardized revolutions covers all speeds from 0·118 to 10,000 r.p.m used for the heaviest boring and turning machines of, e.g 35 feet diameter (100 h.p) down to the light high-speed drilling machines for drills of 0·4 in. diameter and less (1 h.p). There is no machine, the gear box (or stepped pulleys) of which could not be designed according to these speed standards. The designer would be limited a little, it is true, but this would be justified by the establishment of an indispensable and invariable basis on which all ratefixers could work, and thus increase the output of every metal machining workshop to its maximum. The principal standard running speeds of electric motors, both A C. and D.C , are included in this most important and very practical standardization; they comprise: 3000–1500–750–375, 1200–1000–600–500 for the continent, including Great Britain. But 3600 (3550)–1800–900–450 for the frequency of 60 cycles are also contained in this table, used in the U.S.A.—

The common ratios are so graded that the maker can select the difference between two steps of speed approx. from 5 to 50 per cent (Table XL).

TABLE XL

SPEED STEPS

Standardized Common Ratios	Numerical Value	1 06	1 12	1 26	1 41	1 58	2 0
	From $\sqrt[n]{10}$	$\sqrt[40]{10}$	$\sqrt[20]{10}$	$\sqrt[10]{10}$	—	$\sqrt[5]{10}$	
	From $\sqrt[n]{2}$	$\sqrt[12]{2}$	$\sqrt[6]{2}$	$\sqrt[3]{2}$	$\sqrt{2}$	—	2
Difference in speed between two steps in per cent	Exact %	5 6	10 9	20 6	29 2	36 9	50
	Approximate	5	10	20	30	40	50
I S A designation	—	R 40	R 20	R 10	—	R 5	
Remarks				steps most used			

The choice of the maker is usually made according to the range which is desired by the ordinary user. For instance, for medium steps (30 per cent) 750 to 47·5 revs., 1·41 would be selected, for bigger differences of diameter the series 1·58 (40 per cent) from 750 to 19 revs would be preferable. There would be an enormous advantage in the international use of these "preferred numbers" for speed ranges, applied by continental makers over a period of twenty-five years with full success and it would ensure that all machine tools, whether of British, American, or continental origin, would have the same actual figures on the speed and feed plates, thus stabilizing the basis for the ratefixer and guaranteeing the bonus for the operator, at the same time standardizing the manufacturing conditions of gears for the designer and maker. No one would suffer inconvenience thereby, in fact all would share in the benefit The user could take an ordinary slide rule and with one setting (e.g 1·41), check that the speeds on the plate of the machine corresponded with the true running speed.

Of course the production workshop cannot use the compendious table of standard-speed conditions which covers all machine tools which now exist and which may be designed in future. The production shop has a collection of real machines, consisting of different ages, designs, types, and countries of origin Therefore, it is advisable to gather the speeds of the existing machines of the workshop into a table for the use of the ratefixing department and to show the most useful speeds for thread cutting, "machining of to-day" and "machining in future." Again, from this table an abstract may be made for the different machines in the workshop (see Table XLII) and the workman can easily be taught to use his own part of the table according to his requirements. (See also page 205.)

Table XLI gives a review of the cutting speeds for a big turning department of 120 lathes based on a series of standardized diameters from ½ in. to 40 in. and a series of standardized revolutions, based on "preferred numbers" and the standardized common ratio of 1·26. This arrangement is better than the ordinary Table which shows the speed in feet per minute on top

TABLE XLI

SPEED TABLE FOR 120 LATHES OF A TURNERY

Diameter of Workpiece ins.	Speed of main spindle n, r.p.m.																						
	6	7.6	9.2	11.8	15.0	19	23.6	30	37.6	47.6	60	75	95	118	150	190	236	300	375	475	600	750	950	1180
½	785	98	1.25	1.55	1.97	2.5	3.1	3.93	4.9	6.2	7.9	9.8	12.5	15.5	19.6	25	31	39	49	62	78	98	125	155
¾	1.18	1.47	1.86	2.3	2.95	3.7	4.6	5.9	7.3	9.3	11.8	14.7	18.6	23	29.5	37	46	59	73	93	118	147	186	230
1	1.57	1.94	2.5	3.1	3.9	5.0	6.2	7.8	9.8	12.4	15.7	19.6	25	31	39	50	62	78	98	125	155	196	250	310
2	3.14	3.9	5.0	6.2	7.8	10.0	12.4	15.7	19.6	25	31	39	50	62	78	100	125	155	196	250	310	390	500	620
3	4.7	5.9	7.5	9.3	11.8	15	18.5	23.6	29	37	47	59	75	93	118	150	186	236	290	370	470	590	750	930
4	6.2	7.8	10	12.5	15.7	20	25	31	39	50	62	78	100	125	155	200	250	310	390	500	620	780	1000	1250
5	7.8	9.8	12.6	15.5	20	25	31	39	49	62	78	100	125	155	200	250	310	390	500	620	780	1000	1250	1560
6	9.3	11.8	15	18.5	23.6	29	37	47	59	75	93	118	150	185	236	290	370	470	590	750	930	1180	1500	1850
7	11.0	13.7	17.4	21.6	27.5	35	43	55	69	87	110	137	174	216	275	350	430	550	690	870	1100	1370	1740	2160
8	12.5	15.7	20	25	31	39	50	62	78	100	125	156	200	250	310	400	500	620	780	1000	1250	1570	2000	2500
9	14.1	17.7	22.5	28	35	45	56	71	88	112	141	177	225	280	350	450	560	710	880	1120	1410	1770	2250	2800
10	15.7	20	25	31	39	50	62	78	98	122	155	200	250	310	390	500	620	780	1000	1250	1560	2000	2600	3100
12	18.8	23.4	29	37	47	59	75	93	118	150	185	236	290	370	470	590	750	930	1180	1500	1850	2360	2900	3700
14	22	27.6	35	43	55	69	87	110	137	174	216	275	350	430	550	690	870	1100	1370	1740	2160	2750	3500	4300
16	25	31	39	50	62	78	100	125	157	200	250	310	400	500	620	780	1000	1250	1570	2000	2500	3100	3800	5000
18	28	35	45	56	71	88	112	141	177	225	280	350	450	560	710	880	1120	1410	1770	2250	2800	3500	4500	5600
20	31	39	50	62	78	100	125	157	200	250	310	390	500	620	780	1000	1250	1570	2000	2500	3100	3950	5000	6200
25	39	49	62	77	98	125	155	197	246	310	390	490	620	770	980	1250	1550	1970	2460	3100	3900	4900	6200	7700
30	47	59	75	93	118	150	185	236	290	370	470	590	750	930	1180	1500	1850	2360	2900	3700	4700	5900	7500	9300
35	55	69	87	108	138	175	216	275	344	435	550	690	870	1080	1380	1750	2160	2750	3440	4350	5500	6900	8700	10800
40	62	78	100	125	157	200	250	310	390	500	620	780	1000	1250	1570	2000	2500	3100	3900	5000	6200	7800	10000	12500

Cutting speeds, feet per min $v\ (=\frac{\pi d n}{12})$

TABLE OF CUTTING SPEEDS FOR VARIOUS DIAMETERS OF WORK PIECE AND SPEEDS OF MAIN SPINDLE.

From the diameter d (in inches) of the work piece (left-hand vertical column) and from the speed n (in revolutions per minute) of the main spindle (upper horizontal row), the cutting speed v (in feet per minute) can be found

Explanation of shading in table

	High-speed steel	Tungsten carbide
Thread cutting	15 f p m	50 to 60 f p m.
Machining of today	30 to 60 f p m.	120 to 300 f p m.
Machining in future		> 300 f p m

and an almost infinite number of revolutions in the centre, many of which are not available. The diameters are given by the drawing; the speeds, if they are standardized, exist on the plates of all machine tools in the workshop. Consequently, the Table shows at a glance which speeds are available for high-speed, stellite, and cemented carbides. The Table shows that the left upper corner contains all the cutting speeds which are too slow, and the right lower corner those which are too high, and shows the limits of each machine for working at economic speeds for the required diameter within the speed range of the machine tool. At least for each group of machine tools, e.g. lathe, capstan, combination turret lathe, and milling, grinding, and drilling machines, the *same* preferred numbers ought to be used; then the fundamental basis of ratefixing is secured. The workman always finds on his machine the speed which the ratefixer has pre-set, the foreman can distribute the work not to a single machine but to a group of machines, the charge-hand has an easier time, and the workman can determine his bonus, or he can object to wrongly set speeds Another important advantage is that the electric drive or the belt drive conforms to the speed plate and that the machine-tool maker can design his speed-box according to standard rules which facilitate the manufacture of the machine tools themselves and the supply of the spare parts Everything else in the design of machine tools may be, and can be, changed according to requirements or development, but not the speeds and feeds.

The aforementioned Manual on Cutting of Metals (A.S.M.E.) deals mainly with the use of high-speed steels, cutting 290 kinds of SAE steels, only a few pages are reserved for the use of stellite J-metal tools and cemented carbide tools. Furthermore, the necessary tables are given for machining ordinary cast-iron The modern trend is towards increase of speed by using hard alloys and cemented carbides, consequently new tables will be necessary. The conversion tables (see Table XXV) which convert high-speed steel values into cemented carbide values are spurious, the ratios depend upon present and future development of new cemented carbides or other cutting alloys and on the increased efficiency of present-day machine tools

Further, only for new machine tools of best workmanship the machine efficiency factors of between 0·75 and 0·85 (including the electric motor) as mentioned therein are valid, and only as long as they remain new. The efficiency factor decreases very quickly, depending upon the organization of the workshop and particularly on maintenance. It is an error to believe that the use of ball- and roller-bearings is a continuous preventive to a fall of efficiency. The writer has investigated machine tools having had only two years' use, equipped almost entirely with roller- and ball-bearings for the main spindle and all intermediate shafts, and has found a degree of efficiency of less than 0·7, whereas well-designed and maintained machine tools with plain bearings for the main spindle have had efficiencies of between 0·70 and 0·75 after five years

The correct combination of high-loaded plain adjustable bearings for medium and high speeds up to 5000 r.p.m. and low-loaded ball- and roller-bearings with high and very high speeds for all intermediate shafts may provide the best solution for this problem Generally the power question is easily solved compared with the correct choice of tool and cutting speed, which in all cases form the decisive factors for economic and undisturbed production.

Shortened extract Table XLII derived from Table XLI, which contained *all* figures used in this workshop, was fastened on each machine tool in the workshop to be used by the operator as follows; he takes the diameter to be turned from the drawing and the prescribed speed from his wages-docket, predetermined by the ratefixer according to the kind of cutting tool. Following *horizontally* from the left side, the given diameter, e g. 2-in. dia., he finds the speed for a cemented carbide tool prescribed by the ratefixer, e.g. 250 f.p m Then going vertically up he finds the necessary revolutions of his machine; here 475 r p.m. If used at present or in the immediate future, before full standardization of speeds has been accomplished, the revolutions shown in the Table will not correspond exactly with the plate of his machine, so he must increase or decrease the number of revolutions within the limits of the common ratio of the range of speeds By increasing he improves his bonus, by decreasing he loses. He should be trained always to try to increase He can, it is true, equalize the loss of speed by increase of feed, but by so doing he endangers his machine, because he increases the cutting forces and this may break a weak tooth. This danger is another important reason for standardizing the speeds and feeds for all existing machine tools

The effective introduction of cemented carbides with positive and negative rake angles into ordinary workshop depends on the possibility of increasing the speed and power of the more rigid machine tools, otherwise the result will be stalled motors and smashed tools. Why is the carbide-tipped tool destroyed if the main spindle is stopped? The cutting forces on the tool are not increased, because the cross-section of the chip must be reduced, when the machine turns at 1000 f.p.m. for cemented carbides instead of 100 f p.m for ordinary high-speed steel. It is the design of the machine tool which causes the destruction If the feed could be released before the spindle is stopped, or at the same time as the rotating movement of the spindle nothing would happen But if the feed moves the tool along only a thousandth of an inch, the brittle cemented carbide tool is twisted and, as it has no elongation, is smashed In all lathes the amount of power consumed by the feed is very low—it is between 1 and 3 per cent of the total power consumption; therefore, the very small movement produced by the inertia of the rotating parts between main-spindle and carriage suffices to cause that small but destructive twist If there is a slipping friction clutch between the feed-drive and the main-spindle drive, this detrimental movement often occurs. It is also necessary that cemented carbides should work at high speed (from 150 ft/min upward) to overcome irregularities of feed by the flywheel action of cone pulley, gears, etc., to secure a flowing chip and to avoid tear or shear chips which are frequently produced by the ordinary high-speed tools with a built-up edge.

A belt drive is only reliable if the belt speed is above 1000 ft/min, it would be even better to design belt speeds of 3000 up to 4500 ft/min,

TABLE XLII

SPEED TABLE FOR A SINGLE LATHE

Lathe No. 2416 - 16" Swing.

Diameter of Workpiece in.	9 Speeds of Spindle r.p.m. Range $\frac{750}{19} \approx \frac{40}{1}$								
	19	30	47.5	75	118	190	300	475	750
½	2.5	3.9	6.2	9.8	15.5	25	39	62	98
¾	3.7	5.9	9.3	14.7	23	37	59	93	147
1	5.0	7.8	12.4	19.6	31	50	78	125	196
2	10 0	15.7	25	39	62	100	155	250	390
3	15	23.6	37	59	93	150	236	370	590
4	20	31	50	78	125	200	310	500	780
5	25	39	62	100	155	250	390	620	1000
6	29	47	75	118	185	290	470	750	1180
7	35	55	87	137	216	350	550	870	1370
8	39	62	100	155	250	400	620	1000	1570
9	45	71	112	177	280	450	710	1120	1770
10	50	78	125	200	310	500	780	1250	2000
12	59	93	150	236	370	590	930	1500	2360
14	69	110	174	275	430	690	1100	1740	2750
16	78	125	200	310	500	780	1250	2000	3100
	Speeds in feet per min.								

	High-speed Steel	Tungsten Carbide
Threadcutting	15 f.p.m.	50 to 60 f.p.m.
Machining of today	30 to 60 f.p.m.	120 to 300 f p.m.
Machining in future		300 f.p.m.

but this is not usually possible for machine tools with pulley diameters smaller than 12 in. A narrow quick-running belt is much superior regarding its driving reliability to a wide slow-running belt or double belt, which is always a failure for small diameters. The advantage of the belt drive, flat, or trapezoidal, which consists in its silent action as a power-carrying element, improving with increasing speed, is then completely exploited. An additional advantage is that an overloaded flat belt slips off automatically For long distances the single flat belt working on the hair side is superior to the multiple texrope belt in many respects.

Cutting Speed, Cutting Forces, and Power Available

Cutting speed, cutting forces, and power available are interdependent.

The machine-tool designer must know and use correctly all factors of drive and machining, cutting forces (F), torque (M), cutting speed (v), spindle revolutions (n) are connected by the driving power (P) as—

1. Forces × Speed ($P = F \times v$) and
2. Torque × Revs ($P = M \times n$).

They must be correctly distributed over machine tool, tool, and work-piece, to reduce deformation, vibration, and heat to a minimum But the relations between each other and the reciprocal influence of tool on work-piece must be well known both by the designer and by the user of the machine in the workshop. If all these conditions are well studied, cemented carbide-tipped tools can safely be used, as single-point cutting tools for existing and rebuilt lathes and planers, and as multiple-tipped tools, counter-bores, reamers, and milling cutters; only the tipped twist drill being reserved for special cases. However, in many cases the design of existing old machine tools is far behind the development of modern cutting tools. Commercial administration often wants to keep the old equipment as long as possible, but it is only possible to "increase the output of the workshop without increasing equipment" by the correct rebuilding of existing machine tools so as to enable the latest modern developments in machining practice to be introduced, i.e. increased cutting speeds with extra-hard tools. The alternative is to purchase new modern machines. Components for aeroplanes, motor-cars, lorries, Diesel engines, electromotors, machine tools, etc., require high-quality machines. In most cases the manufactured parts must be interchangeable, yet produced by semi-skilled male or female operators who cannot compensate for the errors of inaccurate machine tools by their skilled craftsmanship. The quality performance of a well-made and accurate capstan lathe correctly set-up for batches and then operated by a female worker is always equal to that of an ordinary lathe operated by the most skilled craftsman, and it is always more economic. (See Tables XLIV to XLVI.)

High speed requires a bigger motor directly proportional to the increase of speed This involves the danger that the operator, using an ordinary high-speed tool which is strong but cannot withstand high speed, decreases the speed but increases the section of the chip at the same time so as to keep up the weight of chips produced per hour, thus maintaining the same output as before. This increases the stress by force (F) on the driving gears and is likely to lead to a breakdown

Any attempt to transmit greater power by means of increased speed ought to be carried right through the driving train from the tool to the motor shaft

A table giving the connexion between material of tool and part, machinability, kind of cut, speed, feed, depth, cross-section of chip, and power drive of the existing machine was compiled as the practical result of research work carried out by a British workshop of 200 operators manufacturing small tools for the benefit of its own production personnel. (Table XLIII.) Each of these items has to be known to the ratefixer, setter, and operator, who cannot work with cu in per pass, or total cu in. per h p /hour. Such Tables ought to be in the hands of every ratefixer. The formula which connects the driving power of the motor with cutting force and cutting speed is—

Power (h.p.)·

$$P = \frac{\text{cutting force} \times \text{speed per min}}{33{,}000 \times E}$$

Cutting force

$$F = I \times d \times f \text{ (machining index} \times \text{cross-section of chip).}$$

Average speeds for the ordinary workshop with average lathes and capstans up to 1000 r.p.m. were, for machining hard steels (high-speed steels for making tools)—

(*a*) Cemented carbide: v shift = about 180 to 300 ft/min.

(*b*) Stellite 80 and SHS-steels: v shift = about 75 ft/min.

(SHS. = 5 to 12 per cent Co + 18 to 20 per cent W + 5 per cent Cr + 1 to 2 per cent Va)

(*c*) High-speed steel (18–4–1) · v shift = about 40 ft/min.

Average efficiency of lathes and capstans used (idle running plus load influence) $E = 67$ per cent

Machining Index, I (see Fig 56)

For steel of 35 to 40 tons/sq in tensile and using for the known cross-section of chip increasing from 0·001 sq in to 0 006 sq in the decreasing specific pressures 1000 lb/sq in or lb/0·001 sq in (See Fig 53.)

$$I_{180} = 360{,}000,\quad I_{75} = 330{,}000,$$
$$I_{40} = 300{,}000,\ \text{lb/sq in}$$

Feed for roughing f_1 from 0 020 in to 0 050 in

Feed for roughing f_2 from 0 012 in to 0 040 in

Feed for finishing f from 0·004 in to 0 008 in permissible in any case

Depth of cut d is to be found

Cross-section of cut $= d \times f$ (sq in.)

The depth d to be prescribed by the ratefixer can now be tabulated by calculating the constant factors C for the variable speeds $v = 180 - 75 - 40$ f p m and feeds f_1 and f_2. ex formula—

$$P = \frac{I \times d \times f \times v}{33{,}000 \times 0\ 67} = \frac{I \times d \times f \times v}{22\ 000}$$

$$d = \frac{P}{v} \times \frac{22{,}000}{I} \times \frac{1}{f}$$

$$C = \frac{22{,}000}{I} \times \frac{1}{v}$$

Therefore—

$$C_{180} = \frac{22{,}000}{360{,}000} \times \frac{1}{180} = 0\ 00034 \text{ (carbide tool)}$$

$$C_{75} = \frac{22{,}000}{330{,}000} \times \frac{1}{75} = 0{\cdot}00089 \text{ (cobalt high-speed tools)}$$

$$C_{40} = \frac{22{,}000}{300{,}000} \times \frac{1}{40} = 0{\cdot}0018 \text{ (high-speed steels)}$$

Using the existing feeds f_1 from 0 02 in. to 0·05 in. and f_2 from 0·012 in. to 0·04 in. as examples, we can develop the Table XLIII to guide the planning and ratefixing department and to teach the interested foreman. The following

TABLE XLIII

EXPLOITATION OF EXISTING LATHES AND CAPSTANS BY DIFFERENT TOOLS IN A SMALL WORKSHOP OF 30 MACHINES

For the Ratefixer

TOOL		SPECIMEN		Cut	Coefficient $C = \frac{22{,}000}{I \cdot v} = \frac{22{,}000}{360\ 000} \cdot \frac{1}{v}$	ROUGHING CUT		ROUGHING CUT		Cross-section S	DRIVE-POWER		REMARKS
Material	v Speed ft/min	Material	Index lb/sq in I			Constant f_1 feed in	Variable d_1 depth in	Constant f_2 feed in	Variable d_2 feed in		Available h p	Necessary	
Cemented carbide	180	SM-steel 35–40 tons/sq in	360,000	Roughing	0 00034	0 02	0 05	0 012	0 085	0 0010	3	$\leqq 3$	Motor just exhausted
	180		360,000		0 00034	0 02	0 085	0 012	0 14	0 0017	5	$\leqq 5$	
	180		360 000		0 00034	0 02	0 12	0 012	0 20	0 0024	7	$\leqq 7$	
	180		360,000		0 00034	0 02	0 17	0 012	0 28	0 0034	10	$\leqq 10$	
Stellite or SHS-steel 5% Co 18% W	75	SM-steel 35–40 tons/sq in	330,000*		0 00089	0 042	0 064	0 025	0 11	0 00265	3	$\leqq 3$	
	75		330,000*		0 00089	0 042	0 11	0 025	0 18	0 0046	5	$\leqq 5$	
	75		330,000*		0 00089	0 042	0 15	0 025	0 25	0 0063	7	$\leqq 7$	
	75		330,000*		0 00089	0 042	0 21	0 025	0 35	0 0088	10	$\leqq 10$	
Hs-steel (18–4–1)	40	SM-steel 35–40 tons/sq in	300,000*		0 0018	0 05	0 112	0 04	0 14	0 0056	3	$\leqq 3$	
	40		300,000*		0 0018	0 05	0 18	0 04	0 22	0 0090	5	$\leqq 5$	
	40		300,000*		0 0018	0 05	0 25	0 04	0 32	0 0125	7	$\leqq 7$	
	40		300,000*		0 0018	0 05	0 35	0 04	0 45	0 0180	10	$\leqq 10$	

* Smaller index for bigger cross-sections (cf Fig 53)

calculation shows how this table is used. First the ratefixer and then the operator of the machine must know how, for example, the lathes or capstans could be exploited for the different tools which are in use. For an ordinary carbon tool a speed of not more than 20 ft/min is advisable, and even to-day such a speed is often used for thread cutting, using taps or dies.

As we now have numerical values for the machinability factor of most of the ordinary materials (see Table XVIIIB), we have all necessary data of correct ratefixing. The influence of changes of cross-section, up and down, are clearly shown. The ratefixer is obliged to take the maximum cut possible, given by feed and depth, but according to the available power-drive. The Table shows as examples two constant feeds f_1 and f_2 and two varying depths d_1 and d_2 for each speed The depth depends on the material allowance that has to be removed The mutual variation of (f) and (d) is done in such a way, that the cross-section of chip, $d \times f$, remains the same for roughing, therefore the cutting forces are not increased The ratefixer knows by the Table that by taking these maximum or minimum feeds and depths the existing motors of 3, 5, 7, 10 h.p. are just being used to their limit.

Before the Table could be put into use, the machines were checked with regard to the standardization of speeds As most of these machines in this small works were of American origin, provided by the Government between 1940 and 1942, it was very interesting to find out whether they were built according to the standardized range of preferred numbers. The first observation was that five leading American firms provided only a limited number of speeds on their ordinary machines (i.e. between 6 and 12). This simplifies service and decreases the price. Only a toolroom lathe and a large machine had respectively 16 and 24 speeds. All these machines used the common ratios: 1·26, 1·40 and approximately 1·6. This corresponded very closely to the standardized ratios 1·26, 1·41, 1·58.

Not before all this preparatory work is well done can the planning department elaborate the data chart for the ratefixer (see Table XX) containing the material of the parts, that of the tools, and the corresponding feeds and speeds for the principal workshop operations. In the meantime the time-study man can tabulate the handling times, lost time, etc., as these remain constant.

If we complete the operator's piece-docket by inscribing the number of the tool (type and material), speed, depth, and feed, and hand over to him the drawing of the piece to be machined, containing particulars of the material and dimensions, he or the setter knows everything necessary to enable him to adjust his machine according to the pre-set conditions It is very useful, when dealing with big batches, to prescribe the number of pieces after the production of which the tool should be reground Using these data he can produce the piece in the predetermined total time so that he can make a considerable bonus depending on his intelligence, ability, and diligence.

If the ratefixing and planning office is well organized and has sufficient staff, it is advisable to make specification charts for each piece for big batch and quantity manufacturing showing by detailed sketch, the operation, and the jigs and tools needed, and specifying the times allowed (Fig. 97) This achieves the aim of supplying the workshop with all the necessary information for maximum output, based on practical data, thus avoiding talk, argument, and theoretical considerations.

Control of Speeds

The American preferred numbers, the I S.A. recommendations, and Table XXXIX* which the author had elaborated, and which has been in practical approved use for twenty-five years in many thousands of well-designed machine tools, all have the same basis.

As it is impossible to cover the standard speed ranges of modern machine tools, universally used between 1 20 and 1 . 100, by a purely electrical regulation, the largest ratio of which ends usually at 1 10, the use of direct built-in electric drive for the main spindle without gear trains is restricted to high-speed machines with small range and generally of medium size. They are special

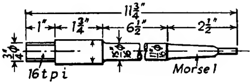
* *Wesen und Auswirkung der Drehzahlnormung* ("Essence and Effect of the Standardization of Speeds of Machine Tools"), by G. Schlesinger, 1931, A.W.F. 239, Beuth-Verlag, Berlin.

machines and cannot be considered as standard design. Further, the increased demands on surface quality within the limits from 1 to 8 micro-inch average (see page 218) generally exclude the use of built-in electric motors for fine finishing cuts within these fine limits. The frequently unavoidable small unbalance of the motor armature after some use necessitates the placing of the motor close to the floor, separated from the machine tool, grouted separately, and connected with the machine tool by an elastic element (belt).

Since the designer of the machine tool has some difficulty in obtaining exactly the figures of the standards table by means of gear trains, a deviation of ± 3 per cent is allowed as a mechanical tolerance.

Because electric motor (or countershaft) and machine tool form a unit, both tolerances are combined for the acceptance of the power drive in (-3) per cent (motor) (± 3) per cent (gear drive) $= -6$ to 0 per cent.

The speeds of the main spindle of the fully loaded machine tool should not be lower than 6 per cent and not higher than the synchronous spindle speeds of the table. The minimum speeds of 6 per cent are read directly in the basic series R 40 (see Table XXXIX) with the common ratio of 1·06

Operation Chart	Description	Reamer 1 in ϕ
	Component	Body
	Numbers per year	1100 + 7 per cent = 1177
	Batch (pieces)	95
	Material	Mild steel 35 tons/sq in
	Rough dimensions	1 in dia × 11 13/16 in
	Weight	6·5 lb

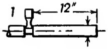
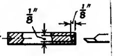
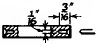
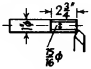
	No	Operation	Machine	Jig Tool Gauge	Revs per min	Cutting Speed ft/min	Feed in	Machining Time (minutes) Setting Up	Machining	Handling	Delay	Total	Pieces per hour
1 	1	Cutting-off	Circular saw	Foot rule	500	65	0·004	20 S 0·21 O	0·27	0·35	0·04	0·87	69
2a 	2a	Centring Counter-boring	Centring machine	Counter-sink	750	30	0·0015	—	0·23	0·09			
2b 	2b	Drilling	Drilling machine	Drill	800	28	0·0015	0·10	0·11	0·09			
								0·10	0·34	0·18	0·16	0·78	77
3 	3	Turning body of reamer	Lathe	Turning tool Snap gauge	270	70	0·015	25 S 0·26 O	0·87	0·30	0·36	1·79	33·5
4 etc.													

Fig 97

The designer is bound by—

(*a*) Range of speed $R = \frac{n_{max}}{n_{min}}$

(*b*) Number of speeds $= k$.

(*c*) Common ratio $= r$

$$r = \sqrt[k-1]{\frac{n_{max}}{n_{min}}}$$

The most widely used common ratios are: 1·26–1·41–1·58 For very fine steps, the ratio 1·12 and for small capstans as an intermediate ratio $\sqrt{1 \cdot 41} = 1 \cdot 19$ are sometimes used, in rare cases the rough ratio 2.

The figures of the Table contain the synchronous speeds of the motors, but they represent those speeds which are used for the mean load which might cause a decrease of the synchronous speed of the motor (slip) of about 3 to 4 per cent. This electrical tolerance is the average slip under the most frequently used (mean) loads The commonest motor speeds are 1000 and 1200 r p.m for large motors, and 1500 or 1800 and 3000 or 3600 r.p.m. for small A C. motors Ordinary motors have the following slips (speed reduction) from no-load to mean and full loads.

H.P.	Slip for Full Load per cent	Slip for Mean Load per cent
0 5 2	8–12	6
2– 4	6	4
5–10	5	3 5
10–20	4	3
20–40	3 5	2 5

The electrical design of the motor speed is invariably based on the synchronous speed In Great Britain and on the Continent the periodicity of alternating current is standardized at 50 cycles (Hertz) per second, and equal to $50 \times 60 = 3000$ r.p.m. In the U.S.A 60 cycles per second and 3600 r p.m. are standardized. The figure 3000 must therefore be available for all common ratios and for the basic series R.40. This is the reason why the standardized speeds of machine tools do not begin with cypher 1, but with either cypher 0·118 which covers all common ratios of $\sqrt{10}$, or cypher 0·19 which is useful for the whole of the ratios of $\sqrt{10}$ and $\sqrt{2}$ as well 3000 is particularly important for A.C motors with interchangeable poles used in ever-increasing numbers for individual machine-tool drives with infinitely variable speed regulation.

The number $3000 = 2 \times 2 \times 2 \times 3 \times 5 \times 5 \times 5$ and $3600 = 2 \times 2 \times 2 \times 2 \times 3 \times 3 \times 5 \times 5$ are particularly useful figures, because they contain the factors 1, 1·5, 2, 2·5, 3, 4, 5, 6, 8, 10, 12, i.e. for all possible pairs of poles (electrical) and for almost all gear ratios, numbers of teeth and gear moduli (mechanical).

The checking of the power drive is made by placing one revolution counter at the electric motor shaft and another at the main spindle. The inspector or setter should take a cut of such a magnitude that the synchronous speed of the motor is decreased between 3 per cent and 6 per cent At the diminished speed the spindle counter of the main spindle should show the value as indicated on the speed plate

The Machine Tool under Load

The stresses imposed by roughing cuts must be kept within such limits that no permanent deformation will result, even after several years of continuous use It must be borne in mind that most machine tools are employed for roughing as well as for finishing, that is to say, for work requiring quite different degrees of accuracy of the machine. The working accuracies are obtained only by *finishing tests* which are specified in the Tables of acceptance tests. These are the only valid tests because the form of a piece after roughing is of no importance either as regards accuracy or surface finish. (See Table XXXVIII, 1 to 13.)

