GRINDING PRACTICE

BOOKS

by

F. H. Colvin and F. A. Stanley

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GRINDING PRACTICE

Typical Machines and Methods Used in a Wide Variety of Work

Including Wartime Data Supplement

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GRINDING PRACTICE

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Preface to the Second Edition

Grinding is playing a big part in the war effort. Concerns never before in this field are building grinding machines for sharpening drills and taps. This is because the demand for small tools has made it imperative that available tools be used to the best advantage. Makers of abrasives are studying new methods of making grinding wheels and different stones to be used in the heads of honing tools. They have found that the use of the right abrasive makes a great difference in the time required to do a job.

Thread grinding has grown in popularity, and the speed possible with this kind of grinding is astonishing. In some cases it is said to be faster than any other method. One of its great advantages is that threads can be ground in hardened work and so distortion of threaded parts is avoided.

Honing of cylinder and other bores is also being extended to new fields. Gun barrels of all sizes are now being honed in some cases. Cylinders for either steam or internal-combustion engines, up to 24-in. bore and 72-in. stroke, can now be honed on equipment that is available.

In selecting examples of war work the authors have tried to include subjects that will also have a bearing on commercial production. This was done with a view to usefulness after the war.

THE AUTHORS.

NEW YORK,
May, 1943.

Preface to the First Edition

Advances in grinding during the last half century have brought it from a mere method of polishing to that of a major operation in the machining of metals and many other materials. It now extends from the roughing of cast or forged surfaces to the finest finish yet known, as in the case of gage blocks that are accurate within unbelievable limits.

The many changes that have taken place have not only developed new operations and techniques but have made many of the old methods obsolete. Grinding machines are better than ever before, and these, plus better grinding wheels in great variety, and more knowledge as to their use, have given industry new standards both in accuracy and finish and at remarkably low cost. It would be difficult to overestimate the part that grinding has played in the production of high-grade work in nearly all mechanical fields.

We have tried in this volume to give a broad, general view of the machines and methods used in modern grinding practice and to give such detailed information as will be of the greatest service to those directly interested. It has, of course, been impossible to illustrate all grinding machines or to give details of all grinding operations. But we believe that the data here presented will form a working basis for the average grinding operation and hope that the special information given may be found useful in many classes of work.

THE AUTHORS.

NEW YORK, N. Y.,
October, 1937.

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GRINDING PRACTICE

CHAPTER I

THE GRINDING MACHINE IN INDUSTRY

The development of modern grinding, with the remarkable degree of speed and accuracy now secured by this process, has been brought about through the combined efforts and ingenuity of machine-tool builders and abrasive-wheel manufacturers, in an endeavor to advance the possibilities inherent in the process and thus to anticipate the increasing requirements of the users of grinding equipment.

These requirements in respect to both quality of work and rapidity of operation have led to a closer degree of refinement in the construction of grinders and to a marked increase in strength and resistance to vibration of different members of the machine.

Once the advantages of the grinding process became apparent to the manufacturers as a means of production as well as for tool-room work, increased effort led to even better workmanship in the machine itself, faster cutting wheels, and improved methods of holding the work and supporting the wheels. This progress has resulted in grinding to closer limits, to finer surface finish, and to a reduction in time required for the operation.

Thus the grinding machine has become one of our most economical tools of production. Finishing work after rough machining or directly from the original casting or forging in some cases, it removes metal rapidly and sizes the work to almost any degree of refinement desired. Automatic devices for holding external and internal dimensions to exacting limits of variation have added to the capacity of the grinder as a rapid producer; and whether the part ground is small or large, tolerances can be cut to very fine measurements without seriously retarding the rate of output.

Besides providing a means of doing good work and doing it rapidly, the grinding machine has enabled us to establish relationships between certain factors in shop practice which were not clearly understood at a time when it was impossible to finish surfaces correctly. The exact effect of a noncylindrical spindle running in an imperfectly finished box was not appreciated before comparison became possible with true, smooth bearing surfaces. Then assembly problems became simplified because of the ability to hold work closely to size. The proper allowance for fits and the desired limits being set up, it became a relatively simple matter to produce parts to such dimensions that they would go together with a minimum of wasted time and with assurance that they would function properly when set in operation.

FIG. 1.—Commercial grinding of armature shafts.

The capacity to produce true, closely gaged parts has permitted running allowances to be reduced with a marked improvement in operation of all rotating members. Where high speed is required, the truth of the running parts and their correctly

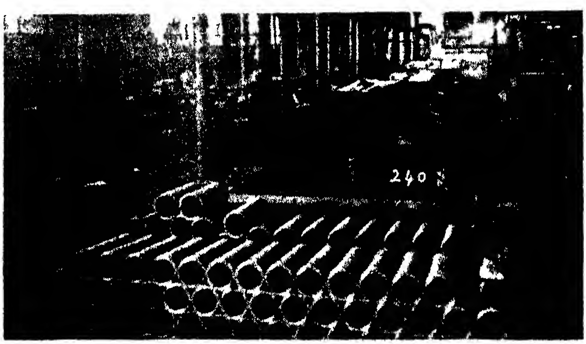


FIG. 2.—Oil-pump barrels ground in large lots.

fitted bearings have reduced noise almost to the vanishing point and simplified at the same time the general problem of maintaining adequate lubrication, which is naturally a great factor in noise elimination. Durability of correctly finished bearings has become a common feature of all classes of precision machinery. New materials of construction have been of great value in connection with the building of long life into machinery. The precision grinder has enabled the designer and manufacturer to make fullest application of every desirable material—hard, soft, cast, forged, or rolled—with the knowledge that whatever material is selected it can be finished to conform to any stipulated requirements in respect to accuracy and surface finish.

Figures 1 and 2 show examples of work ground to close tolerances on a commercial basis. The first shows armature shafts and the second liners for oil-pump barrels.

Growth in Size of Machines.—A remarkable feature of the grinding situation is the increase in the size of machines now available for work which requires excellent qualities of precision and smoothly finished surfaces. Roll-grinding necessities in particular have created a field for the big cylindrical grinder with capacity for handling the heaviest classes of rolls and cylinders of various kinds. Aside from the roll-grinding field, the largest grinder for production purposes at an earlier period was presumably the big machine installed by a British engine builder for finishing trunk pistons. This grinder—an American product—dates back to 40 years ago when it was installed to handle pistons and similar parts ranging up to approximately 36 or 42 in. in diameter. Prior to this time it had been generally considered impracticable to apply the principle of grinding to such a large piece of work. In fact the grinder at the time was commonly used as a toolroom machine and largely for finishing hardened work only.

But modern requirements brought about a more general use of the grinding process, and the development of large machines. The demands of steel mills for smoother rolls led to the adoption of more completely organized grinding departments with facilities for handling all classes of rolls with assurance of suitable finish for any type of roll and with definite saving of time in machining as compared with lathe and polishing methods which had formerly prevailed as a customary procedure throughout the industry. Furthermore, there came a demand for better finishes for paper-mill calender rolls as well as for rolls used in various other classes of equipment.

Such requirements have become more and more exacting. Purchasers of steel for automobile bodies, metal furniture, cabinets, ranges, and kitchen equipment, or for different deep drawing operations created a demand for a better appearing sheet of metal, of more uniform thickness, a smoother and better product that would take finishes of any kind required and show no scratches or surface blemishes. Such sheets require a minimum of attention after leaving the rolls so far as attractiveness of surface is concerned, and necessitate better finished rolls. The installation of suitable grinding machines brought about the desired results in the production of metal sheets and provided a definite economy of time in servicing rolls. But this result was only a part of the gain accomplished. The practicability of producing with the grinder the scientifically crowned and concaved roll contours essential to uniform rolling of sheets has been accompanied by the capacity to increase roll widths and diameters to extreme dimensions, yet without loss of accuracy obtained in the sheets rolled.

The increased widening of mills for rolling metals, for paper, rubber, linoleum, and other sheet products has been made possible by the builders of grinding equipment who have accomplished noteworthy results in the design and construction of their machinery.

As an example of the capacity to which roll-grinding equipment has been extended, the case may be cited of a machine built to grind rolls ranging up to 60 in. in diameter; the length of the work that can be handled in the machine is 34 ft. The longest roll ground measured nearly 25 ft. across the face and was 36 in. in diameter. This was made for a great paper-machine calender. The total length of the roll is 33 ft. 9 in. Its weight was 55 tons in the rough and it is presumably the biggest roll ever produced.

Brief reference should also be made here to the world's largest surface grinder, a machine adapted to the resurfacing of various classes of heavy tools. This grinder has a capacity of 74 by 74 in. through the uprights and a length capacity of 36 ft.

Surface Finish and Truth in Work Diameter.—Before grinding came into common use, file finishing and polishing with oil and emery were the principal method of giving a smooth surface to a shaft or spindle. This method gave no assurance of roundness or accuracy in the work. On the contrary, it usually made any shaft that was out of round still more so, as the hand process always followed the original contour of the surface. With the common use of the grinding machine there is a wide range of surface finish possible, and still the work can be held to a cylindrical form, even though all lathe-tool marks are not removed by the grinding wheel. Some classes of work require a very finely finished surface, while others are satisfactory with a less polished appearance. The amount left for a running fit between the size of a shaft ground, as in Fig. 3, and the diameter of the

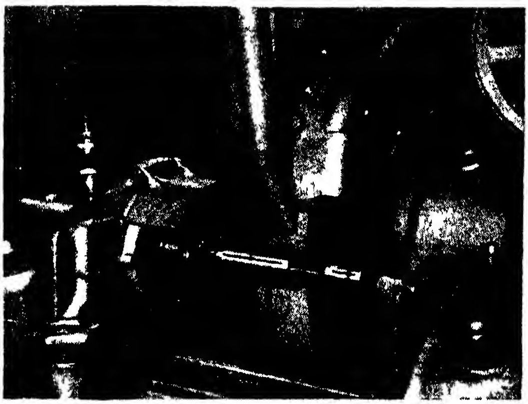


Fig. 3.—Grinding shaft bearing for transmission.

bearing, depends largely upon the class of surface finish just referred to.

If the shaft is ground to a very smooth finish, there is likely to be little wear between the shaft and bearing. On the other hand, if the shaft surface is coarsely finished with the lathe-tool marks little more than smoothed down, there will be considerable wear and the actual diameter of the shaft may be reduced as much as several thousandths of an inch. Thus an abnormal amount of running clearance will develop between shaft and bearing, and either a bearing will require replacement or a new shaft may be required.

In such a case—a heavy machine axle, for instance—the original clearance between shaft and bearing must be fixed at the start to allow for considerable wear which will occur rapidly under ordinary service conditions. Where too wide clearance has been permitted at the outset and the bearing surfaces have been none too smoothly finished, the clearance has been quickly increased to an undue amount and has resulted in reduced service runs between overhauling periods.

The matter of surface finish is important at all times, whether either part or both parts are ground or finished otherwise.

Wheel and Work Speeds.—As the tendency grows to place more classes of work in the grinder for finishing to size, the importance of suitable work and wheel speeds becomes more

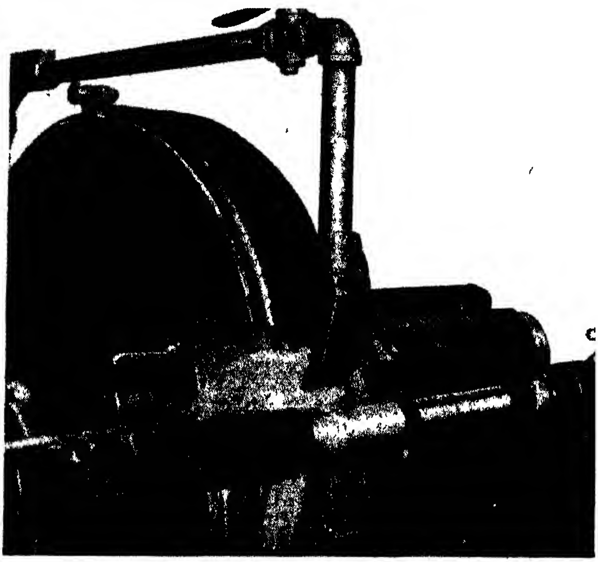


Fig. 4.—Combined plunge and traverse cuts on shouldered spindle. (Note flood of coolant on work.)

evident. Whatever the job, there are a certain grade of wheel and a certain grain of grit that are best suited to the work, and these facts must be considered in selecting wheels. Combined with right speed and feeds the character of the wheel is foremost in producing the best work and doing the work rapidly. The experience of makers of wheels must usually be relied upon as the correct source of information on all matters relating to wheel usage. The speed of the wheel is especially important and, of course, safe velocities as recommended by wheel manufacturers should not be exceeded.

The tendency is for manufactured parts to be held to closer limits with each advance in production practice and this of itself makes it desirable to use all available knowledge in adopting wheels for any given undertaking. Precision methods of dressing and truing wheels and better methods of applying them to the work have led to accuracy in precision parts that was not formerly practicable on production work. In Fig. 4 a spindle is being ground by a combination "plunge" cut and traverse method. The wheel in this instance is fed into within 0.001 to 0.0015 in. of size, using the plunge cut and making as many plunges as are necessary to cover each section ground. On the last plunge cut required for each section the wheel is fed to the stop and the traverse method is used to straighten and size the cut. The number of traverses required is usually two or three, by hand at approximately 48 in. per minute.

Cylindrical and Sliding Bearings.—We know that a number of factors besides surface finish enter into the problem of bearing maintenance and smoothness of operation. Character of lubricant, method of application, speed of spindle or shaft, temperature changes—especially where equipment is exposed to out-of-door conditions—clearances between shaft and bearing surface load, and conditions under which load is applied are some of the points to be considered in connection with any examination of the subject. This applies also to such parts as gears, clutches, or other members which may be arranged to revolve on their shafts. Surface finish will long remain a matter of interest to the average man in the shop and to many operators of mechanical equipment. Many examples of excellent finish are to be found in nearly all commercial work of the present.

The methods of producing surfaces of suitable degree of smoothness have varied from time to time and in accordance with the type of journal or journal bearing undergoing the finishing process. Materials for bearings have been improved, new alloys and mixtures developed, and newer methods of handling the work in the shop have been devised. Cylindrical or running members and their bearings have presented one type of problem, reciprocating and sliding parts another.

Excessive heat and extreme cold set up special factors for study. Desirable effects to be expected from a fine bearing surface may be offset by too liberal a clearance and too great a load upon a limited bearing area. Something like this is very likely to occur in locomotive- and car-axle bearings where nearly every kind of adverse operating condition is set up in the course of a day's run. With shop machinery, the case is somewhat simpler. Few machines of production are exposed to extreme working conditions. There is in fact, a marked tendency toward maintaining even running conditions in modern shops; and, in most cases, machine-tool bearings receive far greater attention than is usually feasible with mechanical equipment of many other classes.

The automobile engine represents a striking illustration of a machine built under a constant effort by manufacturers to impart more highly refined treatment to bearings and particularly to the bores of cylinder walls in order to eliminate all possibilities of even slightly roughened surfaces which may affect the proper fit of the piston rings along the cylinder bore. Saving of oil, elimination of vibration, extended life of the rings, and preservation of the accuracy of the bore are some of the advantages derived from this attention to bearing surface.

Gears and clutches and other operative members for general construction as in machine tool and other work, remain long in service because of suitable materials properly machined, properly heat-treated, and then finished to very definite tolerances and with assurance that correctly fitted surfaces are prepared for all running and supporting members. Rocker arms for certain machines and other oscillating elements are best made for long life when their bearings, whether integral or bushed, are provided with true, smooth bores which take full bearing upon their spindles.

Bearing loads fairly evenly distributed about the surface of a crankpin, or the spindle for a lever arm, or a cam lever, or any similar part which may revolve or rock to and fro, will not produce the localized wear which is a feature of poorly fitted bearing members. There is always some method of applying the grinding process to any kind of bearing problem arising either as a special job or as a feature of large-scale production. Machines and wheels are available for grinding almost any conceivable piece of work.

Mounting and Dismounting Pressures.—The effect of surface conditions can be seen in the handling of wheels and axles in railroad shops. The differences in pressures often noticed between the mounting of the wheel and the forcing of it off the axle at some later date are often noticed. The 10 to 15 tons per inch of diameter allowed in the mounting operation is often exceeded appreciably when the driver and axle are dismounted. In some instances the effect of the tire shrinkage seems to extend to the axle and pin fits. Cases are not uncommon where tires have had to be removed before dismounting became possible. In one instance a wheel mounted under a total pressure of 200 tons could not be started from its axle with an applied pressure of double that amount, fully 400 tons. Removal of the tire gave sufficient relief to permit dismounting at normal pressure.

The nature of the finish on both axle and wheel bore has much to do with the general character of the fit under heavy pressures. If the surfaces in contact are somewhat rough, the metal in the bore of the wheel is smoothed down by the entering end of the axle, and the remainder of the fit is made up with a lessened degree of pressure. The result is that the average pressure applied throughout the length of the fit is well below the maximum permissible, if not even less than the preferred, pressure.

With very smooth parts in contact, there is less disturbance of the surface metal and a closer uniformity of pressure is required for the mounting operation. This also results in a tendency of the two members to hold together more tightly when they are later taken to the hydraulic press for dismounting.

The factor of surface finish also enters into the fitting of crank-pins in driving-wheel centers. Records of large numbers of pin fits show that smoothness of pin surface and bore have an important bearing on the pressure required for forcing the pin into place, and the general character of the surface must be taken into consideration when the allowance for a suitable press fit is being established. The practice in some shops of permitting a reasonable degree of taper in the pin end where it enters the bored hole is of advantage when the pin is being forced home, as the reduced portion provides a comparatively easy fit at the start of the operation. Grinding would assure accuracy here.

Grinding of piston rods, etc., is a regular feature of various railroad shops which now grind many other parts as well. Such parts as pump cylinders, rod bushings, crosshead guides, link block pins, and reverse-lever fulcrum pins are now finished by grinding in some shops.

The grinding of such parts is not only an advantage in putting them through the shop but provides for a fit and finish which are especially important for service where parts must be so fitted in place as to be reliably supported throughout all normal operating conditions. For finishing internal surfaces, for instance, the grinding to size is of special value. On crankpin work the pin

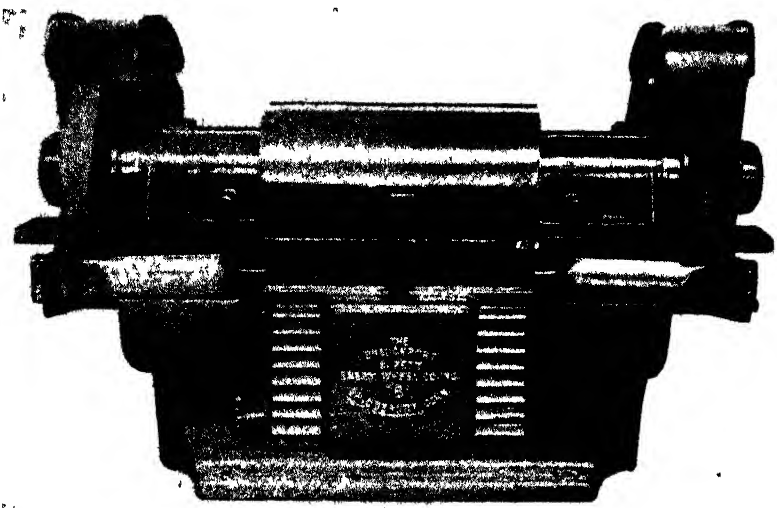


FIG 5 —Bridgeport Safety grinder for snagging castings.

can be sized to an exact dimension which will allow the precise oversize diameter for permitting the desired pressure to force the pin into its seat Other engine parts can also be fitted exactly with the same convenience.

