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THE SELECTION AND ACCEPTANCE TESTING OF METAL-CUTTING MACHINE TOOLS

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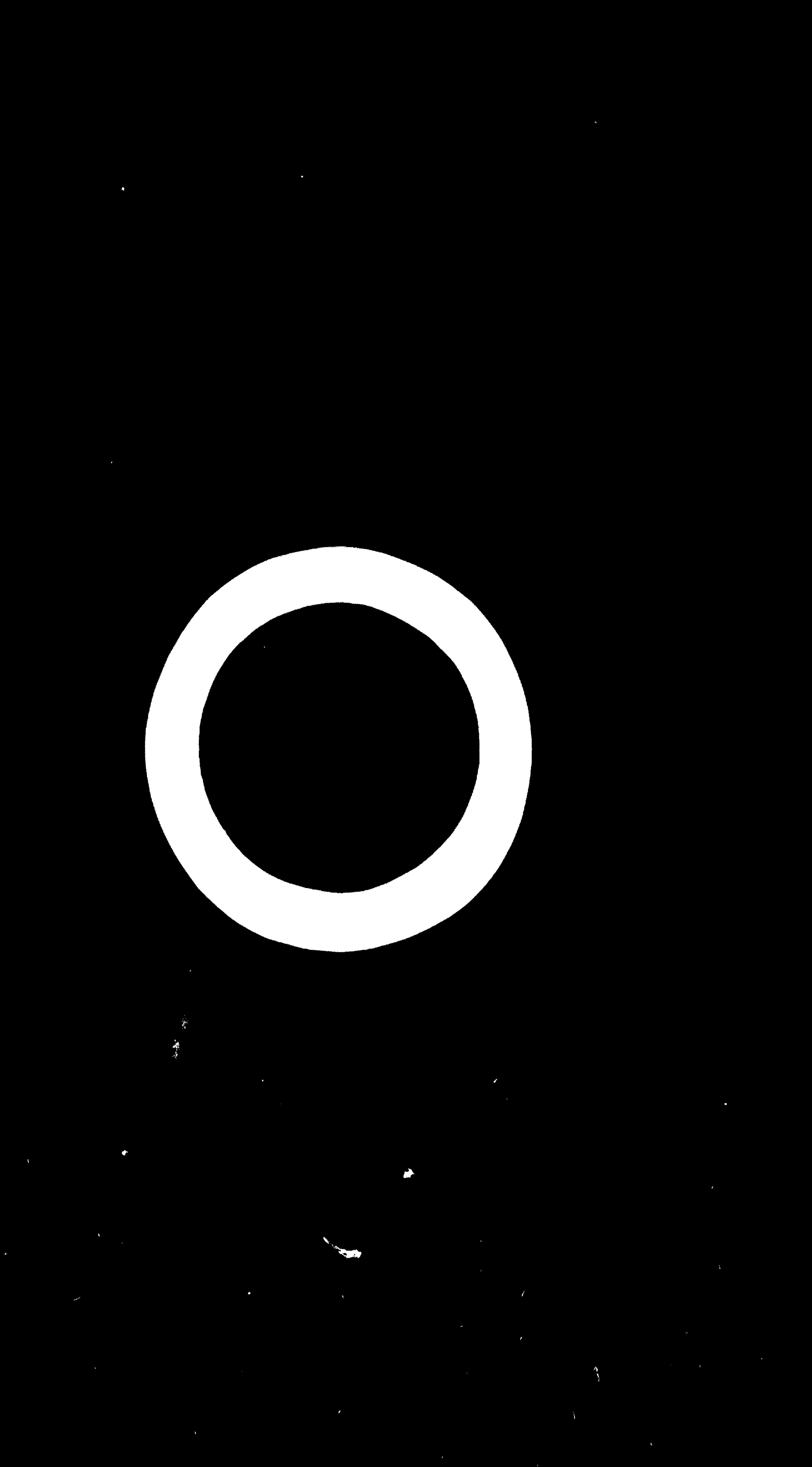

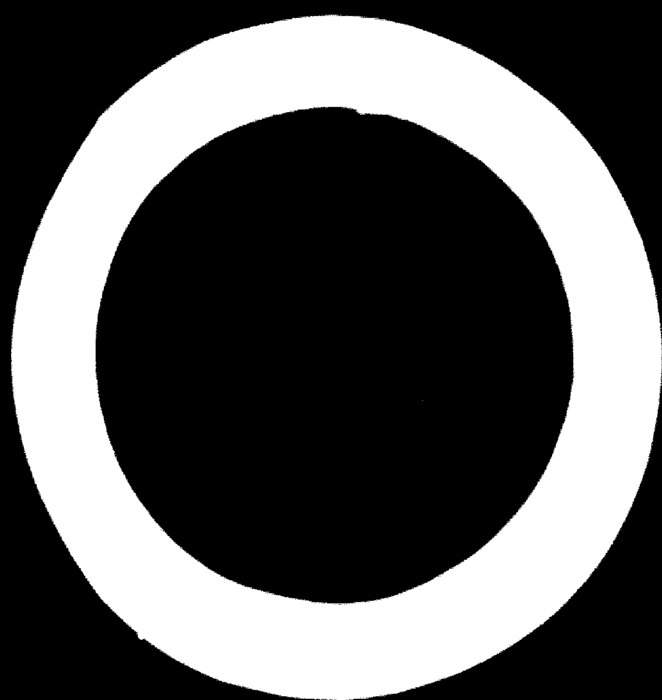

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

THE SELECTION AND ACCEPTANCE TESTING OF METAL-CUTTING MACHINE TOOLS

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Foreword

The machine tool industry was one of the key subjects discussed at the Interregional Symposium on Metalworking Industries in Developing Countries held in Moscow under the auspices of the United Nations in 1966. Machine tools are the reproductive centre of the entire manufacturing economy. Wise selection and efficient operation and maintenance of machine tools are of great importance from the earliest stages of industrial development and therefore it is not only the limited groups of developing countries who establish manufacture of machine tools that need to interest themselves in performance characteristics and acceptance tests.

Recommendation 8 of the Symposium reads:

"Investigations by the United Nations of the possibilities of adapting acceptance tests for new machine tools to present requirements are recommended. These may include the up-dating of the Schlesinger and other accepted tests where required, taking into consideration developments in many countries. Type testing and grading of machine tools with United Nations assistance is likewise recommended for this investigation."[1]

The present study springs from this recommendation. It is based mainly on the contributions of Messrs A. P. Vladzievsky, P. G. Vydrin and A. A. Padogin of the Experimental Scientific Research Institute for Machine Tools (ENIMS), Moscow, and an introductory review by Professor M. Kronenberg, all of whom served as consultants to UNIDO for its preparation.

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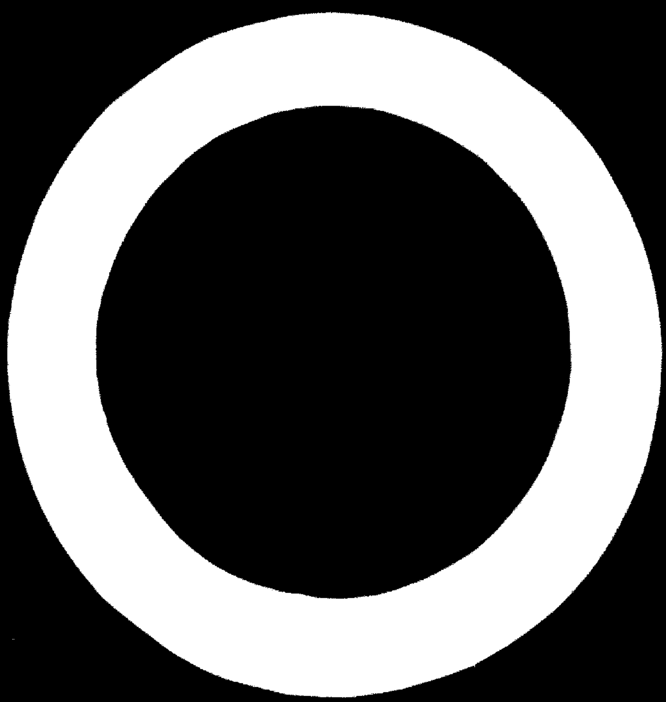
[1] *Report of the Interregional Symposium on Metalworking Industries in Developing Countries*, United Nations (Sales No.: 68.II.B.9) p. 88.



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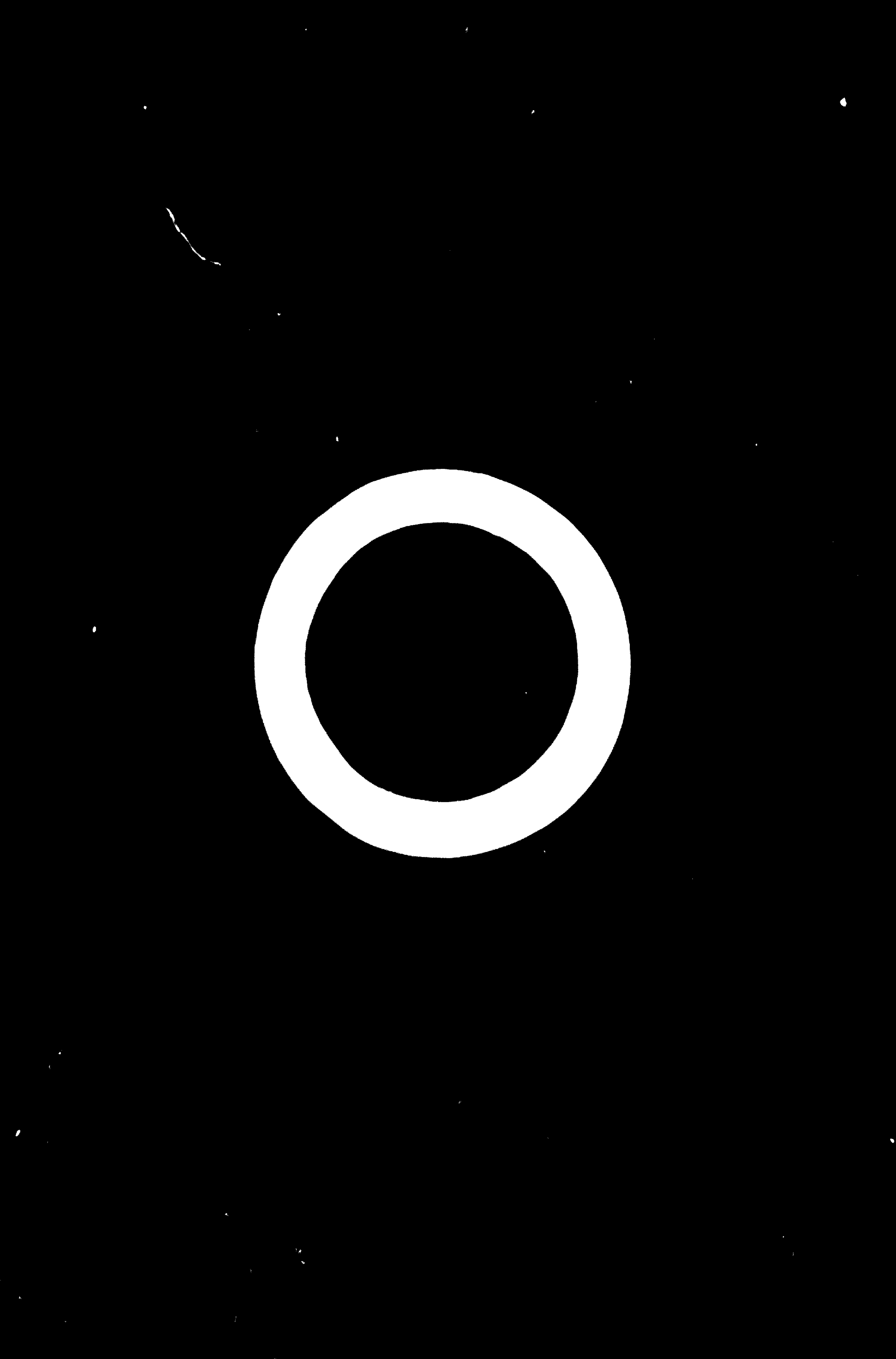

INTRODUCTION

This guide is concerned specifically with metal-cutting machine tools, although much of the text would be applicable to woodworking and some of it to machine tools used to machine components made of plastic. It does not discuss the non-conventional processes of metal removal such as electrochemical machining and spark erosion that find growing, if specialized, application in the industrially advanced countries.

The selection of machine tools may appear at first sight to present great difficulties for the developing countries, owing to the diversity of types and performance characteristics. In fact, the machine tools made in all industrially developed countries to perform a given task tend to be of broadly similar design in major respects and this facilitates comparisons.

Chapter 1 discusses the different categories of machine tools —lathes, drilling machines, grinding machines and so forth— from the point of view of the operations they perform and the branches of engineering in which they are employed. The roles of general-purpose, special-purpose and specialized machine tools are distinguished. There is a brief explanation of changes in technology, where these have occurred during the last ten to fifteen years. The chapter concludes by showing the way in which machine tool design influences the capacity of the machine to retain its original accuracy of work and likewise its probable service life. The object is to give general, practical guidance since it is evident that a United Nations body cannot recommend the products of any given manufacturer. Further investigations would be necessary before making any recommendations for United Nations assistance in regard to type testing and grading of machine tools. Other factors that influence the decision to buy a particular machine, apart from its technical performance, include the efficiency of the after-sales service provided by its manufacturer, as well as price and the offer of favourable terms for payment.

Chapter 2 takes up the subject of acceptance tests for machine tools from the point of view of technically qualified personnel in developing countries who need to compare the quality of similar machines offered by different manufacturers or to install and check the quality of a particular imported machine. It seeks to answer three basic questions:

— What characteristics of the machine tool and the workpiece should be tested?
— How are these tests to be performed?
— What are the tolerances that can be accepted, that is, the permissible deviations of the measurements taken from theoretical values?

First, the general conditions are enumerated that are essential prerequisites for the execution of acceptance tests. Then the various kinds of test and the checks are described that should be included in the acceptance procedure. These have evolved in the course of manufacturing, selling and maintaining machine tools over a period of at least 50 years.

Professor Schlesinger published his pioneering work on acceptance tests in 1927 in German. First editions in English, Russian, French and other languages followed in the next ten years. Later editions amplified the text and in a few cases modified the test data slightly as experience by industry required.[2] The purpose of the book is aptly described by its sub-title: *For the use of Machine Tool Makers, Users, Inspectors and Plant Engineers.*

More than a million machine tools have been tested, built and rebuilt since 1927 according to the specifications of the Schlesinger tests. Partly as a consequence of Schlesinger's work, associations of machine tool manufacturers in the main producing countries began to codify national practices, and national standards (generally of a voluntary character) were issued. By 1937, the work of aligning national standards to a common international standard was actively proceeding under the auspices of the International Federation of the National Standardizing Associations (ISA). This work has been continued since the Second World War by the International Organization for Standardization (ISO), which succeeded the ISA and has a far wider membership.

It is fair to say that the general structure of acceptance tests remains essentially what was recommended in 1927. The changes relate to reductions or, occasionally, to increases in the tolerances, but the originally recommended tolerances have often been retained. Changes in these minute measurements may seem insignificant to the layman but they are crucial in striking a balance between the degree of precision with which a machine tool can perform and the cost of its manufacture. Let us take as an example a tolerance which has been set at 0.010 mm. Experience in the United States shows that reducing this tolerance to 0.008 mm may raise by 15 to 20 per cent, while increasing it to 0.0125 mm may lower by 20 per cent, the cost of manufacturing the component parts and assembling the machine tool. These are over-all results, the data varying according to the type of machine tool, the labour skills at individual plants, etc. It is clear, therefore, that the cost

[2] The most recent English edition is: Georg Schlesinger, *Testing Machine Tools*, 7th Edition, The Machinery Publishing Co. Ltd., London, 1966.

implications must be most carefully studied whenever changes in tolerances are proposed.

Most developing countries still have to import most of the machine tools they require. It would be greatly to their advantage if all manufacturers constructed machines to comply with a single, internationally recommended set of acceptance tests. This is, in fact, the aim of negotiations conducted by the ISO. The alignment of national standards with ISO recommendations, once they have been approved, and compliance by individual manufacturers are both, however, voluntary matters. It is always important, therefore, to verify what standard of precision the manufacturer claims for his machine. The present status of standardization work in this field is examined in general terms in chapter 2.

A final question has been raised in this chapter: the extent to which acceptance tests for machine tools are adapted to conditions prevailing in the developing countries, such as climate, humidity, the skill of operators and so forth. The acceptance tests have been devised in industrially advanced countries, but most machine-tool manufacturers have extensive experience of the operating conditions in many developing countries. It does not follow that allowance has always been fully made for the special conditions in developing countries. Further investigations would be necessary to highlight the cases where adaptations are still desirable and to propose suitable adaptations for consideration internationally through the medium of the ISO. This is a field in which UNIDO could offer its services, by organizing technical assistance to carry out such investigations.

Chapter 1

DATA FOR THE SELECTION OF MACHINE TOOLS

Metal-cutting machine tools vary widely in accordance with:

(*a*) The types of cutting tool: drill, reamer, tap, cutter, milling cutter, shaving cutter, grinding and polishing wheels.

(*b*) The machining method: turning, milling, drilling, gear-tooth cutting, grinding, polishing.

(*c*) The grade of surface finish, from roughed to finished surfaces.

(*d*) Workpiece dimensions, from bench-type machines to those capable of machining parts dozens of metres across, weighing hundreds of tons.

(*e*) Grade of accuracy, from machine tools for roughing work to those for precise work.

(*f*) Range of work: universal, general-purpose, specialized or special-purpose machines.

(*g*) Number of tools used simultaneously: single- or multiple-spindle, multiple-carriage, multiple-tool machines.

(*h*) Number of parts machined simultaneously: single- or multiple-position machines.

(*i*) Degree of mechanization and automation, from those that are continuously serviced by an operator to fully automatic machines.

(*j*) Certain design features: vertical, horizontal, drum-type, open-side and duplex type, pendulum type, unit-type machines.

(*k*) Other features of operation: stationary or portable machines.

Selection and comparison of machine tools of such diverse performance is made easier because all industrially developed countries produce models with similar main characteristics.

General-purpose machine tools suitable for various operations are widely used in jobbing work, small-scale and batch production. Machine tools of this kind are comparatively cheap, have a wide range of speeds and feeds, are simple to set up and maintain, but their production facilities can be properly used only by highly-skilled workers. The operator must be able, without the aid of fixtures, to mount, align and fix the parts to be machined, set up the cutting tools, perform some operations manually, and make all necessary measurements. The volume and quality of output depend, to a great extent, on the operator's skill.

Centre lathes, knee-type milling machines, shapers, vertical drilling and conventional cylindrical grinding machines are examples of general-purpose machine tools.

Specialized machine tools are designed for machining workpieces of one type but different sizes. They allow quick and precise mounting of workpieces and simultaneous machining by several cutting tools; they give a high rate of output, but are economical only when large batches of workpieces have to be manufactured. Special-purpose machine tools are designed for machining one type of workpiece in a single size.

Among the industries that utilize high-output specialized and special-purpose machine tools are those manufacturing ball and roller bearings, electrical and agricultural machinery, automobiles, tractors, aircraft and railway rolling stock.

So-called unit-type machines were developed with a view to reducing the design and manufacturing time for those special-purpose machine tools that must be custom-built. Unit-type machines cost less, simplify repair and maintenance and combine automatic machining with high reliability. These machines are assembled from standard types of units. Sometimes several units of a single type can be used to construct multiple-station and multiple-spindle machines.

The first transfer lines consisted of some unit-type machines linked together by means of automatic conveyors.

A machine tool of the correct size can be chosen on the basis of the criteria listed below.

DIMENSIONAL CRITERIA FOR SELECTION OF A MACHINE TOOL

Machine tool	*Dimensional criteria*
Turning and engine lathes, relieving lathes	Swing over the lathe bed; distance between centres
Multiple-tool semi-automatic lathes (horizontal and vertical)	Swing over the bed or carriage
Turret lathes, single-spindle automatic and sliding-head automatic lathes	Maximum diameter of bar to be machined
Multi-spindle automatic and semi-automatic lathes:	
(*a*) bar	(*a*) Maximum diameter and length of bar to be machined

Machine tool	*Dimensional criteria*
(*b*) chucking	(*b*) Maximum diameter and length of workpiece
Facing lathes	Maximum diameter of workpiece
Turning and boring lathes	Maximum diameter and height of workpiece
Vertical and radial drilling machines	Maximum drilling diameter for medium-carbon steel
Centering machines, milling and centering machines	Maximum diameter and length of workpiece
Horizontal boring machines	Boring spindle diameter
Jig boring machines	Rotary table diameter or rectangular table width and length
Diamond boring machines	Table width and length
Cylindrical grinding machines	Maximum diameter and length of workpiece machined
Centreless grinding and centreless finishing machines	Maximum grinding diameter
Internal grinders	Maximum diameter of hole ground
Surface grinders	Rectangular table width and length or rotary table diameter
Roughing grinders	Grinding wheel diameter
Spline grinders, thread and worm grinders, super-finishing and external honing machines	Maximum diameter and module of workpiece
Honing machines	Honing diameter and stroke length
Polishing machines	Polishing wheel diameter
Multi-purpose tool-grinding machines	Workpiece diameter and length
Gear milling, gear shaping, gear shaving, gear grinding, spur and bevel gear planing and gear-tooth chamfering machines	Maximum diameter and module of workpiece
Spline milling machines	Maximum diameter and length of workpiece
Machines for hardening by surface rolling	Maximum workpiece diameter
Knee-type horizontal and vertical milling machines, copying milling machines	Width and length of table working surface

Machine tool	*Dimensional criteria*
Single- and double-upright plano-milling machines	Width and length of table working surface
Rotary continuous milling machines	Table diameter
Single- and double-upright planers	Maximum workpiece width and table working surface length
Edge-shaping machines	Maximum workpiece width and length
Shaping machines, slotting machines	Maximum ram stroke and shaping width
Horizontal and vertical broaching machines	Nominal tractive force in tons
Cutting-off machines	Maximum diameter of stock to be cut
Thread-cutting machines	Size range of threads to be cut
Dynamic balancing machines	Weight range of parts to be balanced

The capacities of machine tools depend on their dimensions and follow definite laws.

The types and sizes of machine tools in a manufacturer's range usually follow an arithmetical or geometrical progression in regard to the main technical parameters. A closely spaced progression is used for the common types and sizes of machine tools.

A widely spaced series compels the customer to take a heavier (and therefore probably dearer) machine than he needs, given the size of workpieces he machines. The volume of manufacture for each machine size decreases, however, if the series is made very closely spaced and this inevitably increases manufacturing costs. The main technical

TABLE 1. TECHNICAL

Description					*Swing over*
	100	*125*	*160*	*200*	*250*
Maximum workpiece length,[a] mm	125	185	250	350	500
Range of spindle speeds, r.p.m.	630—6,300	530—5,300	70—4,000	44—3,000	30—3,000
Longitudinal feed rates, mm/rev.	—	—	0.01—0.3	—	0.05—0.7
Power of main drive motor, kW	0.12	0.6	1	1	1.7
Weight of machine, kg	25	210	420	565	560

[a] Maximum distance between centres.

characteristics of some machine tools constitute a dimensional series. Based on them as reference models, modifications are made to the degree of accuracy, the level of mechanization and automation, the dimensions, maximum speed and weight (for machining non-ferrous metals and alloys) etc.

LATHES

Universal centre lathes (or engine lathes) are the most important of the medium-sized machine tools. Such lathes, in which the workpiece is clamped in the chuck or between the centres, are suitable for all turning operations including external cylinder and taper turning, facing, inch and metric thread cutting and boring. With a drill inserted into the tailstock sleeve taper and using the manual feed of the sleeve or the power traverse of the tailstock, the lathe can be employed for drilling operations.

These lathes are widely used in the machine shops and repair shops of large and medium-sized engineering plants, as well as in tool departments and small jobbing shops.

The constant improvement in their design is a result of general technical progress and growing demands for cost reduction and labour savings.

The last ten to fifteen years have brought a number of changes in both specifications and designs of lathes to increase their capacity, spindle speed and accuracy and to reduce their non-cutting time.

To increase the static and dynamic stiffness of the machine, its structure has been made more solid, the spindle supported on three bearings, and the tailstock sleeves strengthened by making them, in some models, prismatic or triangular in shape.

Gearboxes with sliding gears remain the basic transmission for the main drive but, in addition, direct belt drive to the spindle irrespective

CHARACTERISTICS OF LATHES

the bed, in mm					
320	*400—450*	*500—550*	*630*	*900*	*1,000—1,200*
500—1,000	710—1,000 1,400—2,000	1,000—2,000	1,400—2,800	2,800	5,000
11—2,240	15—1,500 12.5—2,000 38—2,500	11.5—2,000	10—1,250	7.5—750 10—1,300	5—500/600
0.08—2.6	0.03—2.0 0.07—4.0	0.07—4.00	0.1—3.2	0.2—3.05	0.2—3.05
4.5	7.5—10—15	10	14	20	28
1,500	2,000—2,400	3,000	4,000—5,000	8,000—12,000	14,000

of the location of the gear box is frequently adopted.

Gearboxes with electromagnetic clutches provide stepless changes in speed and are cheaper than other infinitely-variable speed devices. They also make it possible to change speed during machining, maintain a constant cutting speed and use remote control.

Table 1 summarizes the technical data on lathes of common sizes.

As a rule, these machines are available with various bed lengths, providing a wide range of maximum distances between centres. Modified machines exist with an adjustable bed which slides along the base so as to increase the distance between centres.

To increase the swing over the bed, for machining short workpieces, the front of the bed adjacent to the chuck is provided with a gap in some types of lathes. Sometimes the bed is widened to accommodate light, large-diameter workpieces, and pads are placed under the head- and tailstocks.

Copying attachments on engine lathes, usually hydraulic, help in the automation of the machining cycle, which is particularly beneficial for quantity production. Preselection of spindle speeds, quick gear-change devices and attachments for adjusting spindle speed to cutting speed and workpiece diameter are designed for the same purpose and can be found now on a number of lathes.

Recently there has been a rapid increase in the use of powerful semi-automatic copying lathes with a highly automated operating cycle and high maximum spindle speed.

A further step towards the automation of machine tools is their numerical control. The simplest numerical controls are plug boards or drums, with adjustable stops to programme only the sequence of certain stages of the cycle. The workpiece is shaped with the aid of a template and a copying attachment.

The main drive is usually equipped with d.c. motors, the power of all the motors totalling several hundred kilowatts. The lathe is usually controllable from several places. These machines can use copying attachments to cut intricate curved and stepped contours. For thread-cutting, an electrically synchronized shaft is employed.

Toolroom lathes

For toolroom and other precision work, more accurate machines are required. Higher accuracy in lathes can be achieved only by the use of precision bearings and by more careful finishing of all the important components of the machine tool. Toolroom lathes are not only highly accurate but also versatile, with, in particular, wide ranges of spindle speeds and feed rates. Heavy-duty lathes with a swing over the bed of 1,250 mm or more are available in two or three versions designed for machining heavy, medium and light workpieces. The lathes are suitable for rough and finish turning with high speed steel or carbide tipped tools.