Although forging and casting allowances are kept as small as possible (see Fig. 22), roughing cuts are still necessary during the subsequent machining operations, and these involve considerable cutting forces. In the case of small high-speed lathes (diamond turning lathes), small depths (0·003 in. to 0·008 in.) of cut and very fine feeds (0·001 in. to 0·003 in.) are used. Although heavy roughing forces are eliminated in this case, attention must be paid to the vibrations set up during cutting. In the design of such lathes care must be taken to avoid vibrations that would cause chatter marks on the surface of the work-piece and render subsequent fine grinding or lapping necessary before it would pass inspection. In order to obtain a chatterless finish, the bed of the grinding machine must be particularly stiff. In fact, it was in connexion with the design of grinding machines that the need for a high degree of rigidity or stiffness was first encountered. As far as the grinding machine is concerned, a pure bending or deflection test may be regarded as sufficient, provided that the load applied is a multiple of the normal low cutting pressure (200 lb maximum) of the grinding wheel This overload applied during the trial test will cover or include all the other sources of errors

This method, however, cannot be applied to other classes of machine tools, and especially to those in which the torsional loads have a decisive influence, as, for example, in lathes, radial drilling, and milling machines

For this reason, the method of inspection by taking finishing cuts should be retained, since this reveals not only the geometrical accuracy of the shape produced, but also the quality of the surface finish, the test being at once simple and severe.

The testing of a machine tool for rigidity or stiffness should be carried out with the following objects in view—

(1) Ensuring that permanent deformations of the load-carrying members will not occur under the influence of roughing cuts.

(2) Ensuring that elastic deformations during finishing cuts will not affect the accuracy of the finished work-piece

(3) Ensuring that undue vibrations will not occur.

These three conditions cannot, up to the present, be definitely defined, because the relations between them and the rigidity of the machine are not known, or rather because a suitable unit of measurement is not available. In the final inspection of a machine tool, a distinction should be drawn between roughing and finishing machines. There is, of course, a great difference between the absolute rigidity of a grinding machine and the elastic stiffness of a lathe, and this difference is not yet generally understood.

In the case of a roughing machine, the purchaser should be satisfied in obtaining the specified production rate, without noise and vibration, and without troublesome deformation

The realization of accuracy requirements depends on the workmanship This accuracy can always be brought to a pitch that will satisfy the required standard of static inspection by installing suitable machine-tool equipment and by instruction and training of the operator Errors which are detected in the "static acceptance" tests can frequently be rectified by a subsequent operation.

The realization of efficiency, that is to say, the relation between power input and cutting capacity, is a problem to be solved by the designer, and it must be solved initially and cannot be corrected afterwards. A machine-tool maker who attempted to manufacture machine tools which, although built to accurate static standards, were inefficient in operation, would not survive long in business.

Testing an Assembled Machine

As it is only the assembled machine that is to be tested, no dismantling should take place while testing it. Dismantling is always detrimental to the machine. Frequently machine parts are required to be assembled by force or driving fits, so that force would have to be applied in separating such parts. Hence, a perfect machine may be damaged which otherwise would have shown satisfactory working results for many years. In addition, dismantling and reassembling operations absorb much time and are very expensive

CHAPTER XI

Accuracy of Products

A. Accuracy of Dimension: Fits and Limits

The great majority of parts in engineering works are cylinders, tapers, planes, or helices, as these shapes form most mating parts. If they are produced in batches or quantities their dimensions must be so accurate that the parts are practically interchangeable: either "non-selective" if the accuracy is so great that any male part fits any female part, or "selective," when two mating parts must be selected from the batches and slightly fitted by scraping, filing, or lapping. The two matched pieces are now coupled and cannot be separated from each other. Most parts manufactured in engineering works belong to the selective system.

Tolerance and Allowance

Two factors determine fits and limits: (1) tolerance, (2) allowance.

(1) *Tolerance* is the extent to which duplicate parts of the same dimensions are permitted to vary in size in order to secure sufficient accuracy for the purpose in view. A standard hole of 1 in. diameter, accuracy *B*, unilateral, may be 1·0006 in. as high limit and 1·000 in. as low limit. Tolerance is the permissible deviation of *one* piece (+0·0006 in.) from the nominal dimension.

(2) *Allowance* is a difference in dimensions prescribed in order to secure various classes of fits between *two mating* parts

A standard hole of 1 in. nominal diameter accuracy *B* (Table XLIV) with the tolerances $1^{+0.0006}_{\ \ 0.0000}$, when mated with a shaft of 1 in. nominal diameter (accuracy *R*), which has, in the unilateral system, a high limit of 0·9982 in. and a low limit of 0·997 in., gives an allowance for a normal running fit *R* of —0·0036 in. maximum and —0·0018 in. minimum. The same *B* hole, if mated with the *F* shaft (unilateral) of $d = 1^{+2.4}_{+1.8}$, would have an interference for a heavy drive fit of +0·0024 in. maximum and +0·0012 in. minimum.

It is a very important task of the designing office to insert the correct tolerances both in diameter and length for each detailed piece in tolerance figures and not by code-letters (Fig. 98). The best arrangement is for a well-trained practical engineer in the drawing office to specialize in the control of all drawings before they are

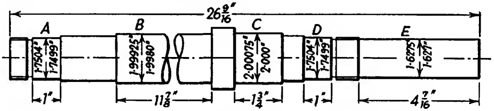


Fig. 98 Insertion of Correct Tolerances Varying with Diameters and Kinds of Fit (*A*, *B*, *C*, *D*, *E*)

Removing 0 015 in stock

Dia	Grinding Time
A	28 secs
B	118 secs
C	54 secs
D	28 secs
E	50 secs

Total working time 4 min 38 secs

issued to the works production department, so that all tolerances are correctly inscribed to secure the desired allowances in the fitting department and that the most suitable surface finish is decided upon at the same time.

There is no man among the production staff who may save more money in manufacturing, and avoid more trouble and delay in the fitting departments for sub-assemblies and assemblies, than the tolerance engineer in the drawing office.

The dimensions of pieces are controlled by limits and fits to secure interchangeability of parts both for present assembly and of spare parts for future maintenance and repair. In particular, mating parts must fulfil various

TABLE XLIV

STANDARD HOLE UNILATERAL/BILATERAL

(B.S. 164 1924—War-time issue 1941)

BRITISH STANDARD LIMITS—BASIC HOLE

H = high limit of tolerance, L = low limit of tolerance

Nominal Sizes	Unilateral Holes (Tolerance unit = 0·001 in.) Very Accurate *B*		Good Quality *U*		Medium *V*		Course *W*		Bilateral Hole Very Accurate *K*	
in	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*
1·0–1·49	+0·6	0	+1·2	0	+2·4	0	+4·8	0	+0·3	−0·3
1·5–2·09	+0·7	0	+1·4	0	+2·8	0	+5·6	0	+0·3	−0·4
2·1–2·79	+0·8	0	+1·6	0	+3·2	0	+6·4	0	+0·4	−0·4

UNILATERAL SHAFTS

Nominal Size	Interference fit: Heavy Drive *F*		Light Drive *E*		Transition fit: Heavy Keying *D*		Medium Keying *C*		Light Keying *B*		Push *K*	
in	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*
1·0–1·49	+2·4	+1·8	+1·8	+1·2	+1·2	+0·6	+0·9	+0·3	+0·6	0	+0·3	0·3
1·5–2·09	+2·8	+2·1	+2·1	+1·4	+1·4	+0·7	+1·0	+0·3	+0·7	0	+0·3	−0·4
2·1–2·79	+3·2	+2·4	+2·4	+1·6	+1·6	+0·8	+1·2	+0·4	+0·8	0	+0·4	−0·4

UNILATERAL SHAFTS

Clearance fit

Nominal Size	Easy Push or Slide *L*		Easy Slide Close Running *P*		Close Running (1) *M*		Close Running (2) *Q*		Normal Running *R*		Slack Running *S*		Extra Slack *T*		Coarse Clearance *TT*	
in	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*
1·0–1·49	0	−0·6	−0·3	−0·9	−0·6	−1·2	−0·9	−1·8	−1·8	−3·0	−3·0	−4·8	−4·8	−7·2	−7·2	−12·0
1·5–2·09	0	−0·7	−0·4	−1·1	−0·7	−1·4	−1·1	−2·1	−2·1	−3·5	−3·5	−5·6	−5·6	−8·4	−8·4	−14·0
2·1–2·79	0	−0·8	−0·4	−1·2	−0·8	−1·6	−1·2	−2·4	−2·4	−4·0	−4·0	−6·4	−6·4	−9·6	−9·6	−16·0

working conditions, which are divided into three classes—

1. Clearance fits (slide, easy slide, close running), close running (1), close running (2), normal slack and coarse.

2. Transition fits (heavy keying, medium keying, light keying, push).

3. Interference fits (heavy drive, light drive).

They are defined by the British Standard 164 : 1924 (war-time issue, 1941) and in use in the

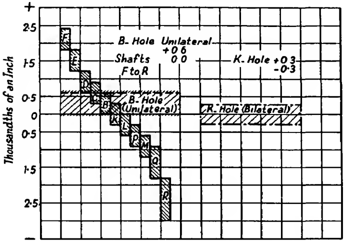


Fig. 99. Diagram to Table XLII, Showing Fits and Tolerances of Standard Hole and Unilateral System

U.K. on the two practical systems. (1) hole basis, (2) shaft basis. The "*hole basis*" is mostly used. Of the two possible positions of the reference line the B.S. Committee recommended *unanimously* the use of a *unilateral* system of tolerances. No doubt these two decisions are fundamental in guaranteeing the selective interchangeability of parts of the same nominal diameter in an industrial country. Both decisions conform to those of the I.S.A. Committee,* which are accepted by almost all countries of the European continent and by the U.S.A.

The standard hole is based on the use of one hole for the different shafts (Fig. 99). For instance a machine-tool manufacturer who is using the same gear or pulley for all running, transition, and interference fits, will make only one component to accurate limits with a well-adjusted set of boring and reaming tools, which are expensive, and then adjust the shafts to the different fits by the same grinding machine

Fig. 100 compares the cutting and measuring tools which are necessary for the basic hole versus the basic shaft. The multitude of reamers and stocked parts is decisive in making the majority of engineering works decide in favour of the standard hole.

The use of the standard shaft is restricted to a few branches, e g. transmission-lines some wood-working machines, etc , and to a few applications in the engineering branch, e.g. to bright drawn materials without machining The design is not generally influenced by choosing one system or the other

It was early realized that "interchangeable" parts need not be identical parts, but that it is sufficient if the significant dimensions which control their fits lie between identical manufacturing limits An international development and collaboration of more than forty years has confirmed this fact.

As above-mentioned, the expression "interchangeability" must be taken cautiously Most mating parts require a slight adjustment by hand-lapping or scraping to make the fit "exact" We call this "selective" assembly, and 95 per cent of all so-called interchangeable parts are selectively manufactured and refitted.

Non-selective assembly requires tolerances of about $\pm 0{\cdot}0001$ in. or less, which are too fine and expensive to be applied to the usual mass-production on an economic basis. The Johansson slip gauges have been made on the non-selective basis for more than forty years, being matched in any combination; but parts of even first-class motor cars, aeroplanes, rifles, instruments, etc., require either a fine subsequent adjustment or they must be selected from the batch produced, systematically marked and stored as matched pairs, as for instance the very fine ground and lapped gudgeon pin of first-class motor cars, and its matched piston.

In the diagram (Fig 99) the unilateral standard

* International Standards Association, founded 1926 in U.S.A Pre-war sponsors of I S.A. were: Great Britain, the United States, France, Russia, Austria, Poland, Czechoslovakia, Germany, Italy, the Scandinavian countries, Belgium, the Netherlands, Hungary, and Rumania.

hole grade *B* for 1 in. diameter, as an example, forms the basis of comparison with all standard shafts, e.g. from *F* to *M*. But if the bilateral hole (fit *K*) is used then the maximum tolerance of this *K* hole becomes smaller in any case at 0·0003 in. and the shaft with former-*slide* fit *L* is transformed into the shaft tolerances of shaft-*push* fit *K*, thus creating a danger of scoring Consequently the use of the bilateral system of B.S. 164 for standard holes requires a shifting of the tolerances of all shafts grades *F* to *M* and an adaptation of the tolerances of the running fits *Q* also.

The cross reference necessary when a "code" fit is quoted on a production drawing is therefore less fool-proof than when clearly stated dimensions appear on all drawings. This should be the strict rule.

It goes without saying that fine tolerances of, say, gudgeon pins must be linked up with fine surface finish, which, for these pins, is about 1 to 2 μ-in average.

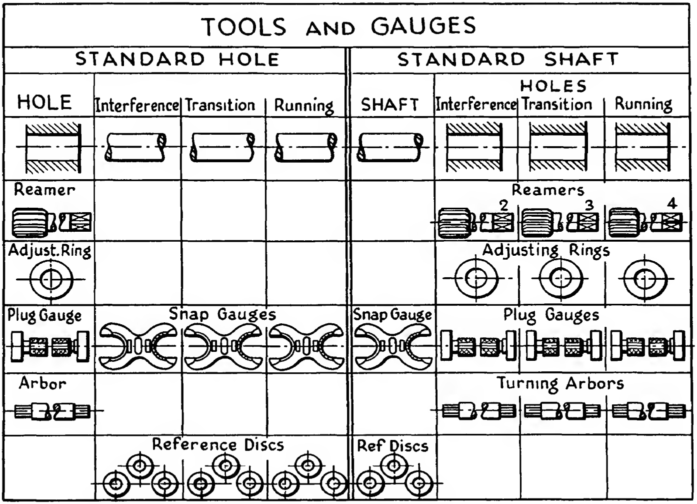


FIG 100 COMPARISON OF TOOLS AND GAUGES FOR (*a*) STANDARD HOLE, (*b*) STANDARD SHAFT

The Reference Line (Zero Line)

The nominal dimension is always the starting point for all questions regarding limits and fits for engineering purposes. The use of the standard ring and plug (Whitworth) required the trained feeling and decision of the craftsman, which is no reliable basis for batch and mass-production with diluted labour. The system of limit gauges was, therefore, introduced with the "go" and "no-go" measuring surfaces of the cylindrical plug gauges and the flat snap gauges The first gauge systems were based on tolerances which allowed bilateral, i.e. ±, deviations from the nominal measure, to get, for instance, an average measure for the standard hole approximately

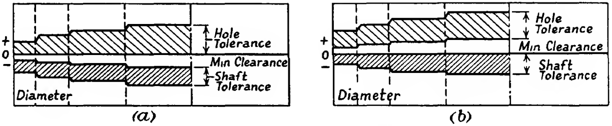


Fig 101a Unilateral System

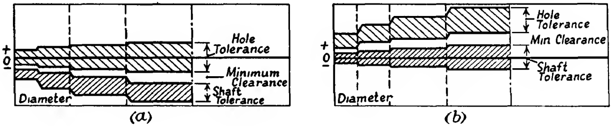


Fig. 101b. Bilateral System

equal to the nominal dimensions as the reference line (zero) of the tolerance zones (Fig. 101*b*). This bilateral system, which was mostly used up to 1916, was then dropped in favour of the unilateral system (Fig. 101*a*), first on the Continent, then throughout the U.S.A. by 1924 (100 per cent use) and in the United Kingdom (50 per cent use) according to the statement of B.S. 164 of 1924.

The two systems exclude each other; when mixed they create confusion, instead of the beneficial influence which follows this fundamental standardization over a whole country.

The unilateral system is based on the nominal diameter of, for example, the standard hole as reference line, i.e. the low limit of the hole tolerances, and at the same time as the high limit of the shaft tolerances for the standard shaft system. The low value of the tolerance then becomes zero, e.g. for 1 in. diameter: 1·000 in. to 1·0006 in. for the very accurate *B* hole, and 1·000 in. to 1·0048 in. for the coarse *W*-hole (Table XLIV). Therefore, this reference line can be used as the zero line of the system, because the *low* limit for all ***standard holes*** is "zero" and the ***high*** limit for all standard shafts is "zero" as well This definition of the zero line has decisive advantages (Figs. 101*a* and 101*b*).

(1) For the standard-hole system it is at once recognizable by the high limit of the shaft, whether it be a running fit or a transition fit, because the high limit of any shaft always represents the minimum (±) clearance

The same is valid for the standard-shaft system. It is recognizable by the low limit of the hole, whether a running or a tight fit will result, because the low limit of the hole again always shows the minimum (±) clearance against the shaft This principle can also be applied to length tolerances. (See Fig 102.)

A tolerance system with the nominal (zero) line as the boundary line, is therefore, clearer and easier to understand and manage than a bilateral system with the reference line symmetrically arranged.

(2) The standard shaft matches with the standard hole as a sliding fit (Figs. 99 and 101*a*),

because both touch each other at the reference (zero) line. There is a natural coincidence of both systems at this line which does not exist with systems with the zero-line as the line of symmetry.

(3) If several degrees of quality are used in the same workshop we have the low limit equal to "zero" for all holes of the different qualities if the standard-hole system is adopted Correspondingly, in the standard-shaft system the *high* limit is equal to "zero" for all shafts of different qualities The consequence is that when changing from one degree of quality to another the minimum clearance remains the same and the interchangeability remains assured

If, however, the tolerances are distributed symmetrically about the zero line, e g the tolerance of holes, it may occur that, although the same minimum clearance for both qualities exists, the running fit becomes a transition fit if the shaft of the higher quality is matched with the hole of lower quality, and if by chance the smallest hole is matched with the largest shaft

The unavoidable use of several qualities in the same workshop demands the selection of the zero line as the boundary line, i e the adoption of the unilateral system

(4) The unilateral limit systems facilitate the adjustment of micrometers and length reference gauges according to the desired low limits (zero) and indicate clearly and lucidly the position of all deviations from zero, up or down.

This is emphasized, if test shafts must be made to fix the necessary clearance with regard to holes which had already been manufactured according to existing standard plugs or limit plug gauges

(5) When changing the manufacturing process from the use of standard single rings and plugs (nominal dimension = zero) to the use of tolerance gauges, the existing standard gauges can still be used, the ring gauge for the standard shaft and the plug for the standard hole

For the manufacture and life of the reamer it is, of course, irrelevant whether the reference line be defined as a line of symmetry (bilateral) or as a boundary (unilateral). The life of a reamer depends on the amount of the tolerance of the hole and not on the position of the $\pm$ allowances

Furthermore, in the bilateral system of standard holes the reamer is not honed exactly equal to the nominal diameter, but larger than the nominal diameter to the extent of about two-thirds of the hole allowances, so as to obtain the biggest possible allowance for wear, i e. to produce the maximum quantity of holes with one setting of the reamer

In the standard-shaft system (see Fig 100) the reamer deviates from the nominal diameter in any case in order to get holes with the necessary clearance or interference

It is sometimes argued that the bilateral system corresponds better to the psychology of the operator This is not correct, for the following reasons—

1 The absolute values of measurements are irrelevant as regards the practical use of limit gauges

2. It is more consistent to try to obtain the nominal dimension in manufacturing parts and to allow deviation only in the direction of the "no-go" dimension This was the same when working according to the single ring or plug, although then the tolerance itself was not defined.

In concluding his report on tolerances for cylindrical fits, published by the "American Standards Association, 1941." F Gaillard makes the following statement—

"MODERN SYSTEMS ARE UNILATERAL"

"The advantages of a unilateral system of tolerances over a bilateral one have led to the exclusive adoption of unilateral tolerances in all modern standard systems of fit "

Length Tolerances and Design

For tolerance on linear dimensions, the principle of the zero line should also be applied, because only by this method can clearness of drawing be secured and mistakes avoided Further, if the standard hole is here used as a basis, all internal measures, e g slots, distances of gibs, etc., have "zero" as the low limit and a (+) sign for the high limits. All movable parts with outside dimensions have a (—) sign for both limits, so that from the high limit the existing minimum allowances will be obtained at once. All stationary parts with external dimensions will have a (+)

sign for both limits so that from the high limit the maximum allowance is at once recognizable.

Fig. 102 shows a shaft the shoulder of which shall have a maximum length allowance of 0·003 in. in the groove. Shoulder and groove are made

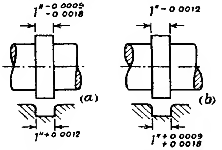


Fig 102. Length Allowance of Shoulder of Shaft

according to standard hole grade U and close-running shaft grade Q in the unilateral system

For the tolerances of a series of subsequent dimensions for one piece it is to be observed that the tolerance data must be so inserted that they do not overlap and contradict each other The bolt (Fig. 103) with two shoulders cannot have tolerances for the three single dimensions and for the total length as well If a tolerance for the total length is desirable the designer must decide which of the single steps can remain as a free compensating length; here 0·7 in. is crossed.

The gear box of a machine tool (Fig. 104) is so designed on the principle of the unilateral standard hole that all length dimensions are free. The six shoulders of the lower shaft are all about 0·04 in. shorter than the corresponding bearings, bushings, and gears; the same is done with the four shoulders of the upper shaft. Linear movement of the lower shaft is prevented by the pulley (left) and the ring (right) which can easily be adjusted, and by one grub screw in the biggest gear of the upper shaft. For this special design the standard hole requires $6 + 4 = 10$ free shoulders, thus avoiding length fitting at all.

The complete elimination of "tolerated" length fits in the workshop cheapens the manufacture of complicated shafts, avoids unpleasant fitting of lengths during the sub-assembly, and facilitates the work of the fitter in putting the parts of such a gear box together and dismantling them when necessary

This example of machine tool is typical for all

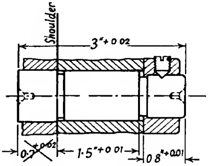


Fig 103 Bolt with Two Shoulders

assemblies of a similar kind, whether for motor cars, aeroplanes, etc

B. Measuring Surface Quality of Work-pieces

The four essentials of all machining operations are (1) shape, (2) dimension, (3) material, and (4) surface qualities Shape is determined by the

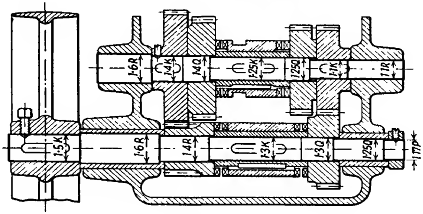
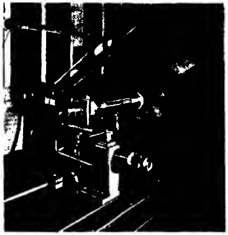


Fig. 104. Gear Box of a Machine Tool, Length Fitting Eliminated

design; dimension and materials are chosen by resistance to stress and wear, and the correct surface quality of the properly selected material is essential for the correct functioning of mating parts, especially in the case of running fits.

The responsibility for the preparation of the component falls upon the designer, who calculates

Assembled Main Spindle of a Capstan Lathe for 6000 r p m (Gear Forward and Reverse Disc Clutches, Bearings, etc)



Balancing Machine for Dynamically Balancing of the Whole Assembled Unit

FIG 105

Although the surface finish produced by a diamond or cemented carbide tool may be fine, vibration at a critical speed will show that there are considerable waves in addition to the normal surface irregularities.

In most cases vibration of the machine can be felt, but the degree of vibration and its influence can best be shown by pen records from a surface analyser (Fig 106) The units and terms—micro-inch, centre line, base line, average and maximum roughness, and bearing area—employed in reading surface records and utilizing data for surface finish may be reviewed briefly—

One micro-inch (one millionth or 0·000001 inch) is the unit used to express all numerical values for surface finish. The centre line is established by finding with the planimeter whether the areas above and below an estimated centre line are equal The symbol h_{ave} denotes the

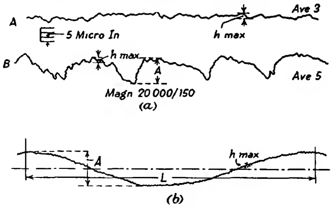


FIG 106

(a) Comparison of—

A *Even Surface* with Fine Roughness h_{ave} 3 mu in, h_{max} 8 mu in

B *Wavy Surface* with Fine Roughness h_{ave} 5 mu in, h_{max} 8 mu in

But with Wave Amplitude A = 32 mu in

(b) *Wavy Pen Record with Fine Superimposed Irregularities*—
Wavelength L = 0 25 in Amplitude A = 375 mu in = 000375 in
Roughness R average = 5 5, h_{max} = 30 mu in
Elektron Cylinder 4½ in dia , 10 in long
Feed = 0 0025 in /rev , Speed 1050 f p m.
Depth = 0 003 in Fine-turned with Cemented Carbide-tipped Tool.

dimensions, chooses the material, and decides fits and tolerances In some cases, a vague note on the drawing indicates that a surface shall be free (rough), semi-fine, or fine-finished.

The drawings now pass to the workshop, where the job is finished by fine turning and boring, grinding, scraping, honing, lapping, and by the new superfine methods of "micro-finishing" or super-finishing. Usually the inspector accepts a component after examining the surfaces by sight and touch, rarely is the surface finish actually measured, and the fitter fits the mating parts as well as he can with file, scraper, and emery cloth If the machine is run-in under careful control before dispatch, the user may be able to run it immediately under full load and at a maximum speed without trouble

Confidence in the experience and reliability of the fitter is typical of trial-by-error methods. For instance, the front bearing of a new lathe may give trouble for weeks, the only remedy being to increase the running fit from close to easy, thus losing precision of guidance and creating conditions resulting in vibration at critical speeds.

Turning and boring lathes are run at high speeds between 300 and 6000 r.p.m., and unless the design is very good and the rotating parts are dynamically balanced (Fig. 105) even the simplest machine will show vibration at critical speeds.

average deviation of the pen record from the centre line upward and is the standard value used in this country for average readings. The symbol h_{rms} is used in the U.S.A and can be compared with the h_{ave} readings without perceptible error.

The symbol h_{max} is found by drawing two parallel lines (the base lines) which enclose the crests and the troughs, but exclude any unusual accidental deviations. The area of metal above the base line of which h_{ave} is the average height is found, and compared with the total area to give the form-factor. This factor is often used, because it is related to the bearing area before the wear-in period begins

It is also necessary to ascertain the "lay," i.e. whether the movement of the mating parts is in the direction of cut or across the feed. The slide-ways of a lathe carriage on the bed, or of the table on the bed, of a planing machine, or the teeth of two spur- or bevel-gears, make much better contact with each other and wear much less if the direction of movement is parallel to the action of machining. The table on a planer bed, planed bevel-gears, shaped spur-gears, and so on, slide on each other in this way, while the turned or ground journal of a spindle and its fine-bored bearing, slide on each other on helical feed curves (turned or ground). The pen records from a ground cast-iron surface show the great differences in the results obtained if the surfaces are investigated across and along the feed, differences of 50 per cent in roughness being observed

In view of the wide range of machine tools it is rather difficult to prescribe a definite quality of finish; the demands of different users vary considerably. The machine must always be capable of producing a fine-finished work-piece without vibration marks, which conforms with the desired limits of dimensional accuracy.

The "Report on Surface Finish" contains much reliable data on surfaces which are turned, milled, planed, scraped, ground, honed, lapped, super-finished. Readings were made with the following types of surface analysers. (1) Profilometer, (2) Talysurf, (3) Brush Surface Analyser, (4) Zeiss Photomicroscope. The parameter for all instruments was the micro-inch, either as r.m.s. or average value or as maximum deviation (Zeiss) The results of some years' practical experience in this country are compiled in Table XLV.

Fine surface quality can only be obtained with a small section of chip, high speed and very resistant hard tools, cemented carbides, diamonds or abrasives For finish-turning mild steel with carbides, e.g a cross-section of chip of 0·002 in. to 0·004 in , feed × 0 004 in to 0·008 in. depth, is

TABLE XLV A

PROPOSED SURFACE QUALITIES FOR THE MOST FREQUENTLY USED MACHINING OPERATIONS

Machining Operation	h_{ave} micro-inches
1 Preliminary finish turning	64–125
2 Finish turning, good ordinary lathe	32·1–63
3 Fine turning—	
(a) Ferrous metals	16·1–32
(b) Non ferrous metals	
(1) carbide tools	4·1–16
(2) diamond tools	1·1–8
4 Commercial boring (boring bar)	16·1–32
5 Fine boring (and reaming)—	
(a) Ferrous metals	8·1–16
(b) Non-ferrous metals	
(1) carbide tools	4·1–8
(2) diamond tools	0·5–4
6 Commercial grinding (unhardened and hardened pieces)	16·1–32
7 Fine grinding—	
(a) First-class	2·1–8
(b) Second-class	8·1–16
8 Superfine grinding—	
(a) Masters, ordinary gauges	1·1–4
(b) Slip gauges	0·3–2
9 Refined surfaces (hardened and un-hardened)—	
(a) Lapping	0·2–4
(b) Honing	0·5–8
(c) Superfinishing	0·2–4
10 Milling—	
(a) Commercial	32·1–63
(b) Fine	16·1–32
11 Planing—	
(a) Commercial	16·1–63
(b) Fine	8·1–16
12. Reaming—	
(a) Commercial	16·1–32
(b) Fine	4·1–16
13 Broaching—	
(a) Commercial	16·1–32
(b) Fine	4·1–16
14 Gear Cutting—	
Rotary milling (round involute)	32·1–63
Hobbing (round involute)	16·1–32
Shaving (round involute)	16·1–32
Shaping, planing (round involute)	16·1–63
Grinding (generating) (round involute)	16·1–32
Form Grinding	8·1–16
Lapping	4·1–8

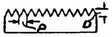
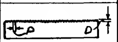
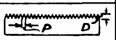
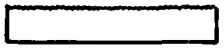
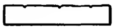
MACHINING OPERATION	DIAGRAM OF SURFACE SHAPE	FEED		DEPTH D mu. in.	CLASS OF ROUGHNESS	TOLERANCES FOR STANDARD HOLES CLASS B—in.	
		P = Pitch in.	D = Depth in.				
Finish Turning		0·002 to 0·010	0·000025 to 0·000400	25 to 400	5 to 9	dia of hole	max. tolerance
Diamond Turning and Boring		0·0001 to 0·002	0·000003 to 0·000016	3 to 16	2 to 4	0·25 0·5 0·75 1·0 1·5 2·5 3·0 4·0 5·0 10·0 20·0	0·0003 0·0004 0·0005 0·0006 0·0007 0·0008 0·0009 0·001 0·0011 0·0016 0·002
Commercial Grinding		0·0005 to 0·002	0·000016 to 0·000125	16 to 125	5 to 7		
Fine Grinding		0·0001 to 0·002	0·000003 to 0·000016	3 to 16	2 to 4		
Honing		regular single scratches	0·000002 to 0·000030	2 to 30	2 to 5		
Lapping		irregular fine criss-cross scratches	0·0000008 to 0·000010	0·8 to 10	0 to 4		
Superfinish		fine random scratches	0·0000005 to 0·000008	0·5 to 8	0 to 3		

TABLE XLV B

COMPARISON OF FEED AND DEPTH SCRATCHES WHICH CAUSE SURFACE ROUGHNESS WITH THE TOLERANCES OF VERY ACCURATE (CLASS B) PIECES

to be recommended, for non-ferrous metals a feed of 0·001 in to 0·002 in, a depth of 0·002 in to 0·004 in, might be used with carbides or diamonds In both cases coolants are helpful

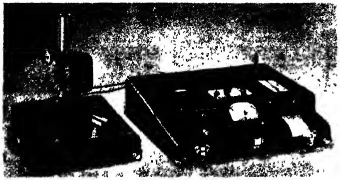
The Profilometer (Physicists Research Department, Ann Arbor, Mich, U S A) (Fig 107) represents the Pioneer surface-meter for the workshop it is designed as a very light transportable instrument. It can be carried to any place, and put on the work-bench, on the machine, or in the inspection department Generally the Profilometer provides only "average" readings (h_{rms}) determining the roughness of the surface without producing conclusions as regards the waviness. The latest development is to use a *skidless* measuring head for gear teeth and other difficult accessible shapes. For measuring exceptionally smooth surfaces with roughness ranging from 0·25 to 1 μ in. a one micro-inch scale can be supplied. The newest type "Proficorder" allows the taking of pen records also.