Importance of Suitable Wheel Speeds.—Individuals in production plants accustomed principally to the precision performance of the cylindrical grinder are not always aware of the amount of grinding accomplished with the aid of the humble floor and snagging types of machines employed so commonly in mills and foundries and in some fabrication plants, as in Fig. 5. Little machine work may be necessary in such places, but the operations of cleaning and smoothing of surfaces require great numbers of grinding wheels. Where such wheels are operated at low speeds as is frequently the case, there is a real loss in cutting efficiency of the wheel and correspondingly low rate of progress on the work. The wheel once set at the proper speed soon becomes slower in surface velocity, owing to circumferential wear, and soon the surface speed is too low to be effective. Proper adjustment of the driving speed would go far toward saving many wheels that have become worn appreciably and at the same time bring about a marked degree of economy of time and labor expended on many classes of work. This is appreciated by grinding experts, but too often there is little attention paid to the actual cutting speed with the types of machine referred to. It is not always recognized that these grinders are production machines in their special departments of the plant, just as the cylindrical grinder and surface grinder are regular producers in the manufacturing division.

The amount of grinding-wheel wastage under the above circumstances, in certain metal-working industries is a very serious item. It is particularly conspicuous in a day when management and efficiency are supposed to travel hand in hand. It is true that under rough service conditions where heavy hand grinding is done as in snagging and smoothing work, it is rather difficult to maintain theoretically proper surface speeds for the wheels and a good deal of wasted time occurs. An 18-in. wheel, running at 5,000 ft. surface speed will drop to a velocity of little over 4,000 ft. when a wear of 3 in. in diameter has occurred. At the latter rate of speed there is apt to be appreciable drop in the efficiency of the grinding process, and unless someone gives special attention to the matter the chances are that the operator will not change to the faster driving speed on the grinder.

Where plants are doing much heavy hand grinding it is too often possible to find stacks of large, expensive wheels worn down a few inches and discarded. It is usually advisable to run the wheels on other grinders with higher spindle velocities and thus extend the ultimate usefulness of the wheel.

CHAPTER II

TYPICAL GRINDING MACHINES

The grinding process consists in the application of a rapidly revolving abrasive wheel to the surface of a piece of work which may be either of metal of any kind or almost any other material sufficiently hard to resist compression under the action of the wheel. Although grinding is commonly considered a finishing operation, it is often employed as a complete machining process of itself, work being ground down from rough condition to the finished dimensions without preliminary turning or other machining cut before the piece is placed in the grinder.

Grinding has come into general use in production for finishing work rapidly and accurately, whether the work is hardened or not. Formerly grinding was confined almost entirely to finishing of hardened parts which could not be machined by cutting tools. The grinding wheel itself is now considered a cutting tool with an infinite number of cutting points.

General classes of grinding machines are for cylindrical, internal and flat-surface work. Cylindrical grinders are used on shafts, spindles, and the like. Crankshaft and camshaft grinders are of the general cylindrical type. Internal grinders are for finishing cylinder bores and other internal surfaces. Surface grinders are for grinding flat surfaces of all kinds. Closer classification of different types will be given later.

Grinding Wheels.—Grinding wheels are formed of the cutting grit which is graded by screened sizes, and of the binding material, or bond, which holds the particles of grit together. The hardness of the wheel depends in the main on the amount of bond. The cutting action varies greatly with the grain or size of the grit which is graded from coarse to fine, according to the size of the screen mesh through which it is passed. The Norton wheel grading ranges alphabetically from very soft to very hard (as from E to Z). Thus a wheel 46-K would have a grain of fairly coarse size (passing through a screen mesh of 46 per inch, and the grade K indicating a soft wheel).

The different bonds and methods of making the wheel are important in fixing the character of the wheel. The selection of the best wheel for a given job is a matter requiring much experience, and wheel makers are best fitted for suggesting what wheel should be used for any specific purpose. Tables showing the gradings of wheels will be found on pages 58, 59, and 230 to 246.

What Kind of Work Is Ground?—Nearly everything goes through the grinding process today, whether the work is a small bushing or a tool shank, or at the other extreme, a big roll for a steel mill or a paper calender. Suitable machines have been designed for each of these lines. This applies to either grinding machines or attachments for grinding such units as crankshafts, camshafts, cylinder bores, and other parts. However, the bulk of work to be ground is handled on standard types of grinders which can be adapted to any work falling within their capacity as to general dimensions. This refers to plain and universal cylindrical grinders, surface grinders, internal machines, and other designs in the usual classes of equipment for grinding purposes.

An early type of grinding machine was built for finishing chilled rolls and other heavy rolls for paper mills and mill calenders. This machine carried two opposed wheels which were traversed along the work by a carriage which admitted of control by a camber or former bar giving the rolled surface a slightly crowned shape, the amount of camber depending upon the length of the roll and its general purpose. Such a machine was built by J. Morton Poole of Wilmington, Del., over 50 years ago.

The rolls were made of such hard material that the usual turning processes then in use could not produce a satisfactory finish. It was soon discovered that the rolls must be ground while running on their own journals, as their weight was such that accuracy of rotation on their centers could not be maintained, owing to wear on the centers in the ends of the work as well as on the machine centers themselves. And so the journals were first finished carefully, and the roll was mounted upon pillow blocks and ground while revolving upon the same bearing surfaces on which it was to run when mounted in place on the calender stack.

Cylindrical Grinders.—In the class of machine known as cylindrical grinders may be included:

Universal Grinders.—These machines differ from plain cylindrical grinders in that they are especially adapted for a wide range of toolroom work and for special operations through the facility with which the swiveling headstock permits work to be ground at any required angle, or face-ground, or otherwise finished. These machines are extensively used on various classes of production work as well as the plain grinder; this is particularly the case with parts used in small machine and special tool construction. The application of the internal grinding attachment extends the field of the machine and adapts it to further production operations as well as to special lines of grinding. A universal grinder is shown in Fig. 6.

The universal grinding machine was invented by J. R. Brown (Brown & Sharpe Manufacturing Co.) in 1868.

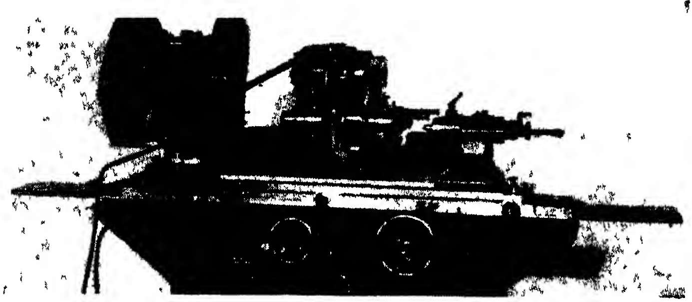


Fig. 6.—Brown and Sharpe motor driven universal grinder

Plain Grinders.—Such machines are used for general production work on spindles, sleeves, shafts, rollers, and many other parts either cylindrical or taper. In certain types they are built up to very large dimensions, particularly for heavy-shaft grinding and roll operations. The plain grinder is used for crankshaft work, form grinding of axles, and many engine and car parts, and in its smaller sizes, it is a valuable machine on much toolroom work where plain cylindrical operations can be taken from the universal machines and the latter relieved of the transferred work. In recent designs the plain grinder has been developed into a number of special forms for rapid production on certain lines of parts where every facility has been included for maximum output of the grinding process. A 16-in. cylindrical grinder is illustrated in Fig. 7.

The use of plunge-grinding methods, the application of very wide face wheels, the use of duplex wheels for grinding two diameters simultaneously have increased the rate of output from the grinding process. Hydraulic operation and automatic size control are among the newer features of certain makes of grinders. The Nortonizer is an electric sizing device with a gage riding the work as the wheel feeds in. The Landis sizing method utilizes an air jet at low pressure, blown directly against the surface being ground. Other methods will be shown later.

Other external grinding machines are roll grinders for finishing large rolls of chilled iron and other hard materials, for paper-mill calenders, rubber mills, steel mills, and other purposes; car-wheel grinders for regrinding wheels while they are revolved on their own journals, and for engine truck wheels; shaft grinders built in

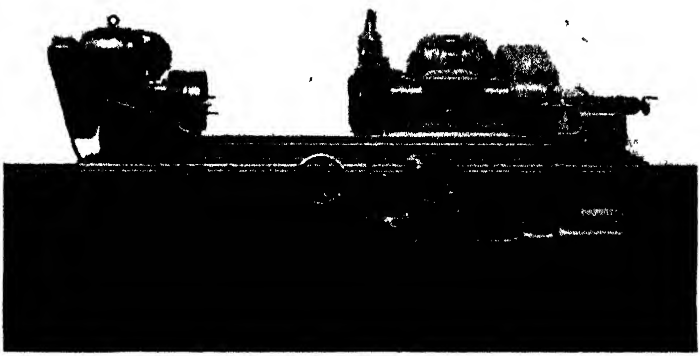


FIG. 7.—Norton type C cylindrical grinder with either hydraulic or mechanical traverse.

large sizes for such work. One machine takes shafts up to 28 ft. in length. Then there are different automatic and semiautomatic designs for specific lines of grinding, where high production is required. Among smaller units of the cylindrical type of grinder are precision bench machines made especially for fine tool work and operations on instrument parts.

Centerless Grinders.—The principle of centerless grinding consists primarily in passing a workpiece between a rapidly rotating grinding wheel and a slowly rotating regulating wheel upon a work rest or blade, one of the wheels being tilted slightly to give the necessary feed to the work. The Cincinnati centerless grinder (Fig. 8) is constructed in sizes taking work from very small parts up to shafts 4 in. in diameter by 18 ft. or more in length.

Internal Grinders.—Internal grinders include machines for finishing bores of gears, gages, bushings, and a multitude of production parts as well as internal surfaces in a great diversity of special work. For very small work like small bushings, internal grinding spindles have been developed to run at very high rates of speed in order to provide sufficiently high surface velocity of the wheel for proper grinding action. Cutter and tool grinders are

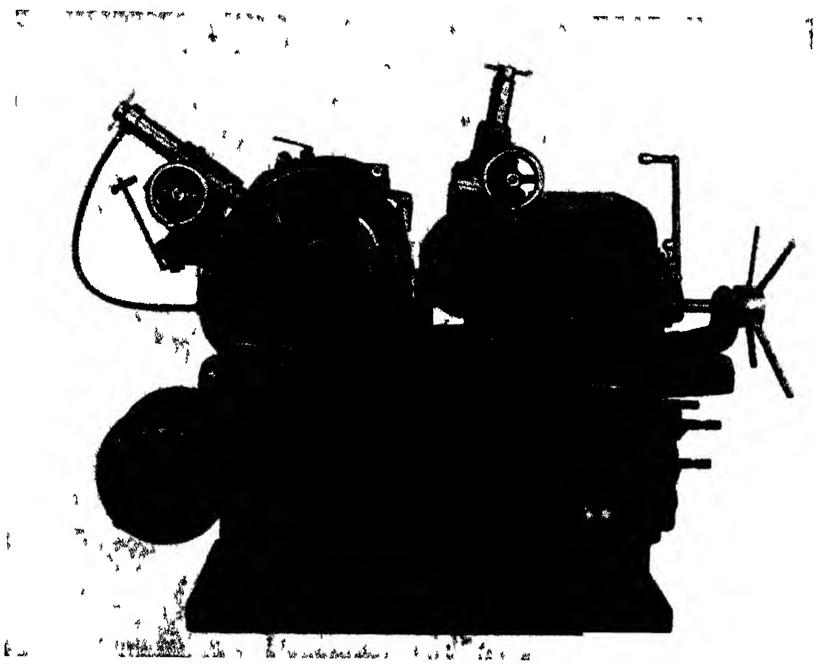


Fig 8.—Cincinnati centerless grinder

frequently adapted for both external and internal work on small pieces. Internal fixtures are also built for use on universal grinders.

The internal grinder is used for grinding holes in hard blocks and plates of various kinds, for example, in locomotive links, and connecting rods; the work is attached to a fixture for locating it square with the spindle, while the wheel travels around inside the hole with a planetary motion. Work of this kind is shown in Fig. 9. Grinders of this type were formerly used in automobile cylinder work.

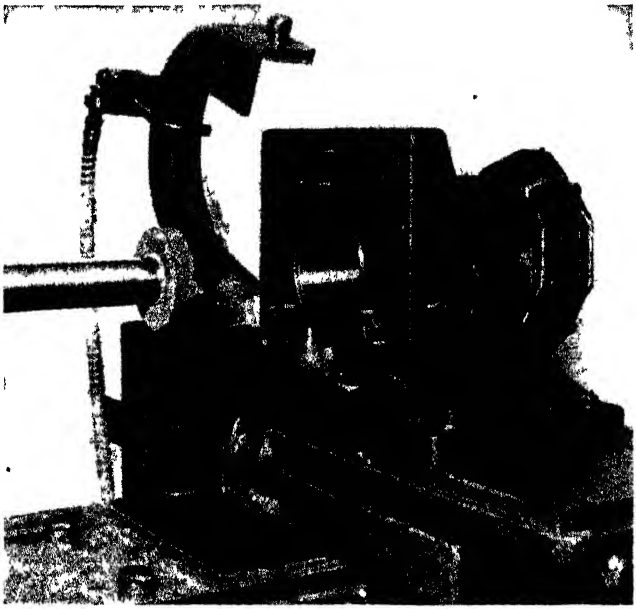


Fig 9 —Planetary-type internal grinder

Fig. 10.—Bryant chucking grinder.

Internal grinders are built for grinding holes down to as small as 0.125 in. The builders of the Heald internal machine, in

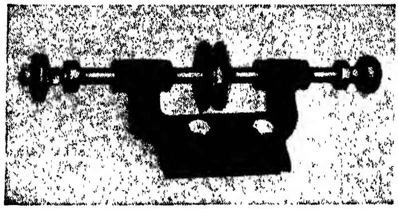


FIG. 11.—Hardinge sensitive-type grinder.

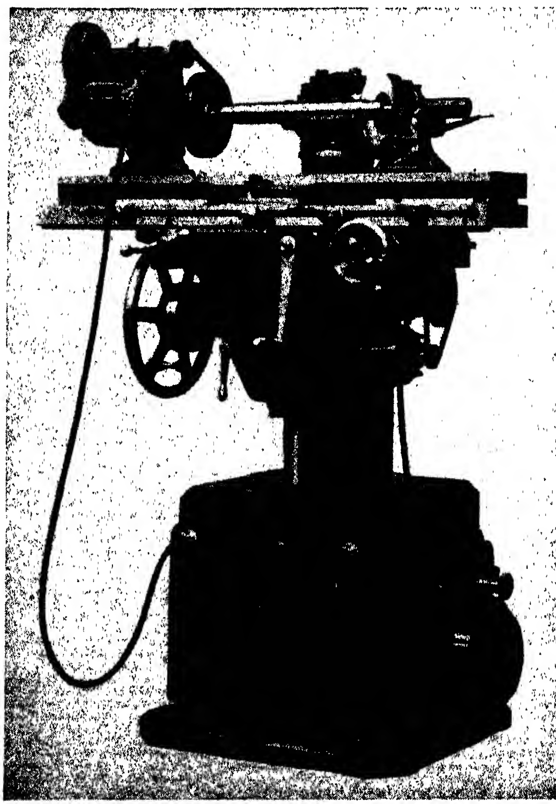


FIG. 12.—Le Blond universal-cutter grinder.

cooperation with the Cincinnati engineers, have produced an internal centerless grinder which is entirely automatic, and is shown in Chap. IV.

The Bryant chucking grinder (Fig. 10) is another type of machine with two or more wheel spindles for finishing the bore and for face-grinding operations at the same setting.

The traverse spindle grinder (Fig. 11) is a precision-tool attachment used on the bench lathe and designed for very accurate internal and external operations on small work, tools, and the like. The wheel spindle is of the sliding type and is moved in and out by hand It is a very sensitive appliance and operates at 10,000 or more revolutions per minute.

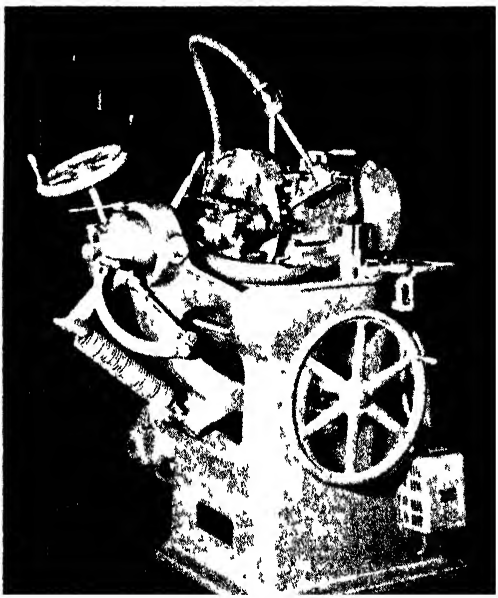


FIG 13 —Sellers lathe and planer tool grinder

Other grinding attachments and portable tools are used in the engine lathe for truing centers and with motor drive, and for grinding all sorts of tool work in the lathe, both externally and internally.

Cutter and tool grinders (Fig. 12) are general toolroom machines for sharpening all classes of mills, reamers, forming tools, and a great variety of work that comes to the tool and die shop. Such machines may be considered almost general-purpose grinders for the tool maker as he can grind work between the centers, in the chuck, and can do surface grinding also. In the universal type, external, internal, and face grinding is done and indexing and other operations are accomplished.

Common floor and bench machines are often used for sharpening tools for lathes, planers, etc. Wet grinders, so called, are commonly used for such purposes and for miscellaneous grinding work. Standardized cutting-tool forms with definite rake and clearance angles are ground on machines, as in Fig. 13, which can be set to give any specified degree of top, side, and front angle, according to whether lathe, shaper, or other tool. Drill grinders similarly are used for sharpening twist drills to the standard angle of point and clearance of lip, etc.

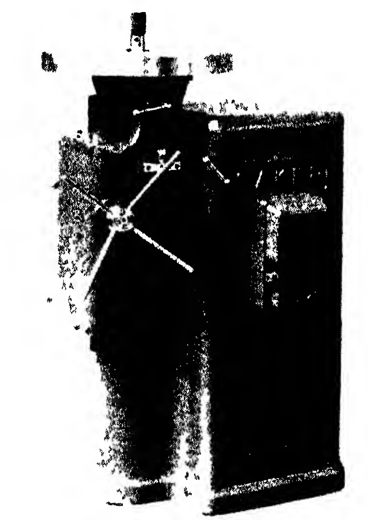


FIG. 14 —Baker contour grinder

There are a number of types of precision grinding machines for work of special character, although it may be in some instances along production lines. The Baker contour grinder (Fig. 14) is built for use in toolrooms for finishing dies, surfacing cams, and grinding many classes of irregular-shaped work. It uses pencil and cup wheels and as the table can be set at an angle, it is possible to grind relief on dies and other work as well as straight surfaces. The flat table can carry the work direct or special fixtures may be applied where desirable.