Turret lathes

In production work, in addition to ordinary and universal lathes, turret lathes are widely used for series production of small steel pieces from bar stock. The types of bar feed and holding fixture employed depend on the lathe design and the diameter of the bar to be machined. There may be manual feed of the bar, clamped in the collet by a lever and weight; spring-loaded mechanism with cam drum, separate electric drive and push-button control; hydraulic operation etc.

These machines have the advantage that they can be set up for multiple-tool machining, the tools being arranged in the turret head on a vertical or horizontal axis and on the cross slides; that they work on an automatic cycle; and that they do not require highly skilled operators.

Once the machine has been set up for machining a certain workpiece, the operator quickly masters the handling of the machine and achieves maximum output.

The manual speed change of the earlier turret lathes required much time and fatigued the operators. Operators' efforts are now reduced, because the spindle speeds and feed rates for every change-over are preselected. Feed rate and spindle speed are changed by indexing the turret, when the built-in friction devices permit the drive gears to be changed while the machine is in operation, without stopping the motor, thus reducing non-cutting time.

Automatic and semi-automatic lathes

Automatic single- and multi-spindle lathes are designed for machining workpieces from cold-drawn bar and are used in large-batch and mass production. Provided that the method of group setting is employed, automatic lathes may be efficiently used in small-batch production.

When these machines are fitted with several cross slides and turret tool heads or with longitudinal tool slides and various auxiliary attachments, they can produce a high output of intricate workpieces.

The use of single-spindle sliding headstock automatic lathes is increasing in precision instrument making, watch making and other branches of industry.

There are also chuck versions of turret lathes, both manually-operated and semi-automatic. A batch of 10 to 30 workpieces can be efficiently machined on well equipped semi-automatic turret lathes, which, in a number of applications, replace the lathes used in series production. Main drive power of semi-automatic turret lathes is up to 30—45kW.

Semi-automatic multiple-tool lathes, because they have a large number of tools moving simultaneously in the same trajectories and several slides, shape the workpieces in short work cycles.

These relatively simple semi-automatic lathes are employed to machine ordinary workpieces, clamped in the chuck or between the centres, in large batch and mass production.

Hydraulic semi-automatic copying lathes use generally one tool to follow the contour. Their set-up is easily changed by replacing a template or a master workpiece and tooling. When fitted with a powerful main drive, they can use to full advantage the cutting properties of tungsten carbide tools.

To machine large but thin workpieces of disc or ring shape, up to several metres in diameter, chuck lathes are used.

Vertical lathes that take heavy workpieces of large diameter and height are increasingly used. Designers of these machines pay much attention to automating the control, clamping and release of rams, and the movement of slides and carriages. In addition, electronic devices for measuring distance are now being introduced.

In addition to general-purpose machine tools, specialized and special-purpose lathes have been greatly developed in countries where there are automobile, tractor, shipbuilding, railway and mechanical engineering industries. Such lathes are used for turning camshafts, crankshafts, special-steel ingots (prior to rolling) and rolling mill rolls; for threading tubes and couplings; for turning axles, wheels and bogies of railway rolling stock, turbine blades, rings for antifriction bearings, and so on.

When selecting and purchasing imported machine tools, both general- and special-purpose, developing countries should consider local conditions and the prospects for the development of various local industries.

Table 2 shows in schematic form the main types of lathes, their dimensions and industrial applications.

TABLE 2. LATHES: MAIN TYPES, ESSENTIAL DIMENSIONS AND INDUSTRIAL APPLICATIONS

Description	*Dimensions in mm*		*Applications*
	Maximum swing over the bed	*Maximum workpiece length*	
Bench lathes	100—160	125—250	Watchmaking, precision instruments
Medium-sized engine lathes	200—1,000	500—8,000	Job and series production, repair shops and toolrooms
Heavy-duty lathes	1,250—6,300	up to 20,000	Heavy engineering
Turret lathes	18—100	—	Series production from bar stock or blanks
Facing lathes	1,400—8,000	—	Machining thin discs and rings of large diameter, in ferrous and non-ferrous metals

TABLE 2 (continued)

Description	*Dimensions in mm*		*Applications*
	Maximum bar diameter	*Maximum workpiece length*	
Relieving lathes	520—690	710—1,000	Relieving of gear-cutting hobs, disc and form-milling cutters, etc.
Semi-automatic lathes:			
Chucking turret lathes	160—500	—	Quantity or mass production at high output rates
Horizontal multi-spindle chucking lathes	50—250	up to 200	Various turning jobs in large series and mass production
Horizontal and vertical multi-tool centre lathes	125—600	300—2,000	High-output rough and finish production of workpieces such as stepped shafts, the high output being obtained by high power, machine rigidity and multiple tooling
Automatic lathes:			
Single-spindle turret lathes	8—65	60—90	Series or mass production of workpieces from round, square and hexagonal bar stock
Sliding headstock lathes	3—40	50—80	Intricate workpieces from cold-drawn bar stock in watchmaking, instrument making, optics, electrical and other branches of industry
Horizontal multi-spindle bar lathes	10—140	150—260	Various turning jobs in large series and mass production
	Maximum swing	*Maximum workpiece height*	
Vertical lathes	800—25,000	800—6,300	Turning and boring cylindrical and taper surfaces, grooving, drilling, counter-boring and recessing heavy workpieces (up to 500 tons)

Drilling machines

Drilling machines include upright bench and column or pillar types; radial machines, including portable ones; deep-hole drilling machines, both vertical and horizontal; internal thread-cutting and centre-drilling machines; and centre-drilling/face-milling automatic and semi-automatic machines. Their applications are drilling, counter-boring, reaming and tapping.

The main types are upright and radial drilling machines. Upright machines drill holes in small workpieces clamped in vices or jigs, the axis of the spindle and the tool remaining stationary. Radial machines drill holes in large workpieces, where it is preferable to move the tool head rather than the workpiece in order to drill several holes.

To increase the accuracy, stiffness and vibration resistance of radial drilling machines, manufacturers have introduced auxiliary uprights, cross slides, square and round rotary tables. In recent years portable type radial machines have been put on the market.

The output of drilling machines can be increased by fitting turret heads, including automatic tool-change devices. Compound tables are provided with devices for automatic movement along both axes.

The use of numerical control ensures fully automatic control of the work sequence, location setting, and operation changes.

In large radial drilling machines, movement of the drill head along the arm and clamping of the head, the arm and the upright sleeve are all usually powered. All the controls are located within the working area. Some machines have a single lever to control movement, rotation, lifting, lowering, clamping and release of the arm; it also changes the spindle speed, reverses the spindle rotation and engages the feed, during drilling and thread cutting. Many firms build machines with only one manual setting: the final accurate positioning of the spindle head slide.

The arm and spindle head of genera'-purpose radial drilling machines can be rotated through 360° and move vertically. The spindle head can be fixed in any position ranging from + 90° to — 90°. The feed is disengaged at a predetermined depth.

There are versions of vertical and radial drilling machines designed for drilling by co-ordinates. These are cheaper than jig-boring machines of the same size and are satisfactory when accurate positioning is not required and the jig is not needed.

In series and high-series production, multi-spindle machine tools with 4 to 8 or even more spindles are used with different tools that successively machine the same or different holes. Upright drilling machines can be equipped with multi-spindle heads having universal-joint drive to the spindles. Their pivoted spindles can be adjusted to the positions of the holes to be drilled.

To meet the demands of special branches of industry, to drill small holes in extremely hard materials, machines are now being built which use wire drills coated with abrasive. Rotating at high speed, these drills simultaneously vibrate axially. Such a machine can drill 200 to 400 holes in 8 hours.

In machine shops working at various scales of output, centre-milling machines can be used to centre and face blanks. The end faces are parallel because they are milled simultaneously. As the centres are perpendicular to the faces, no further work is needed except finish facing.

Table 3 gives similar information for drilling machines to that shown in table 2 for lathes.

TABLE 3. DRILLING MACHINES: MAIN TYPES, ESSENTIAL DIMENSIONS AND INDUSTRIAL APPLICATIONS

Type	*Drill diameter (mm)*	*Drill speed (r. p. m.)*	*Applications*
Bench machines	**1.5—25**	**up to 15,000**	**Drilling, counterboring and reaming small workpieces**
Upright and pillar-type machines	**18—75**	**up to 3,000**	**Drilling, counterboring, reaming and tapping workpieces clamped in vices and jigs**
Upright drilling machines with multi-spindle heads	**from 8**	**up to 1,500**	**Simultaneous drilling of a number of holes**
Radial drilling machines, portable	**25—75**	**10—1,000**	**Drilling holes in different planes of large workpieces**
Radial drilling machines, other	**35—100**	**25—2,500**	**Drilling holes in stationary workpieces**
Co-ordinate drilling machines	**up to 30 and over**	**up to 1,500 and 2,000**	**Drilling, boring, reaming and milling operations with less accuracy than jig-boring machines**
	Maximum workpiece dimensions (mm)	***Speed (r. p. m.)***	
Milling centring automatic and semi-automatic machines	**Diameter: 10—125 Length: 180—2,000**	**Drills: up to 5,000 Milling cutters: up to 1,200**	**Drilling, centring and face milling of blanks**

BORING MACHINES

This group includes universal horizontal boring and milling machines, jig-borers, fine boring machines and unit type multi-spindle machines as well as boring machines and various specialized machines.

In recent years, the basic trends in boring machines have been towards higher accuracy and production efficiency and widening the technical range of horizontal machines.

Modern universal horizontal boring and milling machines have more powerful drives, to enable milling to be done as well as boring. They have rigid beds, uprights and spindle units which are vibration-proof during heavy-duty milling work. They have various accessories and attachments such as indexing tables and copying devices.

The use of d.c. motors with easy control over a wide speed range makes it possible to change the feed rate during cutting and to simplify the machine. The adjustable main drive enables the optimum speed to be selected during machining according to the conditions.

A suspended control panel with devices for visually checking the co-ordinates enables the operator to control the machine from any place convenient during the work process.

Designers have increased the output of horizontal boring machines by introducing the following improvements:

Raising the top speed and the level of mechanization, improving control and gauging systems.

Providing lifting devices on the machines to permit mechanical loading and unloading of heavy fixtures and tools such as milling cutters, or arbors.

Multiple-position drums with adjustable stops, attached to an electronic measuring device when the first workpiece is machined, have formed the basis for automating repeated point-to-point movements of machines producing batches of identical workpieces.

The increased accuracy of horizontal boring machines has come about by including in their design the features of precision jig-borers and by improvements which have made conventional machines more accurate: high-precision measuring scales and optical devices, a reduction in temperature distortions, especially the displacement of the spindle shaft during machining, and greater smoothness in slow movements.

Some firms have begun to manufacture precision horizontal machines to bore holes in specific housings; by reference to narrow horizontal and vertical strips containing holes for pins, positions of the table and spindle head are predetermined. The same machine is used to drill the holes in the strips, the distance between holes being shown on the drawing of the workpiece.

Universal small and medium-sized boring machines are built with a fixed upright, while the large machines have an upright travelling longitudinally. In extra heavy machines the upright travels both longitudinally and transversely.

Table 4 gives some technical details of horizontal boring machines available commercially in various countries.

TABLE 4 TECHNICAL CHARACTERISTICS OF UNIVERSAL HORIZONTAL BORING MACHINES

	Table dimensions mm	*Range of spindle speeds r.p.m.*	*Longitudinal feed rates (mm/min)*	*Power of main drive motor (kW)*	*Weight (tons)*
Machines with fixed upright					
Sliding spindle diameter:					
65 mm	710 × 900	16—2,000	2.2—1,750	5.2—7	6
80 mm	800 × 1,000	20—1,600	2.2—1,760	5.5	7
85—90 mm	900 × 1,120	12.5—2,000	0.25—1,200	7.5—10	12.5
	1,120 × 1,300	15—1,500	2.2—1,760		
100—110 mm	1,120 × 1,300	12.5—1,600	2.2—1,760	7.5—10	12.5
	1,260 × 1,400	9—1,400	0.18—1,680	14.7	16
125—127 mm	1,250 × 1,600	8—1,250	2—800	14	28.8
	1,500 × 1,800	5—1,000	10—2,000	18.5	31.5
	1,220 × 1,830	5.6—1,020	0.3—3,050	22	29.7
Machines with upright travelling longitudinally					
Sliding spindle diameter:					
150—152 mm	1,800 × 2,250	7.5—900	2—1,500	14	52.2
	1,220 × 2,130	5.6—1,020	0.3—3,050	22	33.8
160 mm	1,800 × 4,500	8—600	1—1,000	42	65.5
175—178 mm	4,200 × 4,600	7.5—950	2—1,500	14	42.2
		2—400	13—3,200	30	42.5
Machines with upright travelling longitudinally and transversely					
Sliding spindle diameter:					
220 mm	5,000 × 8,100	1—510	1—400	55	141
320 mm	5,000 × 8,100	0.5—259	0.5—300	100	262.6

These machines can be used in production and repair shops by skilled operators for boring holes in machine parts.

A great many modern horizontal boring machines are numerically controlled. This saves labour and increases output during boring.

Jig-boring machines are used in one-off and series production. They ensure precision boring of correctly located holes without the use of expensive jigs and fixtures.

Accurate location setting is obtained within 2 to 5 microns, depending on the machine size, by means of precision scales, optical measuring devices and interpolating reading devices. The accuracy of the jig-boring machines results from the high rigidity of the structure, smaller temperature distortions and consequential errors, and the use of wear-proof antifriction guideways which greatly improve the sensitivity of point-to-point movements.

Improvements in jig-boring machines, increasing their output and making them more convenient in operation, have been effected by mechanizing and automating the movements of the working parts and tool changes, as well as making provision for preselection of the co-ordinates, control of speed and feed rate.

Various numerical control systems for automatic control of the point-to-point movements of the table and cross slide eliminate human errors by the operator and are widely used.

Many firms produce semi-automatic machines with a completely automatic machining cycle which comprises rapid advance, cutting feed and rapid withdrawal of the spindle, change of the cutting conditions, tool change and movement of the units by co-ordinates. These semi-automatics are complicated and not yet widely used.

When high accuracy is not required it is preferable to employ cheaper machines of lower accuracy (0.02 mm) which are adequately mechanized and give a high rate of output. These machines enable spindle speeds and feed rates to be preselected and have automatic, accurate positioning. In addition, they have push-button control for setting the machine-tool components.

Jig-boring machines are available in a wide range of sizes and in different grades of accuracy. This permits the choice of a machine appropriate to specific production requirements.

For fine boring and turning cylindrical surfaces, horizontal and vertical diamond boring machines are the most effective in large series and mass production. These machines are usually supplied set up for work on a definite part.

Unit-type multi-spindle boring machines of the most varied designs are also manufactured for work on large series and mass production. The machines may be classified according to the layout of the spindle unit (vertical, horizontal, tilting, gang-type, radial etc.).

Specialized drilling and boring machines for series and mass production include those for deep-hole drilling and boring, for machining the grooves in rolls for rolling mills, for boring the crankshaft bearing holes in the cylinder blocks of internal combustion engines, for boring big- and little-end bearings in connecting rods, and many others.

MILLING MACHINES

The basic types of milling machine include:

Knee-type machines

Horizontal plain and universal machines, the latter with pivoting table

Vertical machines with stationary or swivelling heads
General-purpose toolroom machines
Bed-type machines with rectangular or built-in rotary table
Surface milling and plano-milling machines, with swivelling or stationary spindle heads and one or two uprights
Circular saws

Specialized machines

Rotary continuous milling machines
Drum-type milling machines
Copy-milling machines for various branches of engineering

Special-purpose milling machines.

The commonest milling machines, 60 to 70 per cent in number, are knee-type machines of the horizontal or vertical, plain or universal types which many firms produce. Variants of these machines have copying and numerical control systems.

Small knee-type machines with a table width of 100 to 160 mm are designed to handle small workpieces made of non-ferrous metal and alloys or plastic material and for finishing operations on steel or cast-iron parts. The longitudinal, transverse and vertical feeds of these machines may be power- or hand-operated. The longitudinal table feed of the automated machines employed in series production is taken from a drum driven by a gear box.

In machines with a table width of over 200 mm the traverse of the table is power-operated in each direction. Milling is performed on these machines with high-speed steel or carbide-tipped cutters. The range of work that can be done on the machines is widened by using the accessories obtainable from the manufacturer. These consist of universal dividing head, auxiliary cams to set up automatic cycles etc. and universal milling, boring, slotting and grinding subheads. Some firms also produce high-speed variants that differ from the basic models by having a more powerful electric drive and wider range of speeds and feed rates.

General-purpose models with the milling head swivelling in two planes and a universal pivoting table are built in a horizontal knee-type design. These machines are provided with rack-tooth milling and slotting subheads, as well as standard accessories and attachments. They have high accuracy and are used mainly in toolrooms, precision instrument production and the repair shops of engineering works.

The bed-type milling machines with compound table have more rigidly constructed tables than the knee-type ones. This makes them suitable for machining large heavy workpieces.

Copy-milling machines can be of knee- or bed-type design and have vertical or horizontal spindles. Two- and three-dimensional engraving machines are used to perform small-scale jobbing work (e. g. milling of shallow press moulds, outline templates, patterns) and to produce inscriptions, drawings and figures. On these machines, the travel of the tracer is performed manually and the principle of operation is based on the geometry of similar figures. Mechanical, electromechanical and hydraulic copying systems are used in the machines available on the market. In recent years manufacturers have offered increased horsepower in the main drives, a wider range of spindle speeds and twin- and multi-spindle models, in order to raise output rates. The trend towards heavy duty, rigid copying machines has led designers to base their development on bed-type milling machines.

In industrially developed countries the automation of knee-type milling machines is effected by numerical control, which reduces set-up time and enables one operator to service several machines.

In the simplest automatic control systems, the programme is preselected by inserting plugs in sockets on the control board to give the required operating sequence and by setting adjustable dogs to define the dimensions of each motion.

Multi-purpose plano-milling machines are used in one-off and series production for machining large parts made of cast iron, steel or non-ferrous metal. These machines have either one or two columns. The former group includes some models with an overhanging cross-rail, in order to machine large workpieces that cannot be machined on double-column machines of similar table width; they are suitable for work in repair shops and for one-off work.

Plano-milling machines are much more rigid than knee-type milling machines and thus more accurate. Complete machining of large parts at one set-up, which considerably reduces non-cutting time, is facilitated by devices attached to the machines for measuring from point to point. In addition, the machines can take large-diameter arbors and milling cutters; their moving elements are power-clamped; the rapid traverse of the table and other units has been made faster; and, finally, remote control is used.

Many special machines are constructed on the basis of the universal plano-milling machine.

PLANING MACHINES

This group includes the following basic types:

Planers

Single- and double-column machines
Plate-edge planing machines
Combined plano-milling and grinding machines

Shapers
With mechanical main drive
With hydraulic main drive
With electromechanical main drive

Slotting machines
General-purpose
Portable

Internal and external broaching machines.

Machines of the planing group have a wide application in one-off and series production in various branches of engineering. The steady improvement in their design continues to increase output rates and accuracy. These machines have incontestable advantages which ensure a place for them in the production range of factories where machines are built. They give a high production rate in machining long narrow surfaces; they use simple and cheap cutting tools which are easily reground; and they permit finish planing (replacing scraping and grinding) with good surface finish and accuracy.

When a single intricate workpiece has to be machined, planing is the most economical and suitable method because milling requires complex and expensive tooling. For machining heavy structural parts, the use of a combined plano-milling and grinding machine provides a most economical concentration of planing, milling, boring and grinding facilities without moving the workpiece.

Planing machines may be equipped with copying slides for contouring and three-dimensional profiling of intricate parts.

Some makers have reduced the variety of parts in planers, plano-millers and plano-grinders by standardizing the parts used in these machines as far as possible. This is convenient to maker and user, especially for repairs, and reduces the size of stocks of spare parts which both need to carry.

Shaping machines are effective in one-off and series production. They are described by the maximum length of the ram stroke, the dimensions of the table surface, the distance from the cutting tool rest to the bed, the number of double strokes per minute (or the ram speed of hydraulically driven machines) and other technical parameters. Fitment of universal swivelling tables greatly increases the technical capabilities of these machines.

General-purpose shapers with the appropriate tooling can be used for a variety of operations, such as spur and bevel gear-cutting, radius planing, flat template copying, bending, thread rolling.

Shapers should be provided with both screw and hydraulically-operated vices. The latter may be connected to the hydraulic system without disturbing the normal functioning of the machine.

Slotting machines are used to cut keyways and grooves in cylindrical and taper bores and to machine flat and profiled surfaces in one-off and series production. When fitted with the appropriate attachments they can shape the teeth of both internal and external gears and perform copying work.

High-output broaching machines can enlarge circular or profiled holes and do external work in series and mass production. Broaching operations can replace slotting, planing, milling, counterboring, reaming, boring and turning.

High output and efficiency in broaching is obtainable by having a great number of cutting edges in simultaneous contact with the workpiece, high accuracy and finish of the surface being machined, and relatively high wear resistance of the broach. Finally unskilled operators can be used. Special-purpose tooling and high cost, however, confine broaching to large-series and mass production.

MACHINE TOOLS FOR FINE FINISHING

Fine finishing of metal surfaces is generally achieved with abrasive materials. Machine tools in this extensive group perform cylindrical grinding, centreless grinding and lapping, internal and surface grinding, rough grinding, spline shaft grinding, thread and worm grinding, tool grinding, honing, polishing, superfinishing and lapping. Special machines are used to make ball bearings, fuel pumps, tools and turbine blades, as well as in watchmaking, precision instrument making and other industries.

Cylindrical grinding machines are designed to do accurate finishing work and are used under various conditions. For these reasons the research effort of firms concentrates on increasing rigidity and resistance to vibration, reducing thermal distortion, improving the accuracy of manufacture of the most important parts and designing mechanisms which provide a finely graduated, smooth feed of the grinding wheel.

Automatic feed of the grinding wheel has become common practice in virtually all these machines. In-feed mechanisms are often used in general grinding machines. Automatic loading and unloading of the workpiece is provided in some cases. Dimensional checking of the workpiece is either manual or by a measuring device with a pneumatic or electric measuring head.

Surfaces with external and internal taper and cylindrical surfaces are ground by pivoting both the workhead and the wheelhead and by using an internal grinding spindle.

Centreless grinding machines are effective for large series and mass production. They are manufactured in two types, with the following characteristics:

(a) A fixed work rest blade and travelling grinding and driving spindle heads;

(*b*) A travelling work rest blade and a travelling driving spindle head.

The first type has the advantage that the machine has high dynamic stability because the grinding wheel spindle head is fixed to the machine bed.

In some models the driving spindle head travels along inclined guides, pressing the workpiece with greater force against the driving wheel, resulting in better braking of the workpiece.

In the second type, the workpiece axis remains fixed and the grinding wheel is fed gradually towards the workpiece to take up wear. Thus, the loading devices suffer no displacement and the driving spindle head can be more rigidly constructed, because no intermediate carriage is required for the blade rest.

Centreless grinding machines are marketed with manually operated, semi-automatic or automatic control. Semi-automatic in-feed and through-feed devices compensate for grinding wheel wear. Automatic grinders have a special set-up designed for a particular job of work. They are constructed as variants of the semi-automatic machines.

Modern universal internal grinding machines can grind a batch of workpieces in a semi-automatic cycle, as a result of the high level of mechanization and automation incorporated in their design.

For grinding tapered surfaces the work head may be pivoted around a vertical axis. The hole may be ground, and the external end-face may be ground square to it, at one set-up by using a face-grinding device mounted on the work head.

Cylindrical and internal grinding machines are manufactured in standard and high-precision grades. Maximum machining errors are 0.5 micron for circular and 1 to 2 microns for longitudinal dimensions.

Special-purpose grinders of various designs based on the universal machines are used for grinding camshafts, crankshafts, large light workpieces such as jet-engine rotors, ball-bearing rings and so on.

Surface grinders come in various designs for various purposes. They may be classified into four types, with the following characteristics:

(*a*) Rectangular table, horizontal spindle and the wheel grinds with its rim;

(*b*) Rectangular table, vertical spindle and the wheel grinds with its side;

(*c*) Rotary table, horizontal spindle and the wheel grinds with its rim;

(*d*) Rotary table, vertical spindle and the wheel grinds with its side.

Both high dimensional accuracy and good surface finish are obtained when parts are ground with the rim of a grinding wheel. If the accuracy and surface finish do not need to be high, the surface is ground with the side face of the grinding wheel.

Precision surface grinders with horizontal spindle and rectangular cross slide table are used for toolroom work. These grinders are rigid and have a number of other design features necessary for high accuracy and surface finish. The table carriage and the table are usually mounted on antifriction guideways.

High-output surface grinders for series production have powerful drives to the abrasive wheels, rectangular tables and horizontal or vertical spindles.

In the simpler grinders, the movements are manually controlled, except for the spindle drive. In semi-automatic surface grinders with automatic control of the workpiece size, the cycle includes rough and finish grinding and an automatic stop when the workpiece has been reduced to size.

Extra-heavy surface grinders have rectangular tables and are manufactured in several versions, depending on the number and type of spindle heads. Double-sided face-grinding machines grind simultaneously the two faces of a disc, ring or roll.

Rough grinders are used to clean rolled-steel sections, such as round and square bars, slabs and tubes. The use of automatic machines raises output per manshift, improves operating conditions, and eliminates hard manual labour. This work can also be mechanized by using stationary or suspended, manually operated grinders.

Thread-grinding machines are used for making thread gauges, thread-cutting tools and high-precision threaded parts. Universal machines of this type are used in a wide range of industries for grinding cylindrical and taper thread gauges (plugs and rings), fine screws, worms and threading rolls; and for relieving tap threads and fine pitch worm hobs. There are complicated models equipped with mechanisms for additional motions for relieving or grinding tapers etc., when machining various tools. Special-purpose machines grind long lead screws, female threads etc.

Tool grinders, which range from the simplest grindstones to special automatic machines, are indispensable pieces of equipment in the smallest workshop and likewise in the machine shop of the largest engineering factory. In machine shops of small factories, it is advisable to use tool grinders with abrasive wheels mounted on both ends of the shaft of a fixed motor. The abrasive wheels are protected by covers connected to dust-exhausters. A slewing toolrest upon which the tool is placed during sharpening enables it to be ground to the right geometrical shape. Tool grinders are usually equipped with devices for grinding drills and for the diamondless dressing of abrasive wheels. Polishing wheels may also be mounted on them.

If extra-high surface finish, straightness or sharpness of cutting edges, or accuracy of a cutting-tool nose radius have to be achieved, grinding and sharpening should be done with diamond tools on lapping machines, sometimes with several wheels on one spindle.

Electrochemical grinding of carbide-tipped tools is done with a metal-bonded diamond wheel; a low voltage current (6 to 12 volts) passes between the diamond wheel and the tool to be sharpened through an electrolyte which is continuously pumped into the working area. Electrochemical sharpening of tungsten carbide tools is twice or three times as efficient as conventional methods. Electro-chemical grinding machines have therefore been developed and built on a commercial scale.

