EDITOR: H. WRIGHT BAKER D.Sc. M.I.Mech.E.

Professor of Mechanical Engineering in the College of Science and Technology, University of Manchester

MODERN WORKSHOP TECHNOLOGY

IN THREE PARTS

PART II

MACHINE TOOLS & MANUFACTURING PROCESSES

SECOND EDITION

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PART II: MACHINE TOOLS & MANUFACTURING PROCESSES

MODERN WORKSHOP TECHNOLOGY

EDITOR: H. WRIGHT BAKER D.SC. M.I.MECH.E.

PART I: MATERIALS: PRIMARY AND INTERMEDIATE

PART II: MACHINE TOOLS AND MANUFACTURING PROCESSES

PART III: PRODUCTION PLANNING AND AUTOMATIC MACHINES (in Prepn.)

PREFACE

In the preparation of the second edition of Volume II we have endeavoured to make a somewhat more systematic approach to the subjects covered, and to bring each section up to date within the scope of the book. This has involved not only the introduction of new topics, but the rewriting of several chapters, sometimes from a different angle and by fresh contributors. The result has been a notable increase in the length of the volume, but it is hoped that there is a more than proportionate increase in its value.

It has seemed essential in the first section to break with the old traditions according to which each type of machine tool was considered as a separate creation, and, instead, to see them as members of a single family having many features in common and with differences dictated more by convenience than by principle. There are many books which show how a lathe can turn, and which indicate the very wide range of work which, if necessary, it can be made to cover, but there is very little information available in a convenient form which shows how the work can be done economically by modern standards, perhaps with automatic operation and control, and using materials which were undreamed of a generation ago.

In certain fields—such as that of the understanding of the processes involved in the actual cutting of metals—much new knowledge is being gained, but at present the intricacies of the new theories tend to explain known facts rather than point the way to new practices. In this section the trends of recent researches have largely been omitted to avoid complicating general problems. On the other hand it has been felt necessary to deal in detail with some of the intricate problems of "Surface Finish" in order to help the reader to weave his way with fair safety through the maze of technical and academic literature which appears at times to bedevil his progress, the latter type sometimes seemingly justifying the use of inverted commas and a capital "A".

The recently developed techniques of ultrasonic and electrical machining have been added, and much care has been given to the coordination of all these contributions, so as to form a coherent picture of the latest views and practice.

It is hoped the book will provide answers to many of the machining problems which arise in small and medium-sized workshops and that a third volume will add information concerning the principles involved in the selection and running of more complex plant for large-scale production.

H. WRIGHT BAKER

Manchester,
May 1960

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CHAPTER I

METAL CUTTING MACHINE TOOLS
PRINCIPLES OF DESIGN AND USE

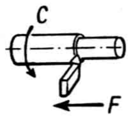
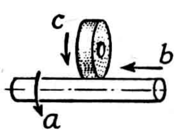
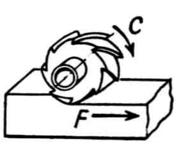
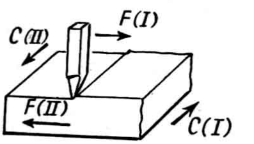
By F. KOENIGSBERGER, D.Sc., Dipl. Ing., M.I.Mech.E., M.I.Prod.E., Mem. A.S.M.E.

Reader in Machine Tools and Production Processes, University of Manchester

Spindle and Feed Drives. The action of a metal cutting tool is based on the relative movement between the tool edge and the material to be cut. If the cutting action is intermittent, as in the planing machine and the shaper, then, as soon as the cut has been made, fresh material must be fed in front of the cutting edge if the operation is to be repeated. If, however, the operation is continuous, as in the lathe, drilling machine, cylindrical grinder or milling machine, both cutting and feeding motions may be simultaneous and continuous. Machine tool mechanisms have to provide both the cutting and the feeding movements, each of which may be allotted either to the tool or to the work piece (Table 1.1).

Spindle Drives. The relative velocity between the tool edge and the material to be cut is called the cutting velocity v, and its optimum value has to be chosen in accordance with the properties of the tool and those of the workpiece material and shape (*see* page 96). Universal machine tools must be suitable for machining many materials and various shapes of workpieces, and a wide range of cutting velocities, varying between a maximum v_{max} and a minimum v_{min}, must therefore be available. If the relative velocity v of the cutting movement is produced by rotation of either the workpiece or of the tool, the required number of revolutions per minute n of the rotating part (the spindle speed) is determined by its diameter, d in Fig. 1.1. In the equation $v = \pi dn$, d is the cutting diameter of the rotating tool or the diameter of the surface that is to be cut by the machining operation in question. On a universal machine tool, d may vary between possible maximum and minimum depending on the capacity of the machine.