SURFACE GRINDERS

Surface-grinding machines include both horizontal- and vertical-spindle designs with both reciprocating and rotary tables. With the vertical type, the wheel is usually of ring shape, cutting on its end or lower face. In some cases the wheel is segmental, each section being a segment of a ring, to allow the particles ground from the work to escape into the openings between the segments and to reduce wear.

Horizontal Machines.—In the horizontal grinders the table is usually of the reciprocating type, to travel to and fro under the wheel mounted on a horizontal spindle, as in Fig. 15. The table may be hand-fed across the wheel or it may be power-operated. In some designs, however, for such work as flat rings, disks, and

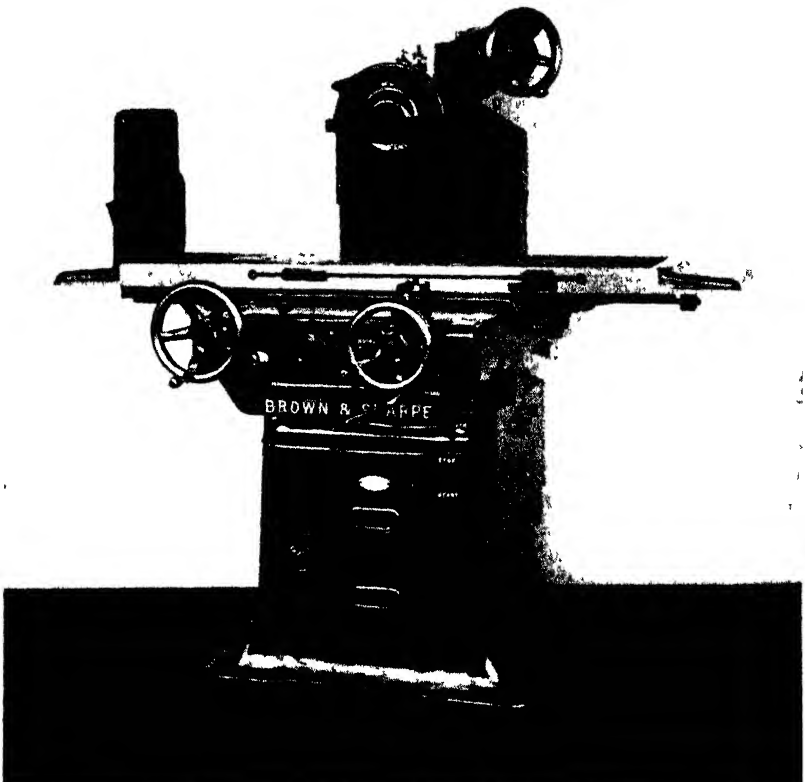


FIG. 15.—Brown and Sharpe toolroom and production grinder.

the like, the table is of rotary type (Fig. 16), carrying the work in a horizontal plane under the flat periphery of a plain wheel which is fed across the face of the revolving work. A magnetic chuck may be used here for holding small parts which are to be ground to exact thickness. These are also called *ring grinders*.

Similarly, the magnetic chuck is applicable to much work handled on the horizontal surface grinder of the toolroom and production type in which the table is reciprocated back and forth past the wheel on its horizontal spindle, as in Fig. 15.

The *planer-type grinder* is another horizontal machine with the wheel spindle carried on a saddle similar to a planer head and with the work traversed under the wheel. Large sizes of surface

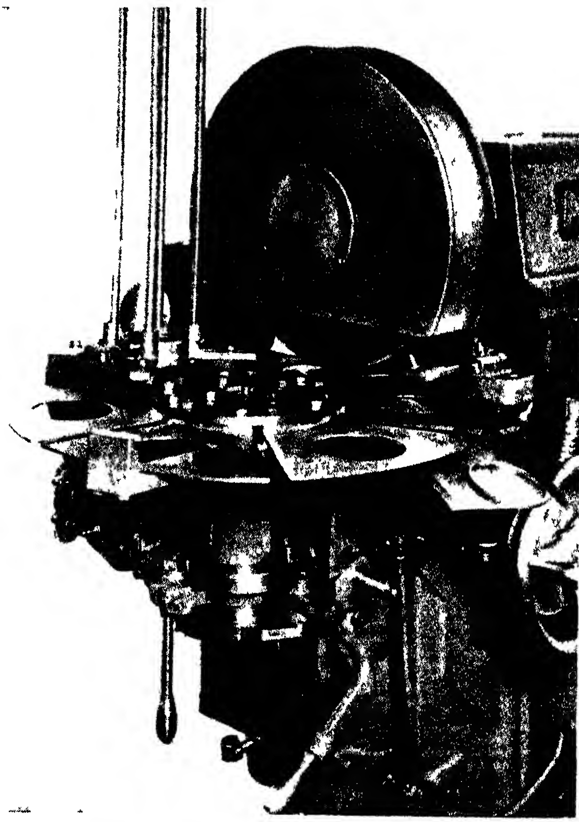


Fig. 16.—Arter rotary-table or ring grinder

grinders are built of various classes and types for long, heavy work.

Vertical-spindle Grinders.—Machines with vertical spindles are built for different sizes and classes of production work, for handling work on either revolving or reciprocating tables. The work may be held magnetically or mechanically, according to shape and proportions. High power vertical machines are

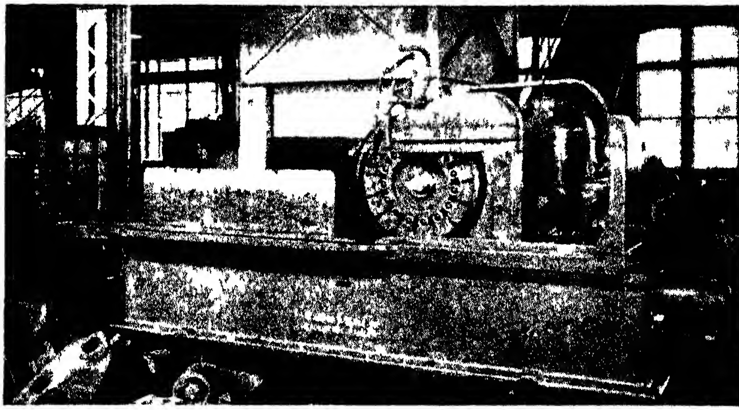


FIG 17 —Face grinder Diamond

FIG 18 —Besley disk grinder.

shown later. Castings and irregular forgings are handled rapidly and on a production basis by surface-grinding methods.

The surface grinder has been developed into very high-powered types capable of removing metal at fast rates of speed and with accurate results. A recent design is the Pratt & Whitney 14-in. vertical-spindle surface grinder with hydraulic table drive and with table speeds up to 100 ft. per minute. Both this and the Blanchard machine will be found in Chap. X.

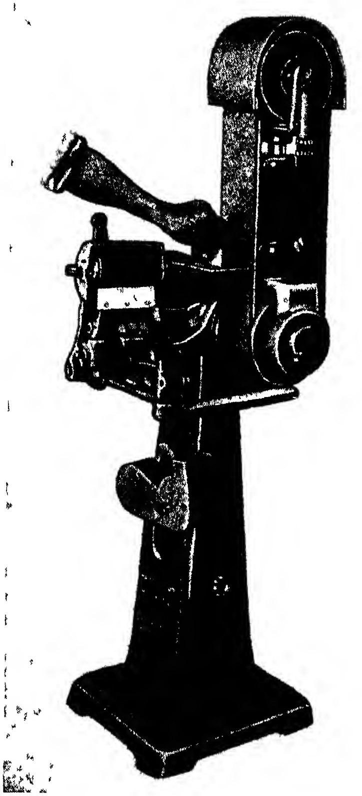


FIG. 19.—Production type of belt grinder.

The face-grinding machine is a type of surface grinder with the wheel usually on a horizontal spindle and the work held to be ground on its edge or vertical face. Knife-grinding operations (for machine knives) and long blades of one kind or another are carried on with such machines in different forms. Castings are faced and forgings ground also. The wheel is commonly of a ring type and cuts on its end, the path of rotation of the cutting face being in the vertical plane, as in Fig. 17. The vertical-spindle machines are also face grinders.

In another type of grinder the periphery of a plain wheel is used to grind such work as piston rings, as in Fig. 16.

Disk grinders with single or double abrasive disks are employed for many classes of work, particularly for production purposes where fixtures are frequently applied for holding the work and feeding it past the abrasive surfaces. Forgings and castings are faced by holding on tables, or by fixtures. Duplex machines receive the work between the disks which are set to give the desired width of finished surface, as in Fig. 18.

The horizontal-disk grinder runs on a vertical spindle with the work on the face of the flat revolving table.

Belt grinders are continuously running belts with abrasive surfaces for grinding and polishing materials held in contact with the belt. There are other special types of surface grinders developed, for finishing rings, disks, and other work. Figure 19 shows a typical belt grinder.

Floor-grinder stands with suitable wheels are used for grinding, polishing, and buffing on all classes of materials. Much grinding

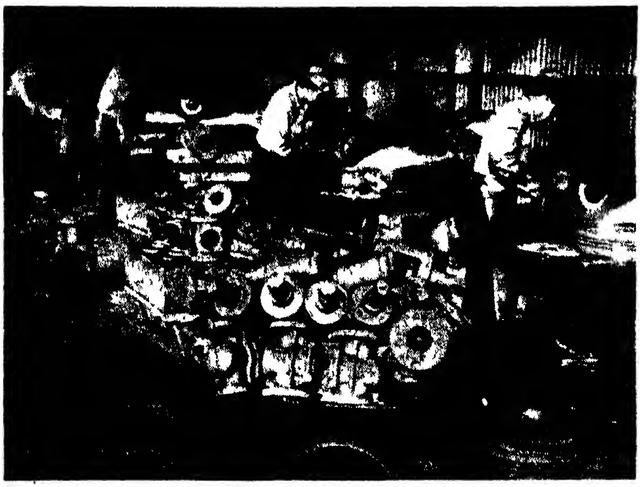


Fig. 20.—Swing type of grinder used in foundry and structural work.

is done in shop and foundry by applying the work directly by hand to the abrasive wheel. Thus many castings are cleaned and forgings smoothed by hand grinding, so called. Bench and floor machines are used for such work and swing types and portable designs of grinders are used particularly in the foundry, as in Fig. 20, for grinding castings and snagging preparatory to sending them to the shop for machining. Rubber- and bakelite-bonded snagging wheels are run at high rates of speed—as high as 9,500 surface feet per minute, on swing-frame grinders and floor stands in the foundry and steel mill.

CHAPTER III

CYLINDRICAL GRINDING IN GENERAL

Cylindrical grinding, the oldest and most commonly applied division of machine-grinding practice, comprehends the sizing and finishing of a variety of work ranging from the smallest class of tool parts to enormous rolls measuring many feet in length and weighing many tons. The types of work falling between the extreme size range of machine parts cylindrically ground are too numerous to be even suggested here, but common applications of the process will be recognized as especially useful for such operations as the sizing of shafts, spindles, axles, and the like.

The grinding of automotive crankshafts and similar parts for other engines, and the grinding of cams and certain other pieces which are not straight cylindrical objects, form nevertheless a branch of cylindrical grinding in that the work is revolved about its own axis while its contour or periphery is acted upon by the face of the wheel. Taper parts such as tool shanks, spindle bearings, and other objects are also subject to being cylindrically ground; for, the adjustment of any machine suited to this purpose is adequate to permit of any normal degree of taper being ground on any piece within the capacity of the grinder employed for the work.

Whatever the material, and whatever its physical condition, whether hard or soft, whether it is a toolroom special job or a factory product finished in large lots, the grinding machine stands ready to handle the work in what would have been considered a short time ago phenomenally short working time and with a remarkably smooth finish and equally remarkable degree of precision. In fact, the feature of precision is the most conspicuous and important of the several features adherent in the grinding process. Precision comes almost automatically with the application of the grinding process under suitable conditions as to character of machine and wheel, speed of work and wheel, and in general, correct operation of the machine as a whole. While cylindrical grinding comprises both the grinding of work between centers and centerless grinding, this presentation of the subject is confined to the handling of work between centers.

WORK SPEEDS

There exists a peculiar situation in regard to work speeds in grinding, as expressed in surface feet per minute. When we are contemplating setting speeds for turning work in the lathe, there are certain generally accepted and suitable speeds which can be adopted for the average run of work within reasonable range of sizes, assuming that the material is of one given character. But when cylindrical grinding is under consideration, there are a number of things to be kept in mind besides what might be a theoretically good rate of surface speed for the piece of work that is to be ground.

For instance, in place of the turning tool used in the lathe we have a rapidly revolving abrasive wheel whose action upon the surface of the piece being ground will depend not entirely upon the kind of metal to be finished, nor upon the exact rate of feed laterally and the depth of cut, but which will depend, instead, upon these and other factors perhaps even more important individually than the ones specified.

The selection of the wheel itself will rest upon more factors than the single one of class of material to be ground. This is seen in the tables of recommendations in wheel manufacturers' catalogs where steel articles alone account for the necessity for different kinds of wheels varying in their makeup as to type of bond grade, class of abrasive, and grain of abrasive.

Speed of work and relative speeds of work and wheel require close attention. The relatively slow rate of work speed as expressed in feet per minute and compared with wheel speed means that for every fraction of an inch of rotating work surface exposed to the action of the wheel, a hundred times that amount of wheel surface is applied to the work. Under a certain typical line of operations, the work might have a surface velocity of 50 ft. per minute. A wheel velocity of 5,000 ft. per minute would ordinarily be considered conservative, but even this speed would be in the ratio of 100 to 1 as compared with the speed of the work.

This fairly high ratio of wheel speed to work speed is often exceeded, even with a fixed speed for a fixed wheel diameter. For work speeds are not set for just so many feet per minute regardless of diameter. In fact, other conditions being fixed, speed of work will ordinarily be increased with increase of diameter. Thus we find that in the case of the largest class of work where cylindrical grinding is employed, namely, roll grinding, the speed of the roll may be as high as 100 to 200 ft. per minute, though much smaller work, even composed of somewhat similar material, may have an operating rate of perhaps only 20 or 25 ft. per minute. Indeed in some small diameters the surface speed is held down to a very low rate.

Different Diameters and Speeds.—Authorities on grinding tell us that, ordinarily, the larger the work the faster must be its surface speed. This is because of the increased length of arc of contact with big diameters between wheel and work, the effect of which is offset by speeding up the work. This advance in speed may result in faster wheel wear, but wheel wear is not necessarily of itself a detriment if real production is the goal. Excessive wear must be controlled, however, and the higher the ratio between wheel and work speeds, the less work will the wheel have to do in a given time, with consequently less wear occurring on the wheel. This will mean the use of a softer grade of wheel for either roughing or finishing.

A little consideration of the difference between the contact of a small piece of work with a wheel, and the contact of a large diameter with the same size of wheel will lead to the understanding that the small diameter of work has a much shorter arc of contact than the large piece. This is true for any two or more sizes of work where the wheel is fed into the same depth of cut for each piece of work. Some thought has to be given to the depth of cut taken by the wheel on any given diameter of work.

OPERATIONS BEFORE GRINDING

This leads to a determination of the amount of stock that should be left by turning operations preliminary to grinding, for upon that amount which is left for finishing depends largely the depth of wheel cut in reducing the work to its final dimensions. Not that the entire amount of surplus stock is to be removed in one cut, but under a system of roughing and finishing cuts in grinding the roughing operation will naturally be adjusted to remove a very liberal percentage of the stock by fair depth of wheel in the work.

There is a tendency in some classes of work, particularly on medium- and large-size shafts, to turn the work quite roughly, leaving less actual stock to remove than would be the case if the same diameter were retained with smooth lathe work. But it is necessary in this case to leave the work larger in diameter than it would be otherwise, or the wheel will not grind out the rough turning marks completely. However, the completion of the job is a matter usually of both turning and grinding and the division of the operations between lathe and grinder should be so made as to produce the most economical results as measured in terms of time consumed on total operations as well as cost of the performance as so divided.

Wheel wear must be considered and turning and grinding rates taken into consideration. Study may be necessary for any given line of production to determine the best way to split the work between two or more successive operations or processes.

Much work is ground from the raw piece, whether forged, cast, or otherwise prepared for finishing. This presupposes a certain amount of preparation for the work so that it shall be suitable for finishing under the wheel alone. More commonly, however, there are certain turning or other cuts required before the piece comes to the grinding stage.

Whatever the allowance left in turning before grinding, a division is again required as between roughing and finishing grinding cuts. Length of work, character of finish, and surface required, diameter and resistance to whipping and deflection under operation, general nature of the piece as to kind of metal of which it is composed, all these are some of the factors which have been dealt with when one is arranging to set limits for roughing cuts in grinding as well as final tolerances to which the finished pieces are to be definitely held.

DEPTH OF CUT AND RATE OF TRAVERSE

The depth of cut taken with the wheel at each pass across the work is variable within limits usually established to suit the size and type of machine. Ordinarily a depth of cut automatically applied by power feed may be varied from say 0.00025 to about 0.003 or 0.004 in., and this can naturally be increased in the event that the wheel head is fed forward by hand. But, in general practice, it has not been found desirable to apply excessive depth of feed into the cut. Such procedure imposes too rapid a degree of wear upon the wheel and in any event is a factor in cutting down rapidity of lateral traverse so that speed in production is not necessarily increased particularly by heavy depth of cut, unless other factors are varied to suit. Cost of wheels must be weighed in this connection and, further, frequency of wheel truing must not be overlooked.

Wheels are made wider than formerly with the intention that in cylindrical grinding operations they shall be suited to a wide traversing movement per revolution of work, or again for broad "in feeding." Table speeds are therefore arranged to provide broad latitude in their range from slow speeds to maximum rates. Naturally work diameter and other factors have important bearing upon the table speed to be used for any given job.

FUNDAMENTAL PRINCIPLES

In a recent A.S.M.E. paper on Cylindrical Grinding, Howard W. Dunbar of the Norton Company has clearly explained the fundamental principle of cylindrical grinding, described as "grain depth of cut" which treats with:

1. The penetration of the grain in the object being ground.
2. The arc through which the grain moves by virtue of the fact that the wheel is revolving.
3. The area covered by the grain by virtue of the fact that the work revolves.

Mr. Dunbar continues: By viewing the three factors which govern this principle, it will be observed immediately that with varying depths of penetration, and varying speeds of both wheel and work, varying conditions will result. It is immediately obvious that were the wheel the only moving element, then the amount the grain penetrated the work, when the center of the wheel was moved toward the center of the work, would be the radial depth of cut and the grain depth of cut as well. But when motion is applied to both the wheel and the work, and each revolved at different rates of speed, these two factors become different values. The area of the work covered by the movement of the wheel and the work produces the chip of material which is removed from the object being ground. It must follow, therefore, that when the grain starts to enter and penetrate the material, the depth of cut is zero. But as the work revolves and the wheel revolves, the depth of cut gradually increases to the maximum at a point somewhere between the point where it enters and leaves the cylinder. Since the wheel usually revolves much faster than the work, this point is practically at the point where it leaves the work.