Finish grinding of gears is discussed at the end of the following section on gear-cutting machines.

GEAR-CUTTING MACHINES

Gear-cutting can be performed by milling, shaping, planing and broaching.

Gear-milling machines use worm hobs, disc or end-milling cutters. They are mainly employed in machine shops making spur gears and produce at a high rate. The way to operate these machines and their cutting tools is well known. Both rough and finishing operations on spur gears can be done with them.

Because of their great versatility and ease of set-up, gear-milling machines in which the cutting tool moves along the tooth to be produced are most suitable for small-series and batch production.

In large-series and mass production it is more effective to use machines in which the workpiece travels along the tooth of the cutting tool, because they need less floor space. The provision of loading devices makes these machines fully automatic; their disadvantage is that they are difficult to set up.

In one-off jobs or small-series production it is best to avoid expensive fully automatic machines and to use simple machines in which the adjustment of spindle speeds, feed rates, other movements and the gear train is effected by means of changeable wheels.

It is most important that the manufacturer's instructions should be followed. A set of measuring instruments is necessary to check the accuracy of the work. Usually it is sufficient to have levels, square gauges, mandrels, dial gauges, micrometers and autocollimators.

Table 5 summarizes the technical characteristics of the widely used universal gear milling machines with vertical carriage movement.

Gear-shaping machines have a lower rate of output than milling machines because the latter cut continously, which is essential when cutting internal and external gear rings. All gear-shaping machines are now semi-automatic. The following types are made:

(*a*) Vertical machines with gear-shaping cutters;
(*b*) Vertical machines with multiple-cutter heads;
(*c*) Horizontal machines with rack-shaped cutters;
(*d*) Vertical machines with rack-shaped cutters.

TABLE 5. TECHNICAL CHARACTERISTICS OF GEAR-MILLING MACHINES

(in mm except where otherwise stated)

Description	Maximum diameter of gears to be cut						
	200—250	400—500	630—800	1,250	1,800—2,000	2,500—3,200	5,000
Maximum module	4	6—8	8—10	12	18—20	18—30	40
Milling cutter speed, r.p.m.	45—450	40—310	40—310	32—200	8—100	10—60	10—60
Workpiece feed per revolution:							
Axially	0.32—5.0	0.4—5	0.4—5	0.5—5.6	0.3—15	0.3—15	0.3—15
Radially	0.08—1.0	0.2—2	0.1—1.3	0.2—2.5	0.08—1.5	0.08—1.5	
Tangentially	0.16—2	0.15—3	0.15—3	0.08—3.8	0.08—1.5	0.08—1.5	
Power of main drive motor, kW	5	7	7	10	14	25	25

There are variants designed for cutting gear racks.

The vertical machines with gear-shaping cutters can cut gears of up to 3,000 mm diameter with a module of up to 12 or 15 mm and a tooth rim up to 200 or 275 mm long. Almost double these gear dimensions can be achieved by machines of groups (c) and (d). Gear shaving is widely used as a finishing process in large-series and mass production sectors of engineering, such as automobiles, tractors and aircraft, in which the stability of the materials used and heat treatment of workpieces makes it possible to eliminate the final treatment after hardening. The residual unevenness which inevitably occurs is dealt with by leaving a slight extra thickness of metal during the earlier operations, which the gear shaver removes.

The main kinds of machine tools that produce bevel gears, with straight or circular-arc teeth, are gear planers, gear millers, gear-cutting machines with cutter heads and gear grinders. Machines are also produced for gear lapping, testing, hardening and other auxiliary processes.

Spur-gear planers are widely used in one-off and series production, owing to their versatility and the simplicity of the tool employed. These machines have a low output; for example, a gear wheel with 40 teeth and a module of 6 mm takes no less than 30 or 40 minutes to produce. The straight-bevel-gear milling machines, with their higher output, are therefore widely used in large-series and mass production, despite the fact that they are more complicated to set up than gear planers and the cost of the milling cutter is much higher than that of the cutting tool.

The advantages of circular-arc bevel gears in service (smooth running and strength) and the use of simple multiple-cutter heads to cut them have resulted in increased demands for the gear-cutting machines which produce them. Grinding is used to obtain highly accurate bevel and spur gears made from hardened blanks.

In large-series and mass production, lapping is preferable to grinding after press hardening, for gears that must be accurate as well as hardened, because it increases the rate of production and cuts machining costs.

Finish grinding of gears

Usually hardened gears are finished by grinding. Gear wheels with a small module (up to 1 mm) are made by completely grinding the tooth form from a plain workpiece. Gear grinding is expensive and the rate of output is low. Moreover, highly skilled operators are needed to handle gear-grinding machines. Nevertheless, the increasing accuracy required for gears operating at high rim speeds has enlarged the field of application of gear grinding.

Gear grinding is performed with tapered abrasive wheels and various types of grinding wheels — disc, saucer-type, profiled, worm-type. The principles of operation and fields of application are as follows.

Tapered abrasive wheel

The workpiece rotates slowly and moves forward in a straight line while the wheel travels rapidly along the tooth in synchronized motion. Tooth surfaces are ground either in turn or simultaneously depending on the machine tool design. The machine indexes before each tooth is generated.

Many of these machines operate on a pre-set automatic cycle which includes wheel dressing; they are simply set up by gear changes. Their field of application is one-off and small-series production.

Disc grinding wheel

The gear-cutting motion is produced by an involute cam and the indexing by a special indexing disc. Only one side of the tooth profile is machined. These machines are neither versatile nor is their output high but their very short gear train makes it possible to obtain high accuracy. They are used in precision instrument manufactures when grinding gear-shaping cutters, shaving cutters and master gears.

Saucer-type grinding wheel

A tooth space is ground from both sides simultaneously and it is possible to produce a tooth of a considerable length because the work-piece travels along the abrasive wheel. The relatively small contact surfaces ensure that the tooth surfaces are not burnt. Teeth are ground with high accuracy but at a lower production rate than on machines with disc grinding wheels.

Profiled grinding wheel

The profiling method is finding increasingly wider use, following considerable improvements in the design of these machines in recent years. External and internal spur and helical gears are also machined nowadays in this way. The disadvantage is the high cost of dressing the grinding wheels. Involute templates not supplied with the machines can be produced only by highly skilled toolmakers.

Worm-type grinding wheel

This method is used in large-series and batch production, since output is four to ten times as great as by the other methods, owing to continuous indexing of the machine and the relatively large cutting surface of the tool. The latest machines can grind gears with barrel-shaped teeth.

THE INFLUENCE OF MACHINE-TOOL DESIGN ON RETENTION OF ACCURACY AND SERVICE LIFE

The service life of a machine tool and the maintenance of its initial accuracy for years depend to a great extent on its design. Short-term tests throw no light on these important matters: they have to be evaluated indirectly by considering the parts of the machine whose performance is critical to accuracy and durability.

Guideways and spindle bearings are decisive for maintaining the accuracy of most machine tools; the index worm gearing must be added in the case of gear-shaping and hobbing machines, since it determines the accuracy of pitch of the gears.

The great variety of operating conditions makes it difficult to specify general requirements for guideways. The feed-motion guideways of medium-sized machines such as most types of lathe tend to suffer abrasive wear from the ingress of dust, dirt, metal and scale particles, for which reason they must be hardened. Cast-iron bed guideways are sometimes hardened by gas flame or induction methods, sometimes case-hardened or nitrided.

The guideways of heavy-duty machine tools tend to suffer from the scoring of cast-iron sliding parts. During the last ten to fifteen years most manufacturers have begun to plate the cast-iron guideways of mated parts of such machines with plastic materials or non-ferrous alloys that have no tendency to cause seizure.

The chief means of ensuring a long service life for guideways is to limit the ingress of dust and particles of dirt by fitting whenever possible special protectors (figure 1) such as telescopic shields, expanding

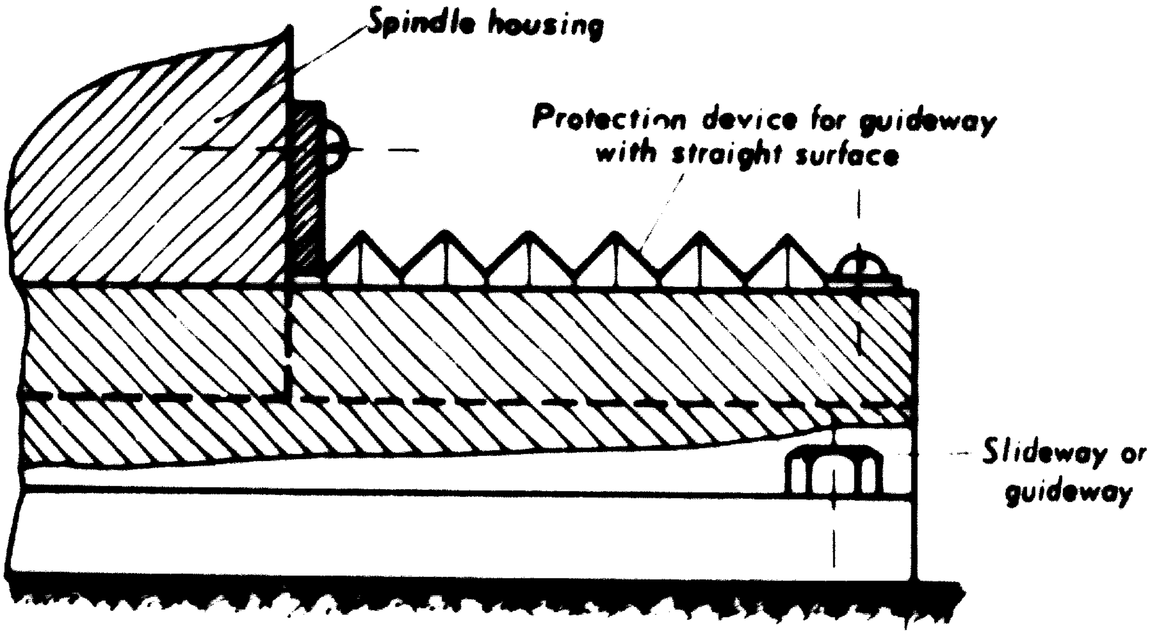

Figure 1. Protection devices for guideways

bellows or steel or plastic bands and by fixing seals to the faces of movable parts (figure 2). These measures are supplemented by appropriate means of lubrication and arrangements to remove contaminants from the lubricating oil by settlement and fine filtration. The machine tool manufacturer should indicate the grade of oil he recommends for lubrication in the operating instructions supplied with the machine.

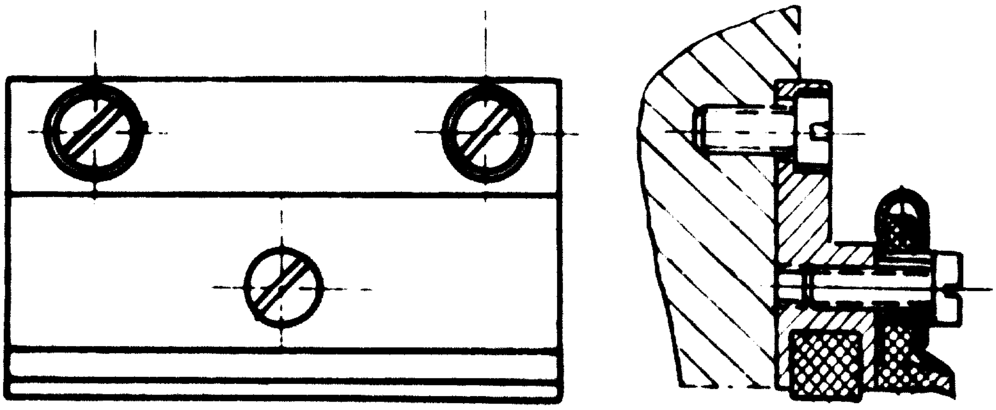

Figure 2. Seals for guideways

Where antifriction ways are used on a machine tool, they must be even more carefully protected than ordinary guideways against the ingress of dust and particles of dirt, because their design renders them more susceptible to fouling.

Antifriction spindle bearings must be properly lubricated with the correct amount of the right lubricants, in accordance with the instructions of the machine tool manufacturer. Deviations from these instructions can lead to premature failure of the bearings. Correct adjustment of spindle bearings has to avoid overheating (when they are too tight) and also too large a clearance in the cold state (which causes machine chatter under working conditions).

Slide bearings, used mainly on the spindle shafts of grinding machines, ensure the presence of an appropriate oil film to limit friction by incorporating bearing pads that are self-adjusting over the whole range of spindle speeds.

To conform with the lubricating conditions specified by manufacturers, the temperature of bearing housings should not be allowed to exceed the ambient by more than 15° to 20° C and the peripheral speed of the spindle journal should not exceed 5 metres per second.

Chapter 2

A GUIDE TO ACCEPTANCE TESTING

While metal-cutting machine tools are used in nearly every country, their production is concentrated in a limited, though growing number of countries. Most countries must import the machine tools they need in increasing quantities. It is essential for experts in developing countries to be able to evaluate the quality of imported machine tools and by means of acceptance tests to compare the quality of similar machines manufactured in different plants.

This guide is intended to help experts in these countries to organize machine tool acceptance on the basis of an objective view of the quality of the machine. To obtain this view they must make proper tests and evaluate the design and quality of manufacture of the machine in terms of its ability to achieve a high production rate and maintain its original accuracy. At the same time, the aim has been to avoid making the tests excessively complicated and prescribing the use of intricate measuring instruments of the kind commonly employed when manufacturing machine tools but rarely found at the customers' factories.

In many cases evaluations are proposed that can be made without specialized instruments, since only highly qualified and specialized laboratories are able to carry out proper tests with precision measuring instruments.

The testing programme set out in this guide is not obligatory in its entirety; decisions must be made which tests to use for each machine. Some of the tests mentioned in the guide apply mainly to general-purpose machine tools which perform various operations on steel, cast iron and non-ferrous alloys. Special-purpose machine tools, on the other hand, are tested by doing the operations for which they are designed. The accuracy and production rates of these machines are thus easily checked under working conditions.

GENERAL CONDITIONS FOR EXECUTION OF ACCEPTANCE TESTS

Installation of machine tools before testing, protection against external vibrations

The machine tool should be installed on a foundation or on the concrete baseplate of the workshop, and in accordance with the manufacturer's instructions. It should then be carefully levelled with a spirit level. The levelling accuracy, to be checked by the spirit level, is always specified in the accuracy test charts supplied with the machine tool and also in national accuracy standards for machine tools.

In the precision spirit levels used for levelling machine tools, one division should correspond to a change in slope of 0.02 mm per 1,000 mm (0.0002 in /10 in); the high-sensitivity spirit levels used for high-precision machines must detect half this movement, 0.01 mm per 1,000 mm (0.0001 in /10 in).

In levelling the machine with a spirit level care should be taken that all moving parts are in their middle positions. The spirit level should be placed successively on the ends of the horizontal bed or of the stationary table placed in its middle position (figure 3). By placing the spirit level along the direction of travel, its bubble position will indicate whether the guideways are horizontal. If the spirit level is placed at right angles to the direction of travel it will show the extent of twist in the guideways.

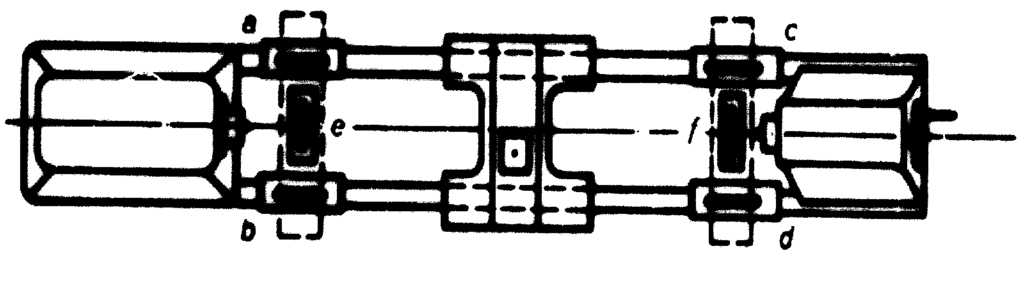

Figure 3. Testing the levelness of a lathe: a, b, c and d are longitudinal positions, e and f are transverse positions of the spirit-level.

When a moving table or other unit has a very short stroke or none at all, the spirit level serves to check that the surface of the unit is horizontal and flat. Except for machines with three locating points, machine tool beds being checked by the spirit level show some elasticity in their deformation. In these cases, the bed should be brought to the state it was in during the accuracy test at the manufacturing plant.

Levelling is accompanied by height adjustment of the elements supporting the machine, including screws, jacks and wedges (figure 4).

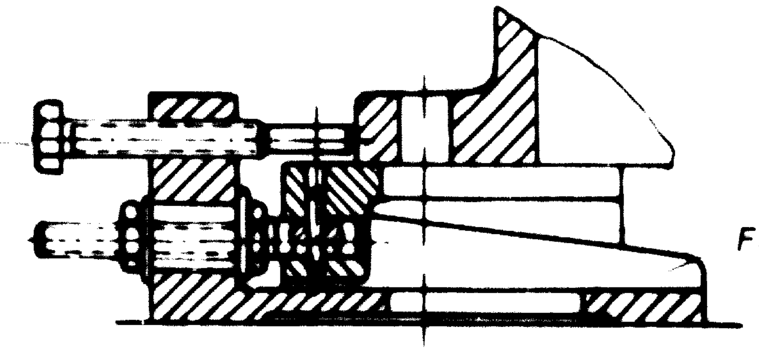

Figure 4. Adjustable mounting for machine levelling

When medium-size machines are being installed and levelled by means of adjustable steel wedges, the foot of the bed should be grouted to maintain the levelling and to increase the rigidity and resistance to vibration of the machine. Machine tools in this group do not have to be fixed to their foundations by foundation bolts unless they are intended for extremely heavy jobs, such as machining unbalanced workpieces or intermittent cutting, or unless foundation bolts are prescribed by the safety rules, as in the case of radial drilling machines.

When long and heavy machine tools are mounted on their foundations, adjustable supporting members (screw jacks, or lifting wedges) should be set close to or co-axially with foundation bolts grouted into the foundations, permitting periodical re-levelling of the machine to compensate for the settlement of the foundation and preventing displacement of the machine tool due to the high-speed reciprocating movement of the table.

To facilitate frequent removal and reinstallation of medium-size machines (when this is a requirement) and to protect them against external vibration, elastically insulating mountings are recommended, with adjustable screws to level the machine tool (figure 5). This method is especially suitable for installing machines on upper floors, since it reduces the dynamic loads on the building structure.

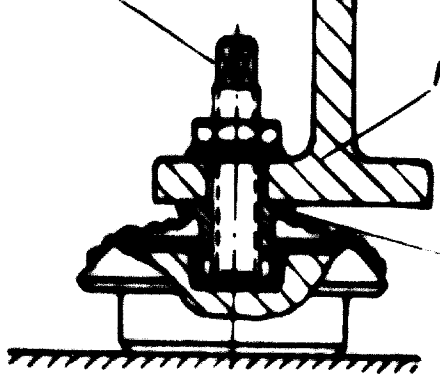

Figure 5. Anti-vibration mounting for medium-size machines

It should be borne in mind, however, that the use of elastically insulating mountings can impair the operation of a machine, when there are forced vibrations caused by unbalanced motors, pumps or spindles, by too sharp a reversal of a reciprocating table, by intermittent cutting combined with coarse chips, and so on. Elastic mountings are not advisable for machine tools with relatively non-rigid beds — for example, long lathes, planers and the like — in whose design the behaviour of the bed and foundation together has been taken into account.

High-precision machines such as jig borers and thread grinders when they need to be protected against external vibration from nearby planers, forge hammers, heavy-duty travelling cranes and so on, must be mounted on insulating foundations. These consist of concrete or reinforced concrete blocks, either sprung (figure 6 a) or supported by special rubber or cork mats (figure 6 b).

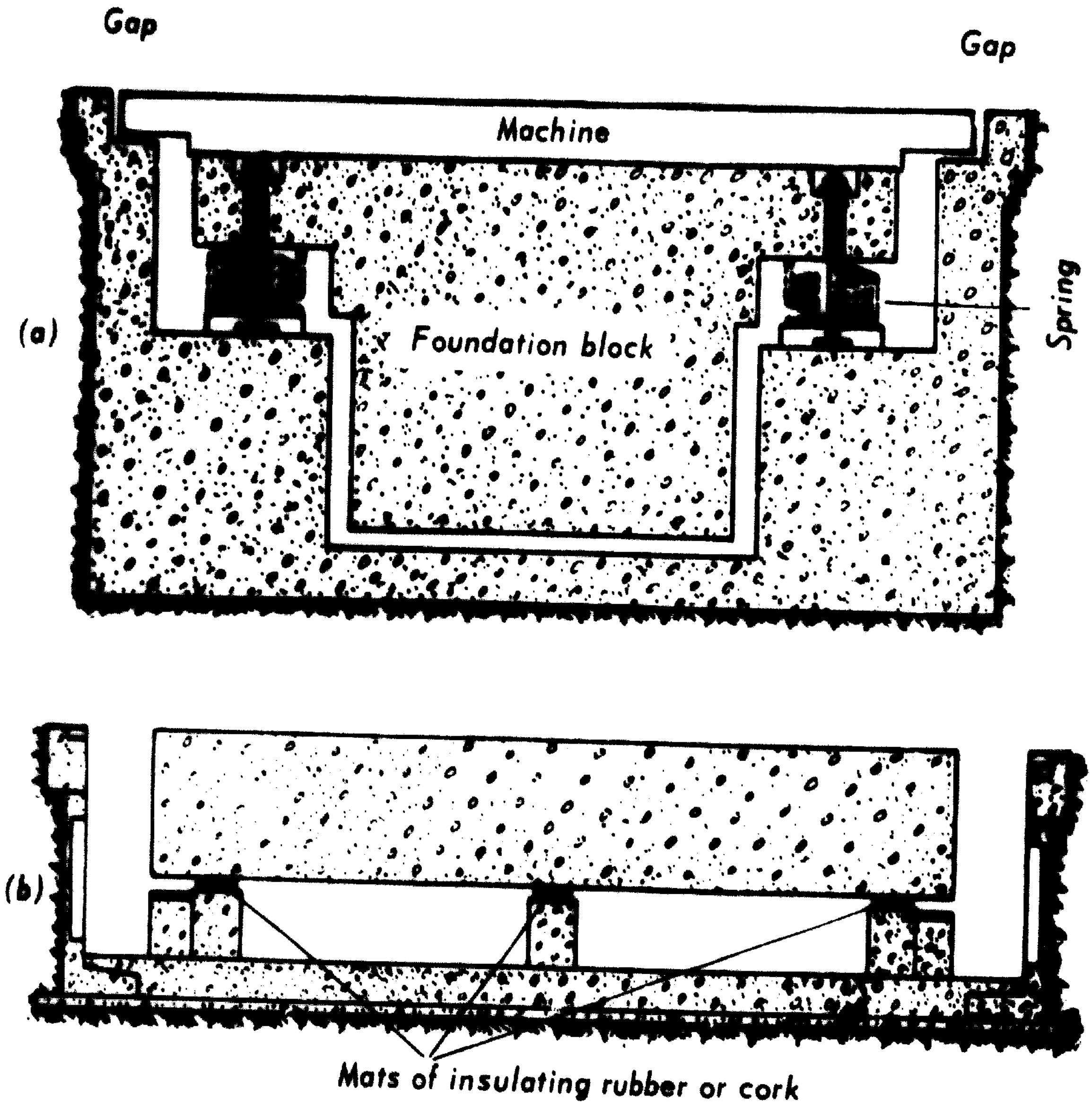

Figure 6. Anti-vibration foundations for high-precision machines

If the machine tool is fixed on its foundation only for testing, steel or cast-iron beams should be grouted into the foundation and provided with T-slots for bolts to fix the machine to the foundation (figure 7).

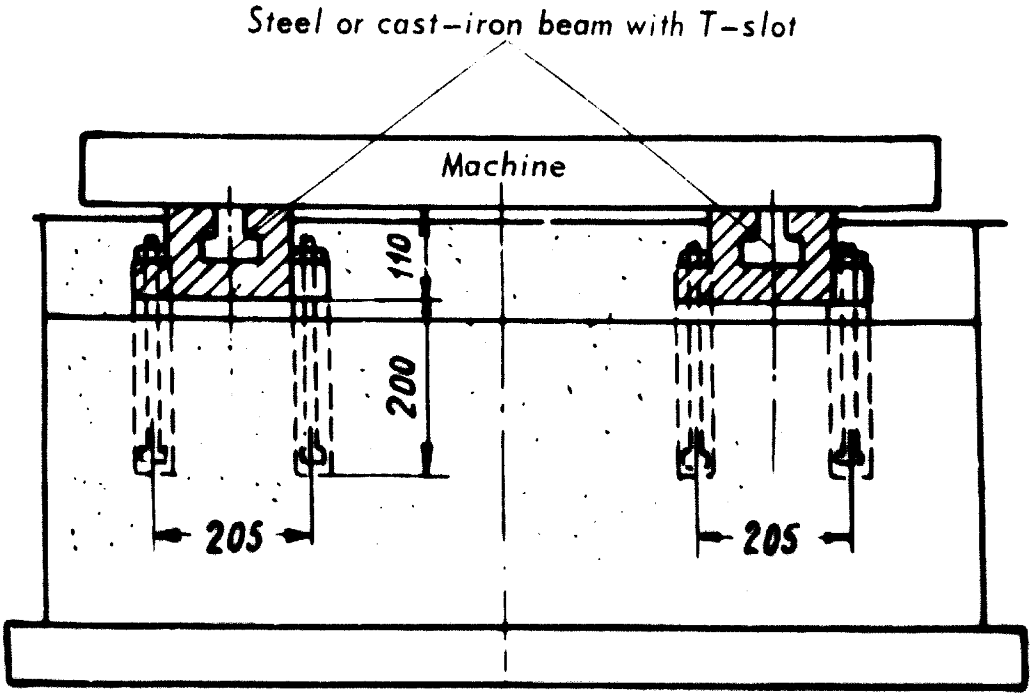

Figure 7. Foundation for machine testing

Temperature control in the test room

General-purpose machine tools which form the bulk of machine shop equipment, such as lathes, milling, drilling, boring, planing, grinding and gear-cutting machines, do not require to be tested in temperature-controlled rooms, but there must be no sharp changes in temperature during the tests for accuracy, including levelling, geometric checking and performance testing. The temperature changes in the room during the tests should not exceed 5° C.

The machine being tested must not be subjected to direct sunlight, nor to currents of warm air from heating systems, nor to cold air whether from ventilation systems or from open doors in cold weather.