The Brush Surface Analyser (Fig 108) (The Brush Development Co., Cleveland, Ohio) requires

(E J Abbott-Ann Arbor, Michigan)

FIG 107 THE PROFILOMETER

the pieces to be transported to the instrument It furnishes only pen records no meter readings



(*Brush Development Co., Cleveland, Ohio*)

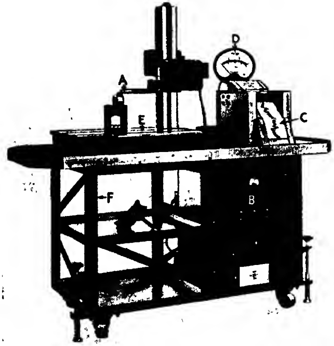
FIG 108 THE BRUSH SURFACE ANALYSER

and has also a special attachment for fine-ground, honed, lapped, etc., surfaces reading down to 0·25 μ in.

The Talysurf (Fig. 109) made by Taylor, Taylor, & Hobson, Leicester, England, allows both pen records and average readings to be made, which form a very useful combination for measuring and showing both waviness and roughness.

If heavy pieces, e g. steel rolls of one to three tons weight, are to be checked for surface fineness the measuring head of the Talysurf can be transported to the piece, allowing the surface to be checked by pen records or meter readings without removing the roll from the bearings. The whole procedure from lifting the stylus up from the column, placing it on the specimen, taking the measurement, and returning it to its place, does not take more than three to four minutes This method is preferable because it checks the end effect of the whole machining process by comparable figures under normal cutting conditions.

The transportable Zeiss-Schmaltz Photomicroscope (Zeiss Werke-Jena) (Fig. 110 (*a*)) allows the maximum heights (crest to valley) to be measured to 0·00025 mm = 0·000010 in. and photosections to be taken of the surface roughness by the light-slit method (Fig. 110 (*b*)). It is the only optical



(*Taylor, Taylor & Hobson, Ltd., Leicester, England*)

FIG 109. TALYSURF

A Analysing Head
B Calibrating Amplifier.
C Inking Pen Records
D Average Meter
E Surface Plate with Column.
F Trolley

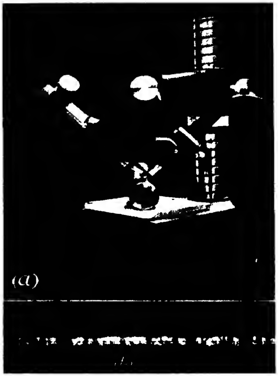


FIG 110. (*a*) ZEISS-SCHMALTZ PHOTOMICROSCOPE (*b*) LIGHT-SLIT PHOTOSECTION

instrument not scratching the surface explored, while the other three use a diamond or sapphire stylus as a feeler, but it cannot measure surface roughness finer than 10 μ-in of h_{max} corresponding to h_{ave} between 2 and 3 μ-in (about three to five times the average).

Measuring the surface quality as a dulling criterion instead of measuring the increase of cutting power by a dynamometer, which requires a certain movement of the tool, is very elucidating and can be recommended for checking finishing operations; further, it corresponds to workshop practice. The instruments mentioned were developed to provide inspectors with a reliable means for really measuring minute roughness.

Table XLVB shows a comparison of the pitch and depth of feed scratches measured by surface analysers in comparison with the magnitude of tolerances for standard holes of the most accurate class B. Consequently, neither running, transition, nor interference fits are influenced by surface-finish irregularities between 8 and 16 μ-in., which is the ordinary upper limit for grinding and fine-turning processes. (See Table XLVI.)

It is agreed that data must be available to enable the knowledge of the necessary surface finish to be applied to practical requirements, i.e. to the function of mating parts, but it is not essential that the finest possible finish, down to zero micro-inches, should be strived for as an aim, irrespective of the use to which the surface is to be put. "Good enough" should be the watchword of production, both for the surface finish and the dimensions of a part

TABLE XLVI

WORKING CONDITIONS AND PERFORMANCE OF FINE-FINISHING ABRASIVE OPERATIONS

F O 6

	GRINDING	HONING	MECHANICAL LAPPING	MICRO-FINISH BY HONING	SUPER-FINISHING
Surface finish μ in (r m s or average values)	From 1 (fine) to 32 (commercial)	From 1–8	From 0 5–5	From 0 5–5	From 0 5–5
Appearance	Parallel lines (sharp)	Cross-hatched lines (semi-sharp)	Random ridges, smooth	Cross-hatched fine lines (smooth)	Random lines (smooth) for plain surfaces of some regular pattern for cylinders
Movements of (a) abrasive, (b) work, mechanically and/or hydraulically driven	Rotating abrasive Rotating } Work Oscillating } (e g cylinder)	Rotating } Abrasive Oscillating } Resting work (e g cylinder)	Rotating and reciprocating { Lap and work (e g wrist pin)	Rotating and oscillating hone Work at rest (e g bore)	Rotating and/or oscillating work Rotating and/or reciprocating tool (e g plane)
Rotative speed of abrasive (surface ft/min)	4000 7000	150–500	30–90 (for plane surfaces)	100–300	3–50 (5–20 preferred)
Rotative speed of work (surface ft/min)	30 60	None	20–75	None	Roughing, 10 40, finishing, 30–60
Rate of reciprocation	Continuous motion, 1/10 to 3/4 width of abrasive wheel	30–100 reversals per min	30–90 reversals per min	30–100 reversals per min (long stroke)	300 -3000 reversals per min (crank motion preferred)
Abrasive tools	Circular bonded grinding wheel	Expanding honing sticks (1 to 6 sticks)	Two parallel lapping metal discs, loose abrasive	Honing of 1 to 6 expanding sticks	1 to 6 expanding sticks (long and wide)
Lubricant or coolant	Coolant 1/40 emulsion	Lubricant (oil of low viscosity)			
Contact of tool (cylinder)	Line contact of cylinder Small part of face	Contact of (1 to 6) surfaces (cylinder) Line contact of planes	Line contact of planes	Surface contact of cylinder or plane	Wide surface contact, automatic cessation on full coincidence of abrasive and work cylinder or plane
Pressure (lb/sq in)	2000–20,000	500–1000	Up to 1200 (for low-finishing)	50–100, but multiplied by wedge action	1–30 internal 3–50 external (3–20 lb preferred)
Working temperature (° C)	180° up to 2000° (burned steel)	20–40	20–40	10–20	Not perceptible
Material removal— (a) Dimensioning (b) Finishing (in)	0 010–0 015 0 003–0 0002	0 002–0 015 0 001–0 0002	Very small 0 0003–0 0001	0 0005–0 001 0 0001–0 00002	Very small 0 0001–0 00005

It is known that on first-class diamond lathes, having properly adjusted faceted diamond tools with blended corners, trained girls can turn aluminium piston skirts with a finish of 1·5 to 4 micro-inches, for months.

Fig 111 shows vibrogram records of horizontal vibration perpendicular to the main spindle. The upper line in each case shows vibrations The castellated line shows time marks for 0·1 second per division. The machine ran very smoothly at 710 r.p m and fairly smoothly at 2,120 r p m. but had periodicity at 1070 r p m Therefore it cannot produce good surfaces between 1000 and 1200 r p.m. The foreman must know of such a deficiency, and must either have the machine reconditioned or take care that the vibrating speeds are not used by the operator

In surface-finish measurement, quality steps are proposed which will probably be accepted by the British Standards Committee, they correspond with the American standardized steps and are as given in the Table at foot of next column, but the American standard begins with a step finer from 0·25 to 0·5 μ-in.

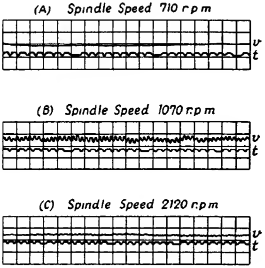


Fig 111

Vibrogram Records v, Time Marks t
A, C Smoothly-running Machine, B Periodicity (vibrations)

Table XLVI is based on the experience of the last five years with mating parts manufactured by ordinary practice and carefully measured.

Surfaces above 125 micro-inches are not measured with fine measuring instruments, for a value of 126 micro-inches represents fairly rough surfaces, while really rough surfaces, which can be estimated satisfactorily by appearance and touch, begin from 250 micro-inches.

Spindle journals and bearings should have very fine surfaces, and lapping, honing, micro-honing,

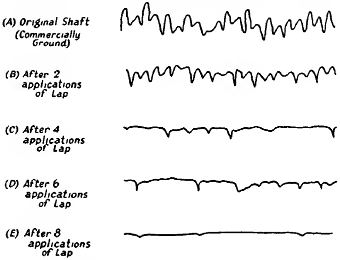


Fig 112 Repeated Lapping Actions Increase the Bearing Area of Surface

and super-finishing are, in the author's opinion, the most suitable processes for these highly important components. Fine surfaces, with roughness of from one to three micro-inches, ensure the formation of an oil wedge and uniform oil films, and so enable fine oils of low viscosity to be used in bearings without oil grooves and with a maximum of bearing surface. Fig. 112 illustrates the favourable effect of repeated lapping actions

A similar case is presented by the measuring surface of snap gauges, sold for commercial,

Step	h_{ave} (micro-in)	Step	h_{ave} (micro in)
1	0·5– 1	7	32·1 – 63
2	1·1– 2	8	64 – 125
3	2·1– 4	9	126 – 250
4	4·1– 8	10	251 – 500
5	8·1–16	11	501–1000
6	16·1–32	12	1001–2000

second-class, and close limits These fine measuring instruments should retain their accuracy during a long life, and the more expensive fine-lapped gauges for close limits are not only justified economically, but provide the only means of maintaining the production of interchangeable parts by unskilled labour. The extra cost of fine-lapped surfaces is outweighed several times by the increased life due to the reduction of gauge wear and to the ease with which good gauges can be repaired by chromium-plating the worn surfaces.

The advantages and disadvantages of ground and scraped surfaces are well known. For batch and quantity manufacture the grinding process is more and more replacing the slow hand-scraping process, in order to eliminate the difficult and expensive work of the scrapers An examination was made of components of radial drills supplied by a well-known manufacturer who had replaced scraping by grinding on all sliding surfaces It should be noted that on the radial drill the guide ways are mainly used to adjust the drilling spindle and not to produce parallel plane surfaces, furthermore, with ground surfaces not only is the quality of the machine improved but the labour cost is also reduced considerably This manufacturer has provided figures showing that the hours of labour required on the commonest type of radial drilling machine were reduced from 170 to 80 by making a more extensive use of grinding, and by more accurate manufacture of the individual components and of the complete machine.

The ordinary classes of manufacturing produce, of course, quite different degrees of surface quality, which ought to be known to designer, foreman, and inspector, in order to obtain the desired quality a short review may distinguish action and result.

Single-point Tools

The production of uniform fine surfaces with single-point tools is only possible if the formation of built-up edges is avoided. The finishing chip must be of pure flow type and the tool must remain in permanent contact with the specimen (see Negative Rake, p 181). Because little heat is created on the piece, if finished under correct cutting conditions, as the chips carry the heat away, a moderate amount of adhesive lubricant often suffices to keep the top surface of the tool clean This is particularly essential for soft non-ferrous metals Even the highly-polished diamond tears the surface if a particle of material rests for only a split second on its cutting edge

Multiple-point Tools

The hand-reamer and cylindrical broach produce bores of fine quality from 4·1 to 16 average, but they require very careful use, all teeth (unequal pitch) must cut simultaneously, and in the case of reamers, axes of piece and tool must be perfectly aligned

Neither the twist drill nor the milling cutter, under ordinary working conditions, produces surfaces which are finer than 32 1 to 63 average The twist-drill must be ground symmetrically and concentrically to the taper shank, and the point must be kept in perfect cutting condition The machine-spindle must run true with the axis of the drill and yet, in spite of this, the active portion of the actual drill body is so flexible that it follows the irregularities of structure and of the flaws of the material. The milling cutter must run true on its arbor, when inserted in the main spindle, with not more than 0·0010 in eccentricity, and must be ground carefully to avoid ' thick teeth " Face-milled surface can be made as fine as 8 μ-in.

Abrasive Tools

It will be instructive to review the characteristics of the various abrasive processes in actual use. Table XLVI shows the typical differences between the processes and the degrees of roughness attainable In all cases the three essential conditions were observed, i.e. (1) high accuracy of the geometrical form, (2) dimensions within very close limits, and (3) high surface quality

The grinding machine, with fast-rotating abrasive, has been recognized for many years in its several forms as the only standard machine tool suitable for removing an appreciable amount of stock from a piece of work and at the same time producing the required accuracy of dimension and acceptable surface finish To-day, commercial grinding (16·1 to 32 average) can be followed by fine grinding (2 to 8 μ-in. average) and completed by other methods, such as honing, so as to produce accurate form and exact dimension (with 8 to 32 average) as a basis for the creation of any fine degree of surface finish. (See Table XLVA.)

It will be useful to give definitions of the modern fine-grinding, boring, and super-finishing methods, all of which use positively-guided tools and work-pieces.

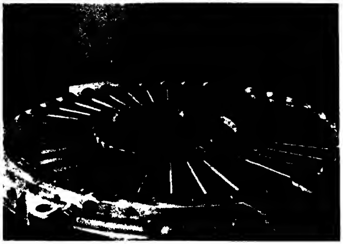


FIG 113 LAPPING OF 32 CYLINDRICAL VALVE STEMS SIMULTANEOUSLY

(1) *Fine Grinding.* The usual well-known grinding process remains unchanged, but the refinement of surface is accomplished by successively grinding with finer wheels and lower speeds (1·500 to 2·500 f.p.m.) and longer dwell. Each grind is intended to remove less than the depth of grain cut on the previous layer, thus it is finally possible to obtain mirror finish.

(2) *Honing.* This is a method of moving fine-grain bonded abrasive to and fro, combined with a twisting motion, on a pre-machined surface of specimen, exerting the necessary pressure to produce a smooth, but not necessarily bright surface. Up to 0·015 in. can be economically removed from the surface of the work-piece by ordinary honing and up to 0·001 in. by micro-honing, so that the marks of the preliminary machining, turning, boring, fine-turning and boring or grinding, can be completely removed. The tools are adjustable, but rigid during the honing action.

(3) *Superfinishing* is a method of moving a bonded abrasive to and fro on a pre-machined surface with less pressure and less speed than in any other refining process, so as to avoid any heat or destruction of the texture of the work-piece. It stops automatically when the grinding pressure becomes less than the specific resistance of the surface against penetration of grit.

(4) *Mechanical Lapping* is a production method in which the work-piece and the tool glide along each other without positive guiding. A loose abrasive and a light lubricant are used, and the direction of attack is constantly changed The shape of the tool-face and the movement of the tool should be so chosen that the perfect form of the tool is retained as long as possible in order to produce the maximum number of work-pieces of accurate shape and dimension and fine finish. Flat and cylindrical work-pieces can be economically produced on lapping machines which have two horizontal discs, usually made of heavy cast-iron

TYPES OF LAPPING MACHINES

Two different types of lapping machines are in general use, i e. with one stationary and one rotating lapping disc, and with two rotating lapping discs which move in opposite directions. The work-pieces, mounted in a special work-holder, are placed upon the lower lap, the upper floating plate is lowered until it rests on the work, and the machine is then set in motion. The amount of eccentric movement imparted to the work-holder (Fig. 113) may be varied to suit the conditions imposed by the shape and size of the work-piece. The disposition of the work in the holder in conjunction with its eccentric movement produces a combined sliding and rolling motion which causes the work to cover the entire surfaces of the laps to keep them plane (random pattern).

That the main difference between external honing and mechanical lapping is one affecting the tools only is shown by the "B S.A." lapping and honing machine (Fig. 114), which is convertible from one method to the other by replacing the cast-iron laps by top and bottom hones of bonded abrasive.

Chipless Forming

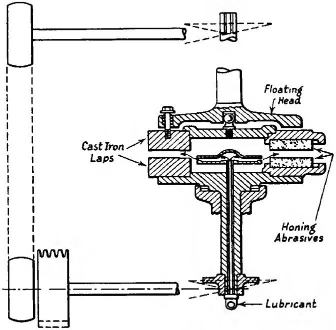
One of the most important of the chipless forming operations is that of "drawing" sheet metal into cups, lids, shells, etc, by the press; often, the external surfaces produced by this operation have visible ridges parallel to the punch action while the internal surfaces are very fine. This process is used for quantity production to close dimensional accuracy. Measurements of the surface in the linear direction of the cups are usually between 32 and 125 μ-in., i.e. fairly rough. To measure around the periphery is useless, because many lids of cans are deliberately "corrugated" to facilitate their removal The internal tin-coating of the boxes covers the ridges produced by the drawing action and protects them against corrosion and, consequently, the internal finish of the tinned surface is often very fine, between 4·1 to 8 micro-in average.

Rolling, as a cold-finishing process, is used in steel mills to give certain work-pieces a very fine surface, reducing the thickness by squeezing out the material in the length direction. As an example of this process, steel bands for razor blades are mentioned. The surface quality of the strips was measured across and along, the average readings were fairly uniform from 2·6 to 3·2 for a dull, and from 0·6 to 1 μ-in. for a bright blade quality. As these surfaces are produced by ground and lapped rolls in a continuous process, it is concluded that the surfaces of the ground and lapped rolls themselves were very fine.

Chatter and its Elimination

No machine tool will be accepted unless the test piece made by the final performance test is free from vibration marks. No good surface can be produced unless the machine tool is free from chatter.

Chatter is vibration between tool and work, sufficient in magnitude to cause a perceptible irregularity in the tool mark on the finished surface. Its frequency appears to be determined by the frequency of pulsation of the cutting pressure and the natural vibration frequency of the work, tool, and machine. Its severity is undoubtedly determined by the degree of resonance between periodic variations in the cutting force, and the natural frequencies of the work, and of the structures supporting the work and tool It is known that the presence of chatter makes a high-quality machine surface impossible but its effect on cutting speed is uncertain. Severe chatter tends to cause excessive wear on the tool.



(B S A Grinding Machine Co, Ltd, Birmingham)
FIG 114 CAST-IRON LAPS (LEFT) WITH LOOSE ABRASIVE HONES OF BONDED ABRASIVE (RIGHT)

feed screws, and bearings of the machine, and to loosen all fastenings.

Causes of Chatter

Chatter is affected by several variables · (1) material cut, (2) chip proportions, as affected by (*a*) depth of cut, (*b*) feed, and (*c*) tool contour, (3) cutting speed, (4) stiffness of work, (5) stiffness of tool, (6) rigidity of machine tool, (7) stiffness of tool support, (8) stiffness of work support, and (9) vibrations caused and multiplied by nature of machine tool and its design, such as the gear conditions, tooth forms, gear ratios.

(1) *Material.* Because the choice of material is usually determined by other considerations than ease of machining, a change of the material cut is generally impossible. Soft materials of low

resistance have less tendency towards chatter than those having high strength. When cutting soft cast-iron it is more difficult to eliminate vibrations than when cutting a medium steel

(2) *Chip Proportions.* A change in the relation between depth and feed, or a change of tool contour. has a marked effect on the tendency towards chatter A change of the angle of approach is particularly effective, at the same time changing the cutting forces, tangential and radial The angle of approach (see Fig. 62*a*) should not be smaller than 45° Further, it has been noted that the relation of depth to feed is decisive, it should be at least 4 1 for roughing. The deeper a chip the less will be the tendency to chatter.

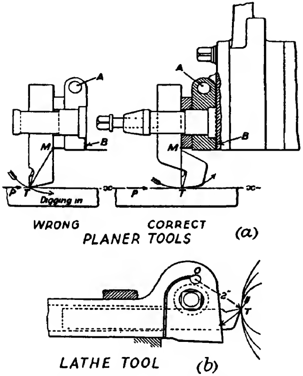


FIG 115. SPRING TOOLS FOR, (*a*) PLANER (*b*) LATHE

(3) *Cutting Speed.* A decrease of speed tends to reduce the severity of chatter, but some experimenters report that an increase had a better effect. There is no other way to eliminate chatter except to make special trials under given conditions.

(4) *Stiffness of Work.* Chatter is affected by the stiffness of the work. Work supported on centres may be quite free from chatter at the beginning and end of the cut, but have considerable chatter midway between the ends. For roughing-cuts a follow rest may reduce or suppress chatter, particularly on long slim work on centres. The use of opposed cutting tools (capstan lathe), taking cuts equal in area, will tend to prevent chatter

Under certain conditions, so-called spring tools or gap-tools are also useful. (Fig 115)

Very often the driver of the work is too weak and too springy Further, the connexion between work-piece and driver is the cause of vibration Chucks with three or four jaws are used with advantage, but care should be taken that all the jaws operate

(5) *Stiffness of Tool* The tool should always be well clamped in the tool-holder with as small an overhang as possible beyond the point of support (See Fig 62*b*)

(6) *Rigidity of Machine Tool* All bearings, particularly the main spindle bearing and the tool slides, should be kept in adjustment with no more freedom than is necessary for proper operation of the machine Little can be done with a machine tool which tends to cause chatter because of an inherent lack of stiffness

(7) *Stiffness of Tool Support* Chatter in turning may sometimes be avoided by setting the nose of the tool above the work centre This gives a steadying effect About 1 to 2 per cent of the diameter would be adequate for this purpose.

(8) *Stiffness of Work Support.* Lathe work on centres should have the centre as tight as possible. If the tailstock has a rotating centre, to facilitate high speed, the clearance of the roller- or ball-bearings ought to be reduced to the utmost minimum. Chucked work should be tightly clamped. Planer and shaper work should be supported for the full length of cut, as nearly as possible under the tool, so as to prevent deformation of the work by the cutting pressure.

(9) *Other Causes of Chatter.* The gear ratios in the machine tool, the choice of prime numbers of teeth, the accuracy with which the gears are cut,

and the natural periodical vibration of the driving mechanism of the machine tool, or of the work, the tool, or the tool supporting structure are all of interest. A heavy lubricant (colloidal graphite) for the gears is often of value in the gear box.

Running a lathe in the reverse direction helps to reduce or even eliminate chatter in a machine with worn gears. This is particularly effective in cutting threads. The reason is that weight and cutting force then act always in the same downward direction and cancel the effect of gear back-lash

CHAPTER XII

The Basis for Ratefixing

Piece-work rates should be based on the actual minutes required to do the job and thus be independent of market prices, wage rates, political difficulties (e.g. war), etc. The times are easily transformed into money by factors which can be adapted to the ever-changing economic and political conditions, and to age, sex, skill, and experience.

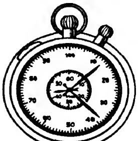


Fig. 116 Stop Watch with Two Pointers (1) Per Single Operation; (2) Total Time

An investigation of any piece-work task rests on three considerations—

1. The method of performing the work.

2. The equipment and accompanying conditions for accomplishing the task.

3. The time required for the performance.

The time required is the all-important consideration, for it is the only measure of production. The tools applied must be installed and kept in effective working order and the method employed must be efficient.

A preliminary standardization both of the tools, jigs, and test gear to be used and of the process to be followed, is the basis, necessary before any standard rate can be established.

The fundamental basis of scientific management is a practical study, predetermining the amount of work that a man can do before he actually begins to do it.

The purposes of the study of unit times are five—

(1) To obtain all the existing information about the trade being investigated.

(2) To get the most exact information regarding the time required to perform each essential element of operation.

(3) To determine which motions and elements are the least fatiguing.

(4) To determine the amount of actual rest that each kind of work requires.

(5) To determine the personal coefficient of each applicant for certain kinds of work.

The taking of time studies calls for an observer —the time-study man—of an analytical type of mind, skilled in the character of the work under observation, without being a technical expert. (See page 67, the unusually well-trained time observers of the "Bedaux" teams, who refuse to propose any technical improvements of the process observed.) He need not be a skilled craftsman or demonstrator, but must be a keen student of human nature

The operator should be a good worker, skilled in the line of activity under investigation, and of somewhat better than average ability.

Time studies as a basis for mass production must be repeated at least ten to twenty times for each single piece, only then can all contingencies and hazards inevitable with a single time observation be excluded The technique of time study is to select a suitable worker, to have a well-trained observer and to make all necessary preparations required for the smooth execution of the work. As a measuring instrument a stop-watch with two pointers is generally used which shows simultaneously the time per single operation and the total time (Fig 116). But time-recording instruments are also in use that record every detail of the observation. These recorders usually show up to fifteen consecutive operations, which is sufficient for most studies, and they give automatic comparisons over a number of timings. Readings are in minutes and tenths or hundredths of a minute.

Time Basis for Piece-work

There are two sources from which to collect time data, viz. (1) recorded experience, (2) time study. Both are complementary. Experience can be gathered only by critical observation. Time study without sufficient experience is useless for the workshop. But there is one great difference. The collection of values by experience is based on *previous* practice. Time study seeks to cover the *present-day* modern methods.

1. Experience

Experience is best preserved in written records, made useful by critical valuation of the main items (see Fig. 117) or by exchange of experience with other experts

If it is mainly a question of manual skill, the time values refer frequently to a combination of machines, implements, and tools With regard to machine work, tables on centring, drilling, milling, and grinding, show practical experience as collected in many good workshops. They give the total time as one figure, i e. they include both the handling time and the machining time, this is the quickest way for the rate-setter, if the tables actually correspond to real working conditions in a workshop. The tables demand long and careful preparation Machining times can be calculated, assuming the cutting speed for a given material, the cross-section of chip and the life of the tool for one hour or for the whole shift. They are elastic, because the increase of speed depends on the quality of the tool, and both the cutting speed and the tool life are gradually improving (See Table XX.) The handling times remain the same for pure handwork with the same equipment

In the majority of cases the handling times predominate, therefore jigs and fixtures for clamping and unclamping the parts, and the chucks to grip and loosen the tools, must be well designed to cut down the auxiliary times to a minimum Here considerable improvements can be made only by improved chucks for tools, and jigs and fixtures for parts and other handling implements such as hoists, chutes, etc.

The full advantages of using the best cutting tool are often lost through deficiencies of the machine tool available. Badly-maintained machines tend to vibrate, and vibration restricts output. Furthermore, the shape of the parts and the limits of accuracy and finish required may necessitate slower or sometimes quicker machining. The values of experience therefore depend also upon the work-pieces and working conditions remaining identical. They are further influenced by the kind of finish · roughing, pre-finishing, finishing, fine and super-finishing, and finally by the working tolerances. It makes a great difference if the accuracy of a work-piece turned on a lathe or ground on a grinding machine must be round and cylindrical within 0·001 in or 0·0001 in. A possible heating during machining of a tube for a telescope, microscope, etc., may demand a reduction of the cutting speed or the feed. Therefore all our tables and graphs apply to the working conditions for a particular workshop only. They can be used to give a general idea as to how such tables are prepared; but the fact must be emphasized that there are no two workshops alike, where identical machining procedures could be established to facilitate the work of the ratefixing department and to stabilize the working conditions and the good relations between employer and employee But the tables do give a solid basis for fruitful discussion between ratefixer, workman, and foreman, when their opinions differ regarding the data of piece-time given on the wages-docket The main objection is that a great many workshops have not sufficient experienced staff in the ratefixing department to ensure that all dockets are sent out with a soundly established piece-time and that there is generally insufficient time, when a new design leaves the drawing office, to detail all the necessary piece-times for the different parts. To make the time studies at such a stage of urgency or to calculate every single operation of a piece is generally impossible; therefore the values of experience established in the Tables XLVIII to LII are invaluable. Doubtful cases with new equipment can be dealt with separately.

The writer has for many years been adviser to a machine-tool factory of 450 workers, where a single experienced ratefixer, with one technical helper and a typist, has set all the working piece-times for more than forty different types of lathes, capstans and combination turret athes, with about 400 to 800 different parts per machine.

It was a strict rule that for every separate operation on the wages-docket the piece-time must be inserted, the principle being that it was always better to have even an approximate piece-time than an uncontrolled hourly rate.

It is essential that the ratefixer should aim at establishing standard conditions which can be repeated at any time in the ordinary course of work, and also the best sequence of events in the conduct of work.

It is a common experience that there is insufficient time between the completion of drawings for a new order and the commencement of work in the shops for adequate time studies to be made for the various new parts involved, e.g. of a machine tool. Therefore the main task of the time-study department (be it only one ratefixer) is to prepare systematic rate-fixing tables or diagrams which enable the department to determine in a few minutes the two essential parts of the piece-time for each operation, namely—

1. The handling time from tabulated experience
2. The machining time by calculation, if the tools are—

(*a*) suitable for the different stages of work, (e g. high-speed steel, super high-speed steel, stellite, cemented carbide). (See Table XX)

(*b*) standardized to shape and material (See Fig. 55 and Table XVIIIA.)

If conditions are standardized in the workshop on the basis of time study investigations the fusion of handling and machining times into one reliable figure is, of course, the quickest solution Then the work of the ratefixer can be done quickly and reliably.

Of the other two groups of factors upon which the timely performance of any piece of work depends, i.e. (1) those within the control of the operator, and (2) those over which he has no personal control, only the first group influences time study This comprises the handling of the work at his machine or bench and the manipulation of the necessary tools and equipment.

The second group covers the supply, quality and quantity of raw material, the tool equipment and all implements with which the worker should be furnished for the effective performance of his work. This is an important duty of management (production control), and it is futile to expect any marked improvement by means of time study of the various operations unless means are provided adequately to control the items of this second group. It must again be emphasized that the work of actual performance and that of management underlie the whole process of manufacture in its every detail and that the two must be harmonized and unified to ensure success

2. *Typical Time Studies*

If the product does not vary in type and character from day to day, operation time studies are helpful. If the product varies frequently it is necessary to determine which of the several elements are to be grouped in building up the various fundamental operations

The time sheet for the simple lever of Fig. 117 shows the analysis of the job as a whole into its elementary divisions.