As the abrasive grain in a grinding wheel is set or fixed in the bonding material of the wheel, it is clear that the deeper the grain cuts into the work, the more the bond will be disturbed or worn away. An ordinary grinding wheel of normal dimensions contains in its face over a million cutting points. This, then, modifies the consideration of the theory of grain depth of cut, which has thus far been described, assuming but one particle of abrasive in action. In practice, of course, there are actually a number of cutting particles in action, which again vary with the amount of penetration of the wheel into the work. Thus the actual grain depth of cut of the combination of all particles in contact in the path of a single grain is equal to the maximum depth of cut referred to in the previous outline, divided by the number of grains actually in contact with the work.

The Wheel as a Cutting Tool.—When the grinding wheel is working properly we may consider the abrasive grain in the wheel as cutting small chips from the work, and the surface of the work as cutting or wearing away the bond of the wheel. It follows then that the greater the grain depth of cut, the more effective will be the action of the work upon the bond of the wheel. So long as the bond is being worn away just as fast as the abrasive grains of the wheel are being worn down, the wheel will continue to work well. If the bond is cut away too rapidly, the wheel will appear too soft, and will wear away too rapidly. If the cutting grains wear down faster than the bond is cut or worn away, the face of the wheel will become glossy, and the wheel will not cut freely. These considerations lead directly to the conclusion that the action of a given wheel on a given amount of work is almost entirely dependent upon the grain depth of cut. If the grain depth is too great, the wheel wears too rapidly. If the grain depth is too small the wheel may glaze. It therefore becomes important to know how the grain depth of cut may be regulated.

From the foregoing it will be understood that the radial depth of cut will increase if the maximum grain depth of cut increases, and vice versa. But the maximum grain depth of cut depends entirely upon the speed of the work revolution. Therefore, if the speed of the wheel remains constant, and the speed of the work is increased, the radial depth of cut will increase. The correct working of the wheel therefore depends upon the proper relationship between the maximum grain depth of cut and the distance the particle travels in its path through the work being treated, or to put it in other words, it depends upon the relation of the work speed to the wheel speed. If the wheel speed and all other conditions, except work speed, remain constant, the grain depth of cut will increase as the work speed increases, and diminish as the work speed diminishes. (See *a*, Fig. 21) Also the work

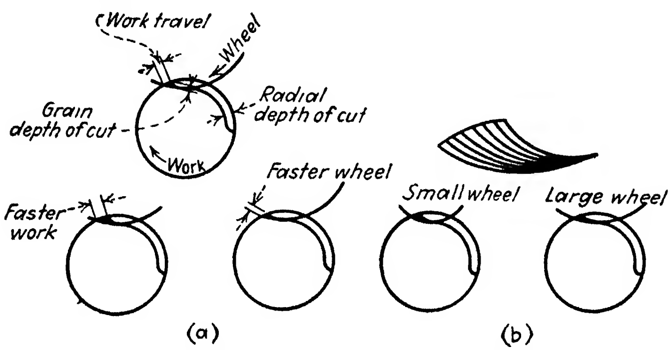


FIG 21 —Cutting action of large and small wheels.

speed and all other conditions except wheel speed remaining constant, the grain depth of cut will increase as the wheel speed diminishes, and vice versa.

Effect of Reduced Wheel Diameter.—In the foregoing analysis, it will be observed that we have assumed the grinding wheel at a fixed diameter. So here is another variable. Let the wheel speed be the same in each case and it will follow that the smaller wheel will have a shorter arc of contact with the work than has the larger wheel; since the wheel speed in both cases is assumed to be the same, the number of chips cut from the work each minute will be the same. But as the chips cut by the smaller wheel are shorter, and as the volume of chips cut each minute is the same, it follows that thickness of the chips cut by the smaller wheel is greater than the thickness of the chips cut by the larger wheel. In other words grain depth of cut increases as the wheel diameter diminishes. Therefore the bond will wear away faster as the wheel grows smaller, and the smaller wheel should appear softer.

In practice, grinding wheels are not maintained at a constant speed as the wheel wears down. Therefore the surface speed of the wheel diminishes, and when this happens, the grain depth of cut will be increased on account of the diminished wheel speed. Following the same line of reasoning, it is easily shown that if the work diameter is increased, all other factors remaining the same, a longer chip will be cut from the work, and as the number and volume of chips remain constant for each unit of time, the thickness of the chips must diminish, or the grain depth must be less. Therefore, a wheel should appear harder as the diameter of the work increases. An increase of work speed on the larger work will bring the grain depth of cut to what it was on the smaller work.

Definite Conclusions.—Summarizing, we are led by purely theoretical consideration to these conclusions:

1. Other factors remaining constant, the increase of work speed increases grain depth of cut and makes a wheel appear softer.
2. Similarly the decrease of work speed decreases grain depth of cut.
3. Similarly, diminishing the diameter of the grinding wheel increases grain depth of cut, and increasing the diameter of the wheel decreases grain depth of cut (see *b*, Fig. 21).
4. Similarly, making the diameter of the work smaller increases grain depth of cut and, conversely, making the diameter of the work larger makes the grain depth of cut smaller.

In applying the principle that grain depth of cut is the main factor in the phenomena of a good grinding wheel, it must be remembered that the correct relative speed of work and of wheel must be found by trial for each wheel and each kind of work. Where this has been done, the principle of grain depth of cut will enable one to know the direction in which to make the changes of work speed or wheel speed and to adapt the wheel to changes in its own diameter, or to other sizes of the same kind of work.

In the foregoing it has been assumed that stock removal was the important factor. But many times we must produce a fine surface finish. So let us take the theory and see how we would apply it to arrive at this result.

From the point of view of grain depth of cut, we should reason that the cut should be small. Therefore, with a fixed wheel speed the work revolution should be slower than for roughing. Slower work speed makes the wheel act harder, so that softer wheels should be used to allow the bond to wear away and maintain the ideal cutting action. It should be noted here that a hard, glazed wheel may produce a shiny finish, but this is usually a burnished surface and not a ground surface—and frequently the cause of burning, which results in discoloration, drawing temper, and surface cracks.

Empirical Rules.—Many empirical rules have been formulated about cylindrical grinding. Such rules have been the result of practical experience, but when examined we find they support the theory of grain depth of cut. After all, the practical application of these theories provides the real acid test.

When turning with a lathe, the larger the work the slower must be the revolution, because the cutting speed must remain nearly constant. But when grinding, the surface speed must increase as the work is larger and decrease as the wheel wears smaller. Therefore the work speeds of a cylindrical grinding machine are provided, not because the machine is to grind different diameters of work, but because of the necessity of changing the surface speed, and because of the variations from grade of wheel, variations in material ground, differences in depth of cut, differences in production, variations of surface speed and arc of contact of the wheel; and finally, to secure the varying surface qualities of the work being ground.

The faster the work revolution the harder the wheel must be, and the slower the work revolution the softer the wheel must be, to produce proper grinding action.

Slow work revolution, hard wheel, and deep cuts cause the wheel face to load with steel, and prevent the wheel from cutting.

Slow work revolution and hard wheel, with light cuts, cause the wheel to glaze, preventing the wheel from cutting.

Relatively fast work revolution with soft wheel causes the wheel to wear away rapidly.

The slower the work revolution and the softer the wheel, the deeper the cut may be. With this combination the maximum amount of metal can be removed in the minimum of time, with a minimum loss of wheel and a minimum consumption of power.

The harder the material being ground, the softer the wheel should be, or the faster the work surface speed.

The softer the material being ground, the harder the wheel should be, or the slower the work surface speed.

The larger the work, the softer the wheel should be, or the faster the work surface speed.

The smaller the work, the harder the wheel should be, or the slower the work surface speed.

Work Speeds and Wheel Speeds.—To counteract the effect of longer arc of contact, the surface speed of the work must be increased; in fact the cutting action of the wheel can be controlled entirely by the work speeds.

The effect of work speeds upon the cutting action of the wheel should be more fully understood. The common belief that the work speed, once established for any one piece of work, will always be suitable for similar pieces of work, is erroneous for the following reasons:

It is impossible for the grinding-wheel maker to guarantee to duplicate exactly the grade and cutting action of a wheel. Just as we have to allow tolerances in the manufacture of steel parts, so does the grinding-wheel manufacturer have to have tolerances in the grade of a wheel.

Oftentimes a small change of grade makes necessary a change of work speed, if we are to secure the ideal cutting action from a wheel.

No two pieces of steel are exactly alike. It is probable that the variation of material is as great in its effect upon the result as are the variations from exact grade in the wheel.

A small change in material makes necessary a change of work speed if we are to secure the best grinding action. This is especially true of hardened work.

The work speed should be changed to get the best result as the wheel wears smaller, because when a wheel is worn, the cutting action is changed. And we should readapt the work speed to the changed diameter of the wheel.

The question may be asked: "Why regulate the work speed and not the wheel speed?" The answer is simple. A change in the surface speed of a grinding wheel has less effect upon the cutting action of the wheel than does a change in the speed of the work. For purposes of comparison let it be understood that speeds of work revolution ranging from 20 to 120 provide the equivalent change in action of the grinding wheel, as would be observed in change of surface speed of the grinding wheel over a range from 850 to 6,500 surface feet. We do regulate the wheel speed in order to keep within a range of surface speed between 5,000 and 6,500 ft. per minute.

Correct Wheel Speeds and Grades.—Grinding wheels are revolved for one purpose only, that is, to distribute the work over the entire number of cutting points in the face of the wheel. When we revolve the wheel at a sufficient speed to secure the maximum work which each point is capable of performing, without wearing away too rapidly, we have the correct speed for that wheel.

While hard grades can perform a given amount of work in a given time at relatively slow speed, they do so with greater pressure on the work. And this greater pressure introduces the possibility of more vibration which has a most damaging effect upon the action of the wheel, resulting in errors of surface finish.

Softer wheels at higher speeds perform the same amount of work with less pressure, and, because of the greater speed, each point is required to cut less each time it comes into contact. It is thus enabled to perform the same work in a given time.

There are many other similar rules which relate to width of wheel, diameter of wheel, traverse speeds, and so on.

The results sought for in grinding are accuracy, refinement, and surface finish, making perfection more readily attainable, but only possible when using good wheels on good machines. Accuracy is necessary because of the improvement in mechanical devices; better finish because of the demand for longer wearing qualities, plus the greater stress now placed on appearance. In large steel mills, rolls are now being finished without a flaw in the surface, and to a dimension having an allowed tolerance of less than one-quarter of a thousandth. This leads us to the thought of how accurately can we grind, and following the grinding operation, how accurately can we lap or hone?

Factors Influencing Accuracy.—The accuracy within which we can grind or lap depends upon many different factors, including the skill of the operator. Therefore it is difficult to state specifically a formula which will define this accuracy. Often the surface errors in ground or lapped articles are mere reflections of light, not measurable by any commonly used measuring device.

When we speak lightly of a tenth of a thousandth we have little idea of just what this means. To impress one with the minuteness of this measurement, let's look at the optometer. This is an optical measuring instrument, multiplying errors many times. The graduations on the scale of this device are about 1/8 in. apart. These graduations can be observed with the eye. It represents on the object being tested 1/20th of one thousandth of an inch. To still further emphasize the smallness of these errors we are dealing with, consider this: if we were to multiply 1 in. on an ordinary rule by the magnification seen in the optometer this inch would appear to be 208 ft. long. It is therefore obviously impossible for a man with an ordinary micrometer, to attempt to work within limits as fine as can be produced on the grinding machine and checked by the optometer.

Surface Characteristics.—In treating with these infinitely small dimensions, how are we to determine surface characteristics of ground or lapped parts? This has been the basis for a great deal of discussion and we are trying hard to classify these values; also to discover apparatus or commercial means by which the values can be measured. At the present time the classification of surface finish is based on ocular examination, not because it is believed this method of classification is the best, but rather because no apparatus has yet been developed which is practical for commercial use by the average workman.

A simple, practical method that can be used in any shop is the reflecting method. Surface finish is classified in three groups: rough, commercial, and reflecting. For the purpose of uniformity of measurement we always use the printed column of the newspaper. When the print of the newspaper held under the surface being ground will not reflect the print, such a surface is considered as rough; commercial—when the news print can just be observed; reflecting—when the printed letters are clearly defined and stand out boldly.

Aside from illustrating the reflecting qualities of the surface being measured, this method also can in a measure be an accuracy test for dimension, since the straight lines between the columns of the news print, when reflected in the ground surface, usually show perfectly straight without any waviness, if the mechanical dimensions of that surface are accurate. Any bending of the lines on a flat or straight surface indicates inaccuracy.

A Comparison.—At this point it seems advisable to draw a comparison between the present-day methods in obtaining accuracy and surface qualities by referring to the practice of several years ago. The old grinding notion that a 24 combination K wheel would both rough and finish, performing the "cure-all act" in grinding, is no longer in the picture. Modern thought on this subject has been developed through gradually acquired knowledge, years of experience and research, so that present-day reasoning leads to this theory: No surface finish can be more accurate than the undersurface upon which it is built. Grinding and lapping are built around a simple principle based on a series of progressive approximations, which bring the final result or degree of perfection, to the ideal faultlessness desired. We start with a surface to be treated, and merely by successive operations diminish the error until perfection is attained.

To carry this out involves the selection of proper wheels. This has reference to both the grade and grain, and in many instances it even extends to the mechanical dimension of the wheel, for finishing results often show a definite relationship between the diameter of the wheel and the diameter of the work.

It is a well-known fact that after a wheel face has been corrected by truing or dressing, the wheel face must hold its physical characteristic until it has completely covered the entire surface of the object being ground. When considering this fact, it becomes evident that the wheel is an important factor. For example: roll dimensions for sheet mill work are growing larger and larger, so that it is not uncommon to find rolls more than 36 in. in diameter, and roll faces up to 84 in. in width. Consider the developed surface area of such a roll, and it must immediately become apparent that the wheel face has quite a task to perform to cover all of these square inches without losing its physical characteristics. The moment the wheel face breaks down, the character of surface being produced will change.

Now then, how do we produce an accurate surface, as to both dimension and finish quality, with the foregoing problem in mind? First we use a series of wheels. The roughing-out wheel is naturally of coarser grain than the finishing wheels which follow—this for the purpose of rapidly removing the material and preparing the undersurface. Still its grain size is relatively fine, when judged in comparison with wheels used in ordinary grinding practice. Then we treat the surface with another wheel, still a little finer, and so on, often using as many as five different wheels. For instance, we might start off with a 46 grain, the next combination an 80 grain, and then 150, 320, and occasionally as fine as 400 or 500 grit. Naturally the grades are in the soft range. In finishing, various types of organically bonded wheels are used because of the more gentle, cool-cutting action. This partly answers the question why there are so many combinations of grade and grain, bonding material and wheel structure.

Wheel Developments.—This suggests mention of the developments that have taken place in artificial abrasive wheels, designed to meet demands for greater and greater refinement. Having exhausted the possibilities of grade and grain and common types of bonds, ceramic engineers are tackling the problem of breaking down these factors into subdivisions of themselves. This research work has created controlled structure, B bond, controlled grain shapes, diamond wheels, boron carbide, and so on.

There are three elements which constitute a finished grinding wheel: the abrasive grains with which to do the work, the bonding material which forms the grain setting, and the voids or spaces between. By perfecting the manufacturing processes in wheel making, we have developed a method by which the amount of bond, the amount of abrasive, and the amount of void space are controlled within very narrow limits and can be varied at will. The advantage and value of this lie in the fact that we are able to go beyond the grade and grain characteristics in controlling the grinding action, which again multiplies the opportunity to more nearly suit each wheel to each particular operation.

A grinding wheel is composed of two different materials—abrasive and bond. Formerly the abrasive had one coefficient of expansion, while the bond had another; but by very careful research a bond has been produced that can be used in the manufacture of grinding wheels, which has the same coefficient of expansion as the abrasive itself. This is known as B bond. And herein lies another opportunity to further control the usefulness of the wheel in its application to some particular or special operation.

Boron carbide—another material—which rivals the diamond in hardness (in fact, the hardest material ever produced by man) is coming into the picture of abrasive products. Its full usefulness and application have not yet been realized, but it is sufficient to know that with the development of these materials goes the positive evidence that the everquesting mind of the research engineer is reaching out for new ideas, new materials, new methods to keep pace with the needs of industry.

GRINDING-OPERATION DATA

The foregoing material (pages 30 to 40) by Mr. Dunbar should be of great value to those interested in grinding. His explanation of the principle of grain depth of cut is most important to all students of this subject.

We present in the following pages certain data on grinding operations of various kinds.

Specific Jobs.—Many records are available showing grinder performance on various classes of cylindrical work, some from production plants and others from general shops handling a miscellaneous line of grinding jobs, where the lots are small but

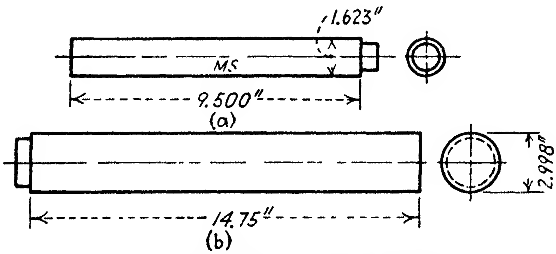


FIG. 22.—Two examples of grinding.

nevertheless typical of average run of work coming to the cylindrical grinder in jobbing and specialty shops.

Some of the sketches herewith show specific lines of grinding, as steel shafts in short lengths (Fig. 22). Some of the examples show greater allowance for grinding than is customary on some production work, but much depends upon the character of the lathe work before grinding. Other examples are more in the way of tests for comparison of results. Practice as to stock left for grinding varies in different shops and depends much upon material, size of work, and other details.

In most cases the times given to do the work are typical only of certain jobs and are based on certain limits as to size and finish. The time for any piece will vary considerably according to the exact degree of accuracy required and whether work is an individual piece or part of a lot where quick methods of handling in and out can be applied as well as most economical setup in general adopted. The number of different diameters on a piece to be ground affects the time appreciably as compared with a plain cylindrical job. The times given in some instances are necessarily approximations and comparable work is handled in various places at appreciably quicker rates.

Taking *A* and *B* as two sizes of work, the former has a surface area about one-third that of shaft *B*, and the metal to be removed from *B* is three times that ground from shaft *A*, the allowance for grinding being the same in both cases, 0.020 or 0.030 in. The wheel speed is the same but an 18- by 2-in. wheel was used on shaft *A* and a 14- by 1-in. wheel on *B*. Shaft *A* was run at 12 ft. per minute, shaft *B* at 24 ft. per minute. A 3846-K wheel was used on *B* and a 3836-L on *A*, this being one grade harder but of considerably coarser grain than the wheel used on *B*. A depth

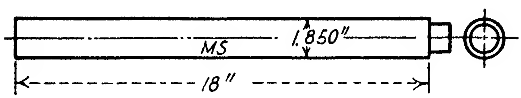


Fig. 23. Test of work speed.

of cut of 0.003 in. was taken with the wider wheel, and 0.002 in. with the other job. The traverse per revolution of work was about 2 in. with the wide wheel on piece *A* and about 1 in. with the narrow wheel on piece *B*. The time for the small shaft was 2 min. and for the large shaft 10 min. In other words, shaft *A* with one-third the area of shaft *B* was ground in one-fifth the time.