Acceptance tests of high-precision machines for jig boring, thread grinding, gear grinding and so forth must be carried out in temperature-controlled rooms. Usually the rated temperature is 20° C, but sometimes, depending on the climate, rated temperatures may vary with the season, for example, 17° C in winter and 23° C in summer. If the machine tool has been tested for accuracy by the manufacturer at 20° C, it is necessary to take into account the difference between the coefficient of linear expansion of the workpiece to be machined (for example, one made of an aluminium alloy) and that of machine parts which ensure positioning accuracy, for example, the linear scale of a jig-boring machine. Deviations from specified temperature must be within very close limits throughout the workshop where a high-precision machine is tested. For most precision machines these deviations must not exceed ± 1.0° C, and for high-precision machines ± 0.5° C.

To maintain the specified temperature the room must be equipped with a suitable air-conditioning system. The ambient temperature requirements for high-precision machines are usually specified in the instructions supplied with the machine.

Condition of the machine tool before testing

Before the acceptance tests are started the machine tool, mounted on the foundation as described above, must be completely equipped with all the accessories and tooling. The lubrication and hydraulic systems of the machine should be filled with oil of appropriate grades, as specified in the manufacturer's instructions.

The machine must be entirely degreased.

If individual assemblies were secured before shipping to avoid displacement, the temporary fasteners and spacers should be removed and the moving units should be traversed manually to make sure that nothing obstructs their travel.

The machine should be fitted with all the safety devices supplied.

Trial run of the machine tool before testing it for accuracy

In the course of machine operation, heat is generated by mechanical losses of power due to friction and restriction of the oil in hydraulic systems, by electrical losses in the built-in electrical equipment and by the metal-cutting process itself. The machine parts are heated unevenly and this leads in turn to thermal distortion of parts, changes in their relative positions and sometimes in their shapes.

Since not all the geometrical checks are affected by the extent of machine heating, some measurements need not be made immediately after the trial run. Before the checks are made, it should be known which of them require a previous trial run of the machine. Thermal distortions in lathes, caused by heating of spindle bearings, greatly affect the spindle position relative to bedways, cross slideways and the tailstock sleeve axis.

The idle running of turret lathes affects the position of the axis of spindle rotation relative to the turret head holes, the direction of the turret head's longitudinal travel and the longitudinal and cross traverses of the tool head slide. In vertical jig-boring machines, heating during idle running deflects the spindle axis relative to the table, i.e. it causes horizontal displacement and skewness of the drilling axis, which should be perpendicular to the longitudinal direction of travel of the table.

In surface grinders, thermal deformation can result in non-parallelism of the ground surface of the workpiece relative to the table surface.

CHECKING THAT THE MACHINE PERFORMANCE AGREES WITH THE CERTIFICATE

It is necessary to make sure that all the operating characteristics correspond with the maker's certificate. These include the stroke lengths of moving units of the machine, nominal sizes of workpieces accepted, spindle speeds or numbers of strokes per minute of the operating units, feed rates, rapid speeds, and characteristics of work done, such as the pitches of screw threads cut by the machine.

CHECKING THE TOOLING AND STANDARD ACCESSORIES SUPPLIED WITH THE MACHINE

Apart from checking the complete set of standard accessories from the packing list, it is necessary to make sure that all the tooling specially ordered for the machine has been supplied. The machine should be set up for each particular operation in turn; the relevant tooling should then be fitted to the machine and tested.

TESTING THE MACHINE RUNNING IDLE

Forced vibrations during idle running

To ensure machining accuracy, it is important to eliminate forced vibrations during idle running between the workpiece and the units carrying the tool, since these vibrations cause unacceptable waviness and out-of-roundness of the machined surface.

Special instruments are required to measure the amplitude of such vibrations, which the customer does not usually possess. The evaluation is therefore usually limited to subjective touch tests in order to compare the vibration of individual parts of the machine tool, headstocks, motors, pumps and so on. As for grinding machines, in the last analysis the judgement whether the level of vibration is permissible or not must be based on an examination of sample workpieces in their finish-machined state.

Smooth reversal of reciprocating units

Speeds of scores of metres per minute are reached by machine tool reciprocating units such as the tables of surface grinders, internal grinders and cylindrical grinders. The reversal of such high-speed units may be so very abrupt that it causes other machine parts and accessories to vibrate; in particular, it may set up relative vibrations between the grinding wheel spindle and work-carrying units (tables, headstocks).

During acceptance tests the purchaser can make only a subjective estimation of the smoothness of reversal, simply to compare the models of different manufacturers. Ultimately, the assessment must be made by machining samples with the grinder set up for minimum idle running at the beginning and end of the stroke. It is essential for the grinding wheel to be kept in contact with the workpiece throughout the operation, because the vibrations caused by a sharp reversal are damped rather quickly.

When a shaft is ground on a cylindrical grinder, forced vibrations caused by reversals lead to waviness in the shaft ends, if incompletely damped before grinding commences.

In grinding operations where the wheel is in constant contact with the workpiece, the danger is evidently still greater that these vibrations will leave their trace on the ground surface.

Noise

The noise of the machine tool should be rated from the point of view of its adverse influence on the operator and those working nearby. If it is necessary to measure the noise level a sound-level meter has to be used. The following meters may be recommended:

- (*a*) Sound-level meter, type 1400C or type 1402C, made by Dawe Instruments Ltd., England.
- (*b*) Precision sound-level meter, type 2203, made by Brüel and Kjaer, Denmark.
- (*c*) Kleinlautstärkemesser type L SM2, made by VEB Werke für Fernmeldewesen, German Democratic Republic.

In any event, meters used for measuring the noise level of machinery should comply with the standards of the International Electrotechnical Commission (IEC).

Shops where machine tools are checked for noise level should meet the following requirements:

(*a*) The background noise radiated by the other equipment running in the same shop or in the adjacent shops must be not less than 10 decibels (db) weaker than the total noise of the machine under test and the background. If the difference is less than 10 db, the correction given below must be subtracted from the noise level reading, in order to allow for the influence of the background noise.

Difference	*Correction*
From 6 to 9 db	1 db
From 4 to 5 db	2 db

(*b*) In order to avoid the excessive distortion of the noise measurement caused by the reflection of sound waves from the ceiling and the walls, the machine tool should be located not less than 2 metres from the walls, and the height of the ceiling from the top of the machine should not be less than 2 metres.

The measurements should be taken in the working area 1.5 m above the floor level and 1 m horizontally from the nearest point on the surface of the machine. The noise check should take place, as a general rule, with the machine running idle. On special occasions, when required by the specification, the machine is noise-tested under load. The noise level measured in the above manner must not exceed 77 to 82 db on the "A" scale of the sound-level meter.

Power losses in the main drive

Power losses reduce the output of the machine to some extent, because they reduce the power effectively spent on cutting.

The degree of power losses or, more precisely, the efficiency indicates the quality of the main drive.

The efficiency, η, is a percentage below the theoretical 100 calculated approximately by the formula:

$$\eta = 100 - \frac{100 N_0}{N_1} - (P_1 + aP_2 + bP_3 + cP_4)$$

where

N_0 = power in kW consumed during idle running by the electric drive of the machine, the losses of the electric motor being subtracted

N_1 = rated power in kW of the electric motor at its shaft

P_1 = losses in the belt drive, per cent (3 per cent for V-belt drives, or 2 per cent for flat-belt drives)

P_2 = losses in the gear trains, per cent (1 per cent)

P_3 = losses in the antifriction bearings, per cent (0.25 per cent)

P_4 = losses in the plain bearings, per cent (2 per cent)

a, b and c = number of gear trains, antifriction and plain bearings, respectively.

The efficiency of the main drive of a general-purpose machine tool with a gear box is usually between 70 and 80 per cent. For high-speed machine tools, the efficiency at maximum r.p.m. is from 55 to 60 per cent.

Checking the controls

Testing for proper functioning of the manual control system includes checking for reliable engagement and disengagement of the friction clutch of the main drive, gear-changing, and the hand controls of other units. The force that must be applied to turn the handles and handwheels is of particular importance and should be measured, if necessary, by simple measuring devices. Safety devices which prevent simultaneous starting of motions that are mutually incompatible should be checked for correct functioning.

In testing the gear-changing, special attention should be paid to the relative position of gears in mesh. After the change they should be in contact for the full length of the teeth.

The automatic stop mechanisms for cutting feed and positioning motions should be checked repeatedly to ensure reliable operation of the switches, accurate positioning of units of the machine tool after automatic stop of the feed, and the required positioning motions with the machine functioning at various speeds. These tests have to be repeated several times in order to determine the degree of variation in the final position attained by the units. A machine tool with an automatic operating cycle must be checked for the proper functioning of the system which controls this cycle.

Checking the warming up of individual units after idle running

This test is applied to spindle bearings, electric motors and hydraulic cylinders after three hours' idle running.

A large rise in the temperature of individual units is not permissible for two reasons. First, the performance of items such as antifriction bearings, plain bearings and electric motors (winding insulation) would deteriorate in these circumstances. Secondly, excessive thermal deformation of individual machine elements reduces the machining accuracy.

Temperature measurements are taken with a thermo-couple placed on the outer walls of spindle heads or against spindle bearings or hydraulic cylinders.

If the spindle head housing is provided with a vertical blind hole beside the spindle bearing, this can be filled with oil, and a mercury thermometer immersed in the oil to measure the warming-up temperature. The performance of the main-drive friction clutch is tested by frequently engaging and disengaging it. The clutch should not heat up more than 70° C above the ambient temperature. The number of successive engagements and disengagements of the clutch should correspond to working conditions when the machine is set up for small workpieces.

TESTING THE MACHINE TOOL UNDER LOAD

Testing the machine under full power

To test the machine under full power, typical workpieces for the machine under test should be machined.

Operating conditions should be selected that use the full rated power (after allowing for transmission losses) of the main drive motor, as measured by a wattmeter. During testing, special attention must be paid to the proper functioning of the main drive elements. In particular, the control of the friction clutch must be checked. It should work without slip or overheating.

The tests are carried out at one of the medium speeds and at the maximum speed of the spindle.

Test for maximum cutting force

The test for maximum cutting force is aimed at checking, above all, the feed mechanism of machine tools in which feed occurs during cutting.

The test is made at one of the lowest spindle speeds, within the lowest quarter of the range of speeds.

The feed rate is calculated with the help of formulae and tables of recommended cutting conditions, and must be such that it calls for the maximum feed force, as stated on the manufacturer's certificate.

During the test particular attention should be paid to the operation of the feed mechanism, especially to safety devices that limit the torque transmitted.

Machine tool chatter during cutting

Harmful vibrations during metal-cutting operations are mainly self-excited by the machine; their origin and nature are determined by the properties of its dynamic system, which is a closed loop consisting (in the simplest case) of the non-rigid machine frame/fixture/cutting tool/workpiece system, of the cutting process as such and of other elements.

Dynamic stability during cutting is one of the most important quality aspects of metal-cutting machine tools to be checked. At the limiting cutting speed, the system is no longer stable and sharp chatter marks appear on the surface. Machining must be stopped and the cutting speed reduced when such vibrations occur, thereby reducing the productivity of the machine tool.

Cutting speeds must be used at which tool stability is high and drive power is effective. In carrying out machine tool chatter tests in specialized laboratory conditions, the task is to define the stability limits, i. e. the dependence of the maximum cutting depth upon the cutting speed for a specific cutting job, tool shape, workpiece and feed.

Chatter tests have lately been carried out without cutting metal, using special devices and instruments which make it possible to determine the dynamic characteristics of a machine tool by subjecting it to vibrations artificially generated by vibrators. Machine tool chatter tests are too complicated to be carried out by customers and so simpler criteria must be employed in the tests they use.

The object of customer tests is to define the maximum depth that should be obtained in a cutting process when a piece of a definite size is machined at the optimum cutting rate for given tool shape and operating feed rate.

The test pieces for lathes are cylinders with a tapered shank inserted into a spindle taper. The dimensions of the cylindrical test pieces used for chatter tests are diameter 50 to 60 mm and length 250 mm, for lathes with a swing over the bed of 320 mm (height of centres 160 mm). For lathes with a swing over the bed of 400 mm the test piece dimensions are diameter 60 to 70 mm diameter and length 300 mm.

For testing knee-type milling machines (vertical and horizontal) rectangular test pieces of steel in the following sizes are used:

For machines with table dimensions of 250 mm × 1,000 mm the test piece is 200—250 mm long, 110—125 mm high and 75—90 mm wide.

For machines with table dimensions of 320 mm × 1,250 mm the test piece is 250—320 mm long, 140—160 mm high and 95—110 mm wide.

In these tests, the cutting tools employed are face cutters with carbide-tipped blades and cylindrical milling cutters made of high-speed steel.

As there are no standards for the dynamic stability of machine tools, comparative estimates of the stability of models of different design and manufacture are usually based on chatter tests.

One can define quantitatively the dynamic stability of a machine tool during metal-cutting by comparing the cutting rate at which vibration begins to occur with the rates at which the power of the machine-tool is effective and resistance to tool wear is at the optimum.

ACCURACY TESTS

General principles

Accuracy tests include both performance tests and geometrical checks. Professor G. Schlesinger published his pioneering work in this field in 1927. The work of devising national standards for accuracy tests and, subsequently, of negotiating internationally recommended standards has been built to a substantial extent on the foundations laid by Schlesinger.

In addition, it is customary for the manufacturers of machine tools to develop accuracy test charts for their own models, copies of which are usually supplied when the machines are delivered.

In both performance tests and geometrical checks, it is necessary first of all to decide the nature of the tests that should be performed and of the checks to be applied. Closely related to these questions, the test procedures have to be established and appropriate measuring instruments prescribed.

The discussion which follows is designed to make clear the general principles involved and the practical solutions generally adopted, rather than to instruct in full detail how any particular machine tool is tested.

Performance tests

Tests for accurate work by machine tools consist of machining special workpieces (test pieces) of definite size and shape under finishing operation conditions and then checking their accuracy. Performance tests are usually included in the accuracy test charts for each machine tool. Sizes of specimens tested have to be chosen so that one specimen can be used for testing the greatest possible number of machine tools. The areas machined are not continuous but in strips, in order to reduce the wear of the tools. When specimens must be held between centres for machining, their holes must be accurately ground. The accuracy of machined specimens must be checked for shape and for position of machined surfaces relative to each other and to the locating surfaces.

When testing lathes, cylindrical and internal grinders and boring machines by machining cylindrical surfaces, it is necessary to check the roundness of the cross-section, the cylindricity of the machined surface and the perpendicularity of the cylinder axis to the end face. When testing milling, planing and surface-grinding machines by machining flat specimens, the surface flatness and its parallelism or perpendicularity to the locating planes must be checked.

When boring machines are tested, the specimen undergoes every kind of machining operation performed by these machines: boring of holes, milling of planes, facing by radial feed of the cutter and machining of flanges by using a cutter on the face plate.

Geometrical checks

Tests of the geometrical accuracy of a machine tool are of the following six types:

(*a*) Tests applied to surfaces on which tools or workpieces are located (fixtures)—for example, the flatness of the tables of milling, planing and surface-grinding machines, and the face-plate flatness of lathes, chuck lathes etc., the accuracy of spindle tapers, whether external (in grinding machines) or internal (in lathes, milling, drilling and boring machines).

(*b*) Tests of the travel motion of machine parts that carry tools or workpieces—the straightness of the motion of tables of milling, planing and surface-grinding machines, lathe carriages, spindle heads of gear-hobbing machines, and so on; the rotation of spindles carrying the tool or workpiece and of rotary tables of turret lathes, surface grinders and gear-hobbing machines.

(c) Tests of the relative angular position of machine parts that carry tools or workpieces—for example, parallelism between the longitudinal travel of a lathe carriage or a boring machine table and the axis of rotation of the spindle; and parallelism between the vertical travel of the spindle head of a gear-hobbing machine and the axis of rotation of the table.

(*d*) Tests of the angular position of the motion of machine parts in relation to locating surfaces on them which are used for mounting a tool or a workpiece—the alignment of the tapered bore or external locating surfaces (tapered or cylindrical) of a spindle with the axis of rotation of the spindle; perpendicularity between the axis of rotation of a drilling machine spindle and the table surface; parallelism between the travel motion of a milling, planing or surface-grinding machine table and the table surface.

(*e*) Tests of the correlation between the speeds of motions of associated machine parts carrying a tool and a workpiece—speed correlations between spindle rotation and carriage movement of a thread-cutting lathe; correlation of the rotational speed of the workpiece spindle with the straight-line motion of a thread-grinding machine table; rotational speed correlation between the milling spindle and the table of a gear-hobbing machine. The last-mentioned test can hardly be checked exactly without using a special measuring instrument and therefore an estimate based on the results of gear-hobbing work is usually adopted.

(*f*) Tests of the angular positioning (indexing) or linear positioning of a machine part—the indexing of the workpiece, the point-to-point motion of a jig-boring machine table etc.

Checks of geometrical accuracy are made with moving parts placed at the middle of their stroke.

Downward deflection from a straight-line path may occur when moving parts reach the extreme position of their travel, if the machine structure is insufficiently rigid. For example, in knee-type milling, horizontal-boring and jig-boring machines equipped with cross-slide tables, there may be excessive tilting of the table in its extreme positions if the cross-slide carriage and table are not rigid enough.

Elements of the geometrical checks and performance tests of machine tools

Geometrical checks of machine tools (and likewise the accuracy tests of machined specimens) include checks on the following elements:

(*a*) Straightness of lines, parts and motions;
(*b*) Flatness;
(*c*) Parallelism of lines, planes and motions;
(*d*) Equidistance and coincidence (or alignment);
(*e*) Perpendicularity of straight lines, planes and motions;
(*f*) Rotation; runout, periodical axial slip and camming;
(*g*) Division of graduated scales, etc.;
(*h*) Accuracy of point-to-point motion.

A detailed description of the methods and necessary conditions for checking with elementary instruments items (*a*) to (*g*) is given in *ISO Recommendation R 230, Machine tool test code,* International Organization for Standardization, Switzerland, 1961. Figures 3 and 8 to 28 are reproduced from this publication and its text has been drawn on to a large extent in this section.

(a) Straightness

Straightness checks on lines and guideways are made with straight-edges and precision spirit levels; for lengths exceeding 1,600 mm (62 in) an autocollimator or a measuring microscope and a taut wire are used. The checks with a level detect errors in a vertical plane whereas those with a taut wire detect errors in a horizontal plane.

A straight-edge (figure 8) is mounted so that its two end points are equidistant from the surface or the guideway to be checked, along which a bar carrying a dial gauge travels. The plunger point of the gauge slides along the straight-edge (figure 9). The length to be checked is divided into a number of sections, and dial-gauge readings are recorded at the end of each section. With these data a diagram of deviations from straightness can be drawn (figure 10). The errors are deviations in the machine tool from the straight line connecting the two ends of the straight-edge.

When a precision level is employed, the total length to be checked is divided into equal sections of 100 to 500 mm. The slope of the line in each section is charted according to the readings of the level (figure 11). The slope of each section is defined as the mean of two measurements, one measured from left to right and the other in the opposite direction. Deviations from straightness are defined as the perpendicular distances from the straight line joining the two ends of the line to be checked.

When machine tool purchasers make acceptance tests they are unlikely to have optical instruments available.

To check the straightness of motion of a machine part, the dial-gauge holder is mounted on the moving part with the plunger point sliding along a fixed straight-edge. If the length to be checked for straightness is too long, a taut wire can be used in order to determine the deviations in a horizontal plane.

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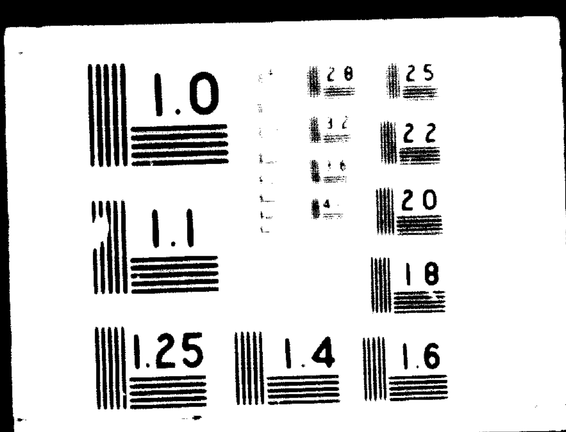

spindle heads of gear hobbing machines, and so on; the rotation of spindles carrying the tool or workpiece and of rotary tables of turret lathes, surface grinders and gear-hobbing machines

(c) Tests of the relative angular position of machine parts that carry tools or workpieces—for example, parallelism between the longitudinal travel of a lathe carriage or a boring machine table and the axis of rotation of the spindle; and parallelism between the vertical travel of the spindle head of a gear-hobbing machine and the axis of rotation of the table.

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Checks of geometrical accuracy are made with moving parts placed at the middle of their stroke.

Downward deflection from a straight-line path may occur when moving parts reach the extreme position of their travel, if the machine structure is insufficiently rigid. For example, in knee-type milling, horizontal-boring and jig-boring machines equipped with cross-slide tables, there may be excessive tilting of the table in its extreme positions if the cross-slide carriage and table are not rigid enough.

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When machine tool purchasers make acceptance tests they are unlikely to have optical instruments available.

To check the straightness of motion of a machine part, the dial-gauge holder is mounted on the moving part with the plunger point sliding along a fixed straight-edge. If the length to be checked for straightness is too long, a taut wire can be used in order to determine the deviations in a horizontal plane.

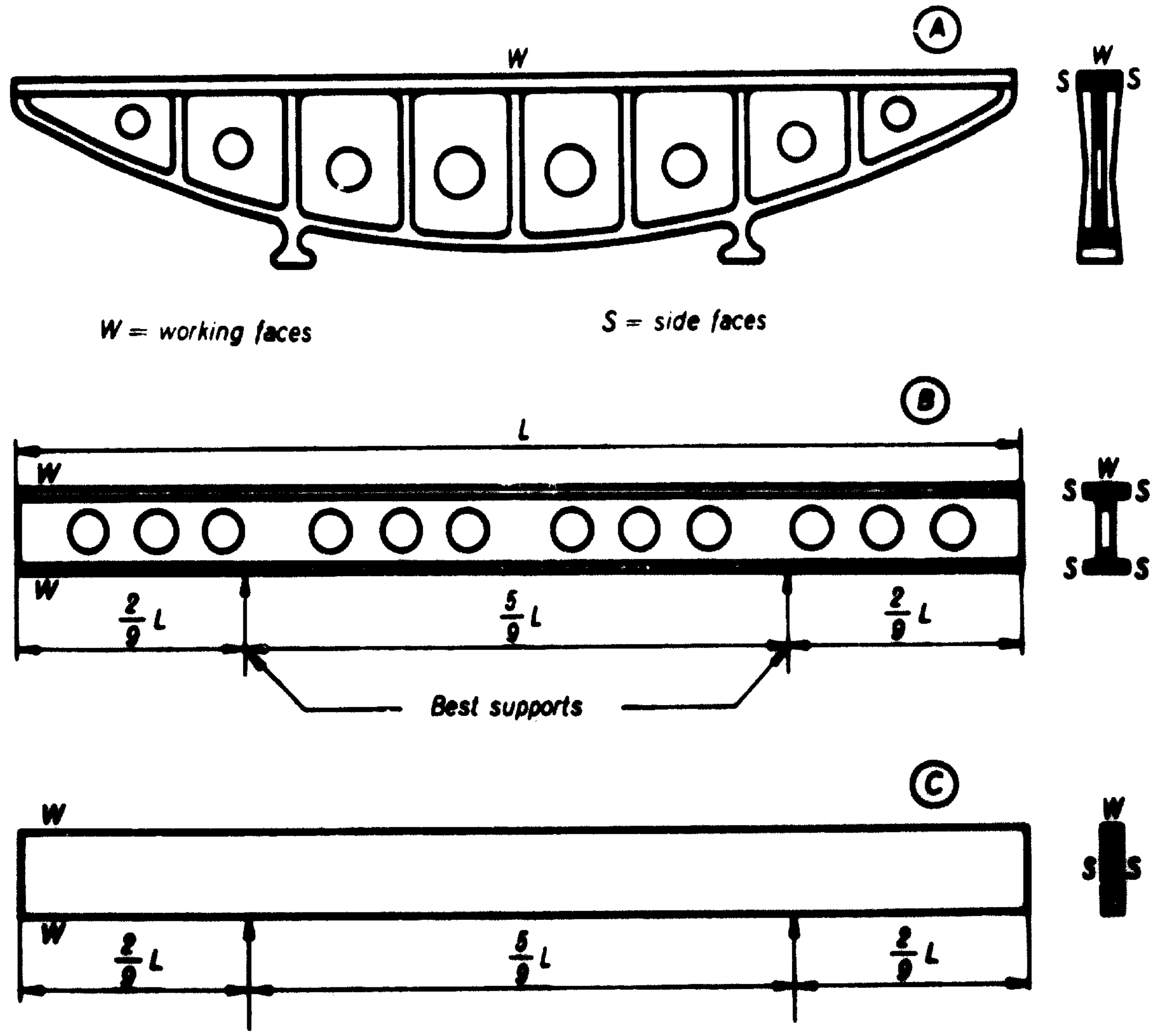


Figure 8. Principal types of straight-edge: A — *bow-shaped straight-edge with a single edge;* B — *straight-edge with two parallel faces, of I-section with a solid or lightened web;* C — *straight-edge with two parallel faces, of plain rectangular section*

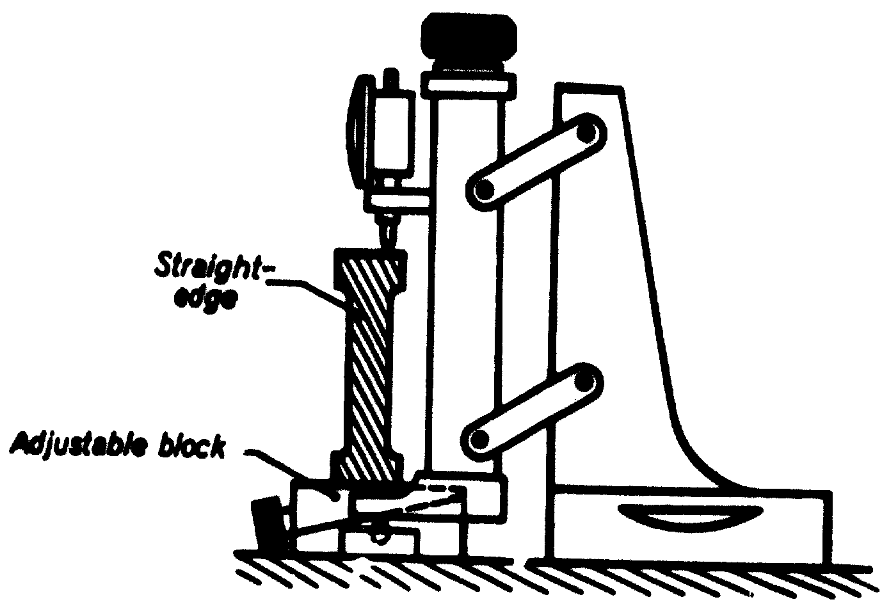


Figure 9. Straightness test with straight-edge

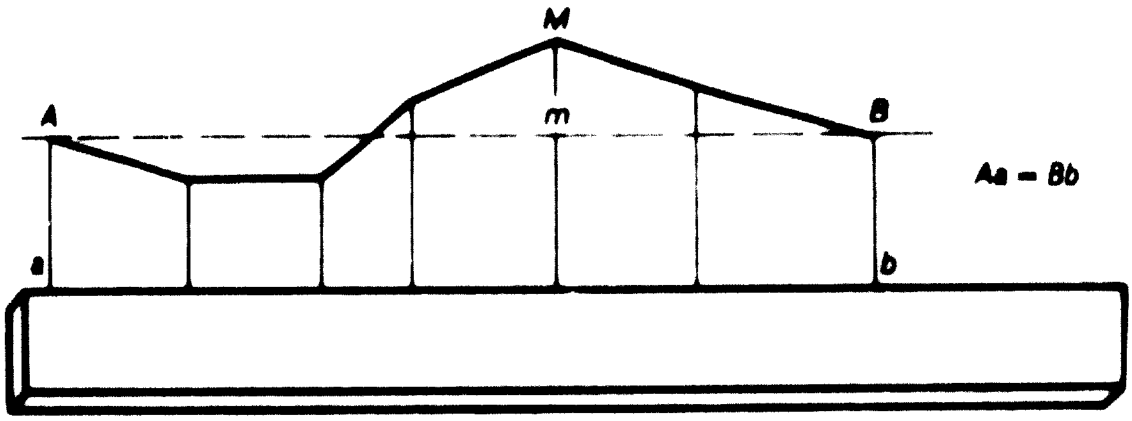


Figure 10. Diagram of deviations from straight edge

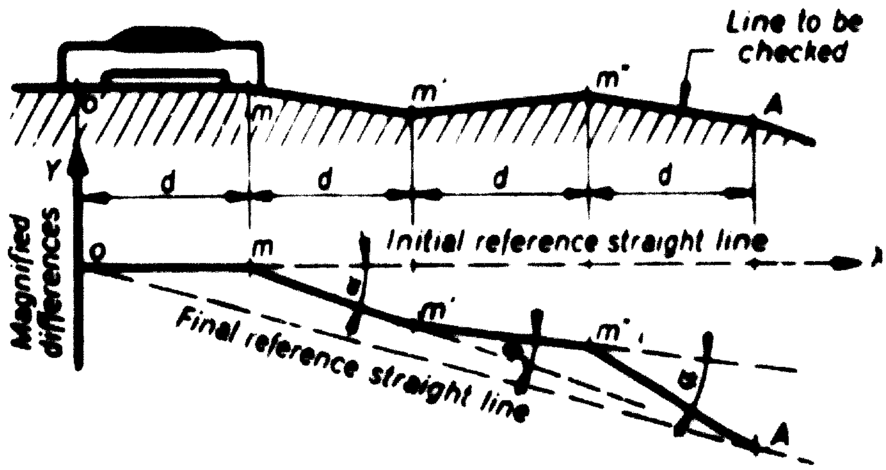


Figure 11. Diagram of slope differences obtained by spirit-level test

For checking the straightness of horizontal motion of a lathe carriage, a cylindrical mandrel may be mounted between the machine centres. The dial gauge is fixed rigidly on the machine tool carriage with its plunger-point pressing against the cylindrical surface of the mandrel.