When the handling of the drilling machine and the actual drilling time are separated, it is seen that the machining times are only 37 per cent of the total time, and that the changing of tools (42·4 per cent) formed the longest operation (as a total). A quick-change drill and reamer chuck, operated without stopping the machine, reduced the tool-changing times from 451 sec to 6·5 sec = 9·2 per cent of the new total of 674 sec per complete cycle from completion of one part to completion of the next A super-high-speed drill reduced the times for drilling the two holes of $\frac{3}{8}$ in. and $\frac{5}{8}$ in. dia to 20 + 30, i e 50 seconds instead of 158 seconds The planning department made these changes by studying the results of the time study and by drawing the correct conclusions

Typical standards for setting the tools of a lathe are—

	Min
Get tool from tool board	0 03
Measure height of tool (centre height)	0 06
Put packing in tool-post	0 07
Put tool in post	0 03
Set tool in position	0 03
Tighten tool-post set-screw	0 08
	0 30

In general the time required for inserting the tool in the tool-post would be entered into the schedule as a single item, viz: 0·30 min.

When the time intervals are extremely small, it is best to group them and treat the combination as a single element. This reduces the possibility of errors in reading and simplifies the application.

Time studies on quick-operating punch and power presses with 150 to 500 strokes per minute may be mentioned as an example, where time studies of single operations are futile and have to be replaced by combination time studies.*

The main difficulty in applying the results of time studies is to introduce an adequate allowance to bring the time for a job into line with the ability of the average operator. This allowance is a percentage of the total of the elementary times that enter into the operation Curves have been derived by C. G Barth† which are a guide to this subject

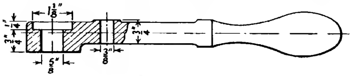
Time study aims, in its broad sense, to establish such a rate of work that the worker will accomplish a maximum output with a minimum amount of fatigue

The fatigue allowance (for lost time, delays, etc) can be kept low by establishing rest periods, or by a change in the monotony of the job; as an average 12½ per cent of the working time may be added as fatigue

In general machine-shop practice the job can be divided into a sequence of elementary operations such as—

1 Preparing the machine for work.
2. Loading work into machine
3. Making work run true
4 Securing work in machine
5. Manipulating machine to set and to start cuts
6. Machining
7 Unclamping and removing work.
8. Restoring machine to normal conditions

Operations 1 to 4 are the acts of preparation, operation 6 frequently involves several repetitions, operations 7 and 8 are the acts of conclusion With the exception of operation 5, which varies considerably according to cutting conditions of work-piece and tool, they form seven fundamental auxiliary operations, the operating time of which can be standardized and used as a fixed component to which is added the variable time for actual machining (operation 5). This enables the ratefixer to speed up the routine work of his task. Of course each improvement of equipment must be taken into account at once, but for this routine



	Single Observations Sec	Sec	Sec	Total sec	Average sec per Piece
Clamping	25	25	25	75	25
Setting jig	30	20	20	70	23
Adjust speeds	12	10	10	32	11
Drilling hole [illegible] in dia	70	60	58	188	63
Change tool	50	20	38	108	36
Drilling hole of [illegible] in dia	95	100	90	285	95
Change tool	195	68	67	330	110
Change jig bushing	28	75	30	133	44
Change of speed	25	16	12	53	18
First reaming of [illegible] in hole	40	20	20	80	27
Change tool	38	40	38	116	39
Second reaming of [illegible] in hole	30	24	18	72	24
Change tool	56	54	52	162	54
Ream [illegible] in hole	65	20	28	113	38
Change tool	106	15	57	178	59
Countersink [illegible] in hole [illegible] in deep	76	86	58	220	73
Change of tool	50	60	48	158	53
Facing surface of small hole	40	42	24	106	35
Change tool	70	36	60	166	55
Facing surface of big hole	35	45	30	110	37
Taking out	50	40	30	120	40
Measuring	130	20	30	180	60
Change tool	40	46	50	136	45
Total					1064

Summary of Main Items	Sec	Per cent	Machining Only per cent
1 Clamping and taking out	65	6 1	
2 Changing jig	67	6 3	
3 Change speed	29	2 7	
4 Drilling	158	14 9	14 9
5 Reaming	89	8 3	8 3
6 Countersink	73	6 9	6 9
7 Facing	72	6 8	6 8
8 Change tool	451	42 4	
9 Measuring	60	5 6	
	1064	100 0	36 9

FIG 117 TIME STUDY OF DRILLING A LEVER

work of adjustment one experienced time-study man, preferably able to act as a demonstrator, is sufficient.

The writer once introduced a feed and speed controller into the machine shop (employing 400 workmen) of a shipyard in Rotterdam, who, as a member of the ratefixing office. checked *every*

* *Die Zeitstudie im Dienste der Kalkulation von Kleinstanzteilen*, Dr Ing Walter Marcus, 1921. Dissertation—Techn Hochschule, Berlin. ("Time Study for the Calculation of Small Stampings," Thesis, Charlottenburg University.)

† Carl D Barth: *Curves of Delay Allowances*

week that the prescribed speeds, feeds and depths of cut were maintained or, if not, noted deviations.

This report (Table XLVII) was countersigned by the works director and it brought to light the amazing fact that some workmen had increased the prescribed speed up to as much as 350 per cent (Lathe No. 219) thereby making 60 per cent piece-work bonus. These earnings were never cut.

The whole time-study work of a machine shop should be closely connected with the rate-fixing department as it improves production and speeds up delivery, i.e forms part of the production control. Only then will time and motion study lose the halo of theory which it has acquired since Taylor and Gilbreth made it the corner stone of scientific management

Conclusion

Time studies are tests systematically made in order to establish the time for a cycle of operations under given circumstances. The basis of the observation is the subdivision of the cycle into its elements according to their time sequence. It may occur, particularly when the operator serves several machines, that handling and machining times overlap (see Figs. 145 and 147) In such cases generally only the total time is observed. How far the subdivision of a job should be made depends upon the economic results in any single case. Excessive subdivision should be avoided On isolated jobs or on small batches it may easily happen that the worker has finished his work before the ratefixer has completed his time study.

Depending on the grade of subdivision necessary, time studies may be divided into three classes—

1. Operation time study.
2. Group time study
3. Studies of the entire operation time.

1. Here the time of the single operation, handling or machining, is measured. Very small operating times are combined

2 Group observation means that single operations are not observed. Whole groups of movements or machining operations are combined This shortens the time study and facilitates the work of the operator

3. Only the total time is measured to perform one or several pieces without subdivision into single operations, such as handling and machining times An example is the operation of automatic machines This is only a makeshift method which cannot be used as basis for a correct ratefixing.

TABLE XLVII

CHECKING CHART FOR RATEFIXING OFFICE. CHECKED BY SPEED DEMONSTRATOR

Inventory No	Kind of Machine	Year of Purchase	Country of Origin	Material	Ratefixing Office (Data of Wages-docket)			Checked by Speed Controller (Ratefixing Dept)		
					Speed v, ft/min*	Feed f, in /rev	Depth d, in	Speed v, ft/min*	Feed f, in/rev	Depth d, in.
395	Lathe	1917	U S.A.	Cast-bronze (soft)	350	0 002- 0 004	0 1 0 2	260	0 03	0 18
386	,,	1917	,,	Hard phosphor-bronze	300	0 002–0 004	0 08–0 15	420	0 015	0 03
378	Vertical boring mill	1916	U S A	Cast-bronze (soft)	350	0 002- 0 004	0 08- 0 15	660	0 016	0 0375
377	do.	1926	,,	,, ,, (hard)	200	0 002–0 004	0 08–0 2	240	0 020	0 125
219	Lathe	1937	U.S.A.	Steel, 35 tons tensile strength	260	0·015	0 08–0·15	950	0 003	0 08
279	Turret lathe	1937	England	Cast-iron (soft)	350	0 025	0·15	350	0 025	0 16
268	Lathe	1937	Germany	Steel, 40 tons per sq in. tensile strength	275	0 02	0 20	420	0 015	0 20
286	,,	1938	U.S.A	Normalized steel, 40 tons per sq in tensile strength	250	0 015	0 06–0 12	460	0 01	0 03

* Cemented carbide-tipped.

Service of Several Machines by One Man

When working in big batches or on mass-production, thorough and repeated time studies are necessary, in some cases even motion studies, in order to find the accurate "cycle" time for single or combined operations. For that purpose the whole manufacturing plan must be laid out so that the single operations can be investigated independently from each other Theory is of little value as the result depends too much upon practical example. Each worker's acts and motions must be set down, analysed, and modified, until the fullest use of the plant is obtained (See page 271)

Several weeks or even months may be required to lay out the production lines for, say, bicycle tyres or for cylinder blocks for motor cars If a motor-car firm is changing over from one pattern to another it is sometimes necessary to close down the works for a period until the new manufacturing line is ready.

Transformation of Time Studies in Practical Tools for the Immediate Use of the Planner and Ratefixer

Effective time studies on machining ought to result in the preparation of data quickly applicable to the needs of the planning department This would be to the benefit of the production workshop performing any continuous repetition programme. This aim can only be reached if tables are compiled for centring, turning, drilling, planing, milling, grinding, etc , on the basis of systematically collected experience, supplemented by time studies, which enable the ratefixer, by taking the dimensions from the drawing, to ascertain quickly the correct time permissible for the workshop, bearing in mind the nature and condition of the existing machines.

Calculation tables of this kind are really correct only for the workshop for which they are made, for they follow its characteristics, but they may be used for any modern shop with adequate modifications. In any case they exemplify the trend towards the practical use of time studies.

1. *Centring* Shafts, spindles, pivots, etc., must be centred on a centring machine on both sides for batch manufacturing. Times are given in Table XLVIII.

TABLE XLVIII

CENTRING BOTH SIDES OF SHAFTS ON A CENTRING MACHINE

Diameter in	Length in in										
	4	8	16	24	32	40	60	80	100	120	160
	Time in Minutes										
1	2·5	2·5	2·5	3	3	4	4·5	—	—	—	—
1½	3	3	3	4	5	5	6	7	8	9	—
2	3	3	4	4	5·5	6	7	8	9	12	13
3	4	4	5	5	7	8	8	9	11	12	14
3½	5	5	6	8	9	10	12	13	13	13	15
4	5·5	6	7	9	10	13	13	14	14	14	15
5	6·5	7	8	13	13	13	14	14	15	15	17
6	—	10	13	14	14	14	15	16	17	18	20

The times above the steps include clamping and taking out by hand, those below the step require a helper and often a crane for handling long and heavy pieces. Setting-up the machine will take between five to fifteen minutes according to size and work.

EXAMPLE. Piece of 3 in. dia , 40 in length, weight about 75 lb, of a batch of five pieces, takes eight minutes machining time per piece

2 *Drilling Holes in Pieces* with cored centre (Table XLIX).

EXAMPLE Cast-iron piece with cored hole 2 in diameter, length of piece 6 in , machining time 5·5 minutes.

3 *Milling* Table L shows ratefixing values for facing, slab, shank, and angle milling cutters, all made of tungsten high-speed steel with cutting speeds of 50 f p m for cast-iron, 65 f.p.m. for malleable iron, and 80 f.p.m. for semi-hard steel of 35 to 40 tons/sq in. tensile strength The finishing cuts were usually taken with 0·040 in depth, the width varied with the shape of the piece: for the feed per minute the maximum was chosen which the machine allowed without showing chatter marks The finishing feed depends much upon the quality of the cutting edges and the strength of shank or milling arbor: the machines were strong enough for even higher speeds, but then they vibrated.

Two average roughing cuts of 0·15 in and 0·3 in. might be taken depending on the material

TABLE XLIX

Machining Times in Minutes to Drill (only) Holes in Cored Cast-iron Bodies

Serving one machine

Diameter of Hole

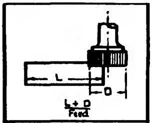
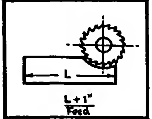
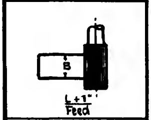
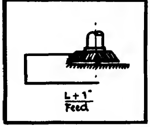
Length of Hole

In	⅜ in to 9/16 in	⅝ in to 11/16 in	¾ in to 1 in	1 in to 1⅛ in	1 3/16 in to 1 5/16 in	1⅜ in to 1½ in	1 9/16 in to 1⅝ in	1 11/16 in to 1⅞ in	2 in to 2 1/16 in	2⅛ in to 2 3/16 in	2¼ in to 2½ in	2 9/16 in to 2 11/16 in	2¾ in to 2⅞ in	2 15/16 in to 3⅛ in	3 3/16 in to 3½ in	3⅝ in to 4 in	In
0.4			0.7	0.7	0.8	0.8	0.9	0.9	1	1	1.1						0.4
0.8			0.9	0.9	1	1	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.6	1.8	0.8
1.2			1	1.1	1.2	1.3	1.4	1.5	1.5	1.5	1.6	1.6	1.6	1.8	1.9	2.1	1.2
1.6			1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	1.9	2	2.2	2.4	2.6	1.6
2.0			1.4	1.6	1.7	1.8	2	2.1	2.2	2.3	2.3	2.4	2.4	2.4	2.6	2.9	2.0
2.4			1.7	1.9	2	2.1	2.3	2.4	2.4	2.5	2.5	2.6	2.7	2.8	3.1	3.5	2.4
2.75			2	2.2	2.3	2.5	2.6	2.7	2.7	2.8	2.9	3	3	3.2	3.6	4	2.75
3.25			2.3	2.5	2.7	2.8	2.9	3	3.1	3.2	3.2	3.3	3.4	3.7	4.2	4.5	3.2
3.5			2.4	2.7	2.9	3.1	3.2	3.3	3.4	3.5	3.5	3.7	3.8	4.2	4.6	5.1	3.5
4.0			2.7	2.9	3.2	3.3	3.5	3.6	3.7	3.8	3.9	4	4.2	4.6	5.1	5.5	4.0
4.3			2.9	3.3	3.5	3.7	3.8	3.9	4.1	4.2	4.3	4.3	4.6	4.9	5.4	6.1	4.35
4.75			3.1	3.6	3.8	4	4.1	4.2	4.3	4.5	4.6	4.7	5	5.4	6	6.7	4.75
5.0			3.4	4	4.3	4.3	4.5	4.6	4.7	4.9	5	5.2	5.5	5.8	6.4	7.1	5.0
5.5			3.7	4.3	4.5	4.7	4.9	5.1	5.2	5.4	5.6	5.7	5.8	6.2	6.7	7.7	5.5
6.0			4.1	4.5	4.8	5	5.2	5.4	5.5	5.7	6	6.1	6.2	6.4	7.3	8.1	6.0
6.25			4.3	4.8	5.1	5.3	5.5	5.7	6	6.2	6.4	6.5	6.8	7	7.5	8.7	6.25
6.75			4.6	5.1	5.5	5.7	5.9	6.1	6.5	6.7	7	7.3	7.5	7.7	8.2	9.4	6.75
7.0			4.9	5.4	5.8	6	6.3	6.5	6.8	7.1	7.5	7.7	7.9	8.4	9.1	10	7.0
7.5			5.3	5.8	6.2	6.5	6.7	7	7.3	7.6	7.9	8.2	8.6	9.1	9.8	10.6	7.5
8.0			5.8	6.3	6.7	7	7.3	7.5	7.8	8.1	8.5	9	9.4	9.9	10.5	11.2	8.0
8.25			6.4	6.8	7.2	7.5	7.8	8	8.4	8.8	9.2	9.6	10.2	10.8	11.4	12	8.25
8.5			6.9	7.4	7.8	8.1	8.4	8.7	9.2	9.6	10.1	10.6	11.1	11.8	12.3	13	8.5
9.0			7.5	7.9	8.3	8.6	8.9	9.4	9.9	10.5	11	11.5	12	12.5	13.2	14.1	9.0
9.5			8	8.5	9	9.2	9.6	10.1	10.7	11.2	11.7	12.3	12.9	13.5	14.1	15.2	9.5
10.0			8.6	9.1	9.5	9.8	10.4	11	11.5	12	12.8	13.1	13.8	14.2	15.2	16.1	10.0
10.25				9.7	10.2	10.8	11.5	12	12.6	11.3	14	14.5	14.9	15.5	16.3	17.2	10.25
10.5					11.2	12	12.6	13.1	13.8	14.5	14.9	15.3	16	16.8	17.3	18.4	10.5
11.0						13	13.6	14.2	15	15.4	15.9	16.4	17	17.8	18.6	19.5	11.0
11.5							14.6	15.2	15.9	16.4	16.9	17.3	17.9	18.7	19.5	20.6	11.5
11.75							15.5	16.3	16.9	17.3	17.8	18.4	19	19.9	20.5	21.7	11.75
12.25							16.4	17	17.5	18.2	18.8	19.4	20.3	21	22	23	12.25
12.5							17.1	17.7	18.5	19	19.9	20.5	21.2	22.3	23.3	24.2	12.5
13.0							17.8	18.8	19.3	20.1	21	21.8	22.5	23.6	24.5	25.5	13.0
13.25							19	19.9	20.5	21.4	22.2	23	23.9	24.8	25.9	26.9	13.25
13.75							20.2	20.8	21.7	22.5	23.4	24.3	25.4	26.4	27.5	28.3	13.75
For each ¼ in. longer							1.2	1.2	1.2	1.2	1.2	1.3	1.4	1.5	1.6	1.6	min

Material allowance, 0.2 in., lengths are the finished dimensions.
For bronze add 20 per cent, for steel castings add 39 per cent

TABLE L

PERMISSIBLE FEEDS, IN INCHES PER MINUTE, FOR THREE GROUPS OF EXISTING MACHINES OF 3–5–7 h.p.

Material			Cast-iron			Malleable Iron			Steel (35–40 tons/sq in tensile)		
			Speed 50 ft/min			Speed 65 ft/min			Speed 80 ft/min		
Time $= \frac{L + X}{\text{feed}}$ in min	Width in	Depth in.	3 h.p	5 h.p.	7 h.p.	3 h p	5 h p	7 h p	3 h p	5 h p.	7 h p.
	Up to 2	0·040	6	6	6	5	5	5	5	5	5
		0·15	4·5	6	7	4	5	6	3	4	4·5
		0·30	2·5	3·5	6	2	3	4	2·2	2·5	3·5
	From 2–4	0·040	6	6	6	5	5	5	4	4	4
		0·15	3	4	6	3	4	6	2·5	3·5	5·5
		0·30	2·5	3·5	5·5	2	3	5	2	3	5
	Up to 1½	0·040	5	5	5	4·5	4·5	4·5	4	4	4
		0·15	4	5	6	3·5	4·5	5	2·5	3·5	4·5
		0·30	2	3	6	1·8	2·5	5	1·5	2	4
	From 1¾–4	0·040	5	5	5	4·5	4·5	4·5	4	4	4
		0·15	2	4·5	5·5	1·75	4	5	1·5	3·5	4·5
		0·30	1·5	2·5	5	1·2	2·5	4	1·2	2	3·5
	Up to 1½	0·40	3·5	3·5	3·5	3	3	3	2·5	2·5	2·5
		0·15	2·5	3	3·5	2	2·5	3	1·75	2	2·5
		0·30	1·75	2	2·5	1·75	2	2·5	1·5	1·75	2
	From 1½–3	0·040	3	3	3	2·5	2·5	2·5	2	2·3	2·5
		0·15	1·75	2	2·5	1·5	1·75	2	1·25	1·5	1·75
		0·30	1·5	1·75	2·3	1·5	1·75	2	1	1·25	1·5
	Up to ¾	0·040	5	5	5	4·5	4·5	4·5	3·5	3·5	3·5
		0·15	2	2·5	3	1·75	2	2·5	1·5	1·75	2·0
		0·30	1·75	2	2·5	1·5	1·75	2	1·25	1·5	1·75
	From ⅞–1½	0·040	5	5	5	4·5	4·5	4·5	3·5	3·5	3·5
		0·15	1·75	2·0	2·5	1·75	2	2·5	1·25	1·5	2
		0·30	1	1·5	2	1·5	1·75	2	1	1·25	1·5

$D = 4$ in. dia., $z = 8$, $b = 2$ in wide   Feeds for high-speed steel cutters allowance of castings and forgings. As the surface quality after roughing is unimportant, the feed ought to be increased up to the capacity of the milling machine, it may sometimes be greater than the finishing feed. Below the sketches the formula for the actual length of the necessary path of the cutter is given, which divided by the feed per minute gives the time per path.

EXAMPLE. A piece of cast-iron 1·5 in. wide, 9 in. long should be roughed with 0·15 in. stock-removal by slab milling on a 5 h.p. machine with 50 f.p.m. cutting speed. The permissible feed is 5 in./min, the cutting time is $\frac{9+1}{5} = 2$ min. The clamping time depends on the existing fixtures, e g. for batch work. The cutter was a standard cutter of 4 in. diameter, 8 teeth; the angle of helix was 50°. Facing requires the shortest time, angle and shank milling the longest.

4 *Planing*. The modern planer has not only different cutting speeds and feeds, but also a variable quick return, further the overrun at the beginning and at the end is an additional loss of time. To bring all these variables into one Table (LIIIA and B) is difficult, so the writer recommends the special slide-rule (Fig. 118) published by the Cincinnati Planer Co., Cincinnati. This slide-rule enables one to combine suitable cutting and return speeds with a chosen feed per stroke and to find by one setting of the rule the time required for a given width and length of cut (width × length = surface planed). For the all-electric driven modern planers such a quick and versatile instrument is invaluable.

Take, for example, a cutting speed of 35 ft/min and a return speed of 200 ft. With a feed of $\frac{3}{16}$ in. the slide is set directly below the intersection of 35 and 200, being the speeds selected. To obtain the time required for this piece 10 ft long by 2 ft wide, or 20 sq ft, we multiply this by 144 and get 2880 sq in. The rule shows (below 2880) that this surface can be planed in about 43 minutes.

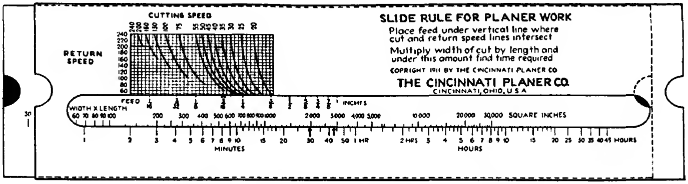


FIG 118 SLIDE RULE

5. *Grinding* (See page 184.) Grinding times both for external and internal grinding cannot be based on the usual basis of cutting speeds and feeds, etc, because the removal of material must be made by a certain number of travels, which depend upon the material allowance and the general preparation of the piece to be ground; it is not a single operation with a sudden termination First the operator must find out how much the piece is out of round and straight, by observing the sparking of the trial tests. Then by means of a micrometer, he must determine the allowance to be removed and must set the number of automatic sizing travels with a maximum cross-feed per path until the diameter of the piece is at the upper tolerance limit as measured by, say, the go-side of the snap-gauge. Finally he does the finishing cuts, which depend on the finish required, varying the dwell at the sizing position.

Surface grinding belongs to a different category and is easier as regards calculation. The basis is generally the amount of metal removed and the area ground Surface grinding is to-day in strong competition with milling and particularly with planing, especially from the point of view of eliminating the final scraping operations (Fig. 94).

Time studies enable one to find for different diameters and lengths the number of single strokes needed to remove the usual material allowance, as shown approximately in Table LI.

TABLE LI

NUMBER OF SINGLE STROKES OF THE GRINDING MACHINE

Diameter in	Allowance in	Length in in: 1	8	16	24	32	40	48	64	80
		Number of Strokes								
1	0 01 -0 018	12	16	18	20	22	24	26	30	36
1¼	0 01 -0 018	10	14	16	18	20	22	24	28	32
2	0 0125-0 020	10	14	16	18	20	22	24	28	30
3	0 015 0 025	10	14	16	18	20	22	22	26	30
4	0 02 -0 025	12	15	16	18	19	20	22	26	30
5	,,	12	15	16	18	19	20	22	26	30
6	,,	13	16	18	20	20	20	22	26	30
8	,,	14	17	18	20	22	22	23	26	30
10	,,	15	18	20	21	22	23	24	28	32
12	,,	16	19	21	22	23	24	26	30	34

The time needed for measuring work-pieces by micrometer (while they are at rest) is approximately in accordance with Table LII for—

(1) Running and interference fits

(2) Transition fits: times of table increased by 40 per cent

TABLE LII

TIME NEEDED FOR MEASURING PIECES DURING GRINDING PROCESS

Diameter in	Length in in: 1	4	8	16	24	32	40	48	64	80
	Time in Minutes									
1	1 5	1 8	2 0	2 4	2 8	3 2	3 5	4 2	5 0	6 5
1¼	1 6	2 0	2 2	2 6	3 0	3 5	4 0	4 5	5 5	7 0
2	1 7	2 2	2 5	2 8	3 2	3 8	4 2	4 8	6 0	7 5
3	1 8	2 2	3 0	3 0	3 5	4 0	4 5	5 2	6 5	8 0
4	2 0	2 4	3 5	3 5	3 7	4 5	5 0	5 5	7 0	8 5
5	2 0	2 8	3 8	4 0	4 5	5 0	5 5	7 0	8 0	10 0
6	2 5	3 2	4 0	4 5	5 0	6 0	6 5	7 5	9 0	11 0
8	3 0	3 7	4 5	5 0	6 0	7 0	7 5	8 5	11 0	13 0
10	3 5	4 5	5 2	6 0	7 0	8 0	9 0	10 0	12 0	14 0
12	4 0	5 0	6 0	7 0	8 0	9 0	10 0	12 0	14 0	17 0

Economic Use of Plant by Competitive Comparison of Available Machines

The planning department must be able to decide quickly which machines of the existing plant will be the most economic for a special purpose. It is, for example, often possible to turn pieces on a centre lathe, a capstan, a combination turret lathe, a single- or multiple-spindle automatic screw machine, or on a vertical turning and boring mill

For drilling accurate holes the horizontal lathe or the turret lathe are again applicable in competition with the vertical drilling machine fitted with jigs and the horizontal and vertical boring machine with or without jigs The choice depends on the shape of the piece and the position of the hole, central or eccentric.

For plane flat surfaces or those guide-ways which have a more or less complicated profile in the cross direction, either the milling or the planing or shaping machine might be used. For the final finish the grinding machine is to-day increasingly replacing hand-scraping Where it can be assumed that these competitive machines perform internal and/or external cylinders, tapers, profiles, or planes with the same quality of dimensional and surface finish, then it is only a question of which machine is free for the performance and is the most economic from the standpoint of manufacture. (See page 143, Economic Tool Life) Furthermore, it is of importance that the production controller should be able to change over from one machine group to another, in close collaboration with the ratefixing department and the foreman, so as to be able to keep promised dates without unreasonably increasing the price of the machine parts

In the choice of the most favourable process, the size of batch is decisive. For medium and big batches the capstan and combination turret lathe will always beat the centre lathe. The question is—Which is the minimum batch number for which the turret lathe ought to be used? This is generally a matter for careful calculation. The solution of the problem is not so easy if milling and planing machines are in competition. Complicated profiles of average quality on very rigid pieces and not too long, will definitely be best milled by gang cutters. (See Fig. 84.) However, the final finish on lathe and planer beds etc , is generally done on the planing machine (Fig. 119) because the single-point planing tool with the cooling effect of the idle return does not

TABLE LIII A
Number of Feet Table Travels per Hour on Cut
All-electric-driven Planer. (Cincinnati Planer Company, Cincinnati, Ohio)

Return Speed, ft/min	Cutting Speed, ft/min 10	20	30	40	50	60	70	80	90	100	120	140	160	180	200	220	240	260	280	300
50	500	857	1125	1333	1500															
60	515	900	1200	1440	1636	1800														
70	525	933	1260	1527	1750	1938	2100													
80	534	960	1309	1600	1846	2057	2240	2400												
90	540	981	1350	1661	1928	2160	2363	2542	2700											
100	546	1000	1384	1714	2000	2250	2470	2666	2843	3000										
120	554	1028	1440	1800	2117	2400	2652	2880	3087	3272	3600									
140	560	1050	1482	1867	2211	2521	2800	3056	3290	3501	3879	4200								
150	563	1058	1500	1894	2250	2577	2864	3130	3377	3600	4000	4350								
160	565	1068	1518	1920	2285	2618	2922	3200	3458	3692	4114	4480	4800							
180	569	1080	1545	1963	2347	2700	3024	3323	3603	3859	4321	4730	5080	5400						
200	572	1090	1565	2000	2400	2769	3111	3428	3726	4000	4500	4950	5340	5680	6000					
220	574	1100	1585	2030	2451	2828	3186	3520	3835	4125	4658	5140	5550	5940	6280	6590				
240	576	1108	1600	2057	2482	2880	3250	3600	3930	4235	4800	5310	5760	6170	6550	6880	7200			
250	577	1110	1608	2069	2500	2903	3281	3636	3973	4285	4864	5390	5850	6280	6675	7020	7350			
260	578	1113	1613	2080	2516	2925	3309	3681	4014	4333	4928	5470	5940	6380	6780	7150	7480	7800		
280	580	1120	1628	2100	2552	2964	3360	3733	4085	4421	5040	5610	6110	6580	7010	7400	7760	8090	8400	
300	581	1125	1636	2117	2570	3000	3405	3789	4150	4500	5142	5730	6260	6750	7200	7620	8000	8350	8700	9000

To obtain strokes per hour Divide number of feet travelled per hour by length of stroke

To obtain strokes per minute Divide strokes per hour by 60.

To obtain time for one complete cycle Divide 3600 seconds by number of strokes per hour.