The factors influencing the respective rates of completion of these two pieces include a coarser grain wheel and slower speed of work for shaft *A*, a deeper cut and a much wider lateral movement of work per revolution. The rate of stock removal per minute was nearly double.

Another soft-steel piece is shown in the sketch in Fig. 23 where two different rates of work speed were used on exactly the same-size pieces and the same grade of wheel (3860-M) was used in both cases with the same speed of wheel. Only, in one case the work was ground with traverse movement of 1 in. per revolution of work and the other at ¼ in. traverse per revolution. The depth of cut was the same (0.004 in.) for each job. The work speed in one case was 12 ft. per minute, in the other 36 ft. The time for the job handled with wide traverse per revolution was about

15 per cent better than for the work ground with narrow traverse per revolution. That is it was 6 min. as compared with 7 min. for the slower traverse. The material ground off was 0.029 in.

A number of units like Fig. 24 were ground under the same conditions as to kind of wheel and speed of wheel (3860-L) at 5,500 ft., but with different work speeds. Half were ground at 6 ft., the other half at 12 ft. per minute. The same speed of traverse per revolution was used, but one set was ground at a depth of cut twice that of the other set. The time required was the same under both sets of conditions. The double rate of work speed with one lot made up exactly for the fact that only half the depth of cut was taken with the shafts in that lot. The stock removed was $\frac{1}{32}$ in. and the time for each piece was approximately 2 min.

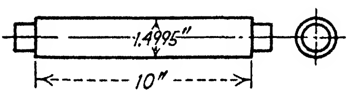


FIG. 24.—Another grinding experiment.

In analyzing a job of this character, it is possible to estimate rather closely what time will be required to perform similar work assuming similar grinding conditions are followed. Thus work $1\frac{1}{2}$ in. (approximately) in diameter as turned, measures 4.8 in. in circumference, and at 12 ft. surface speed it will revolve at the rate of $12 \times 12/4.8 = 30$ r.p.m. Or, at a traverse of 2 in. per turn, this means that the traverse is at the rate of 60 in. per minute. Allowing a traverse of 12 in. for the work, there will be five passes across the piece per minute and if a depth of cut of 0.002 in. is used, the stock will be removed at the rate of about 0.020 in. per minute, or a reduction of $\frac{1}{32}$ in. in less than 2 min.

Time must be allowed in estimating, for truing of wheel, changing work, and calipering and gaging. On ordinary runs the time actually figured "out" from production estimates will range probably from 10 to 20 per cent, depending naturally upon the degree of accuracy and finish required on any piece and general organization of the work. Greatest percentage of lost time is found with short special runs and where work is slender and long enough to require setting of rests; or on the other hand, where the work is very large and heavy and consequently necessitates the application of special handling facilities.

Further Examples of Work.—The work in Fig. 25 is a cylindrical member 4.050 in. in diameter and over 60 in. long. It is rough-ground at 35 ft. speed of work, with 60 ft. finishing speed.

The travel of work (traverse) is 48 in. per minute roughing, and 30 in. per minute finishing. The stock removed in roughing is 0.027 in., leaving 0.005 in. for finishing. The tolerance is 0.001 in., that is, it is held from standard to 0.001 under. The wheel is 24 by 2 in. alundum 3846-K. Wheel speed is 5,000 ft.

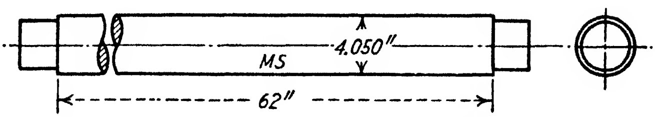


FIG. 25.—Grinding a 62-in. shaft.

Roughing is done at the rate of 7 per hour. Finishing is performed in the same length of time, the work being handled twice.

The two heavy spindles shown at *a* and *b* in Fig. 26 are alloy-steel members finished on practically all surfaces by grinding. These are typical of a number of shafts and spindles for similar uses and the usual speed of work is about 15 or 20 ft. per minute; on some work it is 30 to 35 ft. per minute. The wheel used here

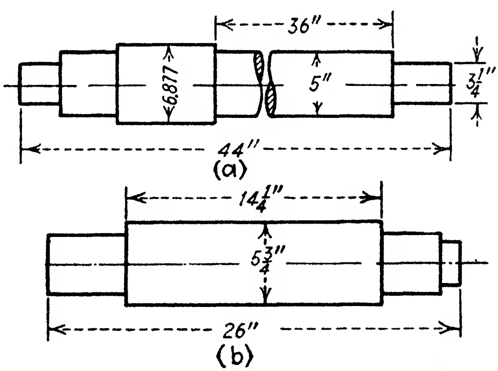


FIG. 26.—Two heavy alloy-steel spindles.

is 24 by 1½ in. and the travel of work—or traverse—is at least one-half the face width per revolution of work. Taking a 5-in. shaft at 20 ft. per minute, this would mean a speed of 15 r.p.m. and a travel of work of 15 × 0.75 in., or nearly 12 in. per minute traverse.

Where work is hardened or casehardened, and especially where it has appreciable length, the allowance for grinding must be sufficient to remove any irregularities due to deformation in the heat-treating process. Because of this, many parts have at least a full $\frac{1}{16}$ in. allowance for grinding straight and true.

Regrinding of parts, especially in automotive work, is done on the principle of removing the minimum of metal required to produce accuracy and truth. Lighter cuts are taken than in production work and rate of travel of work held to an amount to produce smooth surfaces.

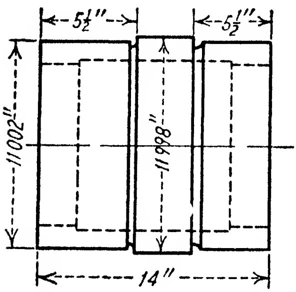


FIG. 27.—A cast-iron part of a machine.

A large crankshaft noted under grinding process was being finished at a work speed of 30 ft. and a travel of $\frac{3}{4}$ in. per revolution, the roughing being done at a depth of cut of 0.001 in. and the finishing at 0.0005 in.

When we consider cast-iron work and handling in the grinder we find recommendations of 3736-J (Crystolon) and recorded rates of work speeds of 9 to 60 ft. or more per minute. The cylindrical casting in Fig. 27 which has to be ground to receive certain fitting members is finished at a rate of 28 ft. per minute with a 3860-M wheel 28 in. in diameter by 3-in. face, operating at 5,500 ft. per minute. For this grinding operation 0.030 to .032 in. is left in the turning operation. Figure 28 shows an alloy-steel ring ground at 45 ft. per minute.

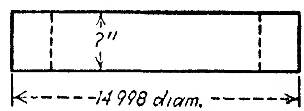


FIG. 28.—Large steel ring ground all over.

Another cast-iron piece 19 in. long by 3.995 in. diameter (Fig. 29) is a thick-walled quill which was ground with a 24- by

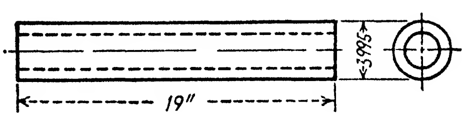


FIG. 29.—Cast-iron quill.

3-in. wheel with a work speed of 36 ft. per minute with a deep cut and a feed of table over $\frac{3}{4}$ in. per revolution of work. The stock removed amounted to 0.075 in. and the work was finished in less than 3 min. The wheel was 3836-L.

GRINDING SCREW-MACHINE PARTS

The casting shown in outline in Fig. 30, at *a*, is a nickel-alloy spindle turret for a four-spindle automatic screw machine. The ground surface at the extreme left is 18⅝ in. diameter by ¾ in. wide; the next ground surface is 17⅝ in. diameter by 4 in. wide; the third ground surface is 17⅝ in. diameter by 4¼ in. wide; and the last ground surface 16⅛ in. diameter by 1 in. wide. The four surfaces are finished at one setting of the work which assures concentricity, an essential feature.

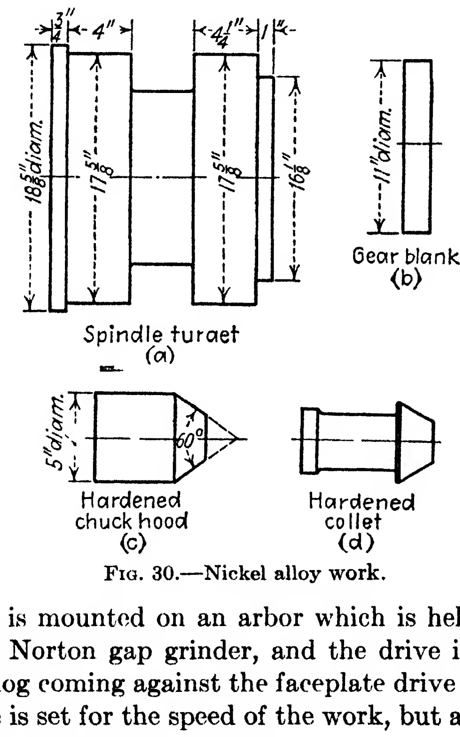


FIG. 30.—Nickel alloy work.

The work is mounted on an arbor which is held between the centers of a Norton gap grinder, and the drive is by the usual means of a dog coming against the faceplate drive pin. No hard and fast rule is set for the speed of the work, but a close approximation is 25 surface feet per minute.

The machine swings 36 in. in diameter, and work 18 in. in diameter can be swung over the ways. The wheel used is 24- by 4-in. 3860 grit, M grade Alundum, and is operated at 5,500 ft. per minute. The usual grinding allowance on this work is about $\frac{1}{32}$ in. The operation is shown in Fig. 31.

The same machine and wheel are used for a variety of other work. The piece shown at *b* in Fig. 30 is an alloy-steel forged gear blank 11 in. in diameter with 1¾-in. face. The object of grinding the outside diameter is to insure the necessary accuracy of the overall dimension before the teeth are cut. The work is placed on a mandrel between centers and rotated at a surface speed of approximately 40 ft. per minute.

Many cylindrical grinding operations require special setups and an example is the piece shown at *c*, Fig. 30, which is a hardened-alloy-steel chuck hood 5 in. in diameter. The nose is finished at an angle of 60 deg. (included). The work is placed on a special mandrel and held in place against a shoulder by a nut.

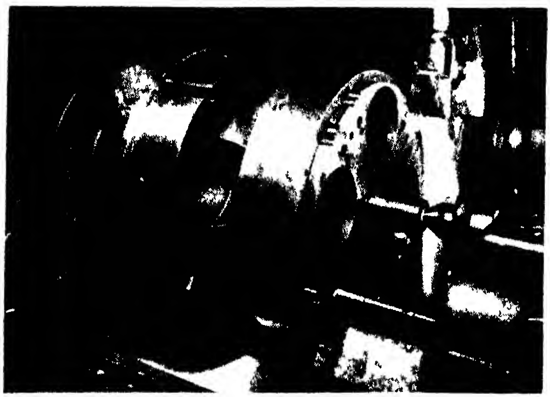


FIG. 31.—Grinding the spindle turret.

The grinder plate is set over at an angle of 30 deg. and the wheel face trued accordingly.

The machine is a Cincinnati cylindrical grinder capable of taking work 16 in. in diameter and 48 in. long. The wheel is an Alundum 14 in. diameter by 1½-in. face, 3860 grit, M grade. This wheel normally is operated at a surface speed of 5,500 ft. per minute, while the work speed is about 50 ft. per minute. The straight part of the work is also ground between centers so that it is concentric with the tapered portion.

The alloy-steel-hardened collet for a 2-in. machine shown at *d*, Fig. 30, must be finished accurately with outside and inside surfaces concentric. A Brown & Sharpe universal grinder is used. It is fitted with an Alundum wheel, 12 in. in diameter by 1½-in. face, 3860 grit, J grade, running at 5,000 ft. per minute. The work speed is 60 ft. per minute. The work is mounted on a special mandrel between centers.

After the taper portion is ground the mandrel is taken out and mounted in another grinder where the remainder of the collet is ground. Two dimensions are finished, the fit at the back and the clearance between the back end and the tapered nose. Also, in the second operation, the back of the collet is faced off with the wheel side. Inasmuch as these four surfaces are finished one after another without removing the work from its mandrel, it is obvious that they will be true and concentric with each other.

In connection with the grinding of screw-machine parts it will be of interest to refer to the grinding of the formed face of circular forming tools, one of the most exacting of grinding operations. As the contour of such tools varies with all cases, the generating of the contour presents a different problem with each circular tool. For such operations an Alundum 6-in. wheel is used, 19150 grit, L grade. The wheel speed is 5,000 ft. per minute, the work speed about 25 ft. per minute.

SEWING-MACHINE WORK

The sewing machine is one of the early examples of precision cylindrical grinding. Its production today includes the application of most precise methods in every detail.

One grinding job is the finishing of two bearings at the ends of an upper shaft with a crankpin at the middle of the length. The shaft is nearly 14 in. long. The portions ground for bearings at the ends of the shaft are 3 in. long by 0.483 in. in diameter, finished with a tolerance of ± 0.0002 in. This same tolerance applies to practically all the other parts finished by grinding.

The work is held between centers and supported by a back rest. The machine is a Norton 10 by 36 in., with oscillating head, the wide-wheel method being used. The wheel is Alundum 14- by 3- in. face, 24 combination grit, K grade, operated at 5,000 ft. surface speed. The grinding allowance is 0.0006 in. As the ends only are ground for a distance of 3 in., this small amount of stock is sufficient. The work speed is 120 r.p.m., or about 15 ft. surface speed.

Cam rolls for sewing machines must be finished with a high degree of accuracy, for if they are loose on their studs or in their cam grooves, the machine operating at high speed will develop objectionable noise. A typical cam roll, casehardened, 0.355

diameter, is ground internally, then wrung on a slightly tapered arbor, and ground with an 80 grit, N grade wheel with the work running at 35 ft. per minute surface speed.

SPINDLE-GRINDING OPERATIONS

A typical example of grinding of machine-tool parts is represented in Fig. 32 where a machine spindle is shown as ground in a Cincinnati saddle-type machine.

Rough turning is done on a Loswing lathe, equipped with a multiple-tool, double carriage. Straight turning requires one setting and the taper turning and necking operations a second setting. All diameters are reduced approximately ½ in. to

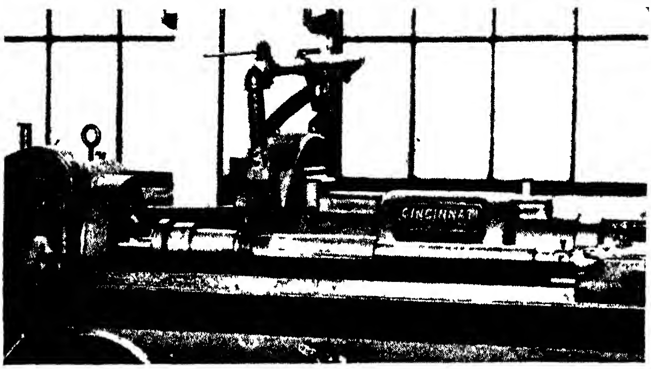


Fig. 32.—Grinding a milling-machine spindle.

insure removal of surface defects. Rough grinding stock of 0.040 to 0.050 in. is left on all milling-machine spindles and from 0.060 to 0.065 in. on all grinder spindles. Thus, it is possible to use high feeds and speeds. Boring is done on a gun-boring lathe, and boring the taper and finish turning and facing the flange is done on a turret lathe. The rough-grinding operation leaves 0.005 in. for finish grinding.

Milling the slots in the flange is done on a Cincinnati horizontal miller. The fixture mounts the spindle lengthwise on the table, being located by two ground, cast-iron bushings that support the rough-ground-bearing diameters. Interlocking cutters make possible the maintenance of accuracy, and vertical feed is employed.

Finish grinding is done in two operations on the machine shown. Tolerances range from 0.0002 to 0.0005 in. on principal dimensions. The first setting consists of semifinish grinding all diameters to 0.0015 in. At this point the hole in the milling spindle is rough-ground concentric with the bearing surfaces in a special Heald internal grinder. The spindle is then finish-ground, the rough-ground hole being used to support a plug from which is obtained the center for external grinding. After finish grinding, the spindle is put back into the special Heald grinder for finish grinding of the hole and face of the flange.

WORM SHAFTS AND GEAR SHAFTS

The illustration in Fig. 33 shows a casehardened steel worm-shaft being ground between centers on a Cincinnati 16- by 120-in.

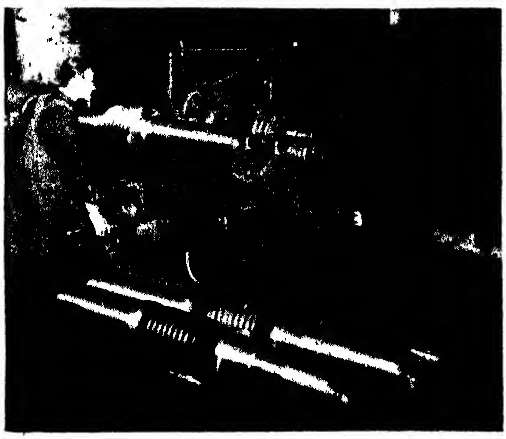


FIG. 33.—Grinding large worm shafts.

plain self-contained grinder. This worm is 12.502 in. outside diameter, 9½ in. long over all, 1¾ in. pitch, 6 leads left-hand, and is ground overall including the thread surface. The machine is used in a plant manufacturing gears and speed reducers.

A 20-hp. motor is used for driving. The headstock is powered by a 2-hp. adjustable-speed motor.