TABLE 1.1

Type of Operation	*Cutting Movement 'C'*	*Feed Movement 'F'*
Turning 	Workpiece	Tool
Drilling 	Tool	Tool
Cylindrical Grinding 	Tool	Workpiece (*a*) and Tool (*b*) or Workpiece (*a* & *b*)
Milling 	Tool	Workpiece
Planing (I) Shaping (II) 	Workpiece (I) Tool (II)	Tool (I) Workpiece (II)

The optimum spindle speed n depends, therefore upon diameter d and recommended cutting velocity v,

$$\text{i.e. } n = \frac{v}{\pi d}$$

and in order to provide the before-mentioned ranges for v and d, spindle speeds should be available which cover a range between

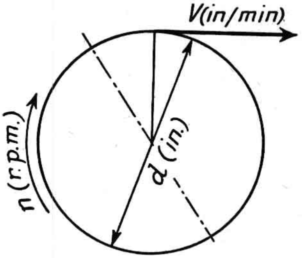


Fig. 1.1

$$n_{max} = \frac{v_{max}}{\pi d_{min}} \quad \text{and } n_{min} = \frac{v_{min}}{\pi d_{max}}$$

It is usually not practicable to provide an infinitely variable range of spindle speeds, and thus the exact optimum value of the cutting velocity cannot always be obtained. However, it is possible to establish certain limits for cutting velocities used in connection with the tool and workpiece materials in question. The top limit v_{max} would be the highest permissible velocity with which a required minimum tool life can be obtained, and the bottom limit v_{min} is the lowest economically justifiable velocity. If the cutting velocity is plotted as a function of the diameter of the rotating part a straight line is obtained for each spindle speed n (Fig. 1.2). If the spindle rotates at n_1 r.p.m., the diameter must not be larger than d_1 and not smaller than d_2, in order to keep between the limits v_{max} and v_{min}. For diameters smaller than d_2 a higher spindle speed n_2 is required, and this is suitably chosen in such a manner as to provide again the maximum permissible cutting velocity v_{max} for d_2, covering an economically machinable range of diameters down to diameter d_3. Similarly n_3, n_4, etc. can be chosen. In general terms

$$\begin{aligned} v_{max} &= \pi d_n \,.\, n_n \\ &= \pi d_{n+1} \,.\, n_{n+1}, \text{ etc.} \\ v_{min} &= \pi d_{n+1} \,.\, n_n \\ &= \pi d_{n+2} \,.\, n_{n+1}, \text{ etc.} \\ \frac{n_{n+1}}{n_n} &= \frac{v_{max}}{v_{min}} = \text{constant.} \end{aligned}$$

In other words, in a range of spindle speeds which allows each diameter to be machined with a cutting velocity of not more than a specified value v_{max}, and not less than a specified value v_{min} the available spindle speeds must be arranged in a geometric progression with the ratio $\varphi = v_{max}/v_{min}$.

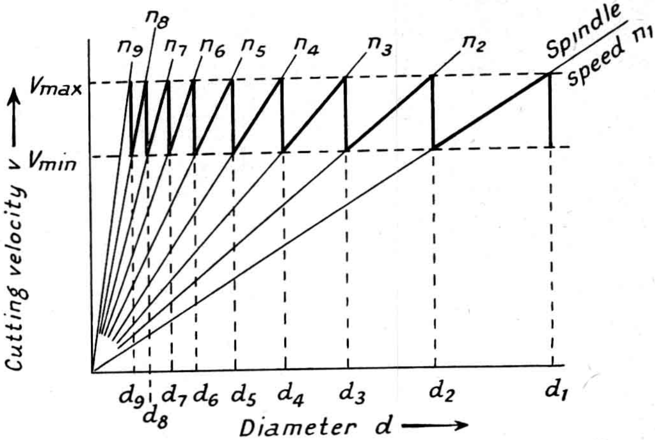


Fig. 1.2. Spindle speeds in geometric progression

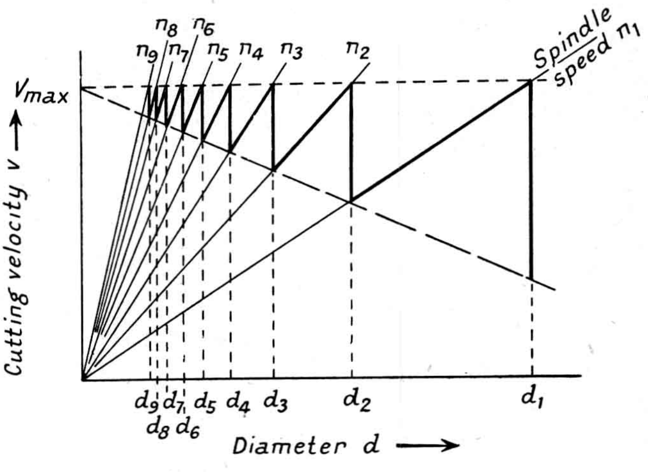


Fig. 1.3. Spindle speeds in arithmetical progression

The diagram, Fig. 1.2, often called the "saw diagram", gives a picture of the conditions; it shows the rather wide gap at the higher end and the larger number of available speeds at the lower end of the diameter range. This is even more pronounced in an arithmetical progression of spindle speeds (Fig. 1.3) which has no constant bottom limit v_{min} and in which the possibility of obtaining economical cutting conditions becomes more and more remote with increasing diameters.