Sample Calculation

Cutting speed = 40 ft/min

$$\frac{60 \text{ sec}}{40} = 1.5 \text{ sec/ft}$$

Return speed = 200 ft/min

$$\frac{60 \text{ sec}}{200} = 0.3 \text{ sec/ft}$$

These times include: Start—Cutting—Stop—Quick return—Stop, etc

For a 1-ft cycle, 1.5 + 0.3 = 1.8 sec required

$$\text{Cutting feet per hour } \frac{3600 \text{ sec}}{1.8 \text{ sec}} = 2000.$$

TABLE LIII B
Planing Machine—Ratefixer Times

Travel ft/min	Time per ft-sec	Travel ft/min	Time per ft-sec
10	6.0	105	0.571
15	4.0	110	0.545
20	3.0	120	0.50
25	2.4	130	0.461
30	2.0	140	0.428
35	1.72	150	0.40
40	1.5	160	0.375
45	1.33	170	0.353
50	1.2	180	0.333
55	1.09	190	0.316
60	1.0	200	0.3
65	0.923	220	0.273
70	0.857	240	0.25
75	0·8	260	0.23
80	0.75	280	0.214
85	0·705	300	0.20
90	0.667		
95	0.631		
100	0.6		

create heat and will consequently avoid warping of beds of lathe, grinding, planing, and milling machines, etc. A suitable combination of preliminary milling and finish planing will, therefore, be necessary in most cases.

lathe; (3) a bevel gear (Table LVI) made of solid steel cut from the bar, but with a central hole, for which the decision is doubtful. Comparison by the Tables of the two different processes proves that the output of the modern combination turret

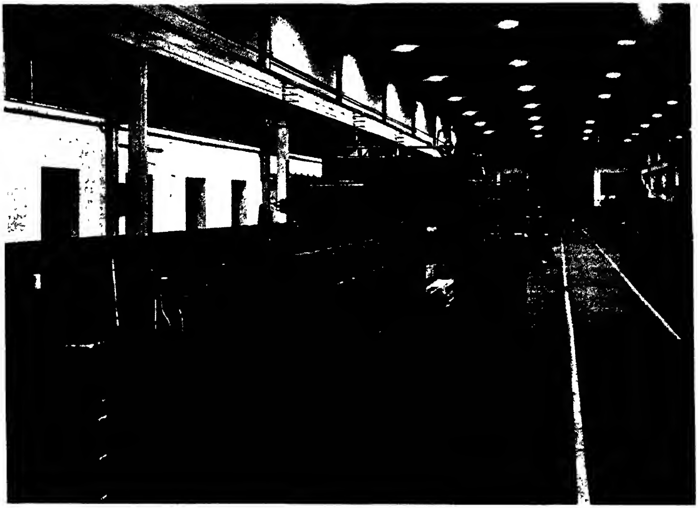
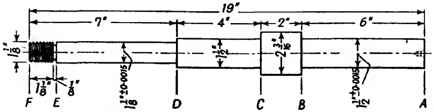


FIG. 119. FINISH-PLANING OF A BATCH OF BEDS

Tables LIV to LVI compare work done on the lathe and the combination turret lathe. Three characteristic pieces are chosen, i e. (1) a long and fairly thin steel shaft (Table LIV) for the machining of which the lathe seems to be indicated, (2) cast-iron bush (Table LV) of 6½ in. outside diameter and 4 in. hole which seems well suited for the combination turret lathe, even for one piece is very near to that of the output of a centre lathe, even when equipped with square or hexagon turrets, However, the turret lathe requires special tools and a special setter, whereas the lathe is generally operated by a skilled turner who does the operating, sizing and setting himself, which is a decisive factor for single jobs.

TABLE LIV

STEEL SHAFT FROM 2¼ IN. DIAMETER BAR—40 TONS/SQ IN. TENSILE STRENGTH
MANUFACTURED IN BATCHES OF 1–10–100 PIECES ON



(*a*) 17-in. Swing Engine Lathe. one process (John Lang-Johnstone with Square Turret)

Operation No	Description (see Drawing)	Material to Remove in	No of Cuts	Depth in	Length in	Speed r p m	Speed ft/min	Feed Cuts/in	Feed in /rev	Handling min	Handling sec	Machining min	Machining sec
1	Centre bar									5	0		
2	Put in lathe									1	30		
3	Rough turn, *A* to *B*	[illegible]	1	[illegible]	6	486	285	192	0 0052			2	30
4	Rough turn, *B* to *C*	[illegible]	1	0 0156	2	486	285	96	0 0105				30
5	Rough face, *A* to *B*						280		Hand			1	30
6	Reverse in lathe									1	30		
7	Rough turn, *F* to *C*	[illegible]	1	[illegible]	11	486	285	192	0 0052			4	30
8	Rough turn, *F* to *D*	[illegible]	1	[illegible]	7	486	207	96	0 0052			2	45
9	Rough face, *F*, *D*, and *C*					486	280		Hand			2	0
10	Finish turn, *F* to *D*	[illegible]	1	[illegible]	7	486	190	96	0 0105			1	30
11	Finish turn, *D* to *C*	[illegible]	1	[illegible]	4	486	204	96	0 0105				50
12	Finish face, *F*, *D*, and *C*					486	280		Hand			2	00
13	Recess at *E*												30
14	Screw, *F* to *E*											15	00
15	Finish water scrape, *E* to *D*	0 010	2	0 005	6	43	13	18	0 056			5	00
16	Reverse in lathe									1	30		
17	Finish turn, *A* to *B*	[illegible]	1	[illegible]	6	486	207	96	0 0105			1	15
18	Finish turn, *B* to *C*	[illegible]	1	[illegible]	2	486	280	96	0 0105				30
19	Finish face, *A* to *B*								Hand			1	30
20	Finish water scrape, *A* to *B*	0 010	2	0 005	6	43	17	18	0 056			5	00
21	Take out of lathe										30		
										10	00	46	50

Operation Sizing is for changing spindle speeds and feeds, setting slide, measuring, indexing turret, engaging feeds, setting tools to depth of cut, changing tools when requiring grinding, etc

Setting Time is for collecting tools from store and arranging tools in tool-holder, adjusted to cut

Finish Water Scrape is the finishing to close limits instead of grinding by means of a flat-nosed tool, slow speeds of 12–20 ft/min with a flow of lubricant

	56 min 50 sec
Operating sizing	28 min 10 sec
	85 min
Setting time	10 min
Total	95 min

(*b*) Combination Turret Lathe · 2 processes (H. W. Ward, Birmingham)

1. *Process*

Operation No	Description	Material to Remove in	No of Cuts	Depth in	Length in	Speed r p m	Speed ft/min	Feed Cuts/in	Feed in /rev	Handling min	Handling sec	Machining min	Machining sec
1	Feed bar to stop									1	00		
2	Centre drill					536						1	00
3	Start turn, *F*, 1⅛ in dia , for roller tool-holder	[illegible]	3	[illegible]	[illegible]	362	220		Hand			1	15
4	{ Roller turn—ditto	[illegible]	1	[illegible]	7	362	220	133	0 0075	}		3	30
	Turn 2 3/16 in dia from square turret	[illegible]	1	[illegible]	2¼	362	220	133	0 0075				
5	Start turn 1½ in dia for roller tool-holder	[illegible]	2	[illegible]	[illegible]	362	220		Hand			1	15
6	Roller turn—ditto	[illegible]	1	[illegible]	4	362	220	93	0 011			1	30
7	Roller end					362	105		Hand				45
8	Undercut back of thread					362	105		Hand				30
9	Screw					26	8						50
10	Cut-off					223	130		Hand			2	00
										1	00	12	35

Floor to floor	say 14 min
Setting time	. 90 min
Total time	. 104 min

TABLE LIV—(*contd*)

2. *Process*

Operation No	Description	Material to Remove in	No of Cuts	Depth in	Length in	Speed r p m	Speed ft/min	Feed Cuts/in	Feed in /rev	Handling min	Handling sec	Machining min	Machining sec
1	Hold in chuck in 1¼ in dia										30		
2	Centre drill					536						1	00
3	Start turn, 1⅛ in dia, for roller tool-holder	⅛	2	$\frac{1}{16}$	¼	362	220		Hand			1	00
4	Roller turn, 1⅛ in dia	⅛	1	⅛	6	362	220	93	0 011			3	00
5	Roller end					362	105		Hand				40
6	Remove										30		
										1	00	5	40

Floor to floor	say	6 min
Setting time		20 min
Total		26 min

Comparison

	Time per	1 Piece Settg min		1 Piece Machg min		1 Piece Total min	10 Pieces Settg min		10 Pieces Machg min		10 Pieces Total min	100 Pieces Settg min		100 Pieces Machg min		100 Pieces Total min
(*a*) Lathe	One process	10	+	85	=	95	1	+	85	=	86	0 1	+	85	=	85 1
(*b*) Combination turret lathe	1 Process	90	+	14	=	104	9	+	14	=	23	0 9	+	14	=	14 9
	2 Process	20	+	6	=	26	2	+	6	=	8	0 2	+	6	=	6 2
						130					31					21 1

TABLE LV

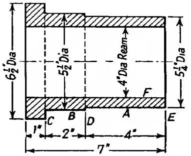
CAST-IRON BUSH

(*a*) Lathe 20 in. centres with Hexagon Turret (John Lang)

One Process

Operation No	Description	Material to Remove in	No of Cuts	Depth in	Length in	Speed r p m	Speed ft/min	Feed Cuts/in	Feed in /rev	Handling min	Handling sec	Machining min	Machining sec
1	Chuck									3	0		
2	Rough turn, *A*, 5¼ in dia	¼	1	⅛	4	103	155	72				2	50
3	Rough turn, *B*, 5½ in dia	¼	1	⅛	2	103	163	72				1	25
4	Rough face, *C*, *D*, *E*				½	103	175	72	Hand			3	0
5	Rough bore, *F*, 4 in dia	¼	1	⅛	7½	145	146	72				3	30
6	Finish bore, *F*, 4 in dia	$\frac{1}{16}$	2	$\frac{1}{32}$	7½	145	152	72				7	30
7	Finish turn, *A*, 5¼ in dia	$\frac{1}{16}$	1	$\frac{1}{32}$	4	145	205	72				2	0
8	Finish turn, *B*, 5½ in dia	$\frac{1}{16}$	1	$\frac{1}{32}$	2	145	213	72				1	0
9	Finish face, *C*, *D*, *E*				½	103	175	72				2	0
10	Finish ream, *F*, 4 in dia	0 006		0 006	7½	38	36	36				8	0
11	Take out of chuck									1	0		
										4	0	31	15

	35 min 15 sec
Operating sizing	19 min 45 sec
	55 min
Setting time	20 min
Total	75 min



	1 Piece	10 Pieces	100 Pieces
	min	min	min
Machining	55	55	55
Setting	20	2	0 2
	75	57	55 2

TABLE LV—(*contd.*)

(*b*) Combination Turret Lathe

One Process

Operation No	Description	Material to Remove in	No of Cuts	Depth in	Length in	Speed r p m	Speed ft/min	Feed Cuts/in	Feed in /rev	Time Taken Handling min	Time Taken Handling sec	Time Taken Machining min	Time Taken Machining sec
1	Hold in step-bored jaws on 6¼ in dia									2	00		
2	Rough bore, 4 in dia	1/4	1	1/8	7	223	240	93	0 011			5	00
	Rough turn, 5¼ in. and 5½ in dia	1/4	1	1/8	6	223	305	93	0 011				
3	Finish bore, 4 in. dia	1/16	1	1/32	7	223	240	93	0 011			5	30
	Finish turn, 5¼ in and 5½ in dia	1/16	1	1/32	6	223	305	93	0 011				
4	Face end	1/4	2	1/8	1/2	223	305		Hand			1	30
5	Ream 4 in	0 006		0 006	7	26	28	18	0 056			5	30
6	Remove from chuck										30		
										2	30	17	30

Floor-to-floor time	20 min
Setting time	60 min
Total time for 1 piece off	80 min

Combination Turret Lathe (Ward) (Cutting speed, 220–320 ft/min)

	1 Piece	10 Pieces	100 Pieces
	min	min	min
Machining	20	20	20
Setting	60	6	0 6
	80	26	20 6

Comparison

		min	min	min
(*a*) Lathe	Total	75	57	55 2
(*b*) Turret lathe	Total	80	26	20 6

75 (1 piece on lathe) versus 20 6 (100 pieces on turret lathe)
Saving, 72 5 per cent

The cutting speed for the longest operation must be, of course, so selected that the tool remains sharp enough to perform 100 pieces to avoid resharpening and resetting. Super high-speed steel tools are, therefore, often combined with cemented carbide-tipped tools.

For repetition work in batches of from three pieces upwards, the combination turret lathe will generally beat the centre lathe for speed, but again the cost of expensive tools for the turret lathe is often prohibitive for small batches. It is easier to adapt the lathe to continuously varying work, but for the examples chosen the lathe beats the turret lathe for a single-bored piece, because it was equipped with a hexagon turret on its carriage. Such a machine is more in line with the combination turret lathe, which fact must be taken into consideration regarding the comparison, it shows also the influence of economic manufacturing according to the design and equipment of the modern centre lathe. Besides these tools are ordinary standard tools both for boring and reaming and for most turning operations The comparisons for one, ten and 100 pieces prove that there is little cost reduction in making batches of ten or 100 steel shafts on the lathe, the difference being only one per cent; whereas on the combination turret lathe the time difference is 32 per cent. A single piece on the lathe at 95 minutes is made 38 per cent quicker than on the turret lathe (130 minutes), the long setting time of 90 minutes versus ten minutes explains the difference, which is, of course, justified on a bigger batch. In this case we have the ratios in minutes $\frac{86}{31} = \frac{2 \cdot 8}{1}$ and $\frac{85 \cdot 1}{21} = \frac{4 \cdot 06}{1}$.

TABLE LVI A

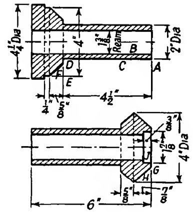
Bevel Gear from Cut-off Piece of Steel Bar 45 tons/sq in. Tensile— 4¼ in Diameter × 6¼ in. Long

Centre Lathe, 20-in. Swing with Hexagon Turret (John Lang)

1 *Process*

Operation No	Description	Material to Remove in	No of Cuts	Depth in	Length in	Speed r p m	Speed ft/min	Feed Cuts/in	Feed in /rev	Handling min	Handling sec	Machining min	Machining sec
1	Chuck									3	0		
2	Rough face, *A*	⅛	1	1/16	2 1/16	206	230	144	0 007			1	40
3	Centre for drill								Hand				30
4	Drill rough, *B*, 1½ in dia				6¼	206	67	72	0 014			2	30
5	Rough turn, *C*	1⅛	4	9/32	4½	206	230	72	0 014			6	30
6	Rough turn, *E*	⅛	1	1/16	1	206	230	72	0 014				20
7	Rough face, *D*, 4¼ in dia		2		1 1/16	206	223	144	0 007			1	30
8	Rough form, *F*								Hand			3	0
9	Finish bore, *B*, 1⅝ in dia	1/16	2	1/32	6¼	206	74	72	0 014			5	0
10	Finish turn, *C*	1/32	1	1/32	4½	300	170	96	0 0103			1	30
11	Finish turn, *E*	1/32	1	1/32	[illegible]	206	223	96	0 0103				15
12	Finish face, *D*		1		[illegible]	206	170	144	0 007				30
13	Finish form, *F*		2		[illegible]	206	223		Hand			2	0
14	Finish face, *E*	1/32	1	1/32	1/16	300	160	144	0 007				10
15	Finish ream, *B*	0 006	1	0 006	7	49 5	15	60	0 017			8	30
16	Take out of chuck									1	0		
										4	0	33	55

	37 min 55 sec
Operating sizing	27 min 5 sec
	65 min
Selling time	20 min
Total	85 min



2. *Process*

Operation No	Description	Material to Remove in	No of Cuts	Depth in	Length in	Speed r p m	Speed ft/min	Feed Cuts/in	Feed in /rev	Handling min	Handling sec	Machining min	Machining sec
1	Chuck									4	0		
2	Rough face, *G*	⅛	1	1/16	2 1/16	206	230	144	0 007			1	30
3	Rough form, *H*				1¼	206	230		Hand			4	0
4	Rough process, *J*, 1⅞ in dia				⅞	300	150		,,			3	0
5	Finish face, *G*				⅜	300	180	144	0 007				0
6	Finish form, *H*		2		1¼	206	230		Hand			3	0
7	Finish recess, *J*				⅞	206	150		,,			2	0
8	Take out of chuck									1	0		
										5	0	13	30

	18 min 30 sec
Operating sizing	16 min 30 sec
	35 min
Selling time	10 min
Total	45 min

TABLE LVI A—(*contd.*)

Comparison of Processes and Times

Times per			1 Piece	10 Pieces	100 Pieces
			min	min	min
(*a*) Lathe with hexagon head	1 Process	Machining	65	65	65
		Setting	20	2	0 3
	2 Process	Machining	35	35	35
		Setting	10	1	0 1
		Total	130	103	100 4
(*b*) Combination turret lathe	1 Process	Machining	26	26	26
		Setting	60	6	0 6
	2 Process	Machining	10	10	10
		Setting	40	4	0 4
		Total	136	46	37 0

1 piece from the lathe, 130 min per piece / 100 pieces from the turret lathe, 37 min per piece = 3 5 / 1

(Time saving of 71 5 per cent)

TABLE LVI B

Bevel Gear from Cut-off Piece of Steel Bar, 45 tons Tensile, 4½ in. Diameter × 6¼ in. Long

Combination Turret Lathe (H. W. Ward)

Cutting Speed 230/250 ft/min for T C Tools

1 *Process*

Operation No	Description	Material to Remove in	No of Cuts	Depth in	Length in	Speed r p m	Speed ft/min	Feed Cuts/in	Feed in /rev	Time Handling min	Time Handling sec	Time Machining min	Time Machining sec	Remarks
										min	sec	min	sec	
1	Hold in 3-jaw chuck on 4½ in dia									1	30			
2	Start drill											1	30	
3	Drill hole, *B*, 1½ in dia					223	75	193	0 005					
	(Rough turn 3 cuts)	1¼	3	⅜	4½	223-362	250-260	133	0 0075			8	30	
4*a*	Finish bore, *B*, 1⅝ in dia	1/32	1	1/32	6	536	180	133	0 0075					
4*b*	Finish turn, *C*, 2 in , and face under head, *A*	1/16	1	1/16	4½	536	280	133	0 0075 Hand			2	30	
5	Face end, *D*	⅛	2	1/16	1/16	536	280	133	Hand			1	30	
6	Support and rough form angle, *F*					223	230		Hand			2	30	
7	Support and finish form angle, *F*					40	42		Hand			2	00	
8	Ream, *B*, 1⅝ in					40	14	26	0 038			4	00	
9	Remove from chuck									1	00			
								Floor to floor		2	30	22	30	say 26 min
								Setting time		60	00			
								Total		86 min				

2. *Process*

Operation No	Description	Material to Remove in	No of Cuts	Depth in	Length in	Speed r p.m	Speed ft/min	Feed Cuts/in	Feed in /rev	Time Handling min	Time Handling sec	Time Machining min	Time Machining sec	Remarks
										min	sec	min	sec	
1	Hold in soft jaws on 2 in dia									1	00			
2	Face ends (2 cuts), *G*, 4 in dia	⅛	2	1/16	1 1/16	223	250	133	0 0075			2	00	
3	Rough turn and form angle, *H*		3			223	250	133	Hand			2	30	
4	Finish form angle, *H*					40	42	133	Hand			2	00	
5	Rough recess bore, *J*, 1½ in dia	⅛	1	⅛	⅜	362	175	133	Hand			1	00	
6	Finish recess bore, *J*, 1½ in dia	1/64	1	1/64	⅜	362	175	133	Hand				30	
7	Remove from chuck										30			
								Floor to floor		1	30	8	00	say 10 min
								Setting time		40	0			
								Total		50 min				

Times per	1 Piece	10 Pieces	100 Pieces
	Hdlg *min* + *Machg* *min* = *Total* *min*	*Hdlg* *min* + *Machg* *min* = *Total* *min*	*Hdlg* *min* + *Machg* *min* = *Total* *min*
1 Process	60 + 26 = 86	6 + 26 = 32	0 6 + 26 = 26 6
2 Process	40 + 10 = 50	4 + 10 = 14	0 4 + 10 = 10 4
	136	46	37

TABLE LVI B—(*contd.*)

Cut Teeth: 60 Teeth—16 D.P.—1¼-in. Flanc Rough Cut Teeth on Gleason Reverse Roughing Machine

3. *Process*

Operation		min	Machining min	Machining sec
	Set up machine for one component	120		
1	Load machine			8
2	Cut teeth 7 2 sec per tooth—60*T* × 7 2		7	12
3	Unload			6
		120	7	26
	Fatigue 12½%			56
		120	8	30
	Total	129 min		

Finish Cut Teeth—12 in Gleason

Operation		min	Machining min	Machining sec
	Set up machine	120		
1	Load machine			8
2	Finish cut teeth 12 2 sec per tooth—60*T* × 12 2		12	12
3	Unload			6
	Fatigue 12½%		1	30
		120	14	00
	Total	134 min		

Influence of Batch—Gear Cutting

	1 Piece					10 Pieces					100 Pieces				
	Settg min		*Machg min*		*Total min*	*Settg min*		*Machg min*		*Total min*	*Settg min*		*Machg min*		*Total min*
1 Roughing	120	+	9	=	129	12	+	9	=	21	1 2	+	9	=	10 2
2 Finishing	120	+	14	=	134	12	+	14	=	26	1 2	+	14	=	15 2
					263					47					26 5

The long steel shaft was selected as favourable for the lathe on which it can be finished by a single process, supported by the tailstock The combination turret lathe needs two processes and consequently two set-ups which last together 90 + 20 = 110 minutes, i e. 6 minutes longer than all the 21 operations on the lathe plus operating and setting times.

The two other examples, the cast-iron bushing and the bevel gear cut from the bar, have central holes; the first of 4 in. diameter is cored, the second of 1¾ in. diameter is drilled from the solid.

Holes as the locating surface for subsequent turning operations on rotating parts can be made either on a centre lathe, a turret lathe, or on a vertical boring mill, which is really an upright and very convenient turret lathe The vertical machine for bigger diameters from 2 in upwards and for heavier pieces has the advantages that—

(1) The setting of a heavy piece, resting on the table, is much more convenient.

(2) The chips produced by the last reaming operations automatically fall down without scratching the surface But the machines cannot work from bars as can the centre and capstan lathes.

Comparison of Influence of Batch and Method—

Part	Batch No.	Lathe with Hexagon Turret min	Combination Turret Lathe min	± min
Bushing	1	75	80	+ 5
,,	10	57	26	− 31
,,	100	55 2	20 6	− 34 6
Bevel gear	1	130	136	+ 6
,, ,,	10	103	46	− 57
,, ,,	100	100 3	37	− 63 3

Manufacture of Accurate Holes in Ferrous Metals

There are four methods of producing accurate holes (grade B; of B S. 164) in batches—

Group 1. Producing a finished hole in solid

FIG 120 SET OF FOUR TOOLS TO PRODUCE VERY ACCURATE INTERCHANGEABLE HOLES ON THE VERTICAL BORING MILL

Example 2-in dia hole—
1 Twist Drill of 1 75 in. dia
2 Shell Drill of 1 95 in dia
3 Shell Reamer of 1 995 in dia
4 Adjustable Reamer $2\,0\left\{\begin{matrix} +\,0\,0007 \\ -\,0\,000 \end{matrix}\right\}$ in

material, using a turret lathe or a vertical boring machine, or a drilling machine with jigs.

Group 2 Producing a finished hole from cored material with a turret lathe

Group 3. Producing a finished hole in cored material on a vertical boring machine.

Group 4. Grinding the prefinished hole.

Processes of—

Group 1. Turret lathe, horizontal or vertical, and a set of standard tools (Fig. 120).

(*a*) Drill hole using two-flute twist drills.

(*b*) Follow by using three-flute or four-flute solid drill or shell drill, according to size. This has the effect of truing the hole and preparing it for the reaming operation.

(*c*) Reaming the hole using a machine reamer,

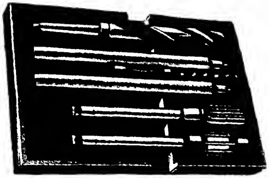


FIG 121 PROTECTING BOARD FOR SENSITIVE TOOLS

solid or shell type to obtain size, parallelism, and finish, or a two-lipped floating reamer

(*d*) If the hole required is of particular accuracy and big batches are performed use a

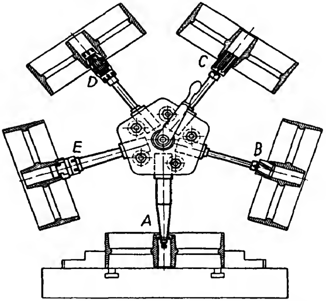


FIG 122 BORING, REAMING, AND FACING OPERATIONS ON A VERTICAL BORING MILL

second adjustable reamer adjusted to the size required.

It is advisable to keep them together on a wooden protecting board (Fig. 121).

Group 2. Turret Lathe.

When the cored hole is in line with the finished hole, use a three-flute or four-flute solid or shell drill and proceed then as for Group 1.

Group 3. Vertical Boring Machine (Fig 122)—

(*a*) When the cored hole is not in line with the finished hole, use a vertical boring machine and a boring bar (*A*) to bore the hole true and to size, less reaming allowance The four-fluted tool (*B*) is dispensable.

(*b*) Finish the hole with a solid or shell reamer (*C*)

(*c*) Use an adjustable reamer for special accuracy (*D*). Finally a facing operation (*E*) from the turret may be necessary

It depends upon the material allowance and the hardness of the material and the desired accuracy and finish whether operations (*b*) and (*c*) can be combined, and whether it is advisable to replace the multiple-edge reamers by the floating reamer with two cemented carbide-tipped blades (Fig 123). The number of holes per grind is increased by the more expensive multiple-edge reamer with unequal pitch from tooth to tooth The multiple-tooth reamer can also be used for hand-reaming and equipped with cemented carbide tips

The machining of a flywheel on a vertical boring mill, using the tools of the turret head for facing and turning the external cylinder, is shown in Fig 124 The times to do this work quickly using a double-blade reamer are given in the accompanying Table LVII.

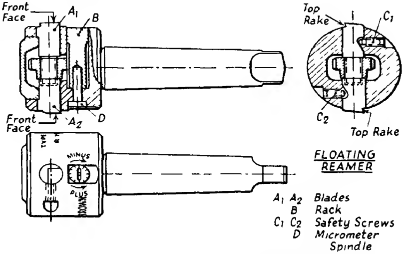
Group 4. Internal Grinding, Honing, Lapping

Planing versus Milling

It is often difficult to decide which is the most economic process, planing or milling This question requires a careful consideration of all advantages regarding the setting-up of the machine and the use of rigid vices or clamping fixtures together with special tools, such as gang and profile milling cutters and profiled cemented carbide-tipped planing tools.

The all-electric modern planer with cutting speeds variable between 20 and 250 f.p.m (300 f.p m. for roughing aluminium) and return speeds of up to 300 f p.m. using the hard metals (stellite and carbide) specially for cast-iron, has become in many cases a strong rival to the vertical and horizontal milling machine, which must often use the high-speed solid cylindrical cutter.

The chosen example of a rigid cast-iron cross slide of a lathe carriage compares the different methods and the influence of the batch size (Fig. 125) and table

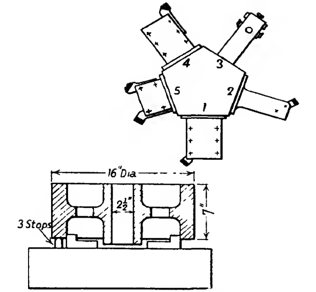


(*David Brown, Huddersfield*)

FIG 123 DOUBLE-BLADE REAMER

For the manufacture of a single piece, the milling machine is superior The short planer worked with 50 f.p m. cutting speed and 100 f.p.m. return speed, the milling machine used feeds between 2 inch and 8 feet per minute corresponding to the kind of cut and strength of machine. Both machines used (for the single piece) the rigid machine vice as a clamping fixture

The summary proves that for five pieces, arranged lengthwise, the planer beats the milling machine by 30 per cent using 100 f.p.m. cutting speed and 200 f p.m. return speed for the longer stroke. The milling machine could not increase its feeds The planed finished surfaces were even superior to the milled ones. Both machines allowed the simultaneous clamping of only five pieces lengthwise, so that a bigger batch would have caused only a reduction in the setting time per piece



(Webster and Bennett, Coventry)

FIG 124 FLYWHEEL TURNING AND BORING

1 Rough Turn O D Rough Face
2 Rough and Semi-finish Bore
3 Size to − 0 007 in and Ream
4 Finish Turn O D and F Face
5 Radius and Chamfer

The output of the milling machine is directly proportional to the feed. The speed depends as usual upon the material of the part and of the tool. As the conditions are quite different for the planer (or shaper) because of the idle though quick return, they will justify some remarks

Planer Speeds and Feeds

The ratio of the cutting and return speeds directly affects the amount of work done by the planer, and it is well to understand just what the results are Table LIII has been worked out particularly for this purpose.* With a cutting speed of only ten feet per minute and a return of fifty feet the table travels 500 feet per hour. Doubling the return speed adds only 46 feet per

* Quoted from *Treatise on Planers, Practical Information and Suggestions for Economically Producing Flat Surfaces*, published by The Cincinnati Planer Co., Cincinnati, Ohio

TABLE LVII

TIME ESTIMATE

MACHINE—36 in Series "D" Mill (Webster & Bennett, Coventry) DRAWING NO (Fig 124)
MATERIAL—Cast-iron JOB—Flywheel

Operation	Traverse	Feed	r p m	ft/min	Time min
Setting machine					10 0 handling
Chucking casting					1 5 handling
Rough turn outside diameter 16"ϕ	7¼	0 062	48	200	
Rough face rim	½	0 042	48	200	0 85
Rough face boss	1	0 021	200	200	0 25
Core drill	6¼	0 042	80	44	1 9
Slack jaws					1 0 handling
Single point bore (two cuts)	12½	0 021	300	194	2 0
Ream	6½	0 100	48	31	1 4
Finish turn outside diameter	7¼	0 062	48	200	2 5
Finish face rim	½	0 032	48	200	0 35
Finish face boss	1	0 032	200	200	0 16
Machine operation, gauge, remove					5 0 handling
					26 91
2nd Setting					
Setting machine					5 0 handling
Locate off plug in bore, drive, and clamp					2 0
Rough face rim .	½	0 042	48	200	0 25
Finish face rim	½	0 032	48	200	0 35
Rough face boss .	1	0 021	200	200	0 25
Finish face boss .	1	0 031	200	200	0·16
Machine operation, gauge, remove					4 0 handling
					12 01

Total Time say 40 min (with cemented carbide-tipped tools).

Pre-reaming. 200–250 ft/min with cemented carbides
Feeds: 0·021 to 0 042 (48 to 24 t.p.i.). } for cast-iron.
Finish reaming. 25 to 35 ft/min.

hour to the table travel, or number of feet cut by the tool. Increasing the cutting speed to fifty feet, however, gives 1500 feet of table travel. Double the return speed as before, and the table travel is only 500 feet per hour more.