(b) Flatness

The flatness of machine-tool surfaces or machined specimens is checked with a surface plate, a straight-edge or a precision level.

When a surface plate is to be used it is first covered with a thin film of marking medium. The flatness of the test surface is confirmed if there is a uniform distribution of contact points over its whole area after the surface plate has been placed on it and rubbed back and forth.

When a straight-edge is used, the flatness is checked as shown in figure 12. Supporting blocks (*a*, *b*, *c*) of equal height are placed in three corners of a rectangular plane which is to be checked. A block, *e*, of adjustable height is put in the centre of the plane. With the straight-edge mounted on blocks *a* and *c*, the adjustable block is brought into contact with it. The straight-edge is next placed on blocks *b* and *c* and the distance between the test plane and point *g* of the straight-edge is measured. An adjustable block is then brought into contact with the straight-edge at this point. Then with the straight-edge mounted in succession on blocks *a* and *d*, and finally on *b* and *c*, the distances are measured from the straight-edge to the mid-points of *a* and *b*, of *d* and *c*, of *a* and *d*, and of *b* and *c*.

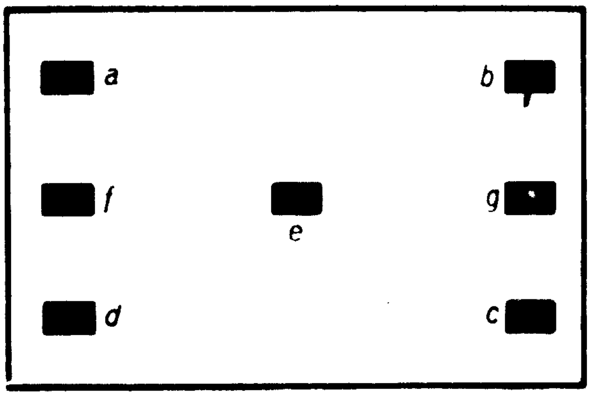


Figure 12. Testing flatness with a straight-edge

The use of a precision spirit level for checking flatness is illustrated in figure 13. Deviations from straightness are first measured along *oA* and *oC*. Then the straightness is checked along *o′ A′*, *o″ A″* ... and *CB*. As a final check, it is again measured along *mM*, *m′ M′* and so on.

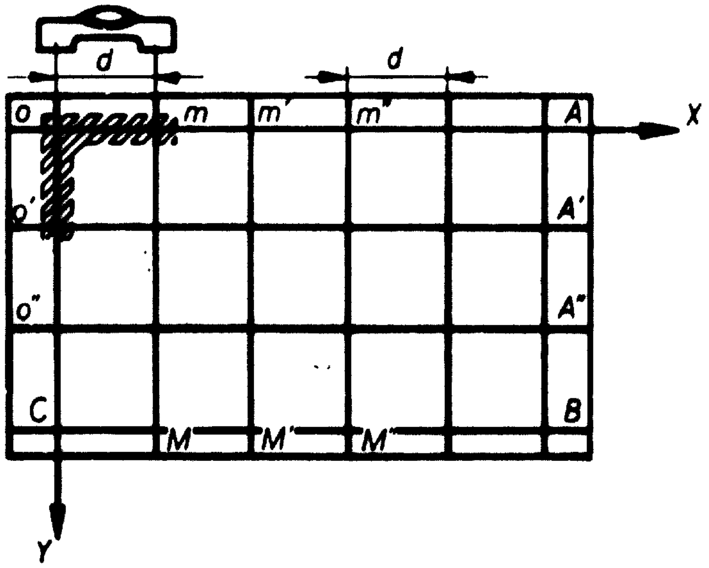


Figure 13. Testing flatness with a spirit-level

(c) Parallelism

To check the relative angular positions of the axes of spindle rotation cylindrical mandrels with taper shanks (figure 14) are used, located in the spindle taper bores. The axis of the mandrel cylinder cannot be made absolutely concentric with the axis of rotation. To eliminate the effect of the non-alignment of the spindle axis with the mandrel, the latter is turned through 180 and the axis of spindle rotation is then checked once again for its relative angular position. The true angular position is the algebraic mean of the readings for the two positions of the mandrel in the spindle.

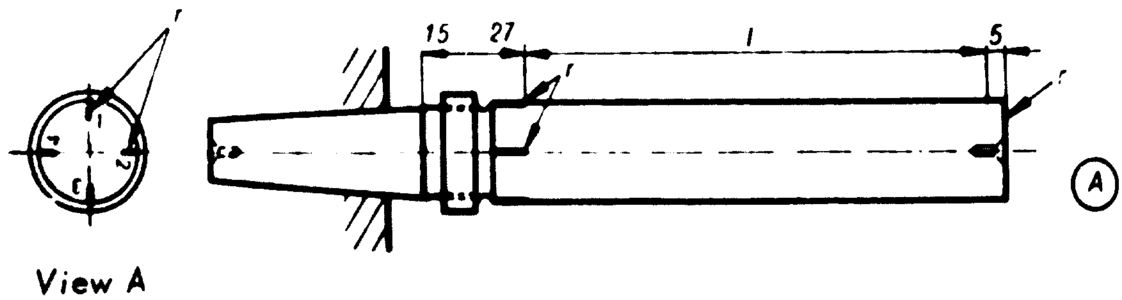


Figure 14. Mandrel for testing parallelism of two axes

The effect of non-alignment may be overcome in another way. The dial gauge may be placed with its plunger point resting against the cylindrical part of the mandrel and, while the spindle is slowly rotated, the dial-gauge readings may be noted and their mean value calculated.

To check the parallelism of two planes, the supporting base of the dial gauge is moved along one of these while its plunger point is traversed over the other (figure 15).

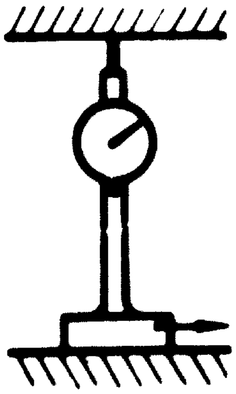


Figure 15. Testing parallelism of two planes

Parallelism of two axes in a plane passing through them[8] is checked by means of a dial gauge mounted on a prism-shaped base, of such dimensions that when it is placed on a cylinder representing one of the axes, its plunger point rests on the surface of a cylinder representing the other axis. To verify that the distance between the shafts is constant,

[8] This expression here means a plane passing through one of the two axes and as near as possible to the second axis.

the dial-gauge holder is slightly rocked and the minimum reading is taken. The reading is repeated in this plane at a predetermined distance from the first reading (figure 16).

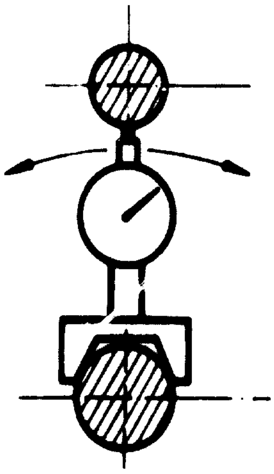


Figure 16. Testing parallelism of two axes in plane passing through them

Parallelism of the two axes in a plane perpendicular to the previous one is ensured by checking each of them for parallelism relative to a third auxiliary plane. When the axes to be checked are horizontal, this may be done by using a precision level mounted on a bridge-piece, the tube of the level being perpendicular to the axes (figure 17).

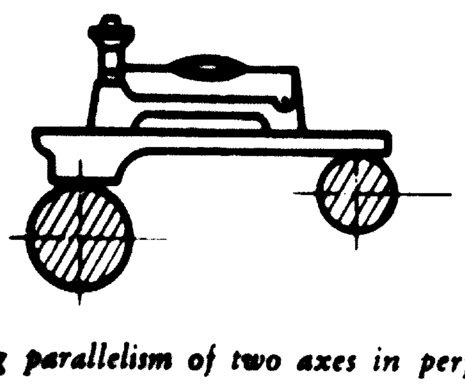


Figure 17. Testing parallelism of two axes in perpendicular plane

Parallelism of an axis to a plane is checked by mounting a cylindrical mandrel in the spindle taper and moving a dial gauge along it while the holder of the gauge traverses over the plane (figure 18). In a similar manner, parallelism is checked between the spindle axis and the guideways of the machine (figure 19).

The same procedures are used to check parallelism of a direction of straight-line movement to a plane, of a guideway and an axis, or of two straight-line motions.

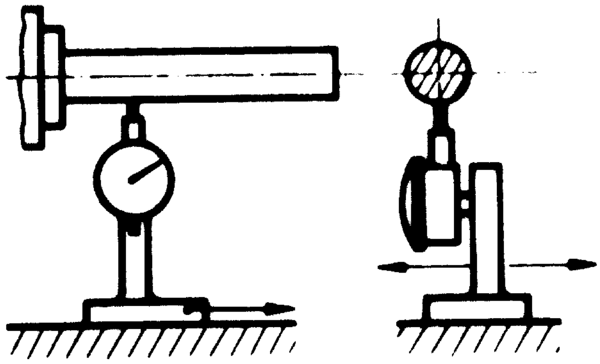


Figure 18. Testing parallelism of an axis to a plane

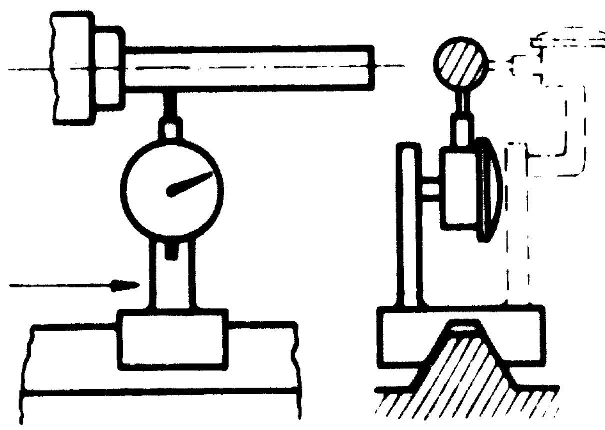


Figure 19. Testing parallelism of an axis to the intersection of two planes

(d) Equidistance and coincidence (or alignment)

The equidistance of two axes, or of an axis rotating around another axis in a perpendicular plane is checked with a dial gauge, as for parallelism. A special case arises when two axes are equidistant from the plane of pivoting of one of the axes. The dial-gauge holder is traversed along the plane and its plunger point rests against the cylindrical mandrels mounted in the spindle tapers (figures 20 and 21).

The coincidence of two spindle axes is checked with a dial gauge. Its holder is clamped on one of the spindles, and its plunger point rests on a cylindrical mandrel mounted on the taper of the second spindle (figure 22).

(e) Perpendicularity (or squareness)

The perpendicularity of the axis of rotation of a spindle or some other part to a plane or guideway may be checked by means of a dial gauge fixed on the spindle at a certain distance from its axis. The

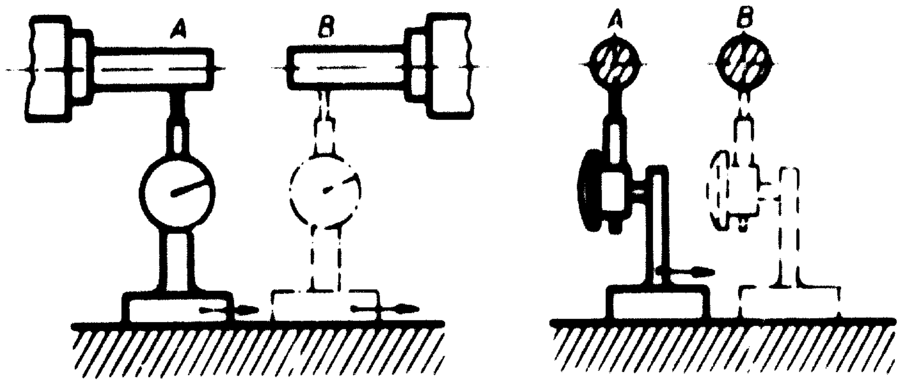


Figure 20. Testing equidistance of two axes from a plane

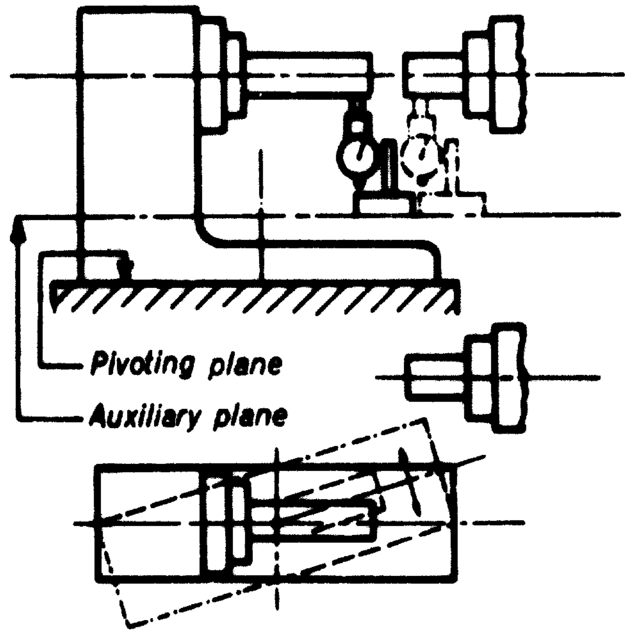


Figure 21. Testing equidistance of two axes from plane of pivoting of one of the axes

dial-gauge plunger point rests on the plane or the slide which travels along the guideway (figure 23). Turning the spindle through 360°, the maximum and minimum readings are noted. The difference between these readings, divided by the diameter of the circle described by the dial-gauge plunger, is a measure of the lack of perpendicularity.

In order to check the perpendicularity of the spindle axis to the guideway, the spindle must be turned through 180° and the slide moved a distance equal to the diameter of the circle (figure 24).

A steel square should be used to check the perpendicularity of planes and guideways. The task is thus reduced to checking parallelism with the free edge of the square. The same applies to checking perpendicularity to a direction of straight-line motion.

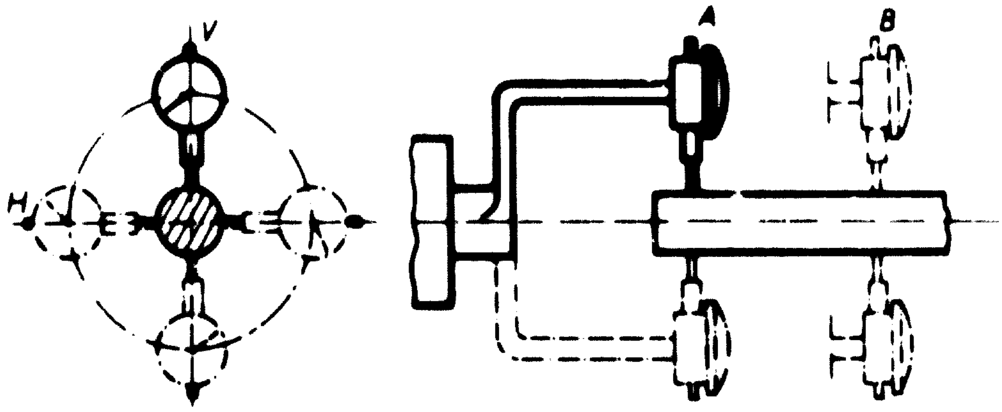


Figure 22. Testing coincidence of two axes: A and B are two sections in which the check should be repeated. H and V represent two separate planes in which variations may need to be recorded

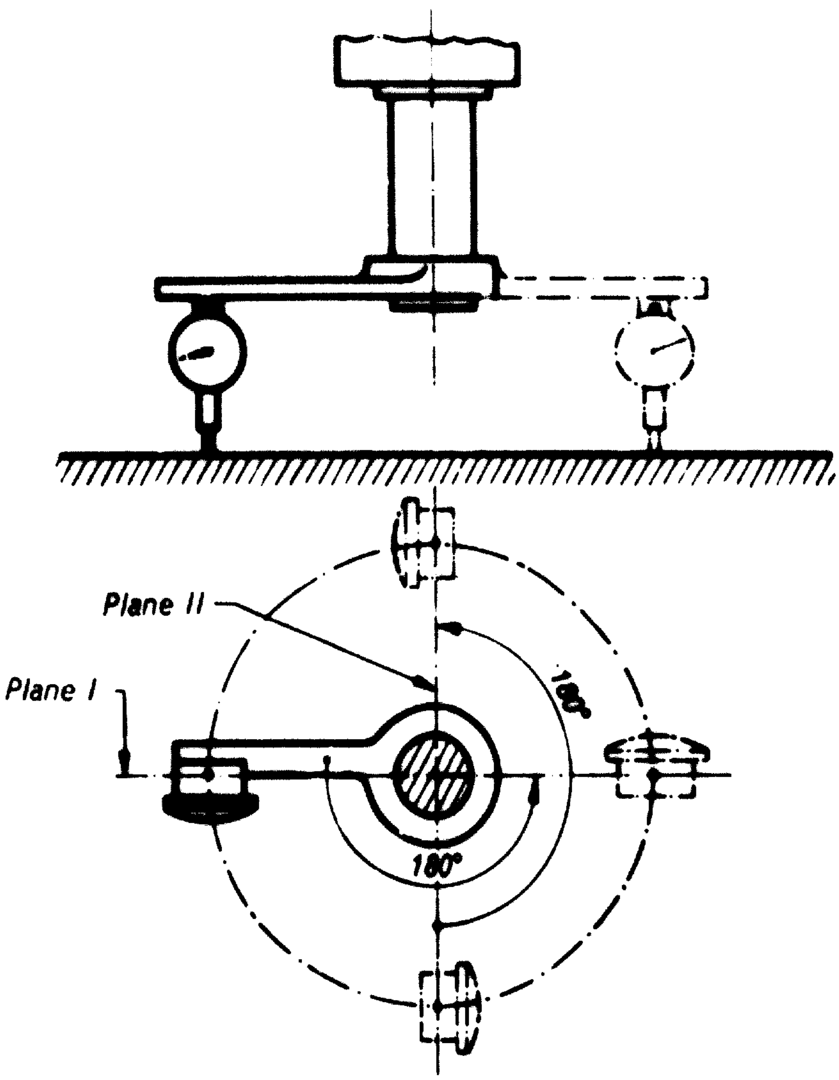


Figure 23. Testing perpendicularity of an axis of rotation to a plane

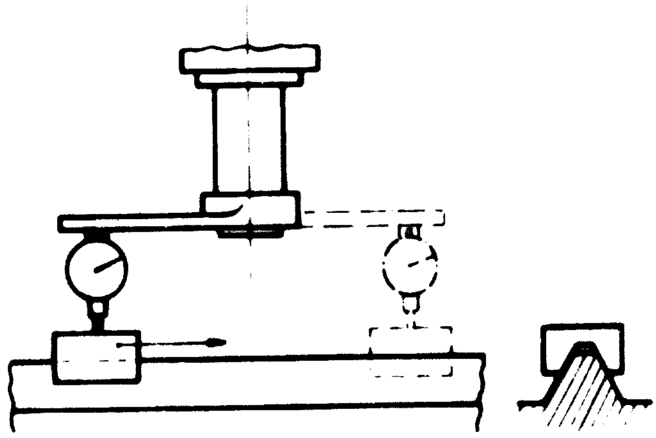


Figure 24. Testing perpendicularity of an axis to the intersection of two planes

(f) Rotation

Accuracy of rotation is checked by determining the out-of-true running (run-out) of the surface of a rotating part, such as a spindle, its periodical axial slip and the camming action of its face.

One reason for run-out of the surface of a rotating part may be inaccuracy of this surface (out-of-roundness). Measuring out-of-roundness, whether of external or of internal surfaces, is not simple and requires the use of sophisticated measuring instruments. It is not sufficient merely to measure diameters, although this does enable the surface ovality to be detected.

Another reason for surface run-out may be the axial slip of the surface from the centre of rotation. Finally, run-out may be caused by defects in antifriction bearings, which result in an unstable axis of rotation. There is then a so-called wandering run-out, in which the period of the run-out does not coincide with a full revolution of the spindle.

In checking the run-out of cylindrical or conical external surfaces, a dial gauge is set up with its plunger at right angles to the generator of the surface (figure 25). In checking the run-out of an internal surface, such as spindle taper bore (figure 26), the taper shank of a cylindrical mandrel is inserted in the spindle and the run-out of the mandrel surface is checked using a dial gauge set up in a vertical plane (position C_1), first at the spindle nose (section A), then at the free end of the mandrel (section B). The mandrel run-out is checked while the spindle is rotating slowly. The dial gauge is then set up for checking in a horizontal plane (position C_2).

To eliminate the effect of the non-coincidence of the axes of the

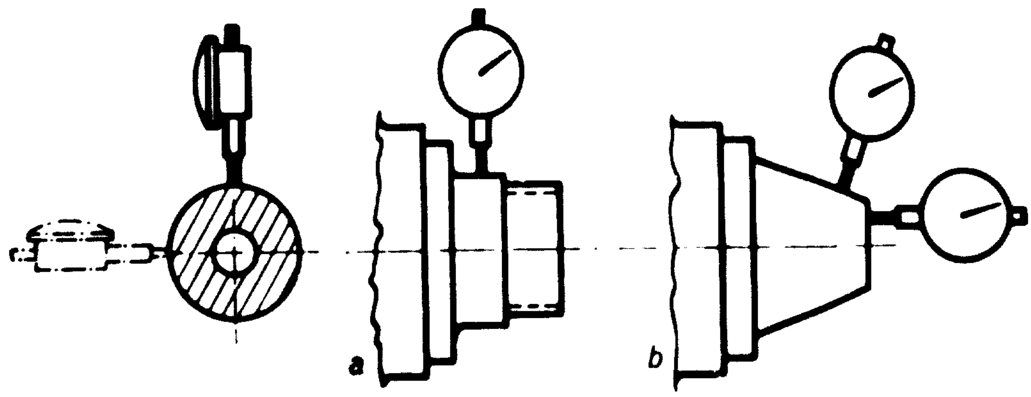


Figure 25. Testing run-out of external surfaces

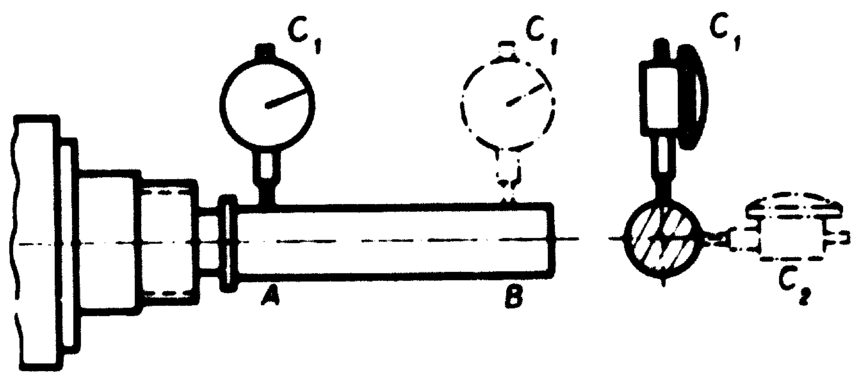


Figure 26. Testing run-out of internal surfaces

spindle and the mandrel, these checks should be repeated four times, with the mandrel turned 90° relative to the spindle each time.

The periodical axial slip of a rotating part, such as a spindle, is defined under conditions in which the influence of the minimum axial play is eliminated by applying a small axial force to the face of the rotating part.

The dial-gauge plunger axis is aligned with the axis of the part to be checked. For this purpose, a flat-faced mandrel, having no centre hole, is inserted in the spindle taper and the dial-gauge plunger point is applied to the face of the mandrel (figure 27 a). Alternatively, a mandrel with a short taper shank may be used, in which case a flat-faced contact end should be pressed against the dial-gauge plunger (figure 27 b). If the rotating part has a centre hole, a steel ball should be inserted therein for the flat-faced end of the dial-gauge plunger to bear against (figure 27 c).