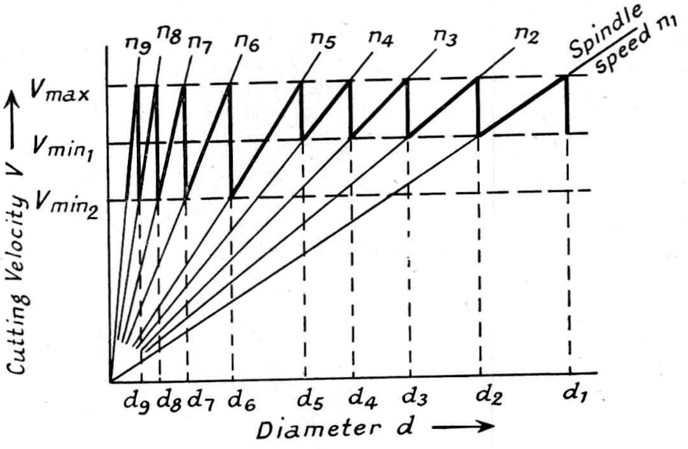


Fig. 1.4. Spindle speeds in two geometric progressions

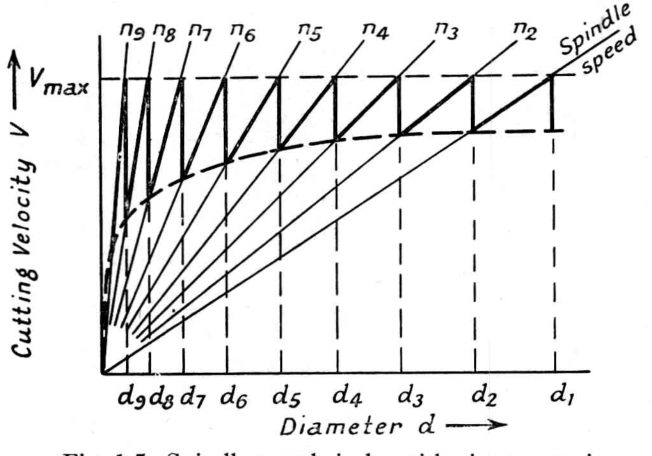


Fig. 1.5. Spindle speeds in logarithmic progression

It has been suggested to use a selected speed range made up from several geometric progressions with different ratios (different values of v_{min} and therefore of v_{max}/v_{min}) (Fig. 1.4).

Another suggestion* advocates the use of a range of logarithmic progression in which the value v_{max}/v_{min} is a function of the diameter (Fig. 1.5). The use of geometrical progressions has already been accepted internationally in the establishment of "preferred

* M. Kronenberg: *Grundzüge der Zerspanungslehre* (2nd edn., Springer, Berlin, 1954).

TABLE 1.2. STANDARD SPINDLE SPEEDS (UNDER LOAD)

$\phi =$						$\phi =$						$\phi =$					
1·12	1·25	1·4	1·6	1·6	2	1·12	1·25	1·4	1·6	1·6	2	1·12	1·25	1·4	1·6	1·6	2
10						100						1000		1000			
11·2	11·2	11·2		11·2	11·2	112	112			112		1120	1120			1120	
12·5						125		125				1250					
14	14		14			140	140		140			1400	1400	1400	1400		1400
16		16				160						1600					
18	18			18		180	180	180		180	180	1800	1800			1800	
20						200						2000		2000			
22·4	22·4	22·4	22·4		22·4	224	224		224			2240	2240		2240		
25						250		250				2500					
28	28			28		280	280			280		2800	2800	2800		2800	2800
31·5		31·5				315						3150					
35·5	35·5		35·5			355	355	355	355		355	3550	3550		3550		
40						400						4000		4000			
45	45	45		45	45	450	450			450		4500	4500			4500	
50						500		500				5000					
56	56		56			560	560		560			5600	5600	5600	5600		5600
63		63				630						6300					
71	71			71		710	710	710		710	710	7100	7100			7100	
80						800						8000		8000			
90	90	90	90		90	900	900		900			9000	9000		9000		

These ranges can be extended by multiplication by ten or powers of ten.

numbers"*, and the advantages, particularly for the designer, who has to design speed-change mechanisms for standardized ranges, outweigh the arguments in favour of other types of speed ranges. To-day the geometrical progression using standardized ratios and speed values (and also feed rates) in accordance with preferred numbers is used almost all over the world (Table 1.2).