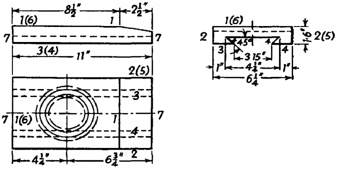


FIG 125 UNDERCARRIAGE OF LATHE

Planing (Shaping) versus Milling (Plain-straight surfaces)

One carriage is taken on both kinds of machines by a machine vice Therefore "Load" and "Unload" require the same time, say 5 min

The angle-faces 45° are made to-day on the planer by means of a formed tool, on the miller with an angle cutter

Therefore, for one piece there is not much difference in time, but the milling machine will be quicker For 5 pieces, however, and more, the advantage of machining by increasing both the cutting and return speed is considerable in favour of the planing machine

Operation No	Description		1 Piece Planing min	1 Piece Milling min
1 (6)	Roughing top surface Finishing top surface	(1) (6)	16	14
2 (5)	Roughing side faces Finishing side faces	(2) (5)	20	15
3 (4)	Roughing bottom faces, including prisms Finishing bottom faces, including prisms	(3) (4)	35	30
4 (7)	Roughing end faces Finishing end faces	(7) (7)	18	10
			89	69
	Fatigue 12½%		11	9
	Total		100	78

Summarized Comparison

Item		1 Piece Planing min	1 Piece Milling min	5 Pieces Planing min	5 Pieces Milling min
1	Setting of m/c	15	10	5	5
2	Clamping	5	5	2	2
3	Machining	62	47	32	42
4	Measuring	7	7	2	2
		89	69	41	51
	Fatigue 12½%	11	9	5	6
		100	78 + 22%	46 + 25%	57

Table LIII is also of interest to those who must estimate the work that can be done by any given planer. It shows the table travel in feet per second for table-travel speeds of up to 300 feet per minute. If, for example, we are cutting at forty feet per minute, we see that the table is travelling at the rate of one foot in 1·5 seconds If the return is 100 feet per minute, the return travel is at the rate of one foot in 0·6 seconds. Adding these together gives 2·1 seconds for one complete stroke. Dividing 60 seconds by the sum of the cutting and return strokes gives an effective or actual cutting speed of 28·5 feet per minute As mentioned above, the adding of five feet per minute to the cutting stroke is more effective than adding ten feet to the return stroke, and this can readily be checked from the table.

The width of feed across a piece of work naturally varies considerably with the work being done An average feed is from $\frac{1}{16}$ to $\frac{1}{4}$ inch, but when planing to a finished edge, as in dovetail work, it may be advisable to reduce this feed to less than $\frac{1}{16}$ inch to prevent breaking the edge on the last strokes

Generally speaking, the feed should be as wide as possible in order to reduce the number of strokes. If a $\frac{1}{4}$-inch feed can be used in place of $\frac{1}{8}$-inch, half the time of both cutting and return strokes has been saved.

CHAPTER XIII

The Determination of the Economic Batch of Manufacturing

A RATHER difficult task, which arises in many works of small and medium size and all big ones which do not have mass production, is to combine short dates of delivery with small stocks of goods, i.e. to determine the economic batch quantity, which should be ordered and manufactured for stock. The decision depends upon many factors—

1. The maturity of design regarding best production processes.
2. The degree of activity of departments.
3. The expense of setting-up machines per batch.
4. The expense of issuing a new order per batch
5. The organization of stores.
6. The supply of parts by subcontractors
7. The conditions of the market.
8. The transport facilities.
9. The financial situation of the enterprise itself.

We are specially concerned with items 1 to 4. Under the assumption that the design is ripe for manufacturing, the degree of activity of departments has a certain influence on the batch, because certain machines which are in constant demand for work on other orders must not be locked up for too long a time. The rate of absorption of the stock depends on the state of trade, and in a period of dullness the stock may be almost stagnant (items 5 to 7). Such periods of dullness are generally used to overhaul the design, and this may mean changes which make the stock in question obsolete

For these reasons the rate of stock depreciation and interest should be taken at a fairly high figure, say, for example 25 to 35 per cent, and this will have the effect of keeping stock to moderate proportions for financial reasons (item 9) and will greatly influence the size of the batch.

A question linked to that of selecting the most suitable quantity of any item to manufacture for stock is that of selecting the most economic lot to manufacture in one batch, especially where a works order covers a number of machines, or where one machine calls for a large number of a certain part (item 2). A large batch may delay manufacture of other parts and therefore delay delivery of orders and may make an excessive demand on the shop floor space for storing and on transport (item 8) Therefore, the size of the batch should be limited by the consideration that it must not interfere with the general manufacturing programme The application of these principles generally results in smaller parts, such as those made from the bar on capstans or automatics, being made in large batches (or bought in the market). The more complex parts should be made in small batches, especially those occupying considerable time in manufacture or demanding the use of machines of which only one or two are available, the decision being an important one from the point of view of efficient manufacture.

Costs of setting and ordering are incurred once only to provide certain quantities, but as the parts are kept in stock before use, it follows that these costs must be balanced against the continuous cost of interest for the invested capital of the stocked batch.

The bigger the batch the bigger the interest and the smaller the setting costs (3) per unit

If 100 pieces are made on a capstan lathe with one setting of 2 hours at 3s./hr., the setting price per unit is $\frac{6}{100} = 0{\cdot}06$s., if only 6 pieces are made, the setting costs are 1s. per piece (See Tables LIV to LVI.)

If a girl earns 1s. 6d. per hour and is making 10 pieces per hour the labour cost would be (1) for

10 pieces, 6s + 1s 6d. = 7s. 6d., i.e. = 9d per unit, (2) for 100 pieces, 6s. + 15s. = 21s., i.e. = 2½d. per unit.

The ratio in favour of the big batch of 100 is $\frac{9}{2\cdot5} = 3\cdot5:1$. If the departmental overhead is 200 per cent of labour, and the price of material per piece is 2d. the manufacturing cost would be—

Number of Pieces	10	100
	s d	£ s d
Material (m)	1 8	16 8
Labour (l)	1 6	15 –
Overhead (o)	3 –	1 10 –
Setting (s)	6	6 –
$m + l + o + s$	12 2	3 7 8
Per unit	1 2½	8 1
Interest, 5 per cent	negligible	

As the interest charges are a purely financial matter, they will be mentioned here only in broad principle. The burden of interest may be felt if very large quantities of fittings, for example, are stocked by a brassware company which either buys them in quantities of 10,000 from a sub-contractor, or makes them in its own works If such fittings cost 5s each, 10,000 cost £2500, for which the financing banker may charge 5 per cent = £125 per year If the 10,000 parts are consumed in one year, the additional expense is appreciable It depends on the purchase rebate for 10,000, as against, say, 2000 parts, whether it is more favourable to buy 5 × 2000 pieces and decrease the amount of interest but increase the purchasing and transport cost for five separate orders, or buy 1 × 10,000 for a cheaper price but with a heavier burden of interest

The formula* to compare such cases contains—

1 The "detached" cost: (D) in shillings = setting and/or ordering.

2. The price of the unit (P) in shillings

3. The yearly rate of interest for the capital invested: (i) as a percentage.

4 The required batch (x).

* *Wirthschaftliche Los-und Bestellziffern und ihre praktische Anwendung* ("Economic Lot and Order Size and Their Practical Application"), by B. Margoninsky, Thesis, Charlottenburg Technical University, 1932.

Price (P) contains no quantities which depend on x.

To find the proportion absorbed on interest, some assumptions must be made regarding stock and issue, which should be modified to suit practical circumstances.

The diagram (Fig 126) shows that x pieces are stored for T days, then the first issue of z pieces

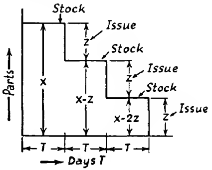


FIG 126 CORRELATION OF STORAGE PERIOD, STOCK AND ISSUE OF PARTS

T = storage period in days
x = quantity received by stores at once
z = quantity issued at each withdrawal

is made Now the remainder of $(x - z)$ may be stored again for T days, then, after another issue of z, $(x - 2z)$ pieces remain, etc, until the quantity x is consumed.

For this purpose the total amount of interest (I) can be calculated for (x) stocked parts and (T) days by—

$$I = x \times P \times \frac{T \times i}{365 \times 100} = C \times x \times \text{(shillings)}$$

where $C = \dfrac{P \times T \times i}{365 \times 100}$.

The amount of interest for the decreasing stock would be—

1 $C \times x$.
2. $C(x - z)$.
3. $C(x - 2z)$ and so on.

The sum of these portions would be—

$$S = P \times T \times \frac{i}{365 \times 100} \times \frac{x}{2z}(x + z)$$

The total amount of detached costs (D) and interest (I) would be ($D + I$), and if we refer to the unit and call the cost per unit y of x pieces of a batch, we get the formula—

$$y = \frac{I}{x} + \frac{D}{x}$$

By differentiation of this equation and introducing the corresponding values for I and D, we get

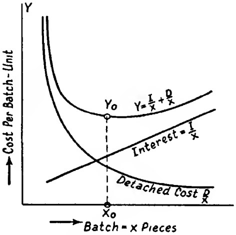


FIG. 127 ECONOMIC BATCH TO FIND THE MINIMUM COST PER UNIT

that batch (x_0), for which y has its minimum value y_0 (Fig. 127)—

$$X_0 = \sqrt{\frac{D}{P \times T \times \frac{i}{365 \times 100} \times \frac{1}{2 \times z}}}$$

The exact value of the interest (i) per cent is known and remains constant for a longer period—a year or longer. The issued quantities (z) and the storage time (T) are also known by the stores report on the bin-cards, or by statistics in any orderly material administration. More difficult is the determination of the cost for setting and/or ordering (D) and the value of the unity of batch (P). In any case it will be worth while to ascertain these values, which will then be serviceable for a long period.

As the formula contains only $\sqrt{\frac{D}{P}}$ the influence of occurring inaccuracies is greatly reduced.

For the production manager the detached cost (D) is represented by the setting cost, which shall be defined for this analysis as those wages which are paid for setting-up machine tools for the (n) different operations, which are to be performed in one clamping.

To these wages the departmental overhead is to be added of the department where the setting is performed.

Overhead arises on behalf of the working place of the setter, the help of the foreman, tools, use of tool grinders, auxiliary material, etc

The value of the unit (P) is composed of the total of: material + labour + overhead, which are recorded by the costing department.

Here the labour cost does not contain the cost of setting-up, because this portion (D) depends on the value of x_0, i.e the most economic batch

T is the number of days which separate the different issues of z parts When there is a uniform issue, for example, for a uniform monthly manufacture of machine tools, electromotors, motor cars, etc., T equals the number of days which elapse between two orders to begin new assemblies

If the factory does jobbing work or is producing single machines or a mixture of single jobs with batch production, the average of days (T) must be taken which lie between two issues of z parts from stores.

The yearly percentage (i) for interest depends on whether the firm's own or outside capital is used.

The number of parts (z) per issue depends on the volume of orders to be effected; it is uniform for a standardized weekly production, and must be averaged for fluctuating production.

A useful practical short formula to find the economic batch under any given circumstances is—

$$X = 50\sqrt{\frac{M \times D}{P \times i}}$$

where

M = monthly consumption of parts for manufacture.
D = cost of settings per economic batch.
P = price per one part (manufactured).
i = rate of interest.

EXAMPLES: The monthly consumption is: (1) M = 200 collar studs (bright drawn steel),

$D = 10$s. (2 settings), $P = 10$d. $= 0{\cdot}835$s., $i =$ 5 per cent, $X = 50\sqrt{\frac{200 \times 10}{{\cdot}835 \times 5}} = 50\sqrt{480} = 1100$ studs, sufficient for $5\frac{1}{2}$ months' work.

Resetting and regrinding is done after each 100 pieces.

(2) $M = 100$ top plates (stainless), $D = 3$s. 9d., $P = 1$s 9d, $i = 5$ per cent

$$X = 50\sqrt{\frac{100 \times 3{\cdot}75}{1{\cdot}75 \times 5}} = 50\sqrt{43} = 326 \text{ plates,}$$

sufficient for $3\frac{1}{4}$ months.

It is obvious that the factor (M) is often an uncertain quantity, therefore the calculated figures must be always taken with a certain reserve, similar objections are valid for the amount of interest However, it is always better to work according to variable but manageable factors, than to guess. The formula for economic batch, $X = 50\sqrt{\frac{M \times D}{P \times i}}$ leads to the following conclusions—

1. The greater the setting-up cost (D), the bigger the batch required to absorb it.

2. The smaller the manufacturing cost (P), the bigger should be the batch.

3 The bigger the rate of interest (i), the smaller should be the batch kept in stock, owing to the loss incurred by paying interest for stocked parts

D should be reduced by improving tools, jigs, fixtures, and test gear The price per piece (P) can be further reduced by decreasing the raw material to the minimum weight and decreasing wages by increasing speeds and feeds

CHAPTER XIV

Jigs and Fixtures

As soon as batches of complicated pieces are to be manufactured, the question of using jigs and fixtures becomes acute A *jig* is a device which clamps the work to a locating surface and guides the tools in their performance of cutting

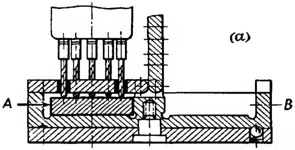


FIG 128a SWIVEL JIG—5-SPINDLE HEAD SIMULTANEOUS DRILLING

operations, for example, a boring jig (Fig 128*a* and *b*).

A *fixture* is a device which holds work by locating surfaces while machining operations are being performed on it, without guiding the tools themselves, which are adjusted and guided by suitable means, for example, a milling fixture (Figs 129 and 130)

Jigs and fixtures are instruments indispensable for exactly duplicating work

If the methods of processing are decided, the tool factor depends upon equipment, operations, and quantities of products to be manufactured.

Design, tooling, jigging, manufacturing, and production control, must all be co-ordinated into a practical workable programme. As the choice of correct and economic processing is decisive for the success of the workshop, the best production experts of the factory must collaborate. They are the designer of the product, the planner or methods engineer, the head of the tool-design section, the production manager as the representative of the manufacturing department including the toolroom, and the chief inspector

The relative economy of the most suitable machine tools, using any special tools, jigs and fixtures which can be applied to the work, must be well considered, e g centre lathe versus capstan, milling versus planing machines, vertical drilling machines using jigs against boring mill and jig borer, horizontal against vertical lathes, etc (See Tables LIV to LVI.)

Using the vertical drilling machine, the bushings of the jig take over the guidance of the tool

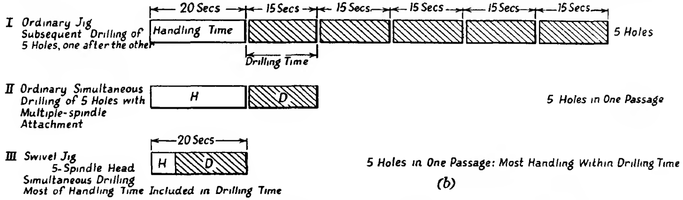


FIG 128b INFLUENCE OF JIG-DESIGN AND KIND OF MACHINING ON DRILLING TIME

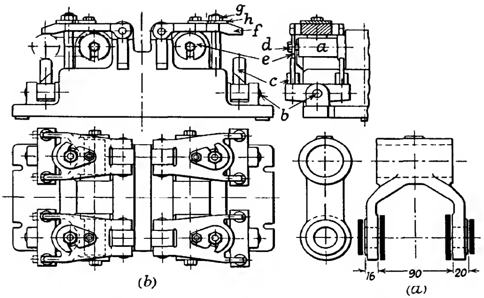


Fig. 129. (*a*) Work piece Steel Casting (*b*) Revolving Milling Jig for 4 Pieces, 4 Surfaces Milled Simultaneously, Output 30 Pieces per Hour

a = receiving pivot, *b* = bolt for *c* = equalizer, *d* = hexagon nut, *e* = slotted swivel clamp, = clamp, *g* = lock nut, *h* = slit washer

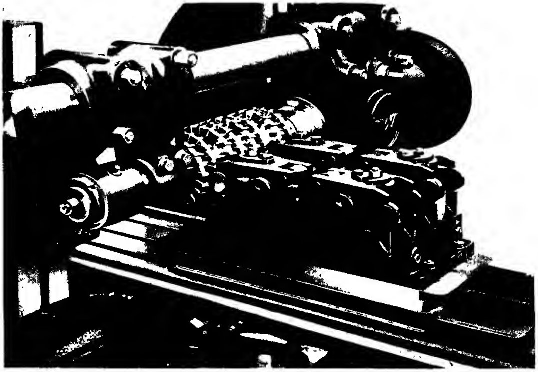


Fig. 130. Heavy Attack of a Gang of 8 Facing Cutters Machining 2 × 4 Parallel Surfaces of Two Steel Castings Clamped in the Revolving Jig (Fig. 129)

Using the horizontal boring mill there are two possibilities. (1) to work without jigs, (2) to use jigs.

1. Because the boring mill and the jig borer are very accurate machine tools with spindle running

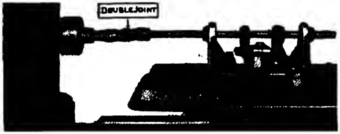


Fig 131 Jig on Boring Mill Boring Bar Driven by Double Universal Joint

in high-grade bearings, single pieces are frequently produced thereon without jigs. The quality of the piece then depends both on the quality of the operator (generally very skilful) and, of course, of the quality of the boring machine

2. However, for repetition work, boring mills are often combined with complicated jigs which have guiding bushings. It is always advisable, then, to use the powerful machine spindle as the driver and to connect the boring bar, guided by the bushings only to the spindle, by a double universal joint (Fig. 131). Fine-boring machines or jig borers are so rigidly built that jigs are unnecessary and even one prototype can be made on the fine borer with highest accuracy.

If jigs, fixtures, and special tools are made inside the plant the tool department will produce them. Ordering and follow-up will be done by the production control to whom it is a very important task All jigs and fixtures should be tried on the work before acceptance by the operating department, using the tool in the presence of an inspector and under the direction of the works production department

Standard methods should be adopted for inspecting jigs, fixtures, and tools *after use*, to have them adjusted, and repaired, etc , before putting them back into storage For example, tolerance plug and snap gauges can only be kept reliable if they are checked by the storekeeper *each time* they are returned by an operator, preferably at the window in the presence of the workman, say, by using the control stands of reference discs

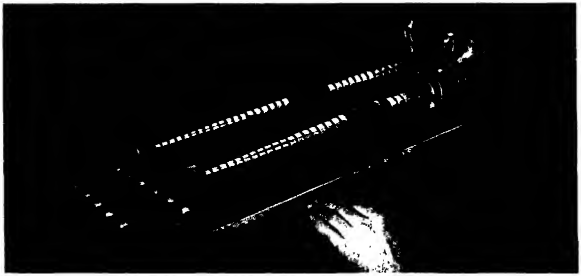


Fig 132. Control Stand of Reference Discs in Tool Room

(Fig 132). Snap gauges, in particular, may be spoilt at once by a careless operator.

To close the economic cycle, a proper plan should be established of charging off the costs of the various tools, either to jobs or as "expense" items. The cost accounting department would regulate this procedure, although the basic data would come through the works production department.

A certain expenditure for tools in the widest sense is advantageous wherever parts are to be produced in quantity How much capital should be put into small and special tools depends on the immediate situation. If jigs and fixtures are so seldom used that they do not pay, it is wrong to tie money up in them However, other considerations are important, such as improved interchangeability of parts, increased accuracy, and ability to use lower-priced labour on accurate production.

Economy of Jigs and Fixtures

To ensure economy of jigs and fixtures, F K Roe* developed a group of formulae which answer one or more of the following questions—

1. How many pieces must be run to pay for a fixture or given estimated cost to show a given estimated saving in direct labour cost per piece?

2 How much may a fixture cost which will show a given estimated unit saving in direct labour cost on a given number of pieces?

3. How long will it take a proposed fixture, under given conditions, to pay for itself, carrying its fixed charges for so doing?

Questions 1, 2, and 3 assume that savings just balance the expense There is another practical question—

4 What will be the profit earned by a fixture of a given cost for an estimated unit saving in direct labour cost and given output?

These questions involve something more than simple arithmetic for an answer, because while the credit items for the fixtures depend mainly on the number of pieces machined, the debit items involve time and also the number of set-ups required (see page 261), i e whether the pieces are often run continuously or in a number of runs.

Roe developed the following four formulae—

(1) $N = 4\dfrac{I\left(A + B + C + \dfrac{1}{H}\right) + Y}{s(1 + t)}$ (wanted number of pieces)

(2) $I = 4\dfrac{N \times s(1 + t) - Y}{A + B + C + \dfrac{1}{H}}$

(3) $V = 4N \times s(1 + t) - Y - I\left(A + B + C + \dfrac{1}{H}\right)$

(4) $H = 4\dfrac{I}{N \times s(1 + t) - Y - I(A + B + C)}$

These formulae contain—

(a) Debit Factors

A = Yearly percentage allowance for "interest on investment"

B = Yearly percentage allowance for fixed charges, as taxes, insurance, etc.

C = Yearly percentage allowance for upkeep

$\dfrac{1}{H}$ = Yearly percentage allowance for depreciation and obsolescence on the basis of uniform depreciation, where H is the number of years required for amortization of investment out of earnings.

I = Estimated total cost of the jig or fixture (or purchasing price in shillings).

Y = Yearly cost of set-ups, including expense for taking down the apparatus and putting machine in normal condition (in shillings).

(b) Credit Factors

S = Yearly total saving in direct cost of labour (in shillings)
= $N \times s$, where

s = Savings in unit labour cost.

T = Yearly total saving in labour overhead (in shillings)
= $S \times t$, where

t = Percentage of overhead on the labour saved.

V = Yearly gross operating profit, in excess of fixed charges (in shillings).

Examples

Estimated unit-saving in direct labour cost. s = 2d. (1d. = 0·0835 shillings).

Overhead on labour saved: t = 50 per cent.

* "Principles of Jig and Fixture Practice," by F. K. Roe, *Mechanical Engineering*, U.S.A., Feb, 1941, p. 118.

Estimated cost of each set-up—

$$\left.\begin{aligned} Y &= 50 \text{ shillings} \\ A &= 6 \text{ per cent} \\ B &= 4 \text{ per cent} \\ C &= 10 \text{ per cent} \\ H &= 2 \text{ years} \\ \frac{1}{H} &= 50 \text{ per cent} \end{aligned}\right\} = 70 \text{ per cent}$$

$$A + B + C + \frac{1}{H} = 70 \text{ per cent}$$

If $I = £100$ ($= 2000$s.) to find the number of pieces to be put through each year in one run per year, we have from equation (1)—

$$N = \frac{2000 \times 0{\cdot}70 + 50}{0{\cdot}166 \times 1{\cdot}5} = 5800 \text{ pieces.}$$

If the pieces are put through with six set-ups ($Y = 50$) per year, then

$$N = \frac{1400 + 300}{0{\cdot}25} = 6800 \text{ pieces,}$$

the increased number of pieces being obviously due to the increased number of set-ups.

Suppose the fixture is to pay for itself in a single run then,

$$\frac{1}{H} = 100 \text{ per cent and } A + B + C + \frac{1}{H} = 120,$$

then $N = \dfrac{2000 \times 1{\cdot}2 + 50}{0{\cdot}25} = 9800$ pieces.

Reversing the foregoing assumptions, we can find $I = 2000$s and $H = 2$ years, etc. Therefore, it is recommended that in authorizing expenditures for all jigs, fixtures, and special tools above some established minimum cost, an estimate can be made of—

(1) Cost of the fixture.

(2) Output of the fixture

(3) Profit due to its use.

When it is put into operation, the actual results, technically and economically, should be checked with these estimates. Planning, manufacture, and costing should again form an integral unity.

Standardization of Tools and Jig Components (Bushings, Clamps, etc.)

Principles of standardization as applied to machine parts are also applicable to small and special tools. Many standard tools, such as twist drills, reamers, taps, dies, etc., can be purchased in the open market and can usually be bought more cheaply and of a quality giving better service than those made in the factory's toolroom. It pays, therefore, to buy standardized tools as marketed and to adapt one's own standards, including bushings for drilling jigs, to standard market sizes.

Advantages of standardization are reductions in—

(1) Purchase prices, owing to increase in quantities manufactured (see pp. 46 and 250).

(2) Spare part stores

(3) Storage space.

(4) Clerical work.

Every tool and fixture should be marked plainly in a conspicuous place with its tool symbol The drawing of every piece to be machined by special equipment should clearly refer to this mark, so as to avoid the proper use of any special tool or jig being overlooked by the foreman, chargehand or operator, thus upsetting the planning, and sometimes even rendering the whole equipment useless

Clear strict rules should be elaborated and strictly followed for the storing, issuing, returning and maintaining of all tools, special or ordinary.*

Before a set of fixtures can be designed, the dimensions of the part to be machined must be definitely determined. It must be fully prepared for manufacturing Tolerances must be inscribed in respect of those dimensions which secure a certain class of fit, whether running, transition, or interference fit, so as to guarantee the desired allowance or clearance of mating parts, and the surface finish indicated The closeness of the tolerances governs the design and workmanship of the jig or fixture quite as much as does the required production rate.

The best grouping of operations (and their reduction to the least possible number) can be facilitated by scheduling on an operation list showing each operation and including the number of inspections needed. The design of fixtures,

* *Production Handbook*, L P Alford and J. R. Bangs; Ronald Press, New York, 1944

for, say, the bolt of a rifle, should be closely connected with the system of gauging. The same points or surfaces should be used for locating the work in the fixtures as for reference points in the gauges. The locating surface of the subsequent

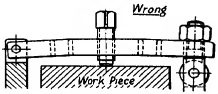


FIG 133 CLAMPING SCREW DESTROYS PARALLELISM OF AXES OF BUSHINGS

fixture should check automatically that the preceding operation was correct. A jig should reject a piece defective from the prior operation.

For example, the rifle-bolt (see Fig 5c) is drop-forged; then the stamping must fit the fixture of the first machining operation. When the hammer die is worn above the limit, the piece is too thick and the operator cannot clamp it, thus affording impersonal inspection of the tools of another department. There is, of course, an inspection of samplings of drop-forgings, but as 1200 or 5000 bolts per day would require a tremendous staff of inspectors for all the different operations—126 operations in the case of the bolt—the interlocked control by the locating surfaces allows the reduction of floor inspection to a minimum concentrated mainly on the so-called "danger-spots"—ten for the bolt—where the locating surface is changed, and where a sharp inspection of the main finished operations is indispensable to avoid serious and expensive scrap Only for good and sufficient reasons should the locating point or surface be changed.

Deburring time can be reduced to a minimum on parts which require several cuts if the direction of the feed and of the various cuts is positioned so as to throw as many of the edges as possible requiring deburring on to the same side of the part.

If a multiple fixture is to be used, of either the reciprocating or indexing type (see Fig. 128), the clamping means must be so designed that the piece can be handled in the time taken for the cut. Multiple drilling machines allow the different tools for say, drilling, counterboring, reaming, tapping, and surfacing to be driven at different speeds so that many operations can be done at one setting A condition for efficiency is that the power consumption of the different tools should be properly balanced about the central drive of the machine.

Jigs and fixtures should be designed so rigid as to guarantee the required distances and dimensions of holes and surfaces It is, therefore, a matter of very careful judgment to make a fixture adaptable to various pieces and operations. Errors in use can be avoided only by a foolproof system of safety devices, which must be applied before the jig is issued by the toolroom or stores

If the spindle noses of the lathes and capstans and the slots of the tables of milling, planing, and shaping machines are standardized, together with the tenons of the fixtures, many of them are

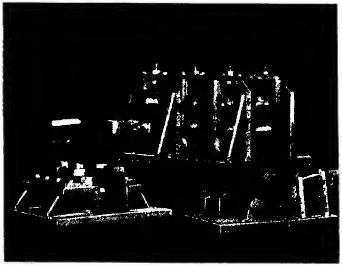


FIG 134 LIGHT JIGS FABRICATED BY WELDING

interchangeable on the various machines on which they can be used

Bushings, latches, handles, thumbscrews, etc., of jigs and fixtures should be standardized for the same reason. This lowers the costs not only of making them in the factory's own toolroom, but also of buying them in the market. (See Figs. 135 and 141.)

Conclusions

Jigs and fixtures should—

(1) Locate the work quickly and positively.

(2) Preclude insertion of the work in any but the position correct for machining.

(3) Where it is necessary to clamp the work from the sides, the clamps should also pull the work against the supports.

(4) When a stop and a support surface on a fixture form a sharp corner, the corner should be relieved to reduce the tendency to catch dirt and also to simplify cleaning.

(5) Provide rapid, positive, and easy clamping

(6) Cause no spring in the work, fixture, or machining table, from either clamping or cutting pressure (Fig. 133).

(7) Allow no movement, vibration, or chatter during the cut.

(8) Have ample clearances for chips, and be easily cleaned.

(9) Allow free access and egress for cutting fluids.

(10) Be as light as is consistent with strength and rigidity and easy to handle (fabricated by welding—Fig. 134).

(11) Be safe for the operator.

(12) Arrange the cutting zone as close to the machine table as possible.

(13) Make those parts subject to wear easily renewable without destroying the jig itself.

(14) Avoid handling of spanners; use thumb or fluted nuts or levers, where possible. They should be made long enough to avoid the use of a steel hammer. In certain cases raw-hide mallets or small lead hammers may be allowed.

CHAPTER XV

Design for Mass Manufacture and Line-production (Progressive Assembly)

In present days it is a good principle to install line production even for moderate batches where only simple and easily-provided equipment is justified and even where it may only be used for some few months of the year The investment of capital remains within reasonable limits, the conveyors work only for a limited time and are then closed down or transformed to some other use. The big advantage of this production method in all cases is the reduction of the price of the manufactured product to the consumer and the shortening of working hours for employees

Standardization of Secondary Parts

To put this idea into practice, for example, in the manufacture of machine tools, which are always made in moderate batches, five to fifty machines according to size, it is important to standardize as many secondary parts as possible which are essential to the completion of the machine, but relatively unimportant to the buyer of the complete product. This is a very effective preparation for mass production

Fig 135 shows internal standards for a continental machine-tool works of 3500 workmen,

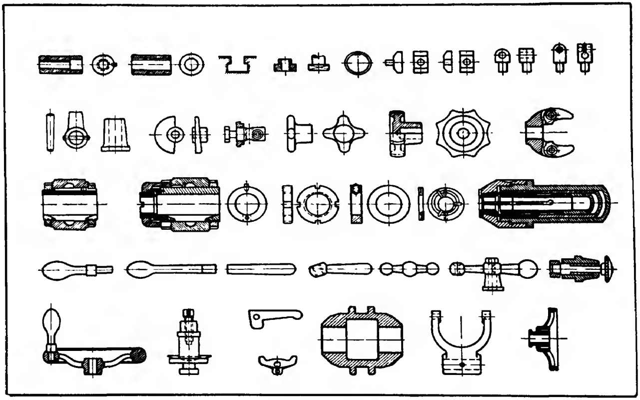


Fig. 135. Internal Standards of a Machine-tool Works

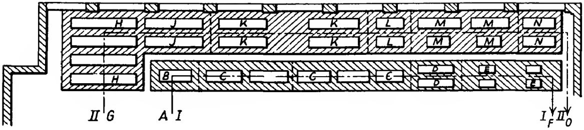
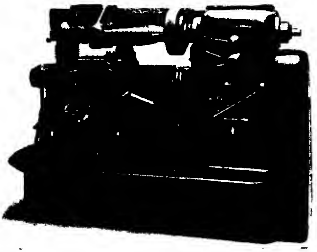


FIG. 136 LINE-PRODUCTION OF MAIN SPINDLE

manufacturing all types of lathes, and milling and grinding machines. They are compiled in a special manufacturing standards department, occupying some 200 men continuously for this purpose only. The products are sold to many foreign customers because most parts are standardized by the Continental Standards Institution



(Geo Fischer-Schaffhausen, Switzerland)
FIG. 137 HYDRO-COPYING RIGID LATHE

and are used by numerous engineering works all over the country, thus avoiding expensive individuality. Standardized products of this kind, manufactured on a mass-production scale, are better and cheaper, are interchangeable, and can be purchased from stock. Universal joints, gear-oil pumps, change-gears for lathes and milling machines, milling arbors, bushings for such arbors, spring collets, etc., are the type of accessory which cries out for at least internal standardization and consequently cheap and first-class manufacturing.