Camming action of a plane surface is checked by a dial gauge set parallel to the axis of rotation at a given distance *A* from the axis (figure 28). Rotating the spindle slowly and applying a slight axial

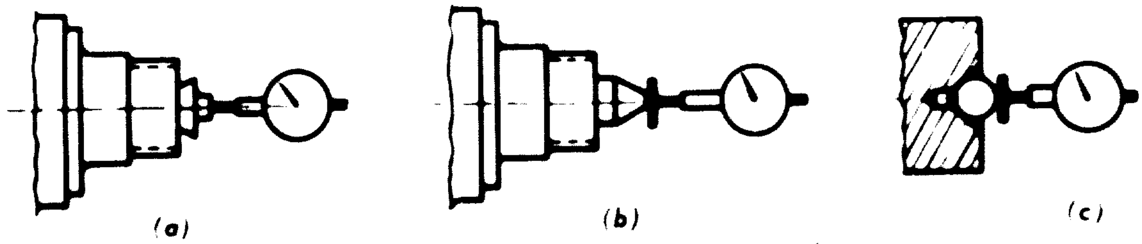


Figure 27. Testing periodical axial slip

pressure, dial-gauge readings should be taken at intervals — for example, every 45°. The difference in the readings taken at two opposite points indicates the camming action at a radius *A*.

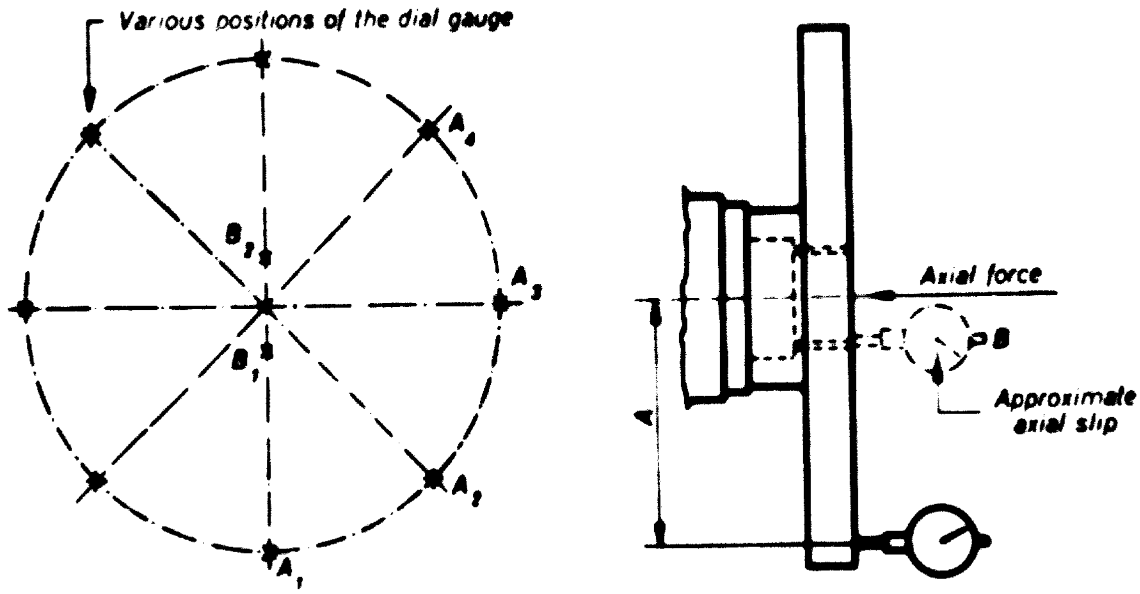


Figure 28. Testing the camming action of a plane surface

(g) Division

Errors of division can occur in graduated scales, gear wheels, dividing plates, pitch of driving screws and so on. Five types of error may be defined: individual error of division, successive error of division, error of division in a given interval, cumulative error (or steps in a given interval), and total error of division. It is not usually necessary, however, to fix tolerances for each type of error. Thus, for linear divisions, the tolerance is always indicated for cumulative error.

The checking of errors of division most often requires special devices that are at the disposal of machine-tool builders or technical institutes but not of users of machine tools.

(b) Accuracy of point-to-point motion

The accuracy of point-to-point motion, using co-ordinates, is checked by special methods that are described in the test charts of jig-boring machines prepared by their manufacturers.

THERMAL DISTORTION TESTS

The heat generated within a machine tool causes thermal distortions and deflections which, as already mentioned, may considerably reduce working accuracy.

In automatic lathes these distortions, when combined with tool wear, may result in the production of a whole batch of components with systematic dimensional errors, unless the tooling is adjusted (which may be done automatically or manually).

Similar difficulties occur in turret lathes and other machines without automatic adjustment of tooling, where a tool has a predetermined position in relation to the workpiece.

More generally, machined workpieces may become non-cylindrical, as the result of local distortion of the machine-tool bed from the heat generated in the hydraulic drive of the table.

The special tests needed for checking thermal distortions in a machine tool consist in comparing the position of machine parts carrying

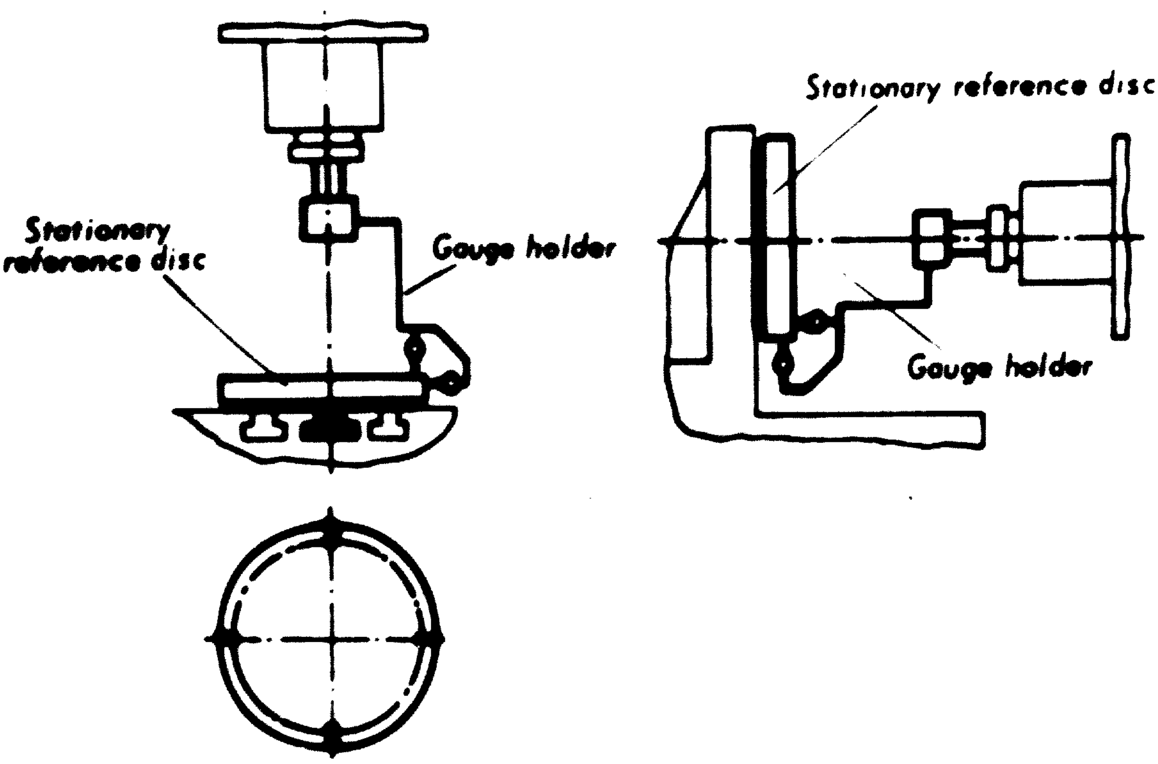


Figure 29. Testing thermal distortion of a jig-boring machine

a workpiece and a tool, when cold and after the machine has been warmed up by running idle for a definite period of time, such as 3 hours. Thus, for example, when checking a jig-boring machine for thermal distortion, a reference disc with its upper face and cylindrical surface fine-finished is placed on the table. An easily removable dial-gauge holder, with two dial gauges attached, is clamped on the machine spindle. The vertical dial gauge has its plunger point resting against the disc face, while that of the horizontal gauge rests against the cylindrical surface of the disc (figure 29).

The reference disc is adjusted so that both dial gauges show zero as the spindle is slowly rotated with the holder and gauges attached. The reference disc is thus aligned and perpendicular to the axis of rotation of the spindle. The mandrel, with the two dial gauges on it, is then removed from the spindle and idle running is carried out for, say, 3 hours. The spindle is rotated at the speed appropriate for fine boring of medium-sized holes. After the idle running stops, the mandrel with its two gauges is put back on the spindle and the measurements are repeated with the spindle slowly rotated by hand. It will be possible to estimate from the dial-gauge readings the horizontal displacement of the spindle nose and the change in slope of its axis caused by the rise in temperature of the machine.

When thermal distortions of the machine tool change the shape of the workpiece, it may be preferable to evaluate this effect by comparing the accuracy of several workpieces obtained from the cold machine with the same number of pieces produced after the machine has been warmed up by running idle for 3 hours. This method may be used in testing cylindrical grinding machines.

TOLERANCES

Accuracy is a relative term and it is obvious that we cannot measure with greater accuracy than is provided by our measuring instruments. In practice, instruments are not the limiting factor when testing the accuracy of a machine tool or workpiece, which has to be prescribed by economic as well as technical factors. The greater the degree of precision, the higher the cost of manufacture as a general rule. At the same time, it is not always easy to determine on technical grounds the exact degree of precision to which a product or a component must be machined. This applies to machine tools as well as to workpieces.

Tolerances, which limit deviations to values which are not to be exceeded, relate to the sizes, forms, positions and movements which are essential to the accuracy of working and to the mounting of tools, important components and accessories. There are also tolerances which apply only to the test pieces used in performance tests.

STANDARDIZATION OF ACCEPTANCE TESTS

Tolerances were laid down by Schlesinger at the same time as he published in 1927 his ideas of specifying and executing acceptance tests, in *Testing Machine Tools*.[4] This work has been carried on both in the national and international field by standardizing bodies. Schlesinger himself modified the test data slightly in subsequent editions of his work as experience in industry and the course of preparation of standards internationally showed to be desirable. Nevertheless the form or contents of the Test Charts in his publication do not necessarily match those of existing national or international standards. This is not of importance, since if the supplier or customer specifies a definite standard then only the latest issue of that standard may be employed for the acceptance testing of that particular machine tool.

In the developing countries, as in industrially advanced countries, customers stand to benefit from standardization of the acceptance tests nationally and internationally. The comparison of test data and tolerances in tests originating from various sources is rather a complex task because of differences in terminology and sometimes in the sequence of the tests. It is considered preferable here to indicate in broad terms how standardization has progressed, with particular reference to the final goal of international standardization.

The Machine Tool Test Code published by ISO in 1961 has already been referred to extensively in this chapter. National standards bodies have been negotiating within ISO to supplement this by a series of Recommendations for testing the accuracy of various categories of machine tools. Two of these have now been approved, ISO/R 1701 and ISO/R 1708, dealing respectively with milling machines with table of variable height, with horizontal or vertical spindle, and general-purpose parallel lathes.

Three other documents have reached the stage of Draft Recommendations, subject to final approval. They are ISO/DR 1984, ISO/DR 1985 and ISO/DR 1986, dealing respectively with milling machines with table of fixed height, with horizontal or vertical spindle; surface grinding machines with vertical grinding wheel spindle and reciprocating table; and surface grinding machines with horizontal grinding wheel spindle and reciprocating table.

Two more documents of a similar nature are under study in the appropriate Technical Committee of ISO. These relate to tests for grinding machines for external and internal surfaces of revolution. As may be noted, this means that accuracy testing of a number of other categories of machine tools has yet to achieve much progress in the technical work of ISO.

The ISO Machine Tool Test Code has by now been effectively

[4] Op. cit.

embodied in numerous national standards. Examples are NF E 60—100 of 1965 in France, DIN 8601, revision of April 1969, in the Federal Republic of Germany and BS 3800 — 1964 in the United Kingdom.

As regards the detailed tests for categories of machine tools, certain national standards have been operative in many countries for a long time. A few examples, chosen at random, are DIN 8620 of 1940 — acceptance tests for horizontal borers and millers up to 150 mm spindle diameter, with fixed column and adjustable table — in the Federal Republic of Germany;[5] ASA (now ANSI) B 5.16-1952 — accuracy of engine and tool room lathes — in the United States; and GOST 25-26 — slotting machines. Precision standards — in the Union of Soviet Socialist Republics.

After agreement has been reached in the ISO Technical Committee and the Draft Recommendation approved, the national standards bodies generally seek to revise their standards where necessary to bring them into line, consulting machine tool suppliers and users. Thus, the French standard corresponding to ISO/R 1701 was published in 1970 and the British one is expected to appear in 1971.

The present UNIDO publication is intended neither as a reference source for detailed checks and tests nor as a training manual for inspectors or plant engineers. Nevertheless, readers may find it helpful to look at sample pages drawn from Schlesinger's work and from published standards. These are reproduced in the annexes. It should be remembered that all such standards are liable to periodic revision by the bodies responsible for preparing and publishing them.

DO DEVELOPING COUNTRIES NEED SPECIAL ACCEPTANCE TESTS?

It is evident from the foregoing discussion that the up-dating of the Schlesinger and other accepted tests has been taking place, although the rate of progress may be considered slow by those who are most likely to benefit from international agreement in this field. Foremost in this group are customers in the developing countries, since most of them have to import most of the machine tools they require.

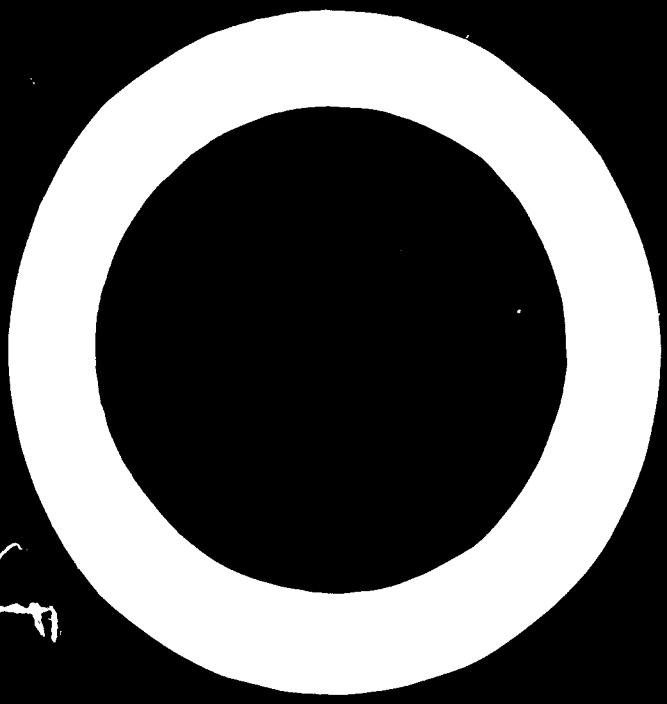
It is notable that acceptance tests for machine tools do not explicitly take into consideration certain conditions that markedly prevail in many developing countries, such as a wide range of ambient temperatures during each 24 hours or a high level of humidity. Yet it would not be disputed that such conditions affect the performance of machine tools.

A final question needs to be asked: how well are acceptance tests for machine tools adapted to conditions that prevail in developing countries but are of little significance in the industrially advanced

[5] About to be withdrawn for substantial revision.

countries? While it is true that the acceptance tests have been devised in industrially advanced countries, it must be remembered that machine tools manufactured in those countries are operating in many developing countries, often in enterprises whose technical managers are thoroughly experienced in modern production techniques. There have been many opportunities, therefore, for machine-tool manufacturers in the developed countries to be told about any lack of suitability to conditions in the developing countries. Moreover, the more advanced developing countries have standards bodies which are members of the ISO and can make their views known when international recommendations are being drawn up.

It does not follow that allowance has always been made for the special conditions in developing countries. UNIDO might assist these countries to work out suitable adaptations, which could then be submitted through the ISO for international action.



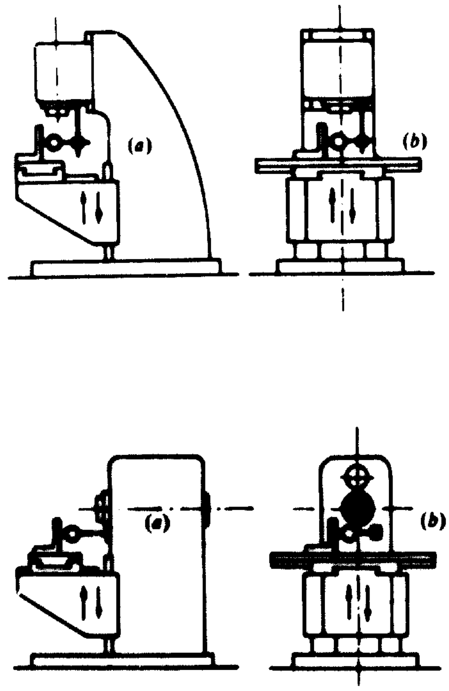
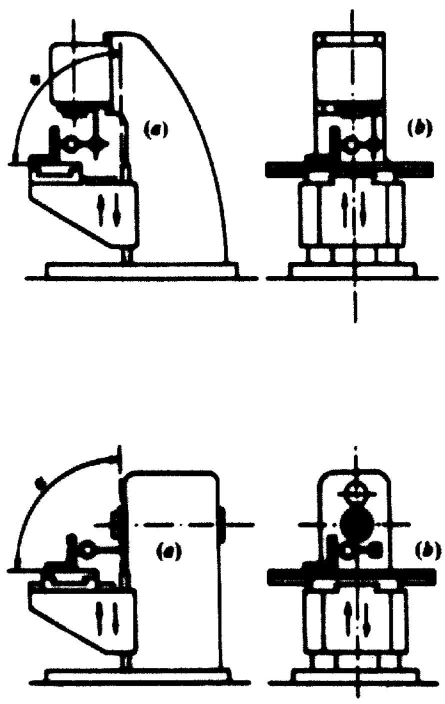
Annex 1

TEST CONDITIONS FOR MILLING MACHINES WITH TABLE OF VARIABLE HEIGHT, WITH HORIZONTAL OR VERTICAL SPINDLE—TESTING OF THE ACCURACY

Extract from
ISO Recommendation R 1701, 1st edition, April 1970
Reprinted with the permission of the publisher, International Organization for Standardization, Geneva, Switzerland

3. TEST CONDITIONS AND PERMISSIBLE DEVIATIONS

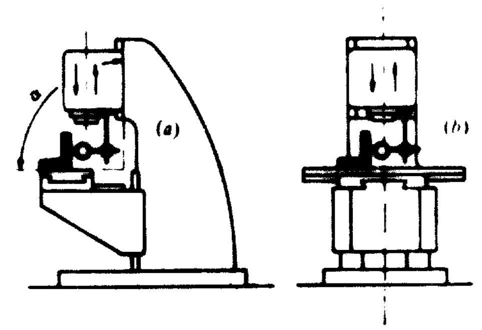
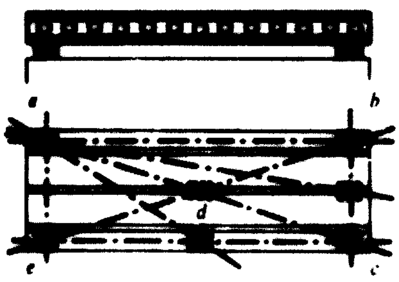
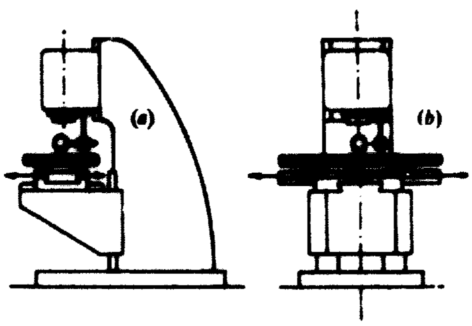
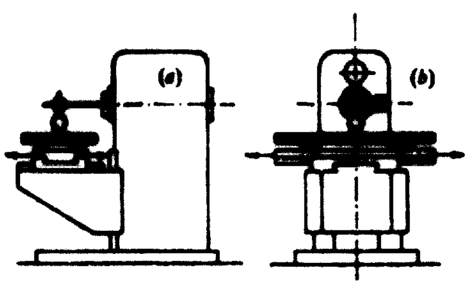
3.1 Geometrical tests

No.	Diagram	Object
G 1		Checking of straightness of the vertical movement of the knee: (*a*) in the vertical plane of symmetry of the machine or transverse vertical plane; (*b*) in the plane perpendicular to the vertical plane of symmetry of the machine or transverse vertical plane.
G 2		Checking of squareness of the table surface to the column ways for knee (in three positions: in the middle and near the extremities of the travel): (*a*) in the vertical plane of symmetry of the machine or transverse vertical plane; (*b*) in the plane perpendicular to the vertical plane of symmetry of the machine or transverse vertical plane.

ISO/R 1701-1970 (E)

Dimensions in millimetres

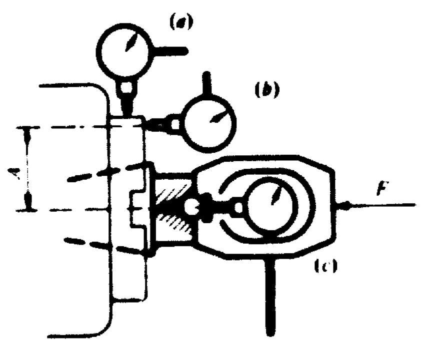
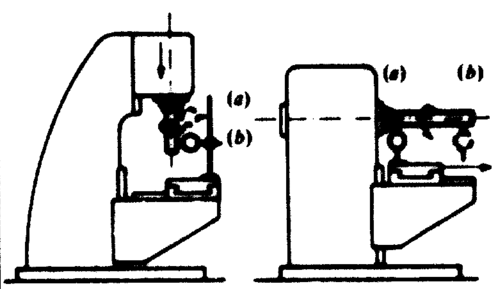
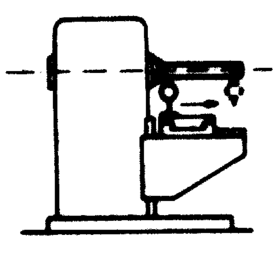
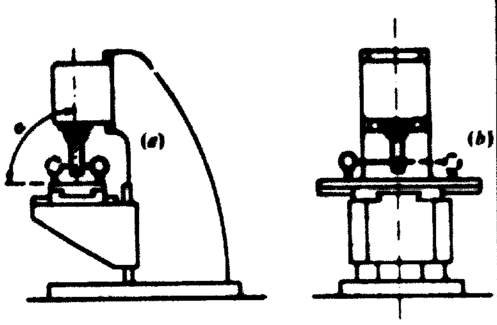
Permissible deviation	Measuring instruments	Observations and references to the test code ISO/R 230
(*a*) 0.025 for a measuring length of 300 (*b*) 0.025 for a measuring length of 300	Dial gauge and square	Clause 5.232.1 Instead of a straight-edge, use the vertical arm of a square. Table in central position, table and cross slide locked, knee not locked. If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge should be placed on a fixed part of the machine.
(*a*) 0.025/300 with $\alpha \leq 90°$ (*b*) 0.025/300	Dial gauge and square	Clause 5.522.2 Table in central position, table and cross slide locked. Knee locked when taking measurements. If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge should be placed on a fixed part of the machine.

No.	Diagram	Object
G 3		Checking of squareness of the table surface to the vertical movement of the spindle head slide: (*a*) in the vertical plane of symmetry of the machine or transverse vertical plane; (*b*) in the plane perpendicular to the vertical plane of symmetry of the machine or transverse vertical plane.
G 4		Checking of flatness of the table surface.
G 5		Checking of parallelism of the table surface to its movement: (*a*) transversely; (*b*) longitudinally.

ISO/R 1701-1970 (E)

Dimensions in millimetres

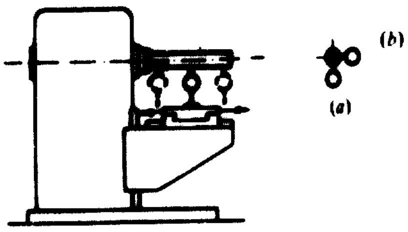
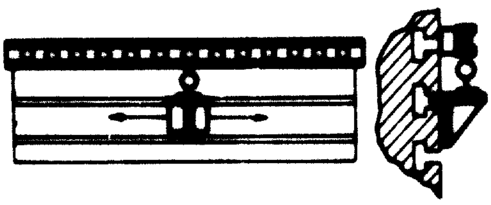
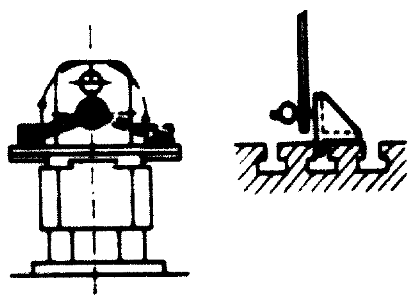
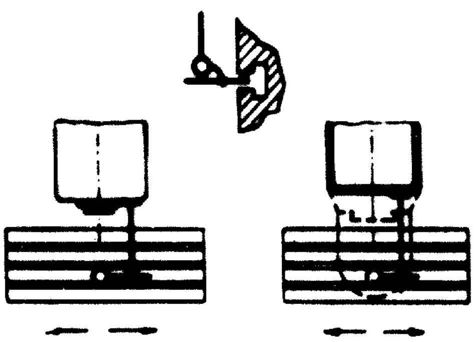
Permissible deviation	Measuring instruments	Observations and references to the test code ISO/R 230
(*a*) 0.025/300 with $\alpha \leq 90°$ (*b*) 0.025/300	Dial gauge and square	Clause 5.522.2 Table in central position, knee and table locked. Spindle head slide locked when taking measurements. If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge should be placed on the spindle head slide of the machine.
0.04 up to 1,000 For each 1,000 increase in table length, add 0.005 Maximum permissible deviation: 0.05 Local tolerance: 0.02 for any 300 length	Precision level or straightedge and slip gauges	Clauses 5.322 and 5.323 Table and cross slide in central position, table not locked, knee and cross slide locked. NOTE. — The alphabetical references on the diagram correspond to those used in Figure 19 of ISO Recommendation R 230.
(*a*) 0.025 for any 300 length (*b*) 0.025 for any 300 length Maximum permissible deviation: 0.05	Straightedge and dial gauge	Clause 5.422.21 The stylus of the dial gauge to be placed approximately at the working position of the tool. The measurement may be made on a straightedge laid parallel to the table surface. If the table length is greater than 1,600 mm, carry out the inspection by successive movements of the straightedge. Knee locked. If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge should be placed on a fixed part of the machine. (*a*) Table and spindle head slide locked; (*b*) Cross slide and spindle head slide locked.

No.	Diagram	Object
G 6		(*a*) Measurement of run-out of the external centring surface on the spindle nose (for machines having this feature). (*b*) Measurement of camming of the face of the spindle nose (including periodic axial slip). (*c*) Measurement of periodic axial slip.
G 7		Measurement of run-out of the internal taper of the spindle: (*a*) at the mouth of taper; (*b*) at a distance of 300 from the spindle nose.
G 8		Checking of parallelism of the spindle axis to the table surface.
G 9		Checking of squareness of the spindle axis to be table surface: (*a*) in the vertical plane of symmetry of the machine or transverse vertical plane; (*b*) in the plane perpendicular to the vertical plane of symmetry of the machine or transverse vertical plane.