For the general case of a speed-change device (gear box, headstock, etc.) of a machine tool, which produces spindle speeds in a range of standardized geometric progression, let φ be the ratio between two adjacent spindle speeds, N the number of different spindle speeds obtainable, n_{max} the maximum, n_{min} the minimum obtainable spindle speed, and R the range of spindle speeds covered by the speed change device. The following relations are valid:

$$R = \frac{n_{max}}{n_{min}}$$

$$n_{max} = n_{min} \cdot \varphi^{N-1}$$

$$R = \varphi^{N-1}$$

$$\varphi = \sqrt[N-1]{R}$$

These relations are shown graphically in Fig. 1.6 for those values of φ, which are standardized in accordance with the series of preferred numbers with the addition of the values $\varphi = 1{\cdot}4 = \sqrt{2}$ and $\varphi = 2$. These latter values have been added to allow for speed ranges which can be produced by pole changes of a.c. motors. It is a fortunate coincidence that the requirement of including the value 2 in the standardization of speeds can be combined with that of basing the range of preferred numbers on the decimal system (values of φ : $\sqrt[20]{10} \simeq 1{\cdot}12$; $\sqrt[10]{10} \simeq 1{\cdot}25$; $\sqrt[5]{10} \simeq 1{\cdot}6$), because $\sqrt[10]{10} = 1{\cdot}2589$ and $\sqrt[3]{2} = 1{\cdot}2599$, and for the purpose of the standardization $\sqrt[10]{10} \simeq \sqrt[3]{2} \simeq 1{\cdot}25$.

Such a standardization is valuable not only for the designer of machine tools. It is even more important for the production engineer because it enables him to rely on identical speeds (and feeds) being obtainable on any of the standardized machines at his disposal.

SPEED CHANGE MECHANISMS. An analysis of those generally

* For a short description of this system, *see* Abbot, W.: *The Dimensioning of Engineering Drawings* (Blackie, 1953). *See also* Kienzle, O.: *Normungszahlen* (Springer, Berlin, 1950).

used in machine-tool drives shows that they consist of a combination of some of the following basic devices (Fig. 1.7):

(*a*) *The Cone Pulley Principle*, Fig. 1.7*a*, applied to belt or chain drives.

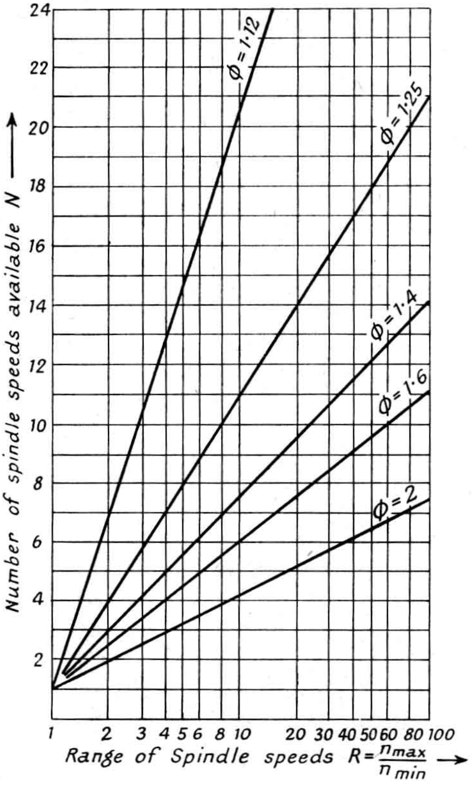


Fig. 1.6

(*b*) *The Sliding Gear Device*, Fig. 1.7*b*. A block of several (usually two or three) gears can be moved along a keyed or splined shaft into different positions in relation to a second block of gears keyed to a shaft parallel to the first one, each position bringing one particular pair of gears into mesh.

(*c*) *The Clutch Arrangement*, Fig. 1.7*c*. One of several (usually two) gears may be coupled to a shaft, the other gears running idle on the shaft.

(*d*) *The Draw Key Drive*, Fig. 1.7*d*. One of a row of gears can be keyed to the shaft by means of a sliding key.

(*e*) *The "Norton" Gear*, Fig. 1.7*e*. A gear carrier with a pinion and an intermediate gear can slide along a splined or keyed shaft, the intermediate gear being brought into mesh with a block of gear wheels through a tilting movement of the carrier.

(*f*) In addition, the slip gear arrangement in which gears are fixed to the shafts in question according to the requirements of transmission ratios may be mentioned. This cannot, however, properly be called a change gear as it involves a relatively lengthy fitting operation and is suitable only where the length of the actual machining process is sufficient to justify the time involved; e.g. for long runs in large quantity production or the cutting of screw threads on a lathe and of helical gears on a universal milling machine.