Even the standardization of the production process for such complicated parts as main spindles

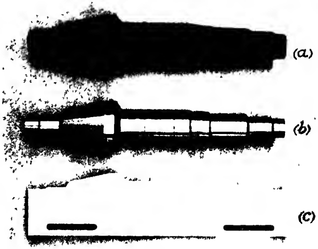


FIG 138 EXTERNAL COPYING

Given·

(a) Forging with $\frac{5}{16}$ to $\frac{3}{8}$ in. allowance in diameter, centred at both ends Material Ni-Cr. Steel (S.A E. No 3115)

(b) Mounting of work-piece· 1st operation between centres with work driver; 2nd operation between centre and 3-jaw chuck.

(c) Template of shape. Description of machining· Copying the whole length in two operations (partially with grinding allowances).

Length 15$\frac{3}{8}$ in ; finished diameters from 1 to 3$\frac{1}{16}$ in.

Spindle speed . .		500 r.p.m.
Cutting speed (on max. dia) . .		400 ft p m.
Feed	7$\frac{1}{8}$ in p min.	0 014 in.p rev.

Machining times.

Handling	1 5 min.
Cutting	2 6 min.
Floor-to-floor time . . .	4 1 min.

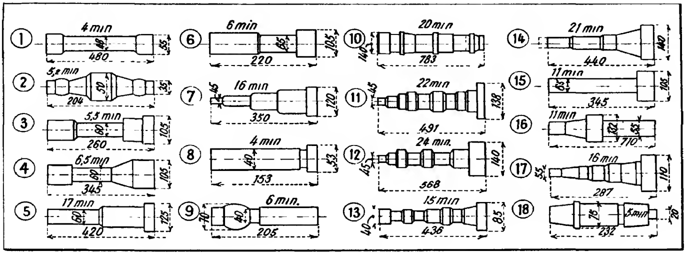


FIG 139 EIGHTEEN SOFT PARTS OF QUITE DIFFERENT DESIGN MADE IN SMALL BATCHES ON THE SAME HYDRO-COPYING MACHINE

of quite different machine tools was realized by using partly special machines which, however, were quickly adjustable for a wide range of spindles of different design and quite different dimensions These machines are then taken out of their group-operation, e g turning, grinding, etc , and arranged for line-production to produce parts in batches as small as three spindles with great savings in time and wages. The essential feature is that the transport from group to group is now shortened very considerably

Fig 136 shows the plan of a production line for main spindles of lathes, turret lathes, automatics, milling and drilling machines, which were used by the above-mentioned machine tool-maker for his whole manufacturing programme. The parted bar or the forging arrives (*I*) from the stores (*A*), is centred (*B*), pre-turned (*C*), inspected (*D*), and grooved (*E*). Then it is transported to the remote case-hardening department (*F*), returns from there (II *G*), is pre-finished by turning (*H*), then the long axial hole (30 to 50 in. long) is drilled (*J*) through the soft core, the spindle is pre-ground and finished-ground (*K*), including the taper at the front end (*L*), and the different threads and journals are ground (*M*) Then passing the final inspection (*N*), it is sent to the fitting department (*O*).

Previously this very difficult work-piece demanded very skilled turners who are now replaced by the universally adaptable special-purpose

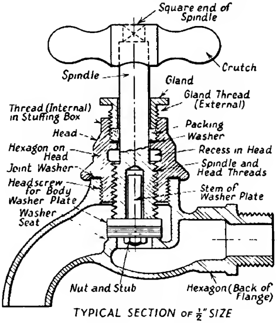
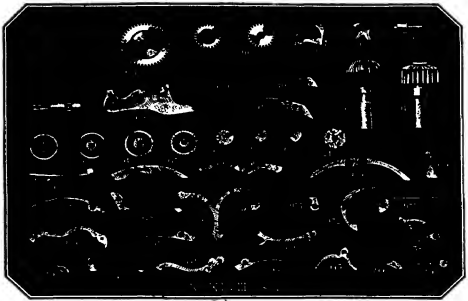


FIG 140 STANDARDIZED WATER TAP (BRIT STD. 1010)

machine (not to be confused with "single-purpose"), the hydro-copying rigid lathe (Fig. 137), which is changed from one spindle pattern to another (Fig. 138) by simply changing the templates and setting the single-point cemented carbide-tipped tool to a suitable diameter. The change-over from one work-piece to another normally requires ten to thirteen minutes. Herein lies one of the essential advantages of this machine. As long as the only single-point tool remains sharp the template ensures that all diameters maintain their correct size and length, which speeds up setting, machining, and inspection.



(a)

FIG 141
(a) INTERCHANGEABLE COMPONENTS, (b) ASSEMBLED "LONGINES" WATCH NON-SELECTIVE INTERCHANGEABILITY

(Montres Longines, St Imier, Switzerland)

The high cutting speeds of 440 f.p m for S A E 3415 (Ni-Cr-Steel), and 590 f.p.m. for S.A.E. 1035 require high-quality cemented carbides. The tolerances of fine-finished turned pieces on this machine are $\pm 0{\cdot}001$ in. which compete at some diameters even with grinding and always suffice, of course, as preparation for the final grinding operations. The tool life is between two to three hours, so that about two single-tool changes are required daily. To take the worn tool from the tool-post, replace it by a new one, and readjust this in working position requires two to three minutes.

Fig. 139 shows eighteen soft parts of quite different design made in batches of three to five and the times for finishing them on the hydro-copying machine.

The standardization of the water tap (Fig. 140 showing bib, hose, pillar, globe, stop, and screwdown tap) has been accomplished to a large degree in Great Britain by British Standard 1010, 1944. Not only the shape, but all dimensions of the different types are tabulated with maximum and minimum tolerances, and even the alloys for the different materials, castings and pressings, their thickness, quality, and test pressure are so specified that the interchangeability of these fittings, and of their spare parts, as used in every household, is guaranteed for the benefit of the user This is the right principle. good quality and interchangeability with the maximum allowance, using the best available experience of experts, without detriment to the good taste of the public. The appearance of the taps may, of course, be improved by nickel-chrome, or cadmium plating, etc., but this has nothing to do with the workmanship of the parts and the quality of the material.

Water taps are not exactly precision products, but they fulfil the demands of non-selective assembly.

Non-selective Assembly

However, there is another large range of products of exceedingly high accuracy where non-selective assembly is a *conditio sine qua non*; it is the manufacture of high-quality watches. Fig. 141* shows the whole assembled watch and some single components all of which represent interchangeable spare parts, made in Switzerland, but applicable all over the world The finished parts are in no way adjusted prior to assembly. Figs. 142 (*a*) and (*b*) show some important parts, together with the tolerances which guarantee their non-selective interchangeability Taking into consideration that a good many parts are made on automatic screw machines using cemented carbides, e g for 900 to 1000 axles per grind, it is clear that the setting-up of these machines and the sampling inspection of parts must be very well organized to ensure the high quality It is true that all pivots for the most important axles which run in jewel bearings and those for secondary purposes which run directly in the brass plates are burnished to exact size as a last operation, but again it is clear that this decisive operation done on a mass-production basis must be performed very carefully and controlled systematically.

The " Ideal " Valve

The "Ideal" valve (Fig 143) for superheated steam was developed as a standard prototype with the intention not only of improving its function by creating an uninterrupted flow of fluid but also of making it particularly suitable for mass production.

The stages of preparation were—

1. Reduction of number of types.
2. Reduction of number of components
3. Reduction of transport by line-production.
4. Well-balanced loading schedule of machines.
5. Economic performance and application of time studies.
6. Complete specification cards for each component.
7. Minimum of inspection with perfect control of personnel and output.

(1) The number of types were derived from the standard pipe diameters. In this case thirteen sizes were chosen, i.e. 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16 inches diameter.

* "Montres Longines," St. Imier, Switzerland.

(2) The previous design had sixty-one parts per valve, altogether 13 × 61 = 793 parts. By a reasonable combination of the main parts of two to three sizes, the total number could be reduced

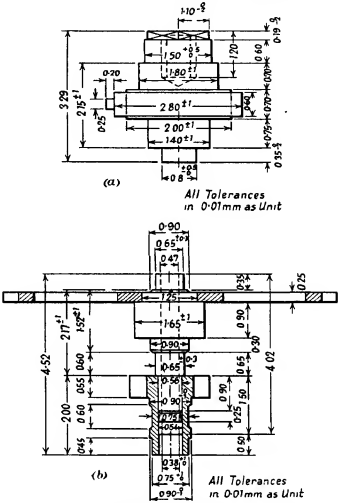


Fig 142 Tolerances of Watch Parts (*Longines*) (Measured in mm)

to 357 For example, the connecting fork (Fig. 143 (*b*)) was now designed as a steel-casting without cores, and moulding machines were used in its manufacture The weight could be reduced by 32 lb as compared with the former design, and the same fork could be used for three diameters, e.g. for 8, 9, and 10 in. pipes Similar reductions were possible with other components All forgings were now drop-forgings made with 8 to 10 per cent material allowance. All operations were made in jigs and fixtures, with self-locating surfaces,

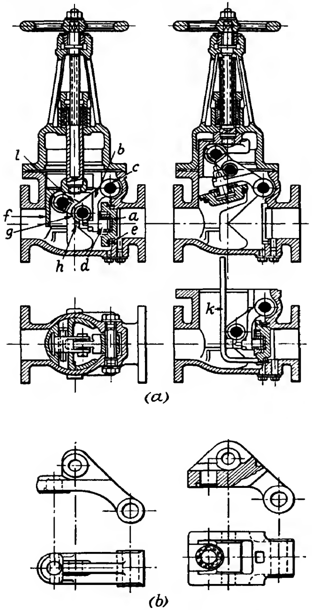


FIG 143. (a) "IDEAL" VALVE FOR SUPERHEATED STEAM (b) CONNECTING FORK USED FOR THREE DIAMETERS

avoiding all marking operations. The special machine tools were adaptable for the turning, boring, and milling, etc., of a series of flanges.

Result. The total time for manufacturing 200 "Ideal" valves of the different sizes was 335,278 min = about 5600 hrs after the rationalization, against 492,832 min = about 8200 hrs with the former design, corresponding to about 32 per cent savings in wages. At the same time a considerable reduction in overhead expenses was obtained.

The Standardization of Gasmeter-counters

Fig. 144 shows an example taken from the manufacture of gasmeters. Ordinary domestic gas meters show by their counters the quantity consumed in cubic feet or cubic meters, recording by three to six figures, partly as decimals The same meter design is sometimes used for automatic performance using coins, the different values of which must be in direct relation to the measuring unit of the different countries, i e cu ft, cu in., cu metre, litre, and arranged to use the sterling currency or the various decimal currencies (dollars, francs, roubles, marks, etc.) or special currencies such as the Indian (16 annas to one rupee) The meters indicate either with a flat dial or with cylindrical rollers, using either trains of wheels or counters with jumping figures, and all variations for different quantities and currencies must fit into the same general design of meters

By practical standardization the number of the basic types was reduced from forty to four counters with the result that the whole manufacture has been changed from small batches into mass production

Service of Several Machines by One Man

It is sometimes necessary to consider a single operation to be performed consecutively on a number of work-pieces by one operator (Fig. 145). As the figure shows, this can occur in three ways—

(*a*) Where the operations (t) do not immediately follow each other, or when a certain interval (I) is required;

(*b*) Where the operations follow each other without interruption, and

(*c*) Where one man operates several machines or when one operation is begun, before the prior one is finished, overlap (O).

Under (*a*) the total time (T) is greater than the sum of the individual times (t): $T > 4t$; with (*b*) it is precisely the same as the sum of the

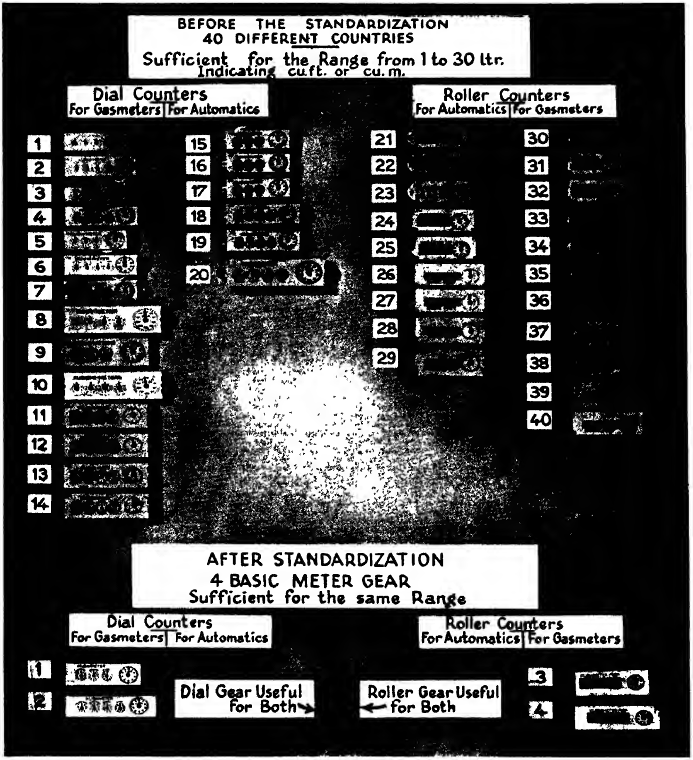


FIG. 144. STANDARDIZATION OF GASMETER-COUNTER

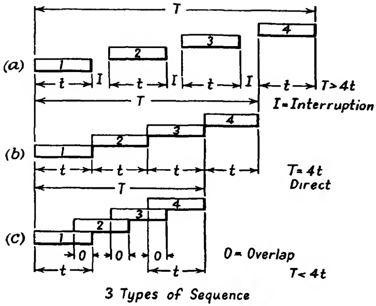


FIG. 145

(*a*) Total Time (T) Greater than Sum of the Individual Times
(*b*) Total Time Equal Sum
(*c*) Total Time Smaller Sum.

individual times. $T = 4t$; and with (*c*) it is less: $T < 4t$.

Which is the best way for one operator to serve more than one machine? The solution is fairly simple if the same work-piece is made on two or more machines, but it is complicated and sometimes impossible if the pieces change continuously regarding shape and material.

Fig. 146 (*a*) shows the schedule when two machines are operated by one man, making one type of piece. Machining time $T_M = 2$ min; total setting time $T_S = 2$ min. Then the worker can just set up one machine while the second machine does the machining. The total time is $T_S + T_M$, but since $T_S = T_M$ the worker finishes two pieces in the same time T_M, so he gets paid only for one piece plus a bonus for his increased attention and efficiency.

Fig. 146 (*b*) shows the schedule for serving three machines. For three machines the setting time is reduced to $T_S = 1$ min, the machining time remains $T_M = 2$ min. The example proves that this is only possible if the reduction of the setting and clamping times is achieved by an improvement of the clamping method. Again the worker gets a higher bonus for the increased effort. Similar considerations arise where more than three machines are operated by one worker.

Fig. 147 (*a–e*) shows as a characteristic example the schedule of line manufacturing for production of ten four-throw crankshafts of a motor-car engine per day, when each of ten workers serves several machines in completely balanced cycles. The different diagrams illustrate—

a Shape and size of four-throw crankshaft,

b. Analysis of operators' (Nos. I to X) working time in $\frac{1}{100}$ hour per operation (Nos 1 to 35),

c. Quantity manufacturing plan for finishing crankshafts: series of operations (Nos. 1 to 35) combined,

d. Finishing plan series of operations Nos 1 to 35 not combined,

e Working plan of every operator cycle per operator $\leq$ 1 hour

I to X operator's No

1 to 35. operation of m/c No

$\frac{7}{100}$ to $\frac{80}{100}$ hr. varying times per operation (4·2 min to 48 min).

(*b*) Ten operators are working (Nos. I-X).

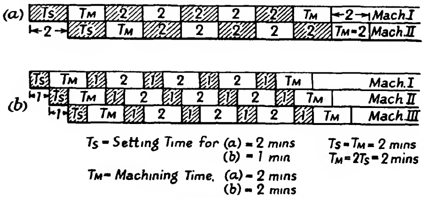


FIG. 146

(*a*) Two Machines Operated by One Man.
(*b*) Three Machines Operated by One man.

Fifty crankshafts form the batch, they have the numbers 1–50, the number of operations is 35. Fifty shafts are always in operation to balance the very different machining times. The times are measured in one hundredths of an hour beginning on Monday morning.

EXAMPLE. Operator I performs operation 1 to 6 on crankshaft KW* 1–10, then he continues KW 11–20 in approximately $\frac{1800}{100} = 18$ hours, then he starts on shafts 21–30 and so on Operator II works first at operations 7 and 8 of shafts KW 41 to 50 (these operations are fairly long $\frac{80}{100} = 48$ mins), and he then continues KW 1–10 from operator I, having finished operations 1 to 6 in the meantime

(Compare (*e*) working plan of operators I to X)

Eventually operator X is finishing KW 41–50 from the previous week

(*c*) Here the whole series of operations are combined to illustrate the collaboration of operators Number of operator and numbers of operation are allocated to the same line, the number of crankshafts, e g from 1 to 20 is shown on the vertical ordinate

(*d*) Those operations in the manufacture of the ten shafts which cannot conveniently be combined are shown singly, dependent upon time For the first ten crankshafts the lengths of time needed for each of the thirty-five operations are compared, e g operations 9–13 have the same length, consequently the lines are parallel with the same inclination; (compare working plan: operators III and IV).

(*e*) The working plan for each operator gives the cycle time per operator which is $\leq$ one hour The diagram combines the number of the operators I–X, the number of operations and machines from 1–35, and the times per operation in $\frac{1}{100}$ hour. The blocks are cross-hatched; inclination to the right means that the operator serves the machine, while inclination to the left shows that the machine is working without supervision.

* KW = Kurbelwelle (crankshaft)

The schedule is a typical example of the difficulties involved and the clear understanding which is necessary for the planner to perform a balanced working cycle for ten operators with quite different single times per operation, yet combined in such a way that the idle and waiting times are practically nil.

In this connexion there have been many recent discussions on whether any material economy has resulted from the use of flow-production instead of the usual batch-production methods.

Fig 148 is a diagram of work in process for parts of crankshafts, ten sets per day being made in an automobile factory, which changed over from the previous small batch-production method of two to four sets per day to a type of "flow" production The first rectangle shows the large circulation of about 160 pieces for a daily delivery of ten shafts due to the longest finishing operation, including waiting and transport times

The second rectangle shows the change-over to a kind of batch production, which reduced the number of parts in progress, first to fifty, then to eighteen shafts per day By means of suitable chutes near the machine, served by the workman himself, waiting times and transporter labour were eliminated The total time needed to deal with the minimum number of circulating pieces now depends on the time for the longest operation, this being the bottleneck For instance, if parts had to be annealed or hardened, requiring an additional day or more, then the circulation of material must be increased accordingly In this case the theoretically desirable minimum of 12 pieces = 10 + 20 per cent, for contingencies could not be reached, but a reduction from 160 to 18 pieces, equal to 12 per cent of the former quantity was a remarkable success.

This effect of moderate line production on the reduction of the circulation of material can in all cases be attained without large installations of special machines and tools, even in older shops when it can often be achieved by the elimination of intermediate transport.

Also it is incorrect to think that line production means in every case the installation of bands, chains, conveyors, and other complicated transport implements. The production engineer must

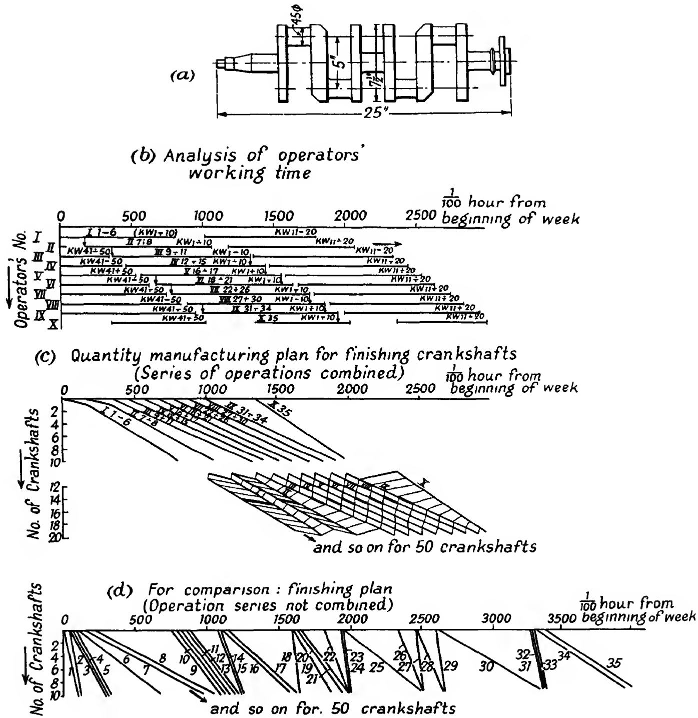


FIG. 147

(Continued on following page)

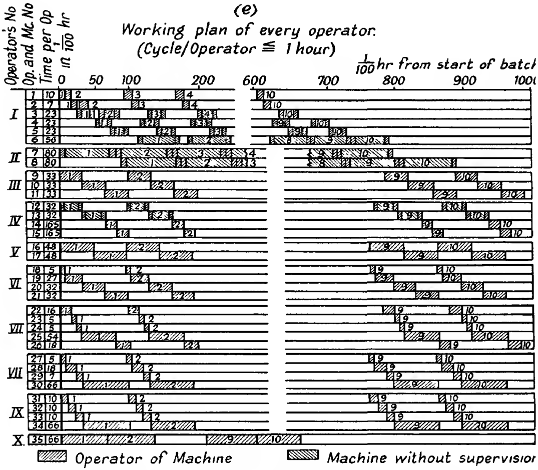


FIG 147 (Contd) SCHEDULE OF LINE MANUFACTURING FOR A 4-THROW CRANKSHAFT
10 Operators Simultaneously 35 Operations Batch of 50 shafts

consider all known devices and pick out the most economic for his case

For all parts, the design of which remains unchanged for a long time, and which can therefore be manufactured in large quantities, specification charts are advisable (Fig. 149), showing in respect of each part all details needed for the most economic batch and mass production

Advantages of Manufacturing in Batches

(1) Perceptible savings both in setting-up and interest costs.

(2) Scrap replacement unnecessary, because economic batches cover the set-back caused by one or more scrap pieces and eliminate the very expensive and troublesome progressing of single pieces by the production control

(3) Quicker assembly, shorter delivery. There is no danger that important parts are missing in the sub-assembly and assembly departments

(4) Clerical work Writing and calculating, particularly in the works production department, is considerably decreased.

(5) Effective use of machines The increased batch number allows work previously done on a lathe to be done instead on a capstan or even on an automatic screw machine.

(6) Psychological effect. The influence on the

mood and output of the workers when bigger batches are ordered is not to be under-estimated.

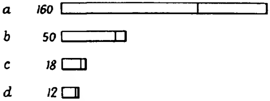


FIG 148 DECREASE OF NUMBER OF PIECES WITH IMPROVEMENT OF MANUFACTURE OF CRANKSHAFTS

Columns to the right of stroke mean additions of various interruptions.

(*a*) Long finishing time; long waiting and transport times; many pieces in progress.

(*b*) Stages on the way to line-production; considerable savings through right arrangements Decrease of waiting and transport times. Small number of pieces in progress.

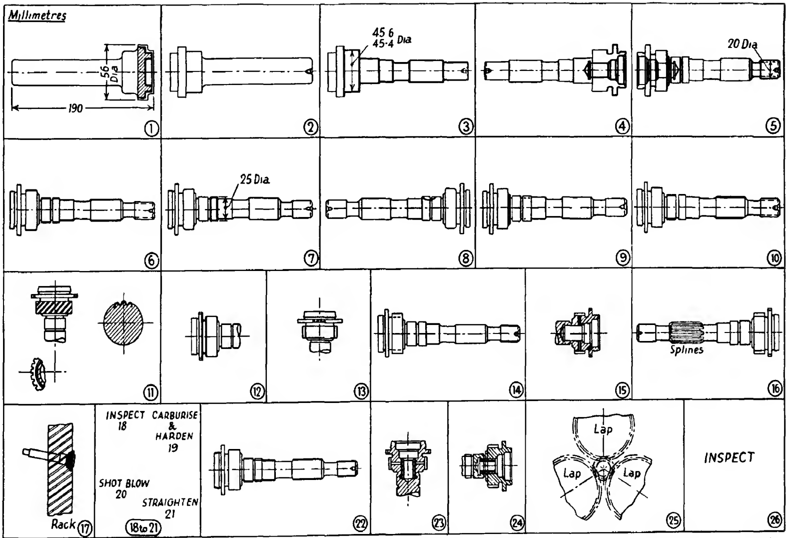
(*c*) Real line-production every piece always in operation. Shortest possible waiting and transport times, minimum pieces in progress. Condition: fairly big batches Type and time of operation is the same in all cases

KEY TO FIG. 149

Operation No	Description	Machine Tool
1	Hold on shank dia, rough turn large gear dia, rough turn cone dia, rough recess; face end and gear.	No. 4 Capstan
2	Locating with vee-blocks on shank centre other end	Corona-horizontal Centring
3	Hold on cone dia with centre at other end. Turn shank dias.	Fay Auto
4	Hold on big dia, locate with centre at rear, face end, face gear Turn gear dia., form cone, groove at back of gear dia, drill, bore, ream U-cut and cham.	No. 3 Auto.
5	Lightly grip on dog dia and locating on front cone face. Thrust compt. back into jaws with centre, tighten jaws, face end to length using roller box for steady. Re-centre form U-cut and turn end dia., using running centre for steady, screw end for gear cutting.	No. 4 Capstan
6	Locating between centres, drive with carrier, locating on dog dia. Turn 4 dias	Small-Piece Lathe
7	Thread milling, 25 mm dia —1 5 P —L H thread	Archdale Thrd Mill
8	Key seat	U S Hand Mill
9	Chuck on dog dia. Skim face.	Selson Lathe
10	Grind dias for gear-cutting (off centres)	6 × 12 Plain Grinder
11	Cut teeth	Fellows Gear Shaper
12	Remove burrs	Holbrook Shaver
13	Chamfer teeth	Parkson
14	Chuck on dog dia Remove thread and chamfer	Selson Lathe
15	Drill 7 holes	Drill
16	Mill 10 splines	B & S Gear Cutter
17	Shave spiral gear	Michigan Shaver
18	Inspect	
19	Carburize and harden	
20	Shot blow	
21	Straighten	Herbert Press
22	Grind cone and 4 dias (off centres)	6 × 18 Churchill Plain grd
23	Press in bush Drill 4—2 5 dia holes through	Logan Air Press 1 S R Drill
24	Hold on gear dia bore bush	B S A 6 × 12
25	Lap spiral gear	Michigan Lap
26	Inspect	

Progressive Assembly

Thorough and extensive time studies are necessary for real line-production of parts and progressive assemblies. Sometimes even motion studies can be recommended to ascertain the "cycle," that is the balanced working time either for single operations or combined group-operations. For this purpose one must have a carefully laid-out schedule, which shows the operations singly and



(*Morris Motors, Ltd, Engine Works, Coventry*)

FIG 149 MASS MANUFACTURE OF DRIVE-GEAR
Schedule of 26 Different Operations

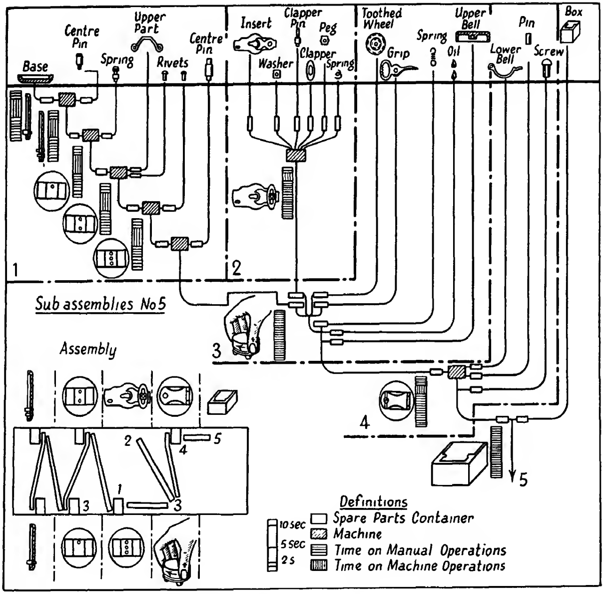


FIG. 150 ASSEMBLY LINE OF A BICYCLE BELL

dependent upon each other. The next step is to get a schedule of the possible working time of each operator for each operation. Finally it might be necessary to combine several operations if a single one is not long enough for the cycle or, vice versa, several operators may have to work at one working place in order to reduce the time needed for a single operation which is too long to fit into the selected cycle time. This creates the line-production schedule. Here pure theory is impossible. One must work on actual examples, because operators work differently and must be rearranged and balanced against each other until the best utilization of each place is ascertained Should the single work-piece be very complicated, and the number of operations (see Fig 149) and the times per operation very different, then the establishment of a really sound line-production is difficult and sometimes impossible. In such cases the line-production is confined to the sub-assembly of finished parts and their final assembly into finished machines The progressive assemblies of motor cars and similar engines are well-known examples

Fig 150 shows as an example the assembly line of a bicycle bell with a cycle of eleven seconds for

FIG 151 BELT CONVEYOR ASSEMBLY OF SMALL SPEED-COUNTERS
(Nine-seconds cycle)

the sub-assemblies and the finished bell Fig 151 shows a belt-conveyor assembly of small speed-counters with a nine-seconds cycle.

CHAPTER XVI

Maintenance and Repair

THE FINAL inspection and testing of a new machine tool in the maker's works is carried out by experienced fitters and inspectors, who have usually been engaged in the various stages of erection and are familiar with every part of the machine. Intimate knowledge of the machine and of the correct use of measuring instruments and finishing tools enable them to assemble the machine in such a way that errors in individual components, within their respective admissible tolerances, have a negligible effect upon the working accuracy of the machine as a whole

In addition the user sends a representative who is capable of conducting the acceptance tests of a machine. He knows which limits must be rigidly adhered to and which may, in debatable cases, be relaxed so long as the machine produces work-pieces within the required limits of accuracy.