ISO R 1701-1970 (E)

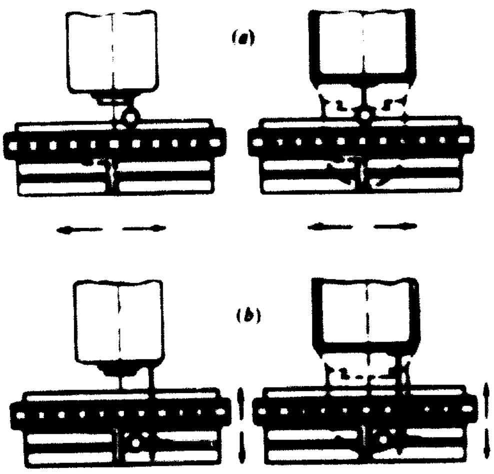
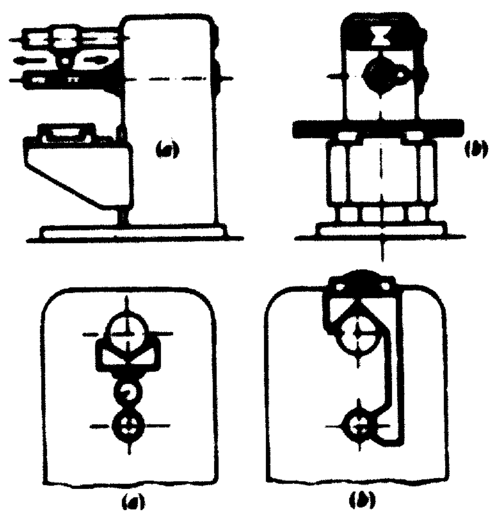
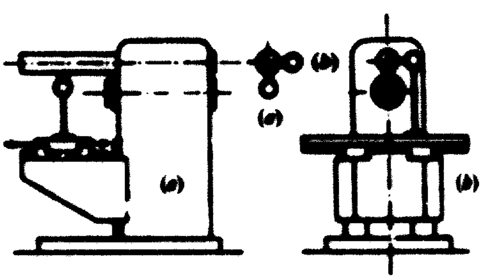
Dimensions in millimetres

Permissible deviation	Measuring instruments	Observations and references to the test code ISO/R 230
(*a*) 0.01 (*b*) 0.02 (*c*) 0.01	Dial gauge	(*a*) Clause 5.612.2 (*b*) Clause 5.632 The distance *A* of dial gauge (*b*) from the spindle axis should be as large as possible. (*c*) Clauses 5.662.1 and 5.622.2 A force *F*, specified by the manufacturer of the machine, should be exerted by pressing towards the housing for tests (*b*) and (*c*).
(*a*) 0.01 (*b*) 0.02	Dial gauge and test mandrel	Clause 5.612.3
0.025 for a measuring length of 300 (free end of the test mandrel inclined downwards)	Dial gauge and test mandrel	Clause 5.412.4. Table and cross slide not locked, knee locked.
(*a*) 0.025/300 with $\alpha \leq 90°$ (*b*) 0.025/300	Dial gauge	Clauses 5.512.1 and 5.512.42 Spindle head slide, table, cross slide and knee locked.

No.	Diagram	Object
G 10		Checking of parallelism of the spindle axis to the transverse movement of the table: (*a*) in the vertical plane; (*b*) in the horizontal plane.
G 11		Checking of straightness of the median or reference tee slot of the table.
G 12		Checking of squareness of the spindle axis to the median or reference tee slot of the table.
G 13		Checking of parallelism of the median or reference tee slot to the longitudinal movement of the table.

Dimensions in millimetres

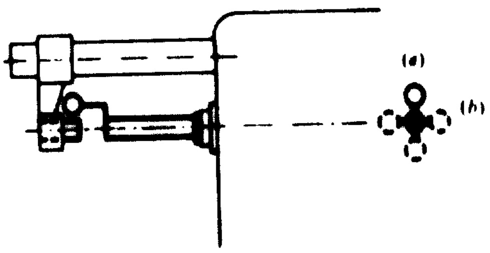
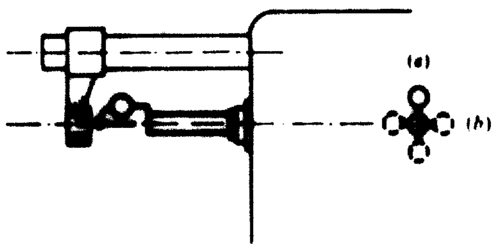
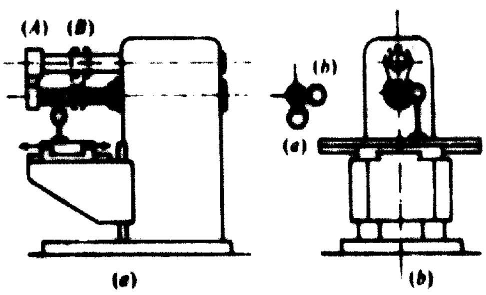
Permissible deviation	Measuring instruments	Observations and references to the test code ISO/R 230
(*a*) 0.025 for a measuring length of 300 (free end of the test mandrel inclined downwards) (*b*) 0.025 for a measuring length of 300	Dial gauge and test mandrel	Clause 5.422.3. Table in central position. Knee locked.
0.01 for any 500 length Maximum permissible deviation: 0.03	Straightedge and dial gauge or slip gauges, or taut wire and microscope	Clauses 5.212, 5.212.1, 5.212.3 or 5.232. The straightedge may be placed directly on the table.
0.02/300 *	Dial gauge	Clauses 5.512.1 and 5.512.52. Table in central position. Table, cross slide and knee locked. * Distance between the two points touched.
0.015 for any 300 length Maximum permissible deviation: 0.04	Dial gauge	Clauses 5.422.1 and 5.422.21. Cross slide and knee locked. If the spindle can be locked, the dial gauge may be mounted on it. If the spindle cannot be locked, the dial gauge should be placed on a fixed part of the machine.

No.	Diagram	Object
G 14		Checking of squareness of the movement of the table transversely to its longitudinal movement.
G 15		Checking of parallelism of arbor support guide on the over arm (or arms) to the spindle axis: (*a*) in the vertical plane; (*b*) in the horizontal plane.
		**Alternative** Checking of parallelism of arbor support guide on the over arm (or arms) to the transverse movement of the table: (*a*) in the vertical plane; (*b*) in the horizontal plane.

ISO/R 1701-1970 (E)

Dimensions in millimetres

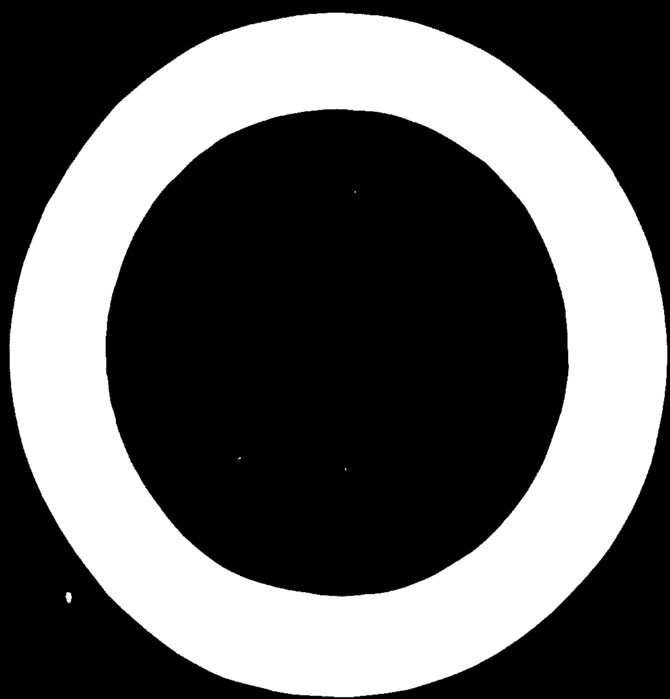
Permissible deviation	Measuring instruments	Observations and references to the test code ISO/R 230
0.02/300	Straightedge, dial gauge and square	Clause 5.522.4. Knee locked. (*a*) The straight-edge should be set parallel to the table longitudinal movement; then the square should be placed against the straight-edge. The table should then be locked in central position. (*b*) The transverse movement of the table should then be checked. If the spindle can be locked, then the dial gauge may be mounted on it after locking the spindle head slide. If the spindle cannot be locked the dial gauge should be placed on a fixed part of the machine.
(*a*) 0.02 for a measuring length of 300 (over arm inclined downwards) (*b*) 0.02 for a measuring length of 300 (*a*) 0.02 for a measuring length of 300 (over arm inclined downwards) (*b*) 0.02 for a measuring length of 300	Dial gauge and precision level.	Clause 5.412.5 or Clauses 5.412.3 and 5.412.1 Clause 5.422.4. Over arm(s) locked.

No.	Diagram	Object
G 16	 **First alternative**  **Second alternative** 	Checking of coincidence of the axis of the bore of the arbor support with the spindle axis: (*a*) in the vertical plane; (*b*) in the horizontal plane.

ISO/R 1701-1970 (E)

Dimensions in millimetres

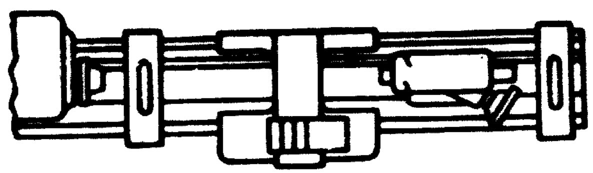
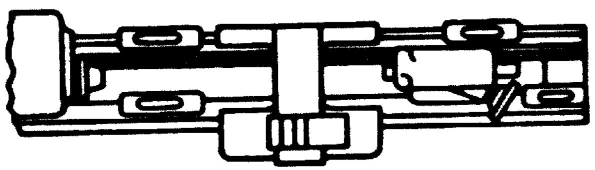
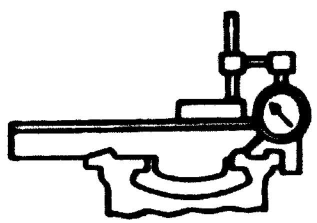
Permissible deviation	Measuring instruments	Observations and references to the test code ISO/R 230
(*a*) 0.03 (Axis of the bore of the arbor support lower than the spindle axis) (*b*) 0.03	Dial gauge and test mandrel	Clauses 5.422.4 and 5.442 Arbor support located 300 away from the spindle nose. The measurement should be made as near as possible to the arbor support. Over arm locked and arbor support not connected to the knee. **First alternative** It is unnecessary to follow the test code ISO/R 230. The dial gauge is mounted on the spindle and the stylus touches the bore of the arbor support. The reading observed on the dial gauge must be divided by 2 for comparison with the permissible deviation.
Second alternative (*a*) 0.04 for a measuring length of 300 (Mandrel inclined downwards on the side of the bore of the arbor support) (*b*) 0.025 for a measuring length of 300		**Second alternative** (*A*) The end of the mandrel or cutter arbor is held by the arbor support. (*B*) The arbor support is positioned mid-way along the mandrel or cutter arbor. The reading observed on the dial gauge must not be divided by 2.

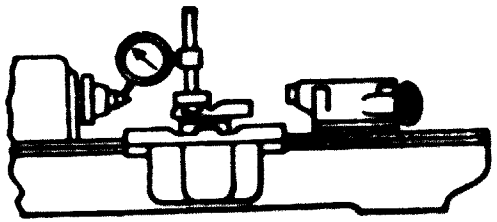
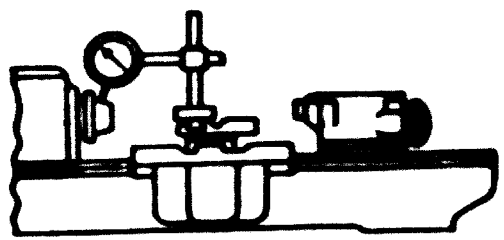
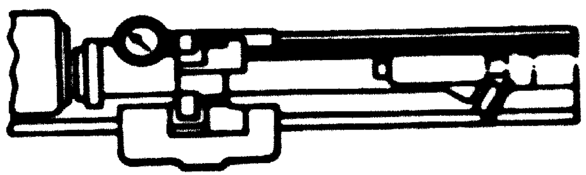


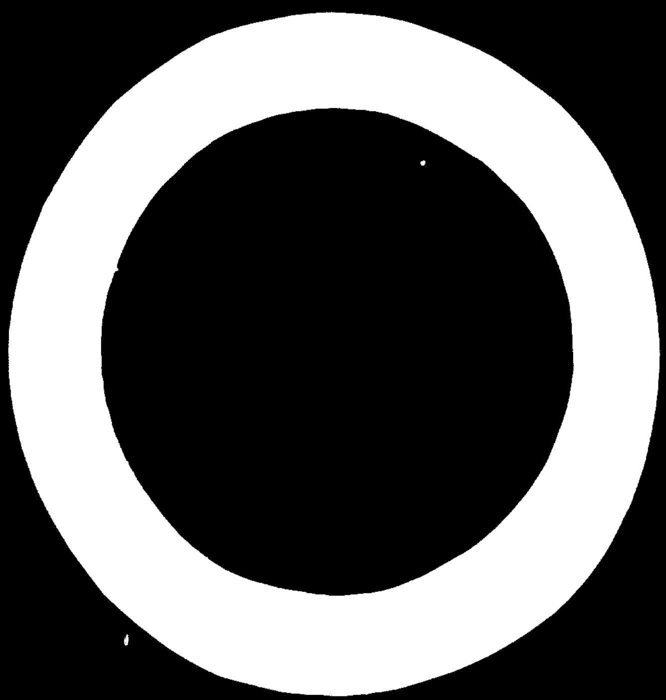
Annex 2

ACCURACY OF ENGINE AND TOOL ROOM LATHES

Extract from American National Standard ANSI B5.16-1952
Reprinted with the permission of the publisher, The American Society of Mechanical Engineers, 345 East 47th Street, New York, N. Y. 10017 and the American National Standards Institute, Inc., 1430 Broadway, New York, N. Y. 10018

Test	Recommended Standards			
	Tool Room Lathes	Engine Lathes		
		12 In. to 18 In., Incl.	20 In. to 32 In., Incl.	40 In. to 72 In., Incl.
 BED LEVEL — TRANSVERSE DIRECTION	When Using Precision Level All Readings to Be Within 0.0005 in 12 In.	When Using Precision Level All Readings to Be Within 0.0005 in 12 In.	When Using Precision Level All Readings to Be Within 0.001 in 12 In.	When Using Precision Level All Readings to Be Within 0.001 in 12 In.
 BED LEVEL — LONGITUDINAL DIRECTION	When Using Precision Level Along Bed Maximum Reading to Be Within 0.0005 in 12 In.	When using Precision Level Along Bed Maximum Reading to Be Within 0.0005 in 12 In.	When using Precision Level Along Bed Maximum Reading to Be Within 0.001 in 12 In.	When Using Precision Level Along Bed Maximum Reading to Be Within 0.001 in 12 In.
 TAILSTOCK WAY ALIGNMENT	Maximum Reading Along Length of Bed 0.0005 in 48 In.	Maximum Reading Along Length of Bed 0.00075 in 48 In.	Maximum Reading Along Length of Bed 0.001 in 48 In.	Maximum Reading Along Length of Bed 0.001 in 48 In.

 SPINDLE CENTER RUNOUT	Total Indicator Reading 0 to 0.0004	Total Indicator Reading 0 to 0.0005	Total Indicator Reading 0 to 0.00075	Total Indicator Reading 0 to 0.001
 SPINDLE NOSE RUNOUT	Total Indicator Reading 0 to 0.0003	Total Indicator Reading 0 to 0.0004	Total Indicator Reading 0 to 0.0006	Total Indicator Reading 0 to 0.00075
 CAM ACTION OF SPINDLE	Total Indicator Reading With Indicator on Rear Side of Test Plate 0 to 0.0003	Total Indicator Reading With Indicator on Rear Side of Test Plate 0 to 0.0005	Total Indicator Reading With Indicator on Rear Side of Test Plate 0 to 0.00075	Total Indicator Reading With Indicator on Rear Side of Test Plate 0 to 0.00075



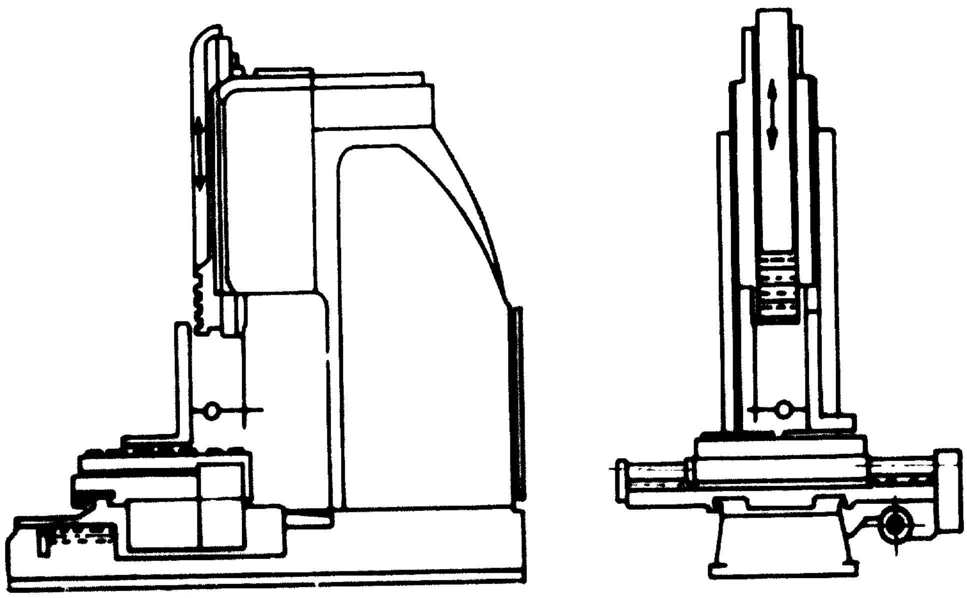
Annex 3

SLOTTING MACHINES. PRECISION STANDARDS

Translated extract from
GOST 26—56
GOST 26—56 is published by The Committee for Standards, Measures and Measuring Instruments, Moscow, USSR

GOST 26-56 Slotting Machines. Precision standards

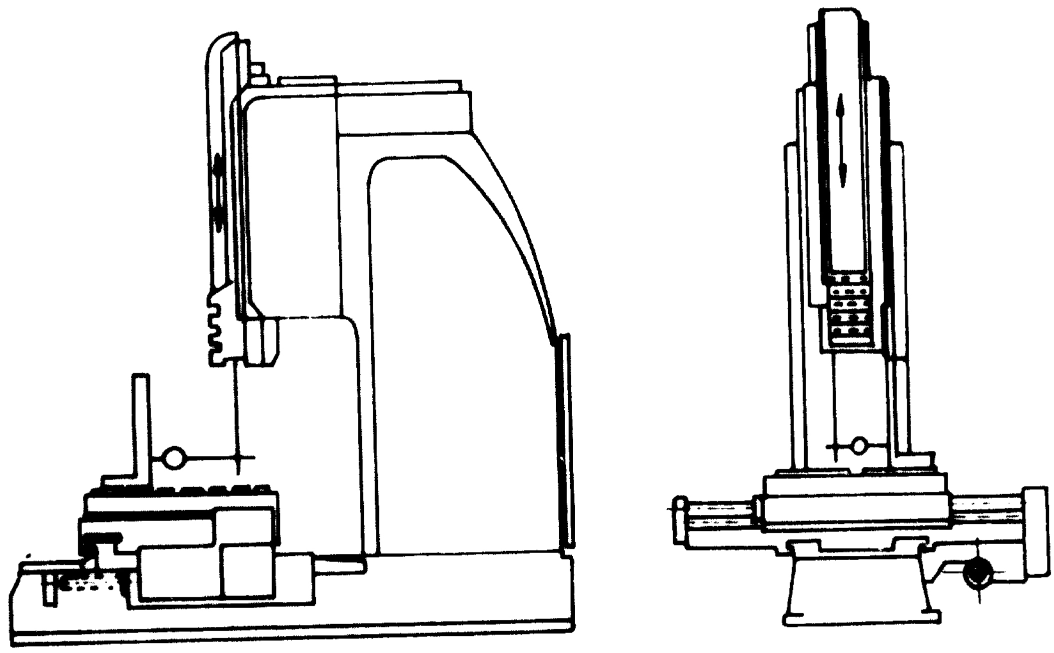
Test 7



Property tested	Testing method	Tolerance mm — for machines with a cutter head stroke, in mm, of: up to 200	from 200 to 500	from 500 to 1000	over 1000
Rectilinearity of movement of the cutter head in the vertical plane: (*a*) in the longitudinal direction; (*b*) in the transverse direction.	A dial gauge is attached to the cutter head in such a way that the feeler pin of the gauge touches the try edge of a square placed parallel to the direction of movement of the table. The square is mounted on the table in such a way that the gauge reading is the same at the top and bottom of the try edge. The cutter head moves along its ways for the whole length of the stroke.	a and b 0.025	0.030	0.040	0.050
		Over the full length of the cutter head stroke in the longitudinal and transverse directions.			

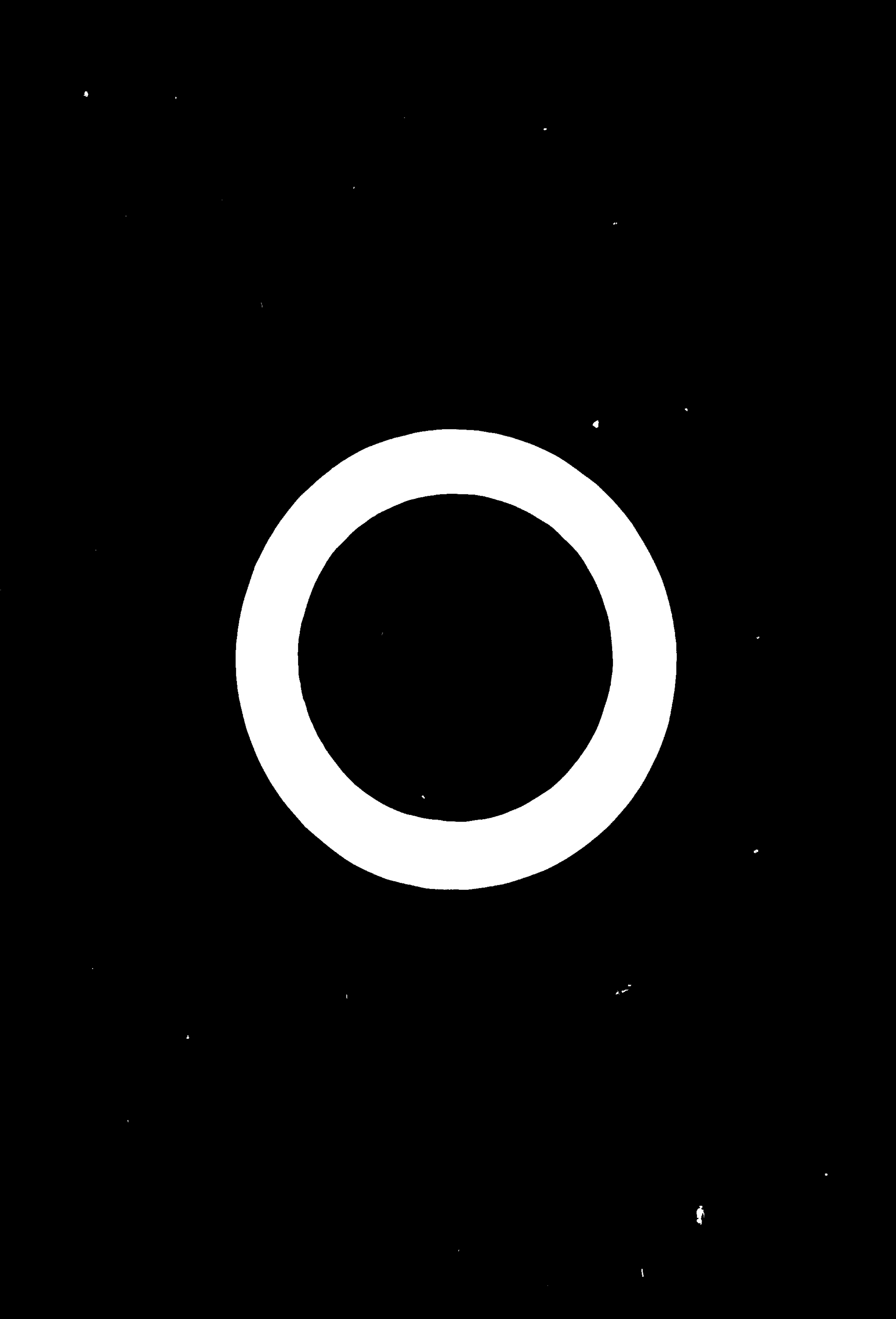
Slotting machines. Precision standards GOST 26-56

Test 8



a b

Property tested	Testing method	Tolerance mm — for machines with a cutter head stroke, in mm, of: up to 200	from 200 to 500	from 500 to 1000	over 1000
Perpendicularity of the cutter head movement to the working surface of the table:	A dial gauge is attached to the cutter head in such a way that the feeler pin of the gauge touches the try edge of a square mounted on the table parallel to the direction of the table's movement.	a			
(*a*) in the longitudinal direction;		0.025	0.030	0.040	0.050
		over a distance of 300 mm	over a distance of 300 mm	over a distance of 500 mm	over a distance of 500 mm
		(The lower end of the cutter head may deviate only towards the column).			
(*b*) in the transverse direction.	The cutter head moves along its ways.	b			
		0.020	0.025	0.030	0.040
		over a distance of 300 mm	over a distance of 300 mm	over a distance of 500 mm	over a distance of 500 mm



Annex 4

TESTING CYLINDRICAL GRINDING MACHINES

Extract from
Testing Machine Tools, by Georg Schlesinger,
7th Edition (1966) revised by F. Koenigsberger
Reprinted with the permission of the publisher, The Machinery Publishing
Co., Ltd., London, United Kingdom

This extract is concerned with specifications for testing the accuracy of main spindles in cylindrical grinding machines and of their alignment relative to other important parts of the machine. In particular, it deals with checking parallelism and perpendicularity. Any textbook on testing machine tools must make use of cross-reference if it is to avoid a great deal of repetition. Thus, there are references in this extract to text and figures appearing earlier in the book, which would need to be studied in its entirety by anyone putting its instructions to practical use.

(C) IN THE CASE OF CYLINDRICAL GRINDING MACHINES, parallelism has to be checked between:

1. The table slideways and the slideways or locating faces for headstock and tailstock. (Test Chart 21, Fig. 2).

2. The spindle axis (internal taper) and the direction of the table traverse in
(*a*) the vertical plane (Test Chart 21, Fig. 6a);
(*b*) the horizontal plane (Test Chart 21, Fig. 6b).