Small Motor Armatures.—In grinding armature shafts the method selected for highest efficiency is dependent upon several factors: The size and the number of different diameters to be finished on the shaft, the limits of accuracy stipulated, and the number of shafts to be ground in the lot have to be taken into consideration. Ordinarily, however, the shafts for fractional-

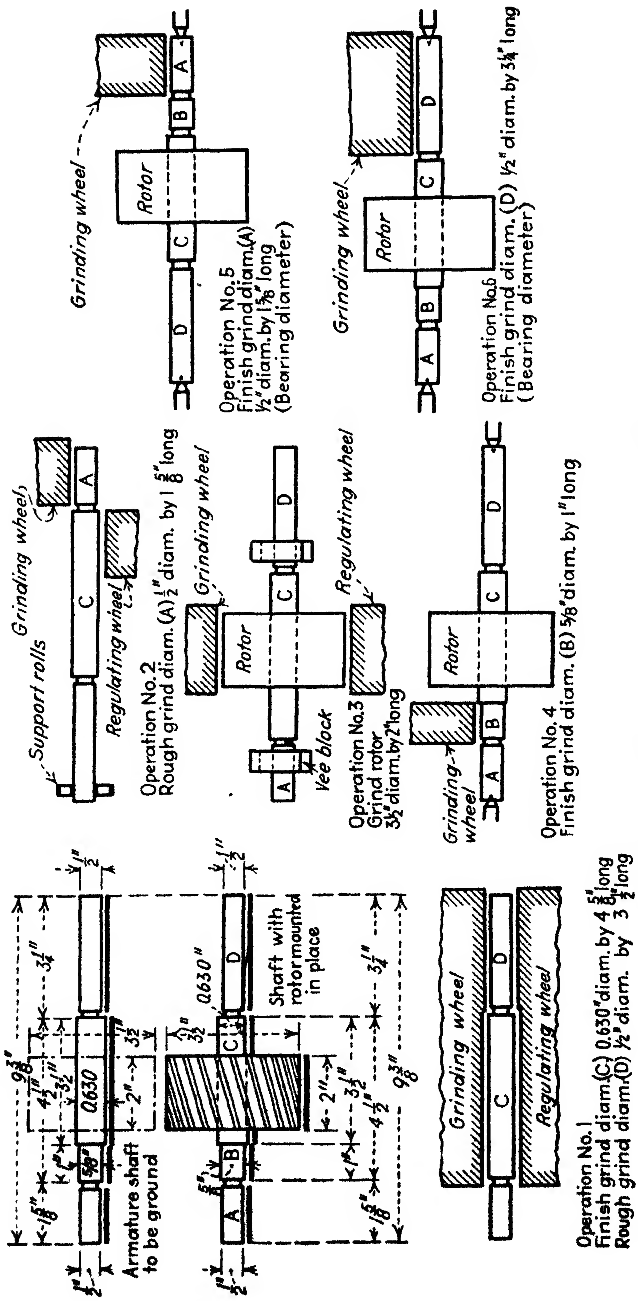


FIG. 34.—Grinding operations on armature shaft.

horsepower motors, such as are used in household equipment, are manufactured in sufficient quantities to justify adoption of most progressive methods and equipment for production. Also the requirements as to silent motor operation necessitate closest accuracy in sizes and a superior degree of refinement in respect to roundness and straightness of bearings and in character of surface finish. Furthermore, as it is essential that the rotor which is mounted on the armature shaft shall run truly concentric with the shaft bearings, the outside diameter of the rotor must be finished true and straight while mounted in place. This accuracy will result in the important requirement of uniformity of air gap between rotor and field of the motor frame.

Drawings from Cincinnati Grinders, Inc., are reproduced in Fig. 34 to show the sequence of operations followed in the production of large lots of small motor shafts of this character. These shafts are produced on the basis of 100 per hour including grinding of both shaft and rotor. The several diameters of the

TABLE 1.—DETAILS OF ARMATURE-SHAFT GRINDING OPERATIONS

Operation	Stock removal on diameter	No cuts	Limits			Production pieces per hour	Type of grinder
			Round	Straight	Size		
Op. 1, finish grind (dia. *C*), 0.630 dia. × 4⅝ in. long; rough grind (dia. *D*) ½ in. dia. × 3½ in. long.	0.010 to 0.012	1	0 0005	0 0005	0 0005	120	No. 2, centerless
Op. 2, rough grind (dia. *A*) ½ in. dia. ×1⅝ in. long.	0.012 to 0.015	1	0 0005	0 0005	0 001	240	No. 2, centerless
Op. 3, grind rotor 3½ in. dia. × 2 in. long.	0 040 to 0.045	1	0.001	0 001	0.003	100	No. 2, centerless
Op. 4, finish grind (dia. *B*) ⅝ in. dia. × 1 in. long.	0.004 to 0.005	1	0.0005	0.0005	0 0005	120	6 × 18 in., saddle type
Op. 5, finish grind (dia. *A*) ½ in. dia. × 1⅝ in. long (bearing dia.).	0.002 to 0.003	1	0.0000	0.0005	0.0005	120	6 × 18 in., saddle type
Op. 6, finish grind (dia. *D*) ½ in. dia. × 3¼ in. long (bearing dia.).	0.002 to 0.003	1	0.0000	0.0005	0.0005	120	6 × 18 in., saddle type

shafts (see sketch in upper left corner) must be concentric and the ½-in. bearings must have a fine finish and be both straight and to size within 0.0005 in. and round to zero reading on a liquid gage.. The work is handled on three No. 2 centerless grinders and three 6- by 18-in. saddle-type machines.

Operations 1, 2, and 3 as noted in Table 1, are accomplished on centerless grinders. Operation 1, as shown in Fig. 34, is accomplished with the infeed method. As indicated in the sketch, diameters *C* and *D* are ground at the same time, diameter *C* being finish-ground to 0.630 in. diameter by 4⅝ in. long, and diameter *D* round-ground to ½ in. diameters by 3½ in. long. Correct steps on the wheel faces are dressed by means of profile attachments with master cams. The work-support blade is also stepped to obtain bearing on the two diameters being ground.

Operation 2, which consists in rough grinding diameter *A* ½ in. by 1⅝ in. long, is accomplished with the use of an offset regulating wheel to insure concentricity. between diameter *A* to be ground and the other shaft diameters. This regulating wheel bears on diameter *C* already ground while an infeed cut is taken on diameter *A*. Adjustable rolls, which form a part of the infeed work rest, support the outer end of the shaft during this operation.

Operation 3 is the grinding of the rotor to 3½ in. diameter and concentric with the bearing diameters *A* and *D* on the shaft. These bearing portions are located in blocks which are arranged with the open sides of the V's toward the regulating wheel.

The V blocks are constructed with an extended side forming a horizontal shelf on which the shaft is loaded in grinding position by mechanical means and as the wheels are moved together to start the infeed cut, the regulating wheel first contacts the rotor and moves the shaft-bearing diameters into the throats of the V blocks. Continued forward movement of the regulating wheel then moves the rotor into the face of the grinding wheel.

This forward movement is accomplished with a backlash attachment for the upper and lower machine slides.

With the bearing diameters of the shaft located in the V blocks the backlash attachment on the upper slide which carries the regulating wheel picks up the lower slide carrying the work-rest block containing the V blocks, and with the regulating-wheel face contacting the rotor, both slides move forward as a unit until the rotor contacts the grinding-wheel face. The outside diameter of the rotor is thus ground concentric with the bearing diameters of the shaft.

Grinding on Centers.—Operations 4, 5, and 6, as shown by the table, are performed on center-type grinders. Operation 4 is the finish grinding of diameter *B*, 5/8 by 1 in. long. The armature shaft with rotor is mounted between centers. In a previous operation the shaft has been centered from the previously ground diameters to establish concentricity between ground diameters and centers. A plunge cut is then taken.

Operation 5, finish grinding of bearing diameter *A*, 1/2 in. diameter by 1 5/8 in. long, is also ground with a plunge cut in the center-type grinder. The face of the wheel is trued slowly to give a high finish to the woik.

Operation 6, is handled in the same manner as operation 5. This finishes the bearing diameter *D* which is 1/2 in. diameter by 3 1/4 in. long.

The grinding of the bearing diameters, referred to as *A* and *D* in the drawings and description, is done with the work running at about 167 r.p.m. This gives a surface speed of about 22 ft. per minute. Normally the work speed is somewhat higher than this when grinding by the center-type method, but in this case in order to obtain the extra-high finish required and the close limits of accuracy, best results were obtained when running the work at this speed.

Typical Heavy Grinding.—Grinding is of importance in the production of many classes of machinery and the application of modern grinding methods has added to the value of the equipment whose elements are finished by this process and are therefore more accurately sized and at the same time provided with a surface of improved wearing properties because of the character of the finish imparted by the cylindrical grinding operation. The capacity to grind to size and closest tolerances applies to any machine part whatsoever without regard to the kind of steel or the nature of its surface treatment, whether soft stock, high carbon, or alloy, or casehardened or otherwise heat-treated. This fact enables machinery to be constructed readily with ideal conditions as to quality of shaft and spindle bearings and fits for all kinds of parts which are to be assembled together.

Good illustrations are such work as gear-reduction units where the shafts are all ground to close tolerances and the gears are finished in their bores by internal grinding to the same close degree of precision. The shafts and gears are of high alloy steels given special heat treatment which adds appreciably to the strength of these parts and providing hardened surfaces to increase by years the length of wear-resisting life imparted to these members.

The fixed tolerances to which the ground dimensions are held are based upon an established system of allowances for suitable fits for different conditions of assembly and operation. Thus the fits for the gears to be mounted by hydraulic pressure on their shafts are produced by grinding so accurately that the requisite pressures can be determined in advance with assurance that in the mounting operation the pressures necessary to apply are in exact accordance with the predetermined values.

Advantage of Proper Fit.—With work in general, whether the work is soft steel or hardened, the grinding process is of first advantage, and especially is this true in finishing parts to properly established tolerances for all classes of fits, not only of the force type but also for running spindles and shafts, for various kinds of sliding fits and for light press and so-called "tunking" fits. In all of these classes of fits the surfaces produced by grinding are finely finished and closely held to desired limits so that all ground parts are alike, whereas with any other finishing method more allowance is necessary for assurance that fitting parts will assemble properly.

Taking, say, any group of axles and wheels put through in a lot for force fits and assuming that these are not to be ground, it will be found that the axles will be left appreciably over theoretical size for the stipulated press allowance, because the character of the surface finish is such that part of the force allowance is "rubbed down" and disappears the moment the parts are started together in mounting the wheel. Similarly, in ordinary running fits, the impossibility of an accurate, fine finish without grinding makes it necessary to leave the fit closer at the start than it should be. Otherwise it will be too free after the rubbing surfaces have become slightly worn down.

The accuracy of the grinder and the ease with which exact sizes are produced by grinding eliminate the probability of variation that exists when parts are sized by earlier methods. Moreover, the ease with which parts hardened to any desired degree are handled on the grinding machine has enabled a very accurate system to be set up for all classes of fit allowances and tolerances where hardened work as well as unhardened is involved.

Limits and Allowances.—In connection with the foregoing paragraphs on the close-fitting possibilities due to the accuracy and smooth condition of the surfaces produced in the grinding machine it will be of value to include certain data pertaining to commercial grinding limits as established over many years of experience. As with many other branches of machine work, grinding practice in respect to limits and allowances varies somewhat in different plants. The data incorporated in Table 2 give Brown and Sharpe practice as recorded by W. A. Viall in a paper before the A.S.M.E. and still in use. As pointed out by him, there are special cases where it may be necessary to increase or decrease these limits. The table is offered as a guide toward selection of suitable limits.

It is important, as stated in earlier pages, to establish sizes to which the work should be rough-turned ready for grinding. In the plant referred to as in others, the aim is to provide desired results as economically as possible. The desired ends have been accuracy and nicety of finish where the parts ground are for fits, and nicety of finish where no fit is required. The amount left for grinding varies in most cases from 0.008 to 0.012 in.

TABLE 2.—GRINDING LIMITS FOR CYLINDRICAL PIECES AS ADOPTED BY BROWN & SHARPE MFG. CO.

The limits shown below should be followed under ordinary conditions. Special cases should always be given special consideration as it may be desirable to vary slightly from the tables.

It is Brown & Sharpe practice to consider the hole as being standard, and the limits shown below are based on the standard hole. The grinding limits for holes apply to hardened pieces. The holes in soft pieces are chucked to standard diameter.

Running Fits, Ordinary Speeds

These limits are satisfactory for shafts running under 600 r.p.m. and under ordinary working conditions. Spindles for all purposes are to be considered as special cases.

To ½-in. diameter, inclusive	0.0005	to 0.001	small
To 1 -in. diameter, inclusive	0.00075	to 0.0015	small
To 2 -in. diameter, inclusive	0.0015	to 0.0025	small
To 3½-in. diameter, inclusive	0.002	to 0.003	small
To 6 -in. diameter, inclusive	0.0025	to 0.004	small

Table 2.—Grinding Limits for Cylindrical Pieces as Adopted by Brown & Sharpe Mfg. Co.—(*Continued*)

Running Fits, High Speed, Heavy Pressure and Rocker Shafts

These limits are satisfactory for shafts running more than 600 r.p.m. and where the working conditions are severe. Spindles for all purposes are to be considered as special cases.

To ½-in. diameter, inclusive	0.0005 to 0.001 small
To 1 -in. diameter, inclusive	0.001 to 0.002 small
To 2 -in. diameter, inclusive	0.002 to 0.003 small
To 3½-in. diameter, inclusive	0.003 to 0.004 small
To 6 -in. diameter, inclusive	0.004 to 0.005 small

Sliding Fits

These limits are for shafts where a gear, clutch or other similar part slides on it continuously while the machine is in operation. These limits are the same as for Running Fits, Ordinary Speeds.

To ½-in. diameter, inclusive	0.0005 to 0.001 small
To 1 -in. diameter, inclusive	0.00075 to 0.0015 small
To 2 -in. diameter, inclusive	0.0015 to 0.0025 small
To 3½-in. diameter, inclusive	0.002 to 0.003 small
To 6 -in. diameter, inclusive	0.0025 to 0.004 small

Standard Fits, where the Load Is Not Heavy and where the Part Is Keyed to the Shaft and Clamped Endwise with a Nut

These limits are suitable for light service only and where no fitting is to be done.

It is possible that where both parts are hardened, closer limits may be necessary, assuming that the parts are to be assembled without fitting.

To ½-in. diameter, inclusive	Standard to 0.00025 small
To 3½-in. diameter, inclusive	Standard to 0.0005 small
To 6 -in. diameter, inclusive	Standard to 0.00075 small

Standard Fits

These limits are to be used where it is desirable or essential that the parts fit together without play, and still be put together or taken apart without difficulty. Some fitting may be required and also some selecting may be necessary to attain the proper results.

The feed and speed cases for milling machines are good examples of where these limits might be used.

It is possible that where both parts are hardened, closer limits may be necessary, assuming the parts are to be assembled without fitting.

To ½-in. diameter, inclusive	Standard to 0.00025 large
To 3½-in. diameter, inclusive	Standard to 0.0005 large
To 6 -in. diameter, inclusive	Standard to 0.00075 large

Driving Fits

For use where parts must fit tightly and where the location of the parts is such that they could not be put together if the drive was too great. These limits will apply where the assembly is permanent.

It is possible that where both parts are hardened, closer limits may be necessary, assuming the parts are to be assembled without fitting.

To ½-in. diameter, inclusive	Standard to 0.00025 large
To 1 -in. diameter, inclusive	0.00025 to 0.0005 large

TABLE 2.—GRINDING LIMITS FOR CYLINDRICAL PIECES AS ADOPTED BY BROWN & SHARPE MFG. CO.—(*Continued*)

To 2 -in. diameter, inclusive.....	0.0005	to 0.00075 large
To 6 -in. diameter, inclusive.....	0.0005	to 0.001 large

Driving Fits

To be used where the assembly is permanent and the duty severe, and where there is room for the handling and the driving of the parts.

It is possible that where both parts are hardened, closer limits may be necessary, assuming the parts are to be assembled without fitting.

To 2 -in. diameter, inclusive......	0.0005	to 0.001 large
To 3½-in. diameter, inclusive......	0.00075	to 0.00125 large
To 6 -in. diameter, inclusive......	0.001	to 0.0015 large

Forcing Fits

These limits may be used where parts are not expected to be taken apart and where service is very severe. This assembling is done under the arbor press for the smaller parts and under the hydraulic press for the larger parts.

The method of forcing the parts together and the length of the parts will have influence on how large to leave the shaft.

It is possible that where both parts are hardened, closer limits may be necessary, assuming the parts to be assembled without fitting.

To ½-in. diameter, inclusive........	0.00075	to 0.001 large
To 1 -in. diameter, inclusive........	0.001	to 0.002 large
To 2 -in. diameter, inclusive........	0.002	to 0.003 large
To 3½-in. diameter, inclusive........	0.003	to 0.004 large
To 6 -in. diameter, inclusive........	0.004	to 0.005 large

Shrinking Fits, for Pieces to Take Hardened Shells ⅜-in. Thick and Less

To 1 -in. diameter, inclusive......	0.00025	to 0.0005 large
To 2 -in. diameter, inclusive......	0.0005	to 0.00075 large
To 3½-in. diameter, inclusive......	0.0005	to 0.001 large
To 6 -in. diameter, inclusive......	0.001	to 0.0015 large

Shrinking Fits, for Pieces to Take Shells, Etc., Having a Thickness of More than ⅜ In.

To ½-in. diameter, inclusive.........	0.0005	to 0.001 large
To 1 -in. diameter, inclusive.........	0.001	to 0.002 large
To 2 -in. diameter, inclusive.........	0.002	to 0.003 large
To 3½-in. diameter, inclusive.........	0.003	to 0.004 large
To 6 -in. diameter, inclusive.........	0.004	to 0.005 large

Grinding Limits for Holes

To 2 -in. diameter, inclusive.....	Standard	to 0.0005 large
To 3½-in. diameter, inclusive.....	Standard	to 0.00075 large
To 6 -in. diameter, inclusive.....	Standard	to 0.001 large

WHEEL RECOMMENDATIONS

Anyone examining a complete chart of grinding-wheel recommendations for different classes of materials and work will realize how completely wheel lines have been developed by variations in abrasive and bond to suit a constantly increasing

TABLE 3.—WHEEL RECOMMENDATIONS FOR CYLINDRICAL GRINDING (NORTON)

Work to be ground	Abrasive	Grain and grade	Structure	Bond	Abrasive (trademark)	Bonding process
Aluminum	37	30-J	8		Crystolon	Vitrified
Armature laminations		36-L	5	B	Alundum	Vitrified
Axles:						
Automobile		46-L	5	B	Alundum	Vitrified
Railway and automobile		46-L	5	B	Alundum	Vitrified
Brass	37.	36-K	5		Crystolon	Vitrified
Bronze		46-K	5	B	Alundum	Vitrified
Bushings:						
Hardened steel		60-L	5	B	Alundum	Vitrified
Cast iron	{ 37 38	46-K 46-J	5 5 }	B	Crystolon Alundum	Vitrified Vitrified
Cam rollers, hardened steel	38	60-N	6	B	Alundum	Vitrified
Cams:						
Hardened steel						
Roughing		60-L	5	B	Alundum	Vitrified
Finishing		60-L	1	R	Alundum	Vitrified
Rough and finish:						
Hand machines		70-P	8	T2	Alundum	Bakelite
Automatic machines		70-O	8	T2	Alundum	Bakelite
Cast alloy						
Roughing		46-M	5	B	Alundum	Vitrified
Rough and finish		{ 70-P	8	T2	Alundum	Bakelite
Hand machines	37	{ 60-Q	6	T2	Crystolon	Bakelite
Car-shaft bearings		46-N	5	B	Alundum	Vitrified
Carwheels						
Chilled iron		16C-N			Alundum	Vitrified
Steel		20-P	5	B	Alundum	Vitrified
Manganese steel		16-Q	8	B	Alundum	Vitrified
Cast iron	37	36-L			Crystolon	Vitrified
Copper	38	60-L	4	L	Alundum	Shellac
Crankshafts:						
Airplane	38	60-K	5	B	Alundum	Vitrified
Diesel		46-L	5	B	Alundum	Vitrified
Automotive:						
Pins and bearings, finish		50-N	5		Alundum	Vitrified
Rough and finish		46-O	5		Alundum	Vitrified
Forgings		46-M	5	B	Alundum	Vitrified
Gages, plug	38	80-K	6	B	Alundum	Vitrified
Housing, automobile axle		46-N	5	B	Alundum	Vitrified
Monel metal		46-L	5	B	Alundum	Vitrified
Piston rods (locomotive)		46-M	5	B	Alundum	Vitrified
Pistons:						
Aluminum	37	36-J	7		Crystolon	Vitrified
Cast iron	37	36-K	7		Crystolon	Vitrified
Pulleys, cast iron	37	30-J	8		Crystolon	Vitrified
Reamers	38	46-M	5	B	Alundum	Vitrified
Rifle barrels		46-M	5	B	Alundum	Vitrified
Rolls:						

TABLE 3.—WHEEL RECOMMENDATIONS FOR CYLINDRICAL GRINDING (NORTON).—(*Continued*)

Work to be ground	Abrasive	Grain and grade	Structure	Bond	Abrasive (trademark)	Bonding process
Alloy chilled iron	37	20-Q	4	T2	Crystolon	Bakelite
Brass or copper						
Roughing	37	46-L	3	L	Crystolon	Shellac
Finishing	37	100-I	9		Crystolon	Vitrified
Cast iron						
Roughing	37	30-K	5		Crystolon	Vitrified
Finishing	37	80-J	7		Crystolon	Vitrified
Chilled iron						
Farrel-type machine						
Roughing	37	30-L	5	L	Crystolon	Shellac
	37	36-L	5	T2	Crystolon	Bakelite
Finishing	37	70-J	4	L	Crystolon	Shellac
Norton-type machine						
Hot-plate rolls	37	24-N	5		Crystolon	Vitrified
Dryer rolls	37	46-J	6		Crystolon	Vitrified
Steel-hardened						
Farrel-type machine						
Roughing		80-M	5	L	Alundum	Shellac
Finishing	37	320-I	8	L	Crystolon	Shellac
Norton-type machine	38	46-L	5	B	Alundum	Vitrified
Roughing	38	100-I	6	B	Alundum	Vitrified
Polishing	37	500-I	9	L	Crystolon	Shellac
Spline shafts		50-O	5	B	Alundum	Vitrified
Steel:						
Hardened	38	46-L	5	B	Alundum	Vitrified
Soft		46-N	5	B	Alundum	Vitrified
High-speed	38	46-L	5	B	Alundum	Vitrified
Stainless	37	46-M	5		Crystolon	Vitrified
Stellite		46-M	5	B	Alundum	Vitrified
Taps, shanks	38	80-M	6	B	Alundum	Vitrified
Tungsten milling cutters						
Rough	37	60-I	9		Crystolon	Vitrified
Finish	37	100-H	9		Crystolon	Vitrified
Valve tappets		46-M	5	B	Alundum	Vitrified
Valves, automobile, stems	46	46-N	5	B	Alundum	Vitrified

variety of work coming to the grinder department. Such tables of recommendations cover all classes of work not only cylindrical, but also internal, surface, and others. If we confine a wheel schedule to cylindrical-grinding operations only, it will be seen that the grit and grade list is much reduced in variety and number. In fact, in the majority of cases the range of grain sizes and bond strength is rather closely held to some particularly adaptable numbers, as will be seen from Table 3 which is condensed to cover cylindrical work, steel, and cast iron, mainly.

This table includes 68 wheel recommendations and of the group nearly 40 per cent are for 46 grain. As would be expected, the range of hardness is rather closely confined to a few soft- and medium-grade letters, as J, K, L, and M.

Combination wheels are conspicuously in demand in general shops where jobbing work comes in limited volume so far as duplication is concerned and where range of wheels stocked is restricted to those most generally useful. In some localities it will be found that a commonly specified wheel is 24 combination grit, K grade, or L grade (Norton). Combination wheels are known as C, as 24C-K or 24C-L for the wheels referred to, and are a composite of different sizes of grains, from finer to coarser to adapt the wheel-cutting action especially to cylindrical work of certain kinds. 19C-K and 19C-L are also used commonly for a variety of work.

CHAPTER IV

THE CENTERLESS GRINDER

Reference is made in Chap. II to the Cincinnati centerless grinder which is shown in Fig. 8. The following pages explain the principles and operation of the machine and illustrate particularly the application to accurate bar finishing. See also Chap. V for description of various operations in grinding on the centerless machine.

PRECISION GRINDING OF STEEL BARS

Production of accurate round bar stock by the grinding process is an interesting branch in abrasive practice that has been developed within the past few years. Formerly the only practical methods of finishing hot-rolled round steel bars were either by cold drawing or by turning and polishing. However, the great demand for accuracy led to the adaptation of the centerless grinder for finish grinding round bars of high-carbon and high-speed steel. In addition to grinding bars to an accuracy previously regarded as impossible, the centerless grinding method removes surface defects and makes possible the inspection of the soundness of the bars.

Many tons of high-chrome or stainless-steel bars, which are later forged or turned into various shapes, are ground annually for the sole purpose of inspecting the soundness of the bar. This inspection is sure and rapid and is of value to the manufacturer of stainless steel in that it saves transportation costs and retains satisfied customers by keeping the defective material in his own plant. The customer, in turn, saves money by the elimination of labor formerly wasted in working on defective bars.

Basic Principles of Centerless Method.—The first installations of centerless grinders were for finishing cold-drawn bars of high-speed and other alloy steels. The steel is generally hot-rolled, pickled, given one pass through the cold-drawing die, annealed, and accurately straightened before going to the grinding machine.

It is very essential that these bars be straight, and the larger the diameter of the bar, the straighter it must be, because the small bars have a degree of flexibility not found in the stock of larger diameter. It is useless to attempt to grind a bar on a centerless grinder if it is not straight, and it must be straight up to the very end.

Although the functioning of the centerless grinder is generally known, a brief review of the principles of operation should help in a better understanding of the following outline of its application to the finishing of round steel bars. There is a grinding wheel mounted in a fixed housing and driven either directly from the motor or from a drive shaft in the machine frame. This wheel revolves at standard grinding speeds approximately 5,000 to 6,000 ft. per minute. Directly opposite the grinding wheel, mounted on a separate slide, there is a smaller wheel, known as the "feed" or "regulating" wheel. The machine is arranged so that this wheel can be tilted and its axis placed at any angle from zero to 7 or 10 deg. relative to the axis of the grinding-wheel spindle. This regulating wheel is driven at a much slower speed, generally from 20 to 80 r.p.m., and serves to control or regulate the rotation of the bar while it is being ground by the main grinding wheel.

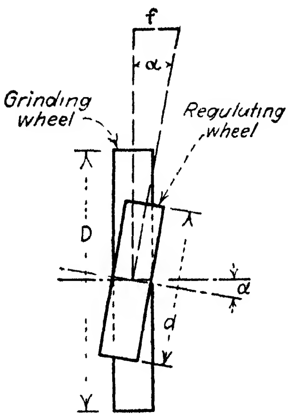


FIG. 35.—The principle of the centerless grinder.

Between these two wheels, on another adjustable slide, there is a work plate or wearing strip, generally called a "blade," which supports the bar directly at the point of grinding. The size of the bar after grinding is controlled by the distance between the grinding and regulating wheels, the adjustment for size being made by a micrometer screw and dial.

The centerless principle is illustrated in Fig. 35. The grinding and regulating wheels are plainly marked; and the angle α is the angle at which the axis of the regulating-wheel spindle is placed relative to the axis of the grinding-wheel spindle. The revolutions per minute of the regulating wheel in conjunction with the angle α determine the feed rate of the bar being passed through the machine. If this angle is increased, or if the speed of the regulating wheel is increased, or both, the feed rate of the bar will be increased proportionately. Therefore, the centerless grinder incorporates the essential elements of the ordinary cylindrical grinder; namely, means for independently varying the rate of rotation and traverse of the work.

The relation of the work being ground to the work-support blade and to the wheels may be noted from Fig. 36. This relationship has been exaggerated in order to show that the center of the bar being ground is placed slightly below a line drawn through the centers of the two wheels. This distance A, below center, is generally about ¼ in. from the center of the work to the center of the wheel. This placement of the work is contrary to the usual practice on centerless grinding machines, but is necessary in order to eliminate the whipping or chattering which might result in the grinding of a bar having slight kinks or bends that have not been entirely removed in the straightening operation. By grinding in this position the bar is held firmly down on the blade, owing to the action of the wheels.

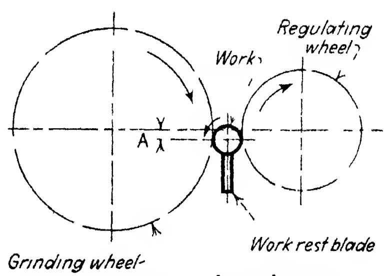


FIG. 36.—Diagram of grinding action

A bar grinding fixture is employed on the Cincinnati No. 2 centerless grinder, which is used for drill rods and screw stock. This fixture is made with long guides which extend to the front and rear of the machine. These guides are adjustable both vertically and horizontally to accommodate bars of various sizes, and should be accurately aligned in order to produce satisfactory results. They are plain strips of hardened and ground steel.

Bars True to Size within 0.0005 In.—When grinding 1-in. bars, a feed of approximately 7 ft. per minute is maintained, removing 0.005 to 0.010 in. stock in the rough grinding operation. This feed is increased to about 15 ft. per minute when grinding ½-in. diameter bars, removing the same amount of material. For roughing, a 502 ISI Aloxite silicate bond, or a 60-J-31 Aloxite vitrified bond wheel has been found to be satisfactory. If the bar being ground is of ordinary screw stock or machinery steel, a 40-M carbide-of-silicon wheel can be used. After the roughing pass the bars are put through the machine again at the same speed, removing about 0.002 in. of stock, which produces a bar the entire length of which is true to size within 0.0005 in. The finished bar is round and has a very high-grade finish. For finish grinding small diameters, a rubber-bond wheel of about 80 grain can be used, and very good results have also been obtained in finish grinding the larger bars, $\frac{1}{2}$ to $1\frac{1}{4}$ in. diameter, by using the abrasive wheels recommended above for rough grinding. These figures give some indication as to the production possibilities of the centerless grinder on the smaller size bars.

Screw Stock or Machine Steel Ground.—After a number of machines were in successful operation on drill rods, steel finishers began to experiment with the grinding of screw stock or machine steel. There was not the problem of seams or pits to worry the steel maker when handling this material, which could be easily finished by the turning and polishing or the cold-drawing methods. However, the advantages of the grinding process soon became evident on this class of work, and the users of such steel began to specify ground stock for screw-machine and other work. A number of manufacturers buy the ground steel in special sizes, which permits them to cut off the bar to the required length and assemble the shaft directly into the machine. An undersized bar, say 0.001 to 0.002 in. under nominal diameter, could be assembled in a hole which had been reamed with standard reamers. One automobile manufacturer is at present buying stock which is regularly furnished standard to 0.001 in. plus and is maintaining special reamers rather than pay the extra price for special sizes. In accuracy and finish, the ground screw stock is better than the cold-drawn bar, and the ease in obtaining special sizes without extra die cost appeals to the steel finisher as well as the user. The latter undoubtedly would ask for more special sizes if he knew that he could get them.

Machines and Fixtures for Grinding Bars Up to 4 In. in Diameter.—The average size of bars of screw stock or machinery steel is larger than the ground bars of high-speed and other alloy steels. The No. 3 centerless grinder with a new type of fixture is employed for grinding bars over 1½ in. in diameter up to 4 in. in diameter. Figure 37 shows the guides and supports for the bar, which extend to the front and rear of the machine. These are adjustable strips of hardened steel, and the bar, as it rotates and feeds along, must slide over the surface. The

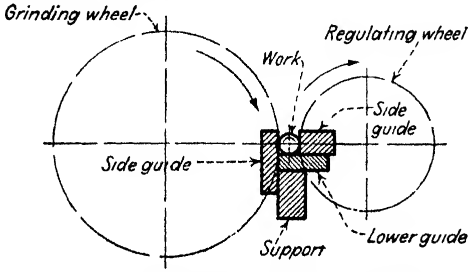


FIG. 37.—Using side guides in grinding

average weight of a 4-in. bar is about 43 lb. per foot, and with bars of this size it was found that the resulting friction between the bar and guides was sufficient to prevent rotation and feed of the bar unless exceedingly heavy cuts were taken. These heavy cuts make it impossible to finish-grind a bar, because the wheel would break down so rapidly that the finish of the bar would be impaired and would not pass inspection. Furthermore, the wheel wore so rapidly on the heavy cuts that accurate size could not be maintained throughout the length of the bar.

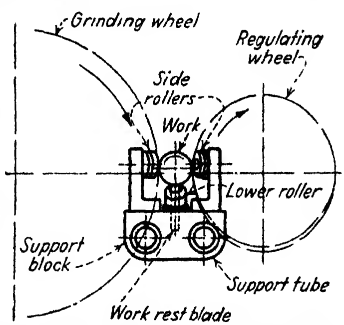


FIG. 38.—Fixture for grinding large bars.

Different Fixture for Grinding Larger Bars.—The elimination of this friction between the work and the guides, experienced with the No. 2 type fixture, was the principal object in developing the large fixture shown in Fig. 38. In this design, the bar rests upon rollers mounted in antifriction bearings and is guided between rollers similarly mounted. These rollers are placed at a slight angle to the axis of the bar and offset slightly as to the relation of the center of the roller to the center of the bar. In this way a feeding effect is obtained as the bar rotates. This action, in principle, is exactly the same as the feed or regulating wheel action described above and shown in Fig. 35, except that in this case the face of the feed wheel, or roller, is used instead of the periphery. The feeding action of the bar as it is rotated is shown in Fig. 39. Since the energy to rotate the bar is derived from the grinding wheel, but regulated and controlled by the feed wheel, it follows that the elimination of as much friction as possible when dealing with heavy bars will permit of lighter cuts, and thereby obtain better finishes.

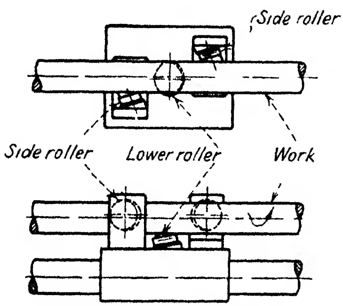


FIG. 39.—How the bars are fed.

Large Grinding Wheel for Larger Bars.—In spite of all the precautions taken to provide a fixture that minimized the friction, it was found that the slight kinks and low spots on the bar would cause it to stop rotating. To overcome this trouble, two rollers, one placed on either side of the grinding wheel, as shown in Fig. 40, are pressed by means of a spring against the bar being ground. In this manner, sufficient pressure is obtained upon the regulating wheel to rotate and feed the bar through the

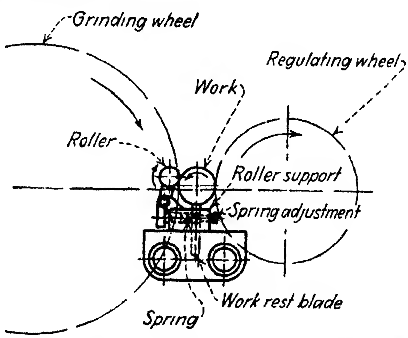


FIG. 40.—Support with rollers and springs.

machine, although the grinding wheel is not touching the work. In this, a fixture was obtained which would control the work, feed it through under any depth of cut, however small, and produce accurate and highly finished work.

In order to obtain this desirable result on a bar 3 in. in diameter, it was necessary to consider the large amount of stock which was being removed and to provide means for eliminating, as much as possible, the wheel wear that naturally resulted from the large stock removal.

An idea of the problem may be obtained in the following comparison. The stock removal on a 3-in. diameter bar 20 ft. long, in reducing the diameter 0.005 in. is equivalent to grinding over 200 1-in.-diameter by 3½-in.-long piston pins, removing the same amount of stock. Therefore, any adjustment for size which may be necessary when grinding 200 pins will be necessary

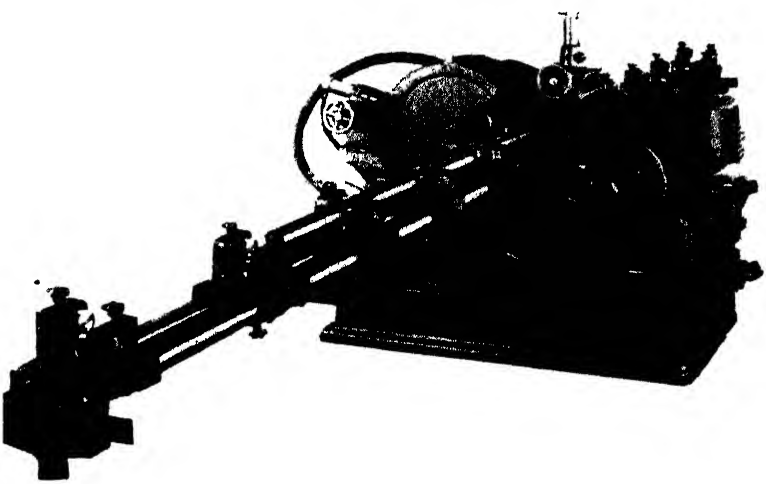


Fig. 41.—Cincinnati machine for large bars.

for each bar being ground. The natural solution was to increase the diameter of the grinding wheel. Therefore the No. 3 centerless grinder for bar work is regularly equipped with a wheel 24 in. in diameter and 6 inches wide, and there is no difficulty in obtaining a bar that is within the required limits throughout its length.

Figure 41 is a general view of the machine, showing the work-supporting fixture, or table, with a 3½-in. bar mounted in position to be ground. The action of this machine is exactly the same as that of the No. 2 grinder described above. By using this method, bars 3½ in. in diameter have been finish-ground from rough-turned stock, round within 0.0002 in. and true to size within 0.0005 in., their entire length. In "trueness" the ground bar is much better than a turned and polished bar, and the finish is superior to the cold-drawn product. A further improvement in the finish can be made by a pass through a polishing machine of the skewed-roll type, which produces an excellent surface but does not change the diameter of the bar. Three passes are usually required on work of this size, about 0.004 to 0.005 in. being removed at each pass. The production per pass is about 6 ft. per minute and it is possible to obtain a net production of approximately 1 ft. per minute.

The demand for finish-ground bars of the larger sizes is increasing rapidly and the users of this material are designing their machines in such a way that ground bar stock can be cut to length, faced, and assembled directly into the machine. There is also an advantage in the fact that bars which are intended for the automatic screw machine can be made more accurate by grinding than the usual tolerance of 0.001 per inch of diameter. A troublesome feature of screw-machine operation has been in maintaining collets that work uniformly on all bars placed in the machine, and it is well known that considerable trouble can be eliminated and time saved in the screw-machine department if bars more uniform as to size can be obtained. There is also the same possibility of economies by means of the grinding process when finishing stainless and other alloy-steel bars of the larger diameter bars. The centerless grinding method has proved tremendously successful as evidenced by the large number of machines in use.

THE HEALD INTERNAL CENTERLESS GRINDER

The principles of centerless grinding which have been so successfully used for external grinding have now been employed for internal grinding.

The principles of external centerless grinding consist primarily of passing a workpiece between a rapidly rotating grinding wheel and a slowly rotating regulating wheel upon a work rest or blade, one of the wheels being tilted to give the necessary feed to the work.

In internal-centerless-grinding machines it is not possible to pass the work through the machine, but the rotating regulating wheel, together with rotatable work rest, or stationary blade, and pressure rolls, is used. The regulating roll rotates and governs the rate of rotation of the workpiece while the grinding wheel is removing material from the bore. In this case the regulating roll takes the place of the grinding wheel of the external machine while the pressure roll takes the place of the regulating wheel thereby providing the usual grinding throat.

Through the combined efforts of the engineers of the General Motors Corporation, Cincinnati Milling Machine & Cincinnati Grinders, Inc., and The Heald Machine Company, the Heald internal centerless grinders have been developed. These grinders are entirely automatic in operation and the size of the finished bore is held within very close tolerances by either the "Size-Matic" principle or the "Gage-Matic" principle. Figure 42 shows how the work is fed into the machine, ground and ejected

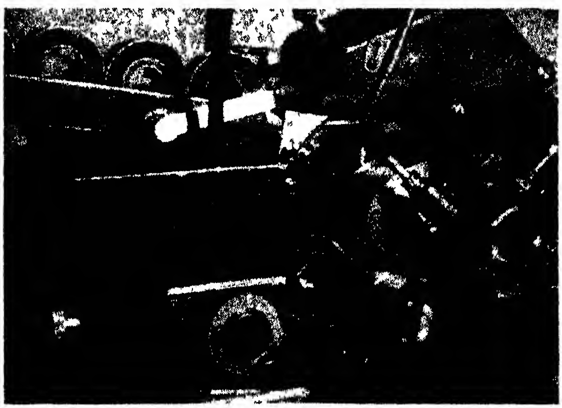


FIG. 42.—Heald centerless for internal work.

to make room for the next piece. These machines can be made with both sizing principles embodied therein whereby either type can be used as conditions warrant and the change from one type to the other is made in a very simple manner. With this type of grinder practically perfect concentricity between the bore and the outside diameter is obtained; in fact, when a workpiece is placed on an arbor and swung between centers the indicated concentricity is within 0.0001 in.

There are two ways of locating the work in internal centerless grinding which consist of:

1. Locating and squaring up from the outside diameter.
2. Locating from the outside diameter and squaring up with the back face.

When locating and squaring up workpieces from the outside diameter the lands on the rolls are slightly less than the width of the workpiece but when squaring up with the back face the lands on the rolls are narrow so that they do not have any great tendency to square up the workpiece. In order to hold the workpiece against the backing plate the pressure and regulating rolls are skewed so as to force the workpiece in the direction of the backing plate.

In setting up a machine using plug gages a finish-ground workpiece is slipped over the gages and the rolls are adjusted to contact with the outside diameter. In setting up a machine using the Size-Matic principle of size determination a special plug having a portion of its length ground to the same diameter as the outside diameter of the workpiece is used.

The centerless loading cycle starts after the finished workpiece leaves the wheel and is controlled by a hydraulically actuated mechanism which is interlocked with the table movements in such a manner that it is impossible for the table to start toward the wheel until the cycle is complete. When a workpiece is finished the table runs out to loading position where the work is ejected from the machine and a new workpiece is positioned for grinding by the loading arm. The loading arm moves in a clockwise direction and discharges the finished workpiece over the regulating roll and at the same time a cam on the loading-arm shaft actuates a work stop which allows an unfinished workpiece to leave the loading chute. The workpiece leaving the chute first rests on the back surface of the loading arm and as the arm moves in a counterclockwise direction the workpiece finally drops onto the regulating roll and is led into position on the rest roll.

As the loading arm starts in its clockwise movement, a cam on the loading-arm shaft causes the pressure roll to be moved away from the workpiece so that it can be ejected from the machine and a new one placed in position after which the pressure roll returns to its original position where it is held by adjustable spring pressure.

The speed of the regulating wheel is generally fixed and, as it drives the work by its outside diameter, different workpieces having the same general proportion between the bore and outside diameter will all run at approximately the same surface speed. If it should be necessary to change the speed of the regulating wheel for a workpiece having a large outside diameter and a small bore, it can be accomplished by changing pulleys.

The work-driving unit which provides the regulating wheel is a compact, self-contained unit, having an individual 1/4-hp. motor to drive the regulating-wheel spindle, carried on a sub-base which is pivotally mounted on the reciprocable table so that taper work can be ground. This work-driving unit is traversely adjustable relative to the table movement in order that different lots of workpieces having different outside diameters can be ground The spindle is mounted in preloaded ball bearings having automatic take-up for expansion and wear. The supporting and pressure rolls are carried by a bracket bolted to the sub-base, the supporting roll being held stationary in adjusted position while the pressure roll may be oscillated.

The wheelhead is mounted on a bridge spanning the table ways. Straight, tapered, continuous, interrupted, open, or blind holes, in parts having finished cylindrical outer surfaces, can be readily ground. By having a fixed relation between the cross slide and the control box it is possible to use positive mechanical controls.

The cross slide is actuated by means of a screw having a spring take-up to eliminate backlash.

The cross-feed mechanism is hydraulically actuated whereby a smooth, continuous feed is imparted to the grinding wheel at any rate suitable for the work being ground. By having this mechanism independent of the table reciprocations the relative speed of the table and feed of the wheel can be readily obtained, which assists materially in obtaining accuracy, finish, and production.

Using a hydraulic medium for actuating the feed mechanism makes possible five separate feed adjustments, although seven distinct functions are performed by the cross slide during each grinding cycle. These functions consist of a pick-up feed upon entry of the wheel into the work, reduction of feed to roughing feed, roughing feed to a semifinish feed, stopping of feed movement to true the wheel, a further reduction of feed to practically nothing for a spark-out feed, and finally, upon the hole reaching the predetermined size, backing off the wheel and compensating for wear due to grinding and truing.

Where an extremely high finish is not necessary, the spark-out feed can be eliminated. The cross-feed screw is directly connected to the handwheel for ease in setting up the machine.

As the table moves to loading position, the piston in the cylinder cuts off its exhaust port and forces the fluid through an auxiliary port which is connected to a vane-type motor on the end of the loading-arm shaft thus causing the loading arm to move in a clockwise direction to eject the finished workpiece. The table is reversed when the loading arm is at the top of its stroke and then the fluid under pressure from the pump flows directly to the vane motor and from there to the cylinder to cause the table to move the workpiece to the wheel, the loading arm having returned to its lower position with a new workpiece prior to the table picking up its working rate of travel. The wheelhead used with this machine is known as the Heald Red Head which has special superprecision-matched bearings and is ruggedly built for speed. Automatic compensation is provided to take care of the reduction in wheel diameter due to wear and truing whereby the wheel is always maintained in correct relation to the finished size of the workpiece.

To prevent damage to the machine when the wheel reaches its smallest allowable diameter a limit switch, adjacent to the cross slide, stops the entire machine at this time. This patented function makes it possible for an operator to run a battery of machines without the necessity of watching the wheel wear.

The main drive for the machine is obtained from a 5-hp., 1,800-r.p.m. motor mounted on the rear of the base close to the floor to minimize any vibration. There are no gears or chains employed as all drives from the motor are by multiple V belts or flexible couplings.

CHAPTER V

CENTERLESS-GRINDING OPERATIONS

The preceding chapter has shown the principles of the centerless grinder and some of its applications. The versatility of the machine is seen by comparing the range of sizes and classes of work commercially handled; from a small needle of a few thousandths diameter to a 4-in. bar of steel 18 ft. long. Figure 43 shows some of the work done on these machines.

Cincinnati Grinders, Inc., describe two primary methods of grinding the work on the centerless grinder. The following paragraphs are from this firm's description of the machine and its application to different classes of work. It should be repeated here that the centerless, as distinguished from center-type machines, has a grinding wheel and an opposed slow-moving regulating wheel which controls the rate of rotation of the work as well as the longitudinal-feeding movement, the rate of feed being controlled by the angularity of the setting of the regulating wheel.

There are two primary methods of grinding the work. One is the through-feed method in which the work passes axially from one side of the machine to the other, entering as a rough blank and being discharged as a finished product, Fig. 44. This is for straight cylindrical work. In the case of taper, form, or shoulder work, the infeed method is preferable, which consists of introducing the work either vertically or laterally into the grinding throat, steadying it in position during the grinding operation, and subsequently ejecting the work from the grinding throat.

A production chart for the through-feed method is given on page 77.

PRODUCTION CHART FOR CENTERLESS GRINDING—THROUGH-FEED METHOD[1]

The maximum rate of production in linear inches per hour obtainable on the centerless grinder operating on the through-feed method depends on the power of the driving motor, the

[1] C. W. Hopkins.

rigidity of the machine and the work-support blade, and the capacity of the grinding wheel. For a specific job the roundness, straightness, and hardness of the work as well as the finish and

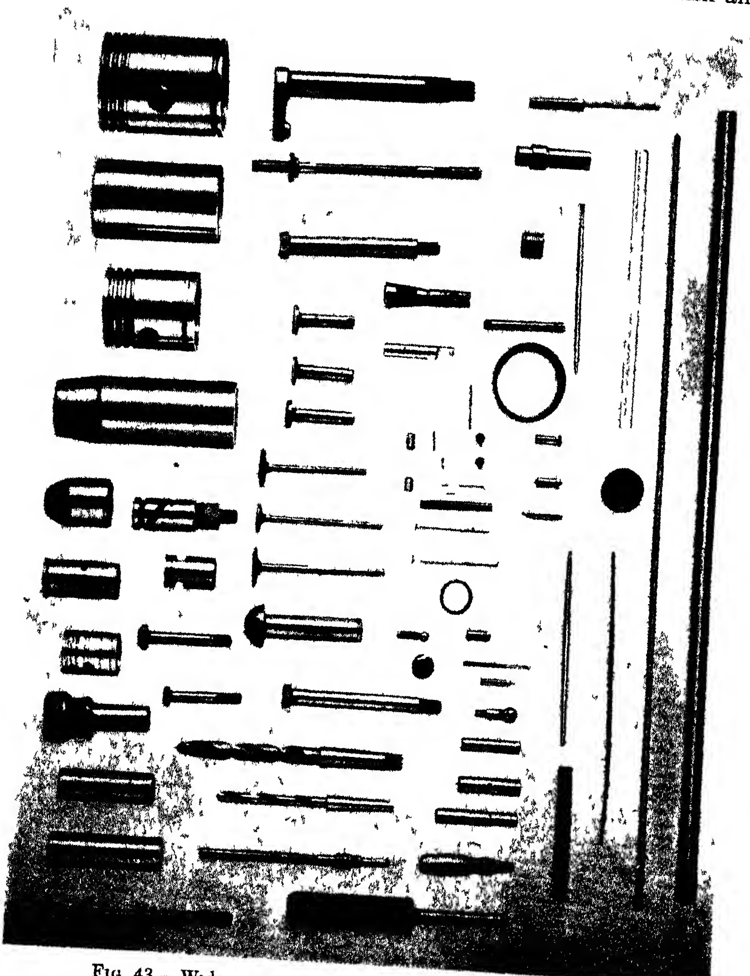


FIG 43.—Wide variety of work done on centerless machine.

accuracy desired determine whether the maximum linear traverse may be used.

The first factor to be considered in determining the maximum linear traverse speed is the depth of cut. The desired finish determines the depth of cut, which for average conditions is 0.0005 to 0.001 in. for a good finish, 0.001 to 0.0025 in. for a commercial finish, and 0.0025 to 0.010 in. for a rough finish.

The second factor is the capacity of the wheel to remove metal. This depends on the available power, the finish desired, and the suitability of the wheel. The table herewith on the chart, Fig. 44-*A*, lists the capacities of the most suitable wheel with reference to the horsepower applied and the finish desired. These capacities are based upon wheels available in 1932.

Fig. 44.—Through feeding of centerless work.

With the rate of stock removal, the depth of cut and the diameter of the work known, the maximum linear traverse is calculated as follows:

$$L = \frac{60 \times V}{3.14 \times d \times T}$$

where L = linear traverse in inches per hour.

V = volume of metal removed in cubic inches per minute.

d = diameter of the work in inches.

T = depth of cut in inches.

When the maximum linear traverse speed is known, the two adjustments of the machine for securing this speed (the speed and angle of inclination of regulating wheel) are readily obtainable. The surface speed of the regulating wheel is the same as the speed of the work. Hence a speed for the regulating wheel must be specified that will give a surface speed within the limits of good grinding practice; that is, from 20 to 60 ft. per minute, depending on the material and the desired finish. With the surface speed fixed and the diameter of the regulating wheel known, the speed of the regulating wheel is

$$N = \frac{12 \times S}{3.14 \times D}$$

where N = number of revolutions per minute.
S = surface speed of the work in feet per minute.
D = diameter of the regulating wheel in inches.

The angle of inclination of the regulating wheel is calculated from the formula:

$$\sin A = \frac{L}{188.4 \times D \times N}$$

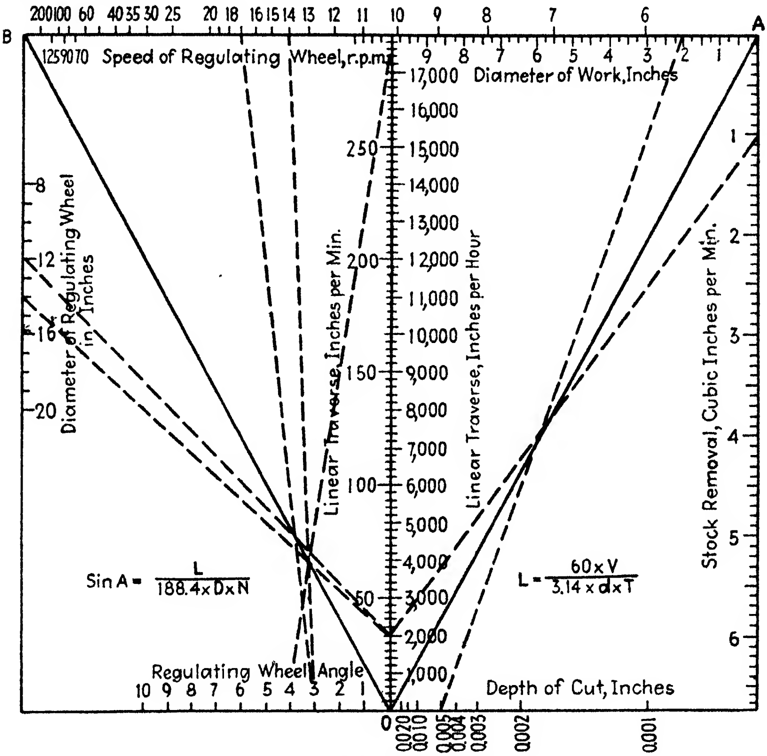
where $\sin A$ = sine of the angle of inclination.
L = linear traverse in inches per hour.
D = diameter of the regulating wheel in inches.
N = speed of the regulating wheel in revolutions per minute.

Calculating the adjustment of the centerless grinder from the above formulas is simplified by the use of the chart in Fig. 44-*A*. An example will serve to illustrate its use.

Example.—Conditions assumed are:
Diameter of work, 2 in.
Depth of cut, 0.005 in. (rough finish).
Diameter of regulating wheel, 14 in.
Surface speed, 50 ft. per minute.
Driving motor, 15 h.p.
Rate of stock removal, 1.05 cu. in. per minute.
(The grinding wheel was not the most suitable; hence the low rate of stock removal.)

On the chart, Fig. 44-*A*, connect the diameter of the work, 2 in., and the depth of the cut, 0.005 in., and note where this line intersects *OA*. Project a line from the rate of stock removal, 1.05 cu. in., through the point of intersection just found on the line *OA* until an intersection is made on the center vertical line, which shows that the maximum rate of linear traverse is 2,000 in. per hour. Next connect the traverse speed just determined and the diameter of the regulating wheel, 14 in., and note the intersection on the line *OB*. Since the surface speed is about 50 ft. per minute and the regulating wheel about 14 in., the speed of the regulating wheel is 14 r.p.m. By projecting a line from the regulating-wheel speed, 14 r.p.m., through the point of intersection just found on the line *OB*, the angle of inclination is discovered to be 3 deg. Should the surface speed of 50 ft. per minute be too great, a speed of 10 r.p.m. may be substituted and the angle would then be (see chart) 4 deg. for the same linear speed of 2,000 in. per hour.

To determine the diameter at which the regulating-wheel speed should be increased, connect the next higher speed available on the machine with the angle of inclination and note the intersection



Capacities of Grinding Wheels—Cu. In. Per Min.

Horsepower	5	7½	10	15	20	25	30	35	40	50
Good finish	0.20	0.30	0.40	0.60	0.80	1.00	1.20	1.40	1.60	2.00
Commercial	0.35	0.52	0.70	1.05	1.40	1.75	2 10	2.45	2.80	3.50
Rough finish	0.75	1.12	1.50	2.25	3.00	3.75	4.50	5.25	6.00	7.50

Fig. 44-*A*.—Production chart for centerless grinding, through-feed method.

on the line *OB*. Through the new point of intersection draw a line through the linear speed, and the wheel diameter at which the speed is to be changed will be found. As indicated on the chart, the next higher speed available on the machine is 17 r.p.m. and the diameter at which the speed is to be changed is 12 in.

Application of coolant should be at the rate of 2 gal. per minute per applied horsepower.

ROUGH AND FINISH GRINDING

The No. 2 Cincinnati Centerless will not only rough and finish, by the through-feed method, straight *cylindrical parts* to the desired limits of accuracy and at a high rate of speed, but also by the infeed method it will grind *shoulder work,* such as shackle bolts, much more rapidly than they can be ground by any other method. The increase in production results from the following:

1. The process of *grinding is more nearly continuous* on the centerless machine than on a center-type machine. The idle time taken up in loading the machine and in adjusting the wheel to the work is eliminated.
2. *Heavier cuts can be taken* because the work is supported by the regulating wheel and work-support blade during grinding.
3. *Extra operations,* such as centering and the inspecting operations which follow, *are eliminated entirely.*
4. *The amount of stock to be removed by grinding can be greatly reduced.* This not only saves time, but reduces wheel wear, which is an important factor in grinding cost.

Proper Grinding Conditions.—*The tilting regulating-wheel bracket* and the regulating-wheel *speed-change box providing* 12 *changes of speed* are responsible for the adaptability of this machine. When through-feed grinding, the speed of the regulating wheel determines the speed in revolutions per minute of the work passing through the machine and the inclination of the regulating wheel determines the feed or lap per revolution of the work. There is a proper speed and proper feed for every job, determined by the characteristics of the job, and the *flexibility* resulting from the above features is *necessary* to approximate as closely as possible these ideal conditions.

In order to round up a piston pin, a small feed per revolution and therefore a small angle of inclination of the regulating wheel is desirable. To straighten a crooked pin, a wide lap per revolution, obtained by a large angle of inclination of the regulating wheel, is desirable. Long bars, such as drill rods, etc., can be ground successfully on the machine because the speed box permits of obtaining a low range of regulating wheel speeds. Such bars are usually not straight and the tendency to whip is so great at high speeds that accurate work cannot be obtained. All long bars should be machine-straightened before grinding in order to eliminate whipping of the bars while passing through the machine. After the proper feed or lap per revolution has been established for any given job, it is possible to increase the number of revolutions of the work and consequently the number of lineal inches produced per minute, to the limit of the job, step by step, by means of the gear box.

Cylindrical work without interfering shoulders is ground by passing it transversely between the grinding and regulating wheels as illustrated in Fig. 44. Work is supported during the grinding cut by a work-support blade, mounted in the through-feed work rest (Fig. 45). This work rest is mounted on the lower slide upon which it is accurately located by a tongue and clamping bolt. It consists of a rigid cast-iron block which holds the