Technical and Economic Importance of Maintenance and Repair

The machine-tool maker of to-day frequently confines himself to the manufacture of certain classes of machine tools, perhaps even to a single class, such as lathes or milling machines. Nevertheless he is himself a user of many types of machine tools. The quality and accuracy of the machine tools which he makes are directly dependent upon the quality and accuracy of the machine tools which he uses. Effective maintenance and repair are, therefore, of the highest technical and economic importance. The "Test Charts"* are the best guide to effective maintenance.

Machine-tool repairers do not generally specialize, as do machine-tool manufacturers. On the contrary, many repair shops deal with a wide variety of machines. Under such conditions it is essential to have at hand standards of tests and acceptance based on long and specialized experience with each individual class of machine tool.

* *Testing Machine Tools*, by G. Schlesinger, Machinery Publishing Co., Ltd., London, 1945, Fourth Edition.

The acceptance charts are also useful for checking machines in use and for the inspection of machines after repair.

To-day the machine-tool user expects to produce parts which conform to B.S.I. limits on machines operated by ordinary experienced workmen. There should be no necessity for special professional skill to "off-set" faulty machines. For this reason inaccuracies due to the wear of the machine must not exceed certain limits. The machine must be watched, and worn or damaged parts replaced or repaired immediately

Effective maintenance and prompt repair are essential to steady production They act as preventives, eliminating those long and costly delays which inevitably occur when an important machine tool breaks down Emergency repairs will, indeed, always be unavoidable, precautions should be taken to avoid their repetition

Maintenance is the act of maintaining, sustenance, continuance, to maintain is to preserve, keep in state, continue.

What Maintenance Involves

Maintenance of machine includes—

(1) Checking the accuracy of the finished work-piece.

(2) The preparation and, if necessary, the assembly of the parts required for replacements.

(3) Estimating the costs of the various items of the repair.

(4) Directions to production foremen and workmen regarding the correct use of machine tools.

(5) Repair or rebuilding of the whole machine.

(6) Emergency repairs.

Errors in work-pieces may appear after a certain time as a result of natural wear of machine parts. This, if noticed in time, can be remedied either by using the existing adjusting mechanism or by some small correction done after working hours. After a long period of work, or if overworked, the machine must undergo a reasonable overhaul, preferably in accordance with a certain time schedule.

Repairs

The repair can either be restricted to replacing the worn-out or damaged parts or surfaces, or can be extended to include the modernization of the entire machine by rebuilding. To be effective, rebuilding must be supervised by a machine-tool expert, who is capable of meeting the increased demands of our times (use of cemented carbides, negative rakes, etc.), by the inclusion of new bearings, hardened and ground spindles, new gears, better lubrication, facilities for the introduction of coolant, etc.

We shall now consider the people who carry out the repair and the methods used

The manager of the repair shop should be responsible to the chief engineer and should have full power to maintain in good condition all machines used in the factory. The foreman and workmen must be carefully selected and instructed on the type of work they have to carry out. They must not only be able to work in accordance with fine tolerances, but must also be conversant with faults in construction and know how to remove them This must not be a department to which inefficient production workers are transferred

In small workshops the inspection and repair are generally done by the same man. In big shops a special inspector works side by side with the workmen who are carrying out the repairs. In order to carry out the work, the only measuring instruments required are those already in general use for machine-tool inspection (Fig. 152). Of course, other tools are wanted for scraping, checking and measuring, as well as the special equipment which will be adapted to the particular demands of each machine.

Besides the regular periodic inspection of the machines, they must be inspected as soon as they produce work-pieces which do not conform to the

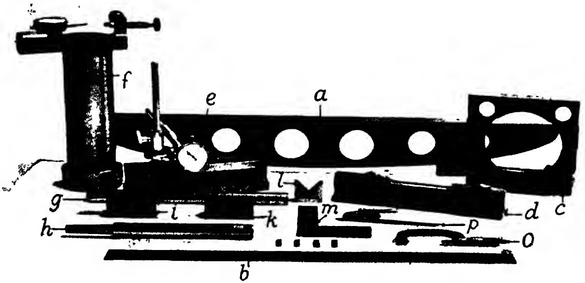


FIG 152 INSPECTION TOOLS FOR MAINTENANCE AND REPAIR

a = Straightedge
b = Straightedge
c = Frame spirit level
d = Straight spirit level
e = Dial gauge on ordinary universal stand
f = Dial gauge on tube holder for capstan lathes
g = Hollow cylindrical test-mandrel-straight
h = Hollow cylindrical test-mandrel-taper shank.
i = Long V-block
k = Long V-block
l = Short V-block.
m = Square and Slip gauges.
o = Micrometer
p = Protractor

required limits of accuracy Only when the reasons for such faults are known can they be remedied.

When it is required to overhaul a machine, or to examine it with a view to overhaul, an overhaul sanction sheet should be made up embodying at least the following information*—

Machine No
Date
Job. No

MACHINE OVERHAUL SANCTION FORM

Description of machine
Date purchased Price
Present book value Present market value
Cost of a new up-to-date machine of same type
A brief statement to denote the relative production value of a new machine of the same type
Hours in use
Repairs for last two years cost
Repairs for current year cost
Last overhaul cost Date
Special reason for overhaul
Extent of overhaul proposed
Estimated cost
Remarks
Length of time machine can be released for overhaul
(Obtained from progress department)

Overhaul sanctioned

Technical and economic factors must be balanced before the repair or the rebuilding of a machine tool is sanctioned

Maintenance and repair are important and active functions of the productive side of a works organization. Their aim is to maintain the productive efficiency of the equipment. They are best done actively, by anticipation, to prevent the delays which are inseparable when breakdown occurs

How to Measure Accuracy in Machine Tools

Acceptance test charts fulfil a three-fold purpose—

(1) The final inspection and testing of a new machine tool.

(2) The control and checking of machine tools in use for manufacturing operations.

(3) Erecting and inspection of reconditioned machine tools during and after repair

(1) Makers and users use the same prescriptions, therefore, disagreement and friction between both regarding the limits of accuracy of machine tools are readily overcome by the use of the "acceptance charts." The charts embody the basic requirements of both the "alignment" and the "performance" tests.

(2) The control of working machine tools is done automatically every day by inspecting the finished work-pieces. Inaccurate work betrays faulty machines Output is decreased, the operator cannot earn his usual bonus or any bonus at all. The workmen know very well which machines are good and which are not. They often ask: Can I not work at that machine? Therefore, a systematic checking at least every half-year is recommended according to a definite schedule Small frequent repairs prevent breakdowns and expensive major repairs The acceptance test charts provide the means to detect in time any deviations beyond those permissible. A complete alignment check, e g of a lathe, takes two hours by trained expert inspectors

(3) Every factory has a repair department frequently connected with the toolroom according to its importance and size Reconditioning or rebuilding should always be done according to a reasonable use of the acceptance tests, modified as necessary

Before the inspector, the foreman, or the reconditioner examines the machine, he must have precise instructions regarding—

(1) The correct shape, position and direction of motion of those parts of the machine tool which affect the accuracy of the work-pieces produced thereon. In the case of the lathe, for example, the shape of the spindle journal is very important: it must run true and be of perfect cylindrical or taper shape. The position of the tailstock relative to the headstock is important: their axes must be in line. The direction of motion of the carriage must be parallel to the spindle.

(2) The best methods of conducting the tests and how to use the tools and instruments required for testing. (See Fig. 152.)

* "Maintenance of Machine Tools," by J. W. Mallett, *Journal of the Institution of Production Engineers*, March, 1938, p 148

Acceptance Test Charts

The requirements of (1) are fulfilled by the "Acceptance Test Charts." Each chart contains limits of error permissible in the shape, position, and direction of motion of those parts of the machine which affect the working accuracy In addition, the permissible tolerances of the work-piece are given in the performance tests at the end of each chart. These tolerances conform to the B.S.I. fits and limits.

The requirements of (2) are supplied by this instruction which gives full information regarding the use of the measuring instruments concerned and details of the methods of conducting the tests (by principal sketches of shape and application).

The test charts relating to any class of machine such as lathes, milling machines, etc., give the general structure together with the tolerances to which the various units, such as spindles, cross-slide, etc , must conform

The general method of procedure followed in the charts is as follows—

(1) The machine is set up and the principal horizontal and vertical planes and axes are checked with a spirit level.

(2) The straightness, parallelism, and quality of the guiding and bearing surfaces of beds, uprights, and base plates are tested

(3) The main spindle, as the fundamental element of the machine, is tested for concentricity (true running), axial slip, accuracy of axis, and position, relative to other axes and surfaces.

(4) The movements of all the working components which generate the shape of the work-piece are then checked.

(5) Working tests are conducted to determine whether the machine, as a whole, produces finished work-pieces within the specified limits of accuracy and without vibration marks. This general scheme is applicable to all machines (See Table XXXVIII, 1 to 13.)

Sequence of Acceptance Tests

(*a*) Accuracy of the machine itself.

I. Levelling.

II. Erecting and setting up.

III. Testing guidance and movements.

IV. Testing the main spindle and its relation to other important units and components.

(*b*) Accuracy of the finished work-piece.

(*c*) Speeds and power consumption.

Levelling beds, base plates, tables, stands, etc , is the indispensable first basic operation in erecting and setting up machine tools.

All new machine tools are manufactured at the maker's on this basis. They are permanently and irreparably deformed by any redistribution of the weights of the different heavy sub-assemblies or parts on the bed, caused by their erection at the user's works in a position different from that intended by the maker. If the floor is unstable, not even the most rigid machine tool would work satisfactorily either regarding dimensional accuracy or still less regarding surface finish. Let us consider ordinary machine tools as examples

(1) The *lathe bed* is stationary, it carries the fast headstock and aligns the tailstock in any position to take up heavy work-pieces; and forms the guide of the moving carriage for the tool. It is the simplest example of levelling of a bed.

(2) The heavy stationary bed of the *grinding machine* is the support for the comparatively light sliding work-table which carries headstock and tailstock of the machine and the work-piece, which may be very heavy, e.g. rolls It also carries the quick-rotating abrasive on a special carriage. It should be levelled on a rigid foundation, even if it is not clamped to it, to secure the correct function of the work-table with its equipment.

(3) The work-table of a *milling machine* is a part which is always movable on an undercarriage or a bed. However, the plane and horizontal surface of the work-table in different characteristic positions guarantees the correct setting-up of the whole machine.

(4) The heavy and usually long bed of the *planing machine* must be carefully levelled before it is grouted, because the very strong work-table with heavy and long work-pieces rests freely on the bed and must stand very heavy cuts sometimes of several tons, whereas the heaviest grinding force will not exceed 200 lb. Therefore, the work-table of the planer must be levelled again after

the correct horizontal position of the bed on its foundation has been secured.

(5) The levelling operations on a ***horizontal boring machine*** are more complicated as this has a moving carriage on the bed, a cross-slide on the carriage, and frequently a rotary work-table on top Because, unlike the lathe, the carriage carries the piece, which is often very heavy with eccentrically distributed weights, all bearing parts, i.e. bed, carriage, cross-slide, and work-table, must be levelled one to the other before accurate pieces can be finished on the machine

(6) The base plate and column of a *radial drill* form a good example of a machine the base of which has no moving guide-ways, but serves only to take up the work-piece and to secure the perpendicular direction of the bore The guide-way of the spindle rests on a column (which must remain with permissible small deviations) at right angles to the base plate when under load.

CHAPTER XVII

When is a Machine Old?

An existing machine should be replaced by a new one if this can be bought for a price which ensures a greater profit as compared with that previously obtainable from the capital invested, when due consideration is paid to all technical and commercial aspects.

The conditions, as expressed by the words "old," "worn-out," "used-up," or "obsolete," are not defined by the number of years a machine tool has been in service, but rather by the quality and quantity of the work produced on it Thus a machine may be "young" in years, but "old" as regards efficiency, whereas another, although "old" in years, may still be reasonably efficient

The answer to the question as to how long a machine tool can usefully perform productive work depends on the class of machine, its design, the price which was originally paid for it, the period during which it has been run in service and the overhead cost which it involves

The shop superintendent will replace a machine only if he is sure that the substitute will offer advantages as regards: (1) greater productivity, (2) a higher degree of working accuracy, (3) reduced production cost

It should be borne in mind, however, that the full economic advantages can be obtained only from such machine tools as are kept permanently employed. Thus it is essential that the productivity of the machine should be in accordance with the demand for the goods produced on it.

The Time Factor

In order that the economic problems entailed may be fully understood, it is necessary to follow the technical development of high-speed production in modern shops. Regarding the time factor, distinction must be made between (1) setting-up times; (2) work clamping and unclamping times; (3) actual cutting times; and (4) time lost due to unavoidable interruptions and unforeseen troubles

Setting-up, Clamping, and Unclamping

Let us first consider the setting-up and the clamping and unclamping times which, together, may account for from 20 to 90 per cent of the total production time, depending on the nature and size of the work. In the case of small components, these idle times may be reduced by using mechanical, pneumatic, or hydraulic rapid-clamping devices, whereby savings of some 10 per cent are not infrequently effected. (See page 254) If quick-acting clamping devices are installed subsequently on old machines, they should be chosen to suit each individual case Although such subsequent installation may be practicable in many cases, it is comparatively seldom that it is actually done.

Cutting Time

As regards the actual cutting times, an attempt should be made to bring the construction of the machine into conformity with the cutting properties of the tools so that these times are lessened.

Choice of a Machine

The choice of the machine depends primarily on the number of pieces to be produced. Thus the ordinary centre lathe is used for batches of from one to five pieces, whereas lots of from three to two hundred pieces should be machined on the turret lathe, and for still greater quantities the automatic lathe should be used. (See pp. 240–245.)

Quantity Production

For quantity production semi- or fully-automatic machines, multi-cut lathes and multi-spindle automatics should be employed. With these machines it is possible to effect considerable savings in time, and consequently to reduce costs.

Makers of telephones, wireless sets, typewriters, watches, and similar products frequently require as many as 10,000 of certain parts per day. If a firm can maintain this output during two hundred days of the year, it should not be difficult to decide whether or not to buy a machine for £3,000 because for one year's production of 200 × 10,000 = 2,000,000 pieces, the allowance for depreciation would be only 0·072d. per piece if the machine were kept in use for five years (£600 per year as depreciation).

Obviously, under such conditions, a high-production machine will always pay, and the salesman will readily be able to convince his customers as to the desirability of purchasing the machine on the ground of its economy and profitability.

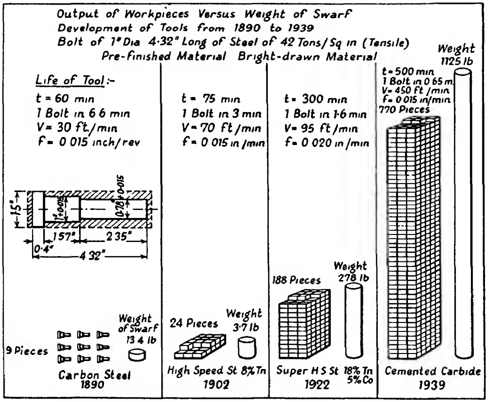


Fig 153. Development of Production Rate by Improved Tools

Variety Production

Much more difficult is the problem of purchasing machine tools for those firms concerned with the production of a wide variety of different work, each part being made in small serial lots.

The present period of tool development is about to revolutionize shop equipment, the improved efficiency of modern plant being clearly evident from the greatly increased production rate, as shown in Fig. 153. In fifty years production per single tool regrind has been increased from nine to more than seven hundred pieces. We are thus compelled to consider the question "When is a machine old?" from quite a different point of view.

The Commercial View

In most cases the answer to this question is given by book-keepers and accountants They fix the percentage to be depreciated, they determine the repair cost for each machine, and draw attention to the necessity of replacing it if the depreciated value is reduced to zero, or if the repair costs have grown inadmissibly high

The Depreciation Rate

The rate of depreciation is generally fixed by striking a balance The greater the rate of depreciation the smaller will be the earnings. This is a disadvantage to the shareholders. If too high a rate is chosen the zero value of the equipment will be reached relatively quickly, but afterwards the earnings will increase to a corresponding extent.

The accounting basis, however, is by no means the only one on which to decide whether or not a machine is to be replaced, and again we may ask the question "When must a machine be replaced?"

irrespective of the amount by which its value has been written down.

The answer to this question will be different according to whether the matter is viewed from the technical or economic standpoint. The commercial attitude depends on the rate of depreciation, the technical attitude on the standard of working accuracy of the machine, and its productive capacity.

As regarded from the commercial point of view the "life" of a machine is estimated for the purpose of creating a reserve fund, whereby the machine may be replaced by a new one when it is worn out. This fund, of course, can only be drawn from the manufacturing earnings The establishment of depreciation funds is regulated by law in some countries In all countries, however, laws prescribe the amount for depreciation which may be included in the balance sheet, even though it is not obligatory for the money to be put aside for this purpose

The amount by which the value is written down depends on the estimated life of the machine, which varies from two to eight years for a multi-spindle automatic and may be as much as thirty years or more for a heavy crankshaft-turning lathe having a capacity for work ten feet in diameter and fifty feet in length

There are shops in which even to-day reasonably economic operations are carried out on heavy lathes built in 1900 and operated by skilled men This leads to the question of the theoretical life, as against the useful or practical life, the former being determined by the ledger and the latter by technical requirements, such as smoothness of surface finish, accuracy, cheapness, and rapidity of production.

The only decisive factor influencing the replacement of a machine, as regarded from the point of view of the manager, will be whether or not the machine is able to do profitable work or to pay dividends The superintendent, however, holds a somewhat different opinion in so far as he wishes to keep in touch with the latest developments and to try out the most up-to-date machinery and tools. The board of directors, on the other hand, looking for profits and afraid that any expenditure on new machine tools may lessen the surplus earnings, may not sanction such purchases.

The Life of a Machine Tool

What is a reasonable life for a machine tool? At least ten years might be the rule. Many firms, however, use their equipment for twenty and more years by utilizing both old and new machines. A new rigid precision machine tool loses its working accuracy if it is employed for taking both roughing and subsequent finishing cuts. After one or two years, the initial working accuracy may be lost, the machine although still strong and rigid, requiring extensive servicing until, after a lapse of say eight years, it must be relegated to the ranks of the second class, and finally, it may be reconditioned at fairly high expense.

The Effect of Overhauling

Owing to repeated overhauling, the quality of the machine will decline and the material will be subject to fatigue stresses and wear out more and more so that finally its useful life is finished A complete reconditioning is not worth while unless in the meantime the efficiency of the small tools has been improved considerably, for example, as regards (1) the cutting power, (2) the cutting speed

In both cases the machine tools have to be redesigned to meet the requirements Thus, for (1) power increased strength of frames, spindles, gears, etc., is necessary, while for (2) speed the introduction of improved bearings and lubricating systems, hardened and ground gears, etc , is necessary

The decisive factors governing the redesign are the need for absorbing the increased cutting forces in the first case, and of controlling vibration and wear in the second case.

Cemented Carbide Tools

The modern high-speed production methods using cemented carbide tools and negative rakes (see page 181) have revolutionized the nature of the shop equipment within the past five years Although they will withstand the increasing cutting forces, the older designs of machine tools do not lend themselves to the high-cutting speeds without considerable modifications. These inefficient machines do not compare favourably with modern types.

The Answer to the Question

It is now possible to give a definite answer to the question "When is a machine old?" both in the technical and commercial sense.

The Technical Problem

Regarding the technical side of the question, the design of modern machine tools is such that the cutting properties of the improved tools can be utilized to their full extent. By way of an example, the considerations to be taken into account in the problem of replacing an old machine by an efficient high-duty machine will now be discussed.

Let us assume that a machine tool and its equipment is ten years old, built for high-speed tools. The pre-war price of the new machine was £500 and the present depreciated value is £200 On quantity production, the machine is in operation during eight hours of the ordinary working day but, e g. 44 hours per week; the total time per piece being thirty minutes, giving a total production of 44 × 2 = 88 pieces per week. This output will change with the number of working hours per week.

With an up-to-date machine operating with modern tools of the cemented-carbide type, the same piece might be finished within fifteen minutes. Assume that the initial cost of the new machine, including tooling, is £1500, that is to say 7·5 times the depreciated value of the old machine. Suppose, moreover, that the old machine could still be used for an additional ten years, and that the new machine is to be depreciated or written off within ten years.

The operator of the old machine may earn 2s. 10d. per hour, while the rate of pay of the operator of the new machine on account of its increased speed is 3s. 2d. The rates are calculated as follows—

1. Basic wage, 2s. 6d. plus 15 per cent = 2s. 10d.
2. Basic wage, 2s. 6d. plus 25 per cent = 3s. 2d.

The overhead on the labour cost is 150 per cent for the old machine and at 165 per cent for the new machine, which involves increased overhead because of its higher power consumption and inspection costs.

Let us ascertain whether the reduction in wages cost will justify a replacement of the old machine. Referring to Table LVIII, this shows that, although the amount of depreciation to be charged against each piece made on the new machine is about four times as high as that for the same produced on the old machine, and although the overhead is 10 per cent higher (165 per cent instead of 150 per cent), the production cost is, nevertheless, reduced by 1s. per piece This represents a reduction of cost of 33 per cent.

In the second part of the Table, under the heading *B*, the comparative selling prices are calculated including the cost of the material It will be seen that a profit of 1s 8d. = about 25 per cent will be obtained with the new machine on account of the reduced production costs, whereas with the old machine, the profit is 6d = 7·7 per cent

This study is the more important because it is in connexion with small- and medium-sized machine tools that the greatest improvements in design have taken place and in the majority of cases such machines are well adapted for high-speed cutting and rapid work-clamping With these machines it is actually possible to reduce the total floor-to-floor times to one-half or even to one-third as compared with the times formerly required.

The increased speeds of which modern tools are capable necessitate powerful driving motors and designs which will resist vibration, and it is partly for these reasons that many relatively new machines have become obsolete. Both technical and economic considerations determine whether a manufacturer should replace his machine or not.

The main requirement in purchasing a machine tool can be briefly summed up as follows: The machine must be capable of manufacturing interchangeable parts at low production costs despite increased wage rates or shorter working hours. There are also other points to be taken into account, as for example, the possibility of manufacturing the work-piece complete on the one machine, the size of serial batches or quantities, tolerances, surface-finish, work-chucking and loading devices, and hoists Cost control, although of importance in determining the various elements of cost, cannot alone ensure economy in manufacturing. Only by the practical use of suitable machines and adequate tooling can cheapness of production be obtained, provided that, simultaneously, the setting-up and work-clamping times are reduced to a minimum Frequently, idle times still exceed the actual cutting times.

It is on this basis that machines should be continually improved and replaced, regardless of their age, as soon as new machines are developed which will produce work more economic than the older types

TABLE LVIII

A Cost Comparison (Excluding Material)

Old Machine		*New Machine*	
Book value of old machine	£200	New machine	£1500
Production time per piece	30 min	Production time per piece	15 min
Machine life (still)	10 years	Machine life (total)	10 years
Wage rate	2s. 10d	Wage rate	3s 2d
Departmental overhead cost	150%	Departmental overhead cost	165%
Labour cost for 30 min at 2s 10d per hour	1s 5d	Labour cost for 15 min at 3s 2d per hour	9½d
Depreciation of machine per piece		Depreciation per piece—	
Book value, £200 = 4000 shillings		Value of new machine, £1500 = 30,000 shillings	
10 years of 50 weeks of 44 hours = 22,000 hours		10 years of 50 weeks of 44 hours = 22,000 hours	
$\frac{4000}{22000}$ = 2 2d per hour, thus for ½ hour	1 1d	$\frac{30000}{22000}$ = 1s 4d per hour, thus for ¼ hour about	4d
Overhead, 150 per cent on labour cost (1s 5d)	2s 1 4d	Overhead, 165 per cent on 9½d	1s 4d
		Cost per piece	2s 5½d
		Reduction 31 per cent (compared with 3s 7½d	1s 2d
Cost per piece	3s 7½d		3s 7½d

B Selling Price 6s 6d. (Including Material)

Old Machine		*New Machine*	
Production per 44 hours, 44 × 2 pieces	88 pieces	Production per 44 hours, 44 × 4 pieces	176 pieces
Manufacturing costs per piece	3s 7½d	Manufacturing costs per piece	2s 5½d.
Cost of material	2s 4½d	Cost of material	2s 4½d.
Profit per piece, 7 7 per cent	6d	Profit per piece, 25 per cent	1s 8d
Selling price	6s 6d	Selling price	6s 6d

Profit on 176 pieces at 1s 8d	= 293s
Profit on 176 pieces at 6d.	= 88s
Increase of profit per week	= 205s = £10 5s

CHAPTER XVIII

The Plant

No workman can do his daily work continuously, properly, and quickly, unless his working place is prepared for the work. Just as the housewife arranges for the efficient working of her home, so should the managing director see to the "housekeeping" of his business He should ask himself· Is my factory managed with the same efficiency as I expect to find in my home? Do I arrange the costing of my internal orders correctly, and do I control them as quickly, promptly and as carefully as I control my profitable production orders? In a good many cases the answer will be: "No." Neither are repair orders properly clarified nor is their execution always in really reliable and expert hands, nor will the result of the repair always be checked as to their quality and durability and still less as to their cost.

The Size of the Repair Department

What proportion does the repair department bear in size to the ordinary workshop? The author found in a copper and brass mill of 3000 workmen, 290 non-productive workers (plumber, carpenter, builder, electrician, repair fitter, etc). In a textile works of 600 workers there were 80 non-productive workers as defined above, in a second textile works with 1200 workers there were 110 non-productive; in a big rubber factory of 3500 workers there were 350 non-productive, in a works making chandeliers, electric fires and heaters, etc., there were 900 productive and 100 non-productive workers. According to these figures it seems that in many factories an average of 10 to 12 per cent of the productive workers are required for repair and similar work. That is sufficient to justify a systematic ordering system and simple but clear costing methods which must be adapted from case to case, and to size and difficulty of the internal work, so as to avoid the reproach of over-organization.

A Telephone Factory

The example of the telephone and telegraph factory will establish the technical question of this problem in detail. (See Fig. 7)

The situation of the factory was carefully chosen with railway and canal facilities for the supply and dispatch of raw material and products. The buildings are well adapted to the manufacturing process and the departments incorporate the flowing sequence of operations The internal transport is done by trucks, lifts, cranes and conveyors, the current for the power, light, telephone, telegraph, etc , is taken from the city supply of 6000 volts Its transformation and distribution to the users at 100 to 800 volt A C. and 100 to 300 volt D C is done at a central substation The steam for heating, cooking, and drying is supplied from the firm's boiler house, from which is also controlled the entire water distribution of the factory for drinking and other purposes, taken partly from the town supply and partly from the firm's own wells which were necessary as a precaution against fire risks. Fresh-heated air is distributed by a correctly-designed ventilating plant, which at the same time removes vapour, gas, and dust, etc , from the electro-plating plant, the hardening department, the kitchen, and from several floors of the eight-storey building, thus improving working conditions especially where they are likely to suffer through the presence of noxious fumes.

In this enumeration we have shown the extent of work of the plant engineer· i.e (1) transport; (2) power, light, telephone; (3) heat economy; (4) supply and drainage of water, fire protection; (5) ventilation; (6) human welfare.

All these duties must be fulfilled in such a way that the production itself may flow uninterrupted. They are performed inconspicuously, and with the smallest expenditure in man-power and money. This is a big task and in some factories, especially those which depend so much on the reliable working of the plant, e.g. in the oil refinery or other big chemical works, the manager of the internal plant holds the position of director, for without him the "household" could not work.

No doubt, the proper provision, layout, and maintenance of plant is the first essential for an easy and effective handling. All piping for steam, gas, water, acid, compressed air and water, power cables and telephone lines must be easily accessible, on the ceiling or in special ducts, so that a simple survey suffices to confirm that they are in good working order. Here again we find that those installations which are technically efficient also conform to the requirements of the costing system and facilitate the performance of this work weekly or monthly according to the organization. If we refer to our Tables of departmental overhead Nos. XI to XIII, we see that all departments need transport, power, water, heat, and sometimes gas, in quantities varying considerably according to the season, and it depends on the layout of the factory whether the determination of each department's consumption can be read correctly from a simple meter, without elaborate calculation with its attendant risks of error

The Plant Engineer

In a well-kept factory a plant engineer has a big but very satisfying job, and, from the departmental returns relating to internal orders, he has a continuous written control of his activity always before his eyes This provides a simple method of tracing mistakes by means of active statistics and tends to eliminate them By this procedure the number of operators working in the plant department, and particularly the repair fitters, can be automatically decreased. In one case they were reduced from 10 to 8 per cent and in another to even 5 per cent of the productive workers, a decrease which increases working profit, improves maintenance efficiency at lower costs, and provides for the early replacement of plant, when necessary.

The Repair Gang

It also reflects considerably to the credit of the repair gang: men who are so often, and so unjustifiably characterized as craftsmen of an inferior grade The opposite ought to be the case. The repair fitter, builder, and plumber, etc , are working on necessary yet not very satisfying tasks. They have not made the machines, jigs, tools, etc , to be repaired, but they must repair things that others have damaged or destroyed; this kind of work has little stimulus, and the payment is seldom high. Piece-work cannot be introduced, because (1) generally the amount of work to be done cannot be correctly estimated beforehand, (2) the work cannot be hurried up by an incentive, because the inspection of the finished work is difficult and repair work must be of good quality, yet quickly done, (3) frequently the worker cannot be controlled by his foreman, because the repair foreman has to send, say, 30 workers all to different remote places where they can be controlled only by perhaps the foreman of the department, who may not be an expert on the job to be done (say, a motor or ventilator to be repaired). Repair fitters work, therefore, on hourly rates, with a bonus for diligence and quality, they must be trained capable craftsmen, reliable and independent, working without inspection or control, and who should have as their single aim the quick yet careful repair of a machine broken down.

The basis of costing is, of course, the hour. The workman attends eight hours per day which he allocates in the evening to the order or orders on which he has worked, any deviations from absolute accuracy will be small and the workmen's time must be paid in every case, regardless of its allocation. A certain check can be done from times given by the foreman.

The Materials Used

The determination of the materials used is also important, this being booked as far as possible against the jobs on which it has been used. For a big repair one should make correct drawings and parts lists and an approximate tender, but no exact pre-calculation because repairs change from hour to hour. For small repairs the reliable man in charge of it may make up a statement of the material wanted, enter a note of it on a material collection sheet, which may be checked by his foreman, and will, of course, always be checked after the work is finished, so that material and wages are known immediately the repair is done, and when the man who ordered the repair has accepted it as satisfactory. Now the circle is closed. The whole costing of repair can be shown in the departmental overhead sheet as an independent cost bearer and ought to be done with the minimum of personnel. In a works of 750 workmen, one accountant was occupied about half a day on costing for the repair gang of 75 to 80 men; both for ordinary indirect labour and internal orders. By this system the works manager can obtain any day the costing of some repair which is of special interest to him. If the plant department is well organized, the costing is simple, quick and accurate. If it is organized in an inferior manner it is very often impossible to have any costing at all.

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