3. The spindle in the swivelling headstock and the direction of the in-feed movement of the grinding head in the vertical plane, measured with the headstock in the 90° position (Test Chart 21, Fig. 7).

4. The tailstock sleeve (internal taper) and the direction of the table movement
(*a*) in the vertical plane (Test Chart 21, Fig. 9a);
(*b*) in the horizontal plane (Test Chart 21, Fig. 9b).

5. The grinding wheel spindle and the direction of the table movement
(*a*) in the vertical plane (Test Chart 21, Fig. 12a);
(*b*) in the horizontal plane (Test Chart 21, Fig. 12b).

6. The internal grinding spindle and the direction of the table movement (see item 5)
(*a*) in the vertical plane;
(*b*) in the horizontal plane.

Testing procedure: 1. This has been covered on page 29 and Fig. 38.

2. (Fig. 72). The table is put in zero position for cylindrical grinding and a 300 millimetres (12 inches) long test mandrel is fixed in the work-

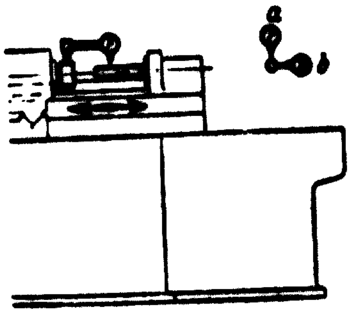


Fig. 72. Parallelism between the Spindle Axis and the Direction of the Table Traverse

piece-spindle taper. The dial gauge is fixed to the grinding-wheel slide, with the dial-gauge plunger touching the test mandrel (in the case of machines with rotating workpiece-spindle this has to be rotated into its mean position). The table is traversed longitudinally by an amount equal to the length of the test mandrel and the readings are taken.

(*a*) The free end of the mandrel must rise,

(*b*) The free end of the mandrel must be inclined towards the grinding wheel.

3. (Fig. 73). This applies only to universal grinding machines. The test is similar to test 2 except for the fact that the dial gauge is clamped to the grinding wheel slide which is moved by an amount equal to the total in-feed

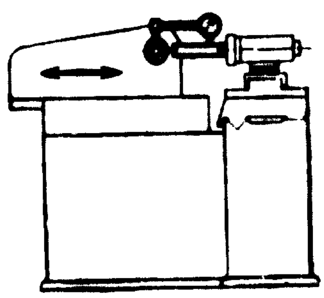


Fig. 73. Parallelism between the Spindle Axis and the Direction of the Infeed Movement (Universal Grinding Machines)

movement. For the 90° setting, it is sufficient to rely on the graduation of the swivelling-head scale, as the measurement is only taken in the vertical plane and excessive accuracy in the angular position is not essential. The mandrel must rise towards its free end. The inspector also checks whether the spindle is level with the mandrel in the zero and 90° position.

4. (Fig. 74). With the table in the zero position for cylindrical grinding, a 300 millimetres (12 inches) long test mandrel is located in the taper of the fully withdrawn and clamped tailstock sleeve. A dial gauge is fixed

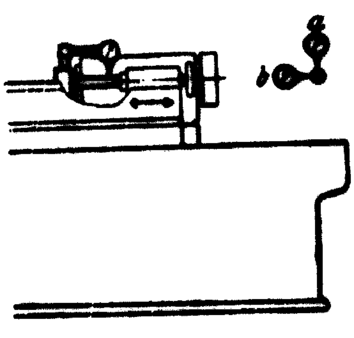


Fig. 74. Parallelism between Tailstock Sleeve and Direction of Table Traverse

to the grinding-wheel slide, with the dial-gauge plunger touching the test mandrel. The table is traversed longitudinally by an amount equal to the length of the test mandrel and readings are taken:

(*a*) the free end of the mandrel must rise,

(*b*) the free end of the mandrel must be inclined towards the grinding wheel.

5. (Fig. 75). A 100 millimetres (4 inches) long test mandrel is fixed to the grinding-wheel spindle (the locating and clamping depends upon the design of the spindle nose), and a dial gauge is fixed to the table with the dial-gauge plunger touching the test mandrel which has been rotated into its mean position. The table is traversed longitudinally by an amount equal to the length of the test mandrel and readings are taken:

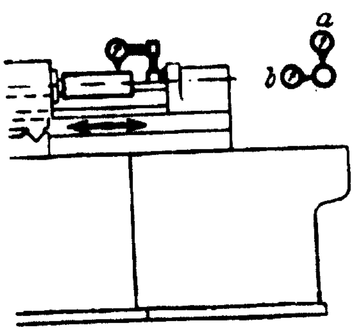


Fig. 75. Testing Parallelism between Grinding-wheel Spindle and Table Movement

(*a*) the free end of the mandrel must rise,

(*b*) the free end of the mandrel must be inclined towards the table.

6. (Fig. 76). A 100 millimetres (4 inches) long test mandrel is fixed in the internal-grinding spindle support (method of concentric location and fixing depending on the particular design). A dial gauge is fixed to the table

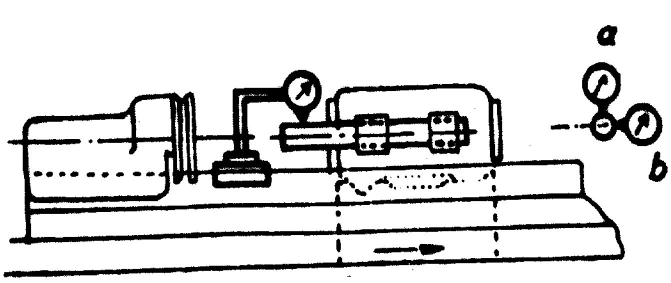


Fig. 76. Parallelism between the Internal Grinding Spindle and the Table Movement

with the dial-gauge plunger touching the test mandrel which has to be rotated into its mean position. The table is traversed longitudinally by an amount equal to the length of the test mandrel and readings are taken.

The height alignment of two corresponding axes is tested in a similar manner as described previously for the case of the lathe (see Fig. 60) and the milling machine (see Figs. 1, 52 and 53). In the case of the grinding machine the following height alignments are checked:

1. Workpiece spindle and tailstock spindle centres (Test Chart 21, Fig. 10).
2. Workpiece and external grinding wheel spindles (Test Chart 21, Fig. 13).
3. Workpiece and internal grinding spindles (as item 2).
4. Rise and fall of grinding wheel spindle during its in-feed movement (Test Chart 21, Fig. 14).

Testing procedure: 1. (Fig. 77). A 300 to 800 millimetres (12 to 32 inches) long hollow test mandrel with accurately centred faces is held between centres. A dial gauge is fixed to the grinding-wheel slide, with the dial-gauge plunger touching the test mandrel (for measurement in the vertical plane). The table

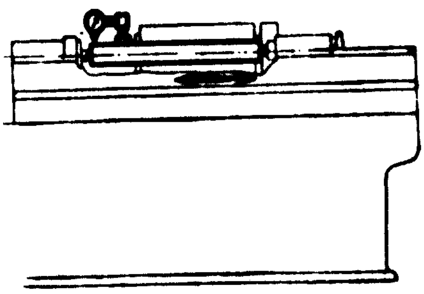


Fig. 77

is moved longitudinally and readings are taken. The tailstock centre must be higher than the headstock centre. Measurement in the horizontal plane is not necessary, as alignment in this plane is adjustable.

2. (Figs. 78 and 79). Two test mandrels (D_1 and D_2), approximately 100 millimetres (4 inches) long, and of exactly equal diameter are used. Test mandrel D_2 has a standard taper shank and is located in the workpiece spindle taper; test mandrel D_1 is fixed to the grinding-wheel spindle, the type of location and fixing depending on the design of the spindle nose.

If the grinding-wheel spindle has a cylindrical portion, this may be used instead of test mandrel D_1. In this case the difference between the diameter of test mandrel D_2 and that of the spindle cylinder must be compensated by block gauges.

The grinding-wheel slide is moved into the middle position of its traverse and the test mandrels D_1 and D_2 are rotated into their mean positions.

(*a*) (Fig. 78). A straight-edge is rested on both test mandrels and a spirit level is placed on the straight-edge. Spirit level readings are taken; or

(*b*) (Fig. 79) A dial gauge is fixed to the machine table with the dial-gauge plunger touching the tops of test mandrels D_1 and D_2 and readings are taken.

The table is swivelled in both directions and readings repeated with the table in extreme position.

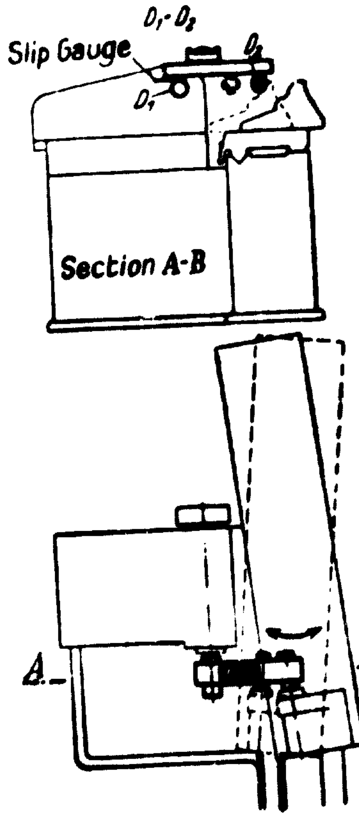


Fig. 78

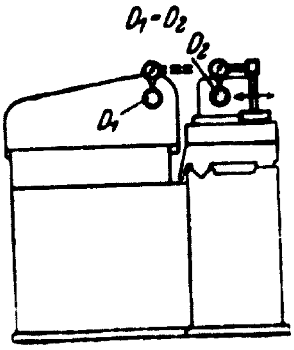


Fig. 79

3. (Fig. 80) (see also item 2). This uses two test mandrels D_1 and D_2 as before, but the test mandrel D_1 is fastened in the internal grinding spindle support. The test mandrels are rotated into their mean positions. The dial gauge is fixed to the machine table. The dial-gauge plunger touches the tops of the free ends of the test mandrels and readings are taken.

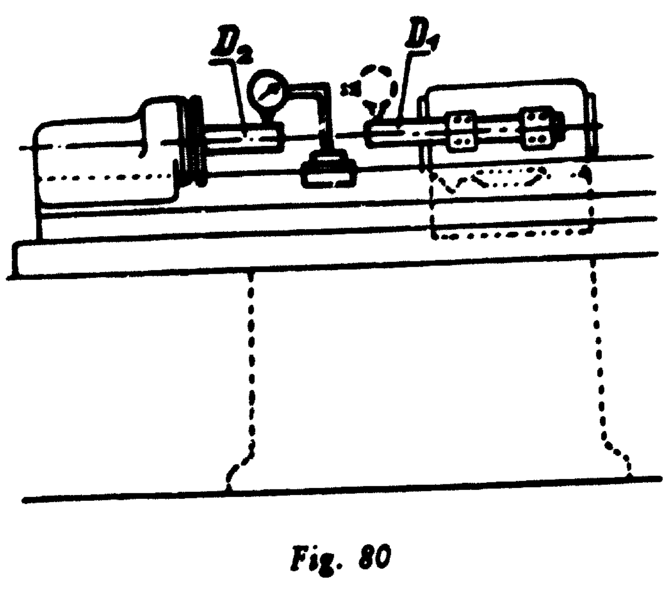


Fig. 80

4. (Figs. 81 A and 81 B). The grinding-wheel slide is located in the extreme backward position. A 100 millimetres (4 inches) long test mandrel is fixed to the grinding-wheel spindle as before, and rotated into its mean position.

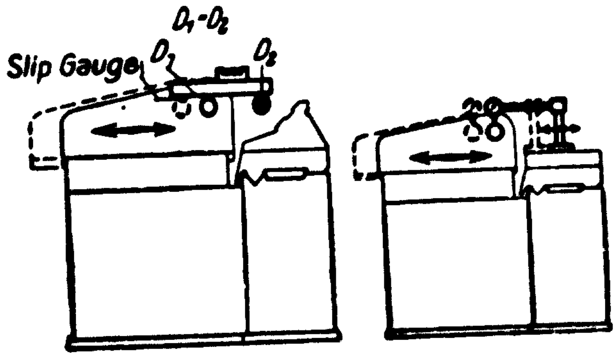


Fig. 81 A *Fig. 81 B*

(*a*) (Fig. 81 A). Here, a straight-edge and spirit level are placed on the two test mandrels D_1 and D_2; or

(*b*) (Fig. 81 B). The dial gauge is fixed to the machine table with the dial-gauge plunger touching the top of the test mandrel and readings are taken. The grinding-wheel slide is fed in into its extreme forward position and readings are taken.

The final test concerns the perpendicularity between the in-feed movement of the grinding-wheel slide and the workpiece axis in the zero position of the table, when the workpiece axis must be parallel to the slideways of the bed (Test Chart 21, Fig. 15).

Testing Procedure: (Fig. 82). The machine table is set in the zero position; and the grinding-wheel slide in the extreme backward position. A 500 millimetres (20 inches) long test mandrel with accurately centred faces is mounted between centres. If possible, the test mandrel should have a 300 millimetres

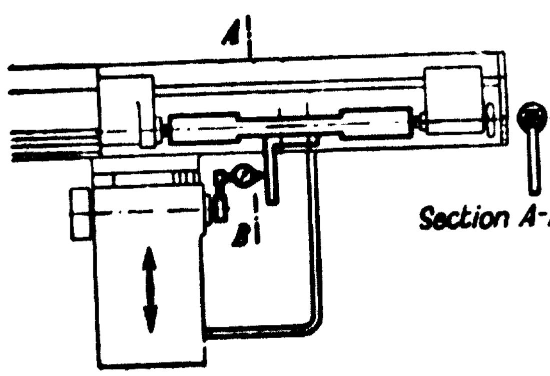
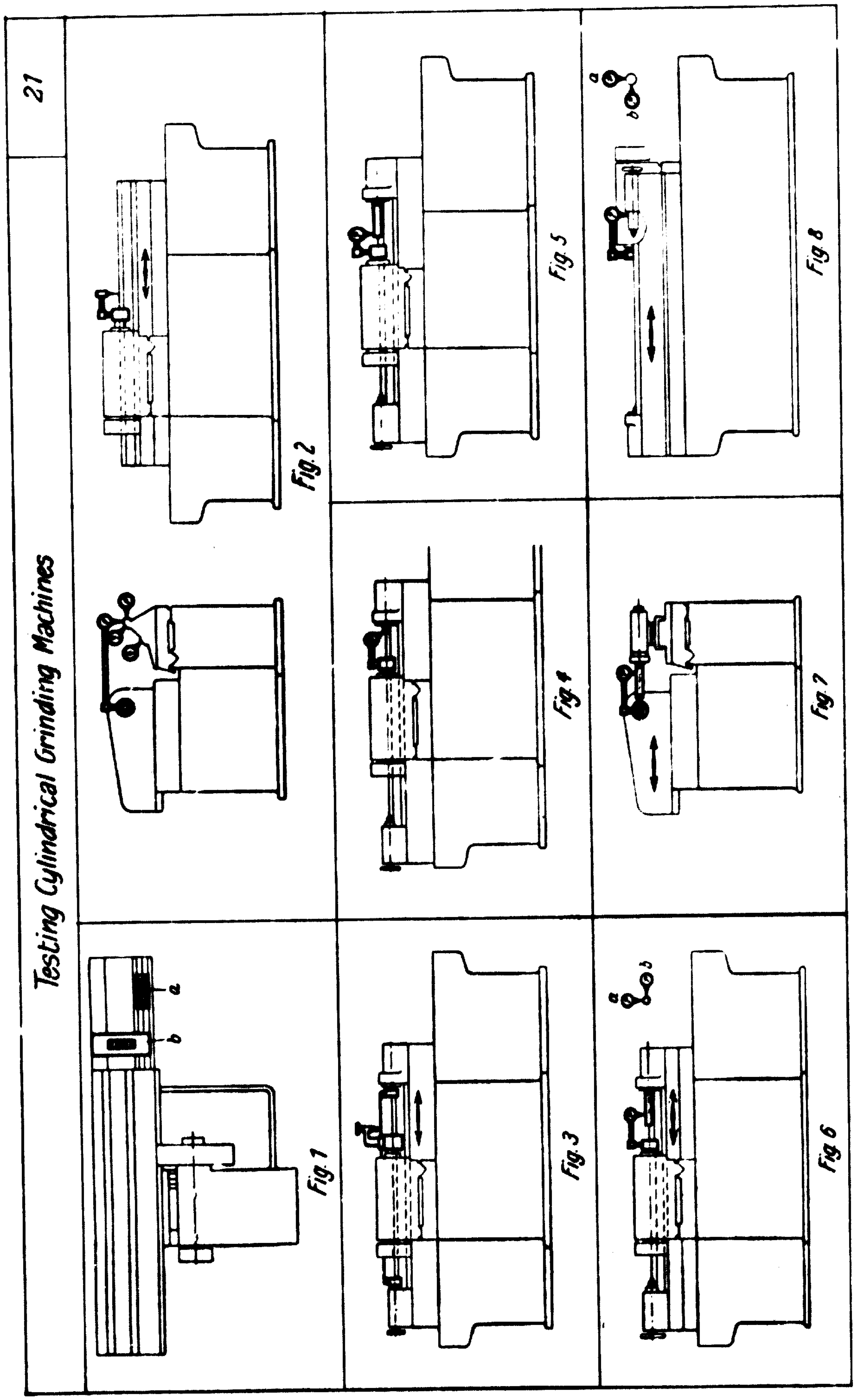


Fig. 82

(12 inches) long flat face about 20 millimetres (3/4 inch) wide, against which a square can be held. The dial gauge is fixed to the grinding-wheel slide, with the dial-gauge plunger touching the free leg of the square. The grinding-wheel slide is moved forward and readings are taken.

It is also possible to fix the dial gauge to the grinding-wheel spindle and take a trammel reading against the free leg of the square.


Testing Cylindrical Grinding Machines
21
a
b
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
a
b
Fig. 6
Fig. 7
a
b
Fig. 8

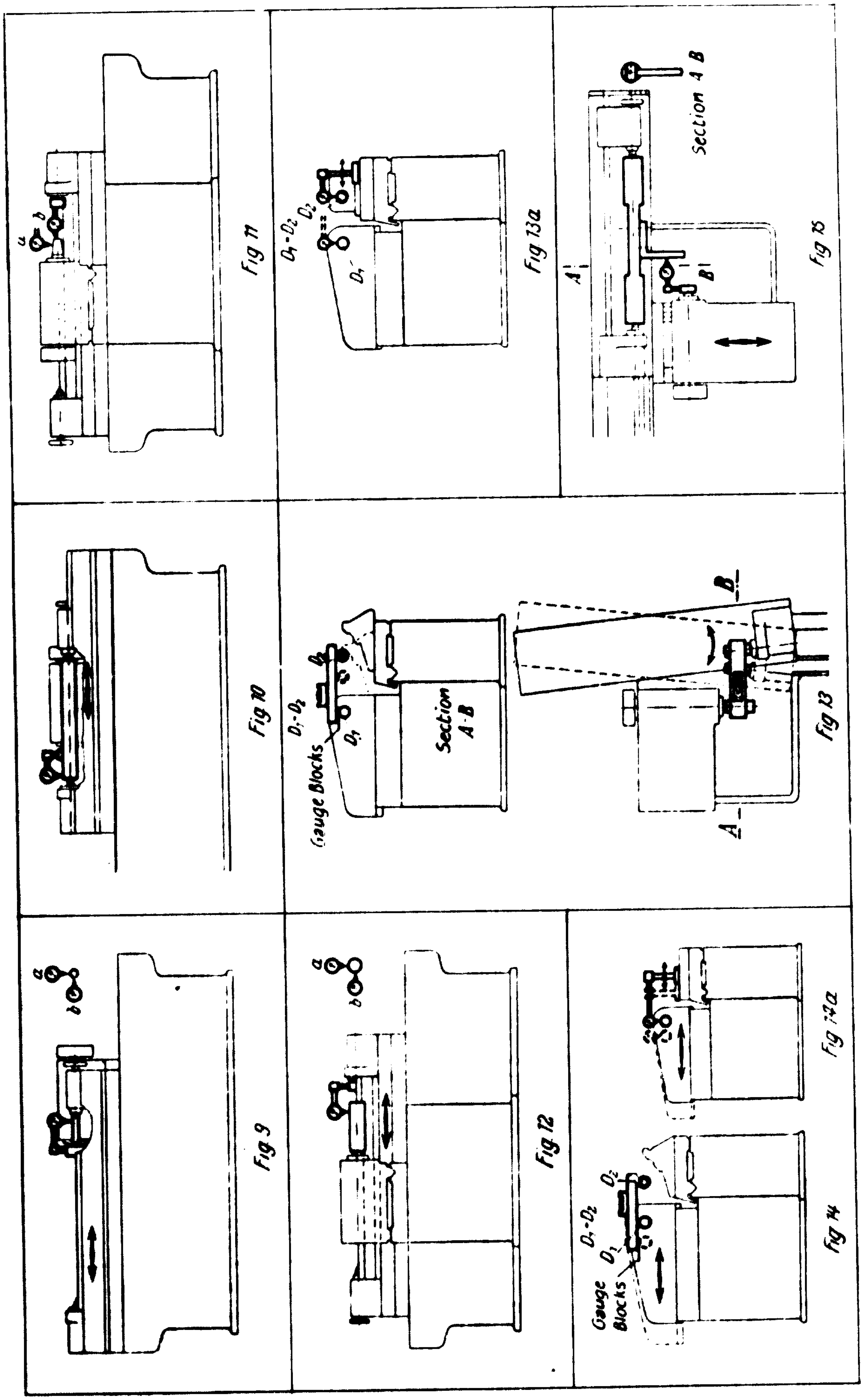


Fig 9
a
b
Fig 10
Fig 11
a
b
Fig 12
a
b
Fig 13
A
B
Section A-B
Gauge Blocks
$D_1 - D_2$
D_1
D_2
Fig 13a
$D_1 - D_2$
D_1
D_2
Fig 14
Gauge Blocks
$D_1 - D_2$
D_1
D_2
Fig 14a
Fig 15
Section A B
A'
B'

Test Chart for Cylindrical Grinding Machines		No. 21 Chart 1
Test to be Applied	Fig. No.	Permissible Error
Bed and table: Bed straight in long. direction	1a	mm. 0.02 per 1,000 mm.
Bed flat or level in transverse direction. No twist permitted	1b	± 0.02 per 1,000 mm.
Guide ways of headstock and tailstock parallel with table movement	2	0.01 per 1,000 mm.
Straightness of table movement (for machines of more than 2 m. (80 in.) in grinding length (grinding convex only))	3	0 to 0.02 per 1,000 mm.
Work headstock and spindle: Centre point for true running	4	0.005
Taper of work spindle runs true: (1) Nearest spindle nose .. .. (2) At a distance of 300 mm. (12 in.)	5	0.005 0.01
Axis of headstock parallel with table movement in vertical plane (rising towards the free end of mandrel; upper table in position of Fig. 2, zero position)	6a	0 to 0.02 per 300 mm.
Ditto, in horizontal plane (free end of mandrel inclined towards grinding wheel)	6b	0 to 0.01 per 300 mm.

Test Chart for Cylindrical Grinding Machines		No. 21 Chart 2
Test to be Applied	Fig. No.	Permissible Error
Axis of spindle in swivelling headstock parallel with in-feed movement of grinding wheel slide in vertical plane, measured in the 90 and 45-degree positions of headstock (rising towards the free end of mandrel; for universal grinders only; the zero position is tested in conformance with Fig. 6 a)	7	0 to 0.02 per 300 mm.
Tailstock: Sleeve parallel with table movement in vertical plane (front end rising only; upper table in position of Fig. 2) for long adjustment by hand	8a	0 to 0.02 per 100 mm.
Ditto, in horizontal plane (front end inclined towards the grinding wheel)	8b	0 to 0.01 per 100 mm.
Taper in sleeve parallel with table movement in vertical plane (free end on mandrel rising; upper table in position of Fig. 2)	9a	0 to 0.01 per 300 mm.
Ditto, in horizontal plane (free end of mandrel inclined towards the grinding wheel)	9b	0 to 0.01 per 300 mm.
Axis of centres (mandrel between centres) parallel with table movement in vertical plane (rising towards tailstock end)	10	0 to 0.01
Grinding wheel spindle: Taper of spindle for true running	11a	0.005
Spindle for axial slip measured at 2 points, displaced by 180°	11b	0.01

Test Chart for Cylindrical Grinding Machines		No. 21 Chart 3
Test to be Applied	Fig. No.	Permissible Error
Axis of wheel spindle parallel with table movement in vertical plane (rising towards free end of mandrel)	12a	0 to 0.01 per 100 mm.
Ditto, in horizontal plane (free end of mandrel inclined towards the table)	12b	0 to 0.01 per 100 mm.
Axis of wheel spindle and headstock at same height with respect to swivel plate	13 13a	0.1
Ditto, for internal grinding spindle		0.02
Rise and fall of wheel spindle in its in-feed movement	14 14a	0.05 on total length of in-feed motion
In-feed motion of wheel slide square with bed ways (upper table set for cylindrical grinding by means of dial gauge)	15	0.01 on total length of in-feed motion
Quick approach to the work, repeats accurately to grinding position (6 repetitions) Fine infeed: sensitive		0.003 mm. 0.002 mm.
Working accuracy of machine: Machine grinds round Up to 80 mm. dia. (3[3]/16 in.) From 80 to 200 mm. dia. (3[3]/16—8 in.) Over 200 mm. dia. (8 in.)		 0.003 0.005 0.01
Machine grinds cylindrically without applying steady rests (convex only): Shafts, 1,000 mm. long, 80 mm. dia. (about 40 by 3[3]/16 in.) Shafts, 500 mm. long, 50 mm. dia. (about 20 by 2 in.) Shafts, 250 mm. long, 38 mm. dia. (about 10 by 1½ in.)		 0 to 0.015 0 to 0.008 0 to 0.005

TABLE OF EQUIVALENTS

1. For Converting Mm. Tolerances into Inch Tolerances

Mm.	Inch	Mm.	Inch
0.003	0.00012	0.03	0.0012
0.005	0.0002	0.05	0.0020
0.01	0.0004	0.2	0.0080
0.02	0.0008		

2. Metric Reference Lengths into Inch Reference Lengths

Mm.	Inch	Mm.	Inch
100	4	1,000	40
300	12		

3. Metric Tolerances Referred to Various Lengths into Inch Tolerances Referred to 1 Foot and 3 Feet

Mm.	Inch per foot	Inch per 3 feet
0.01 per 100 mm.	0.00120	0.00360
0.01 „ 300 „	0.00040	0.00120
0.02 „ 300 „	0.00080	0.00240
0.01 „ 1,000 „	0.00012	0.00036
0.02 „ 1,000 „	0.00024	0.00072
0.03 „ 1,000 „	0.00036	0.00108
0.04 „ 1,000 „	0.00048	0.00144
0.05 „ 1,000 „	0.00060	0.00180
0.06 „ 1,000 „	0.00072	0.00216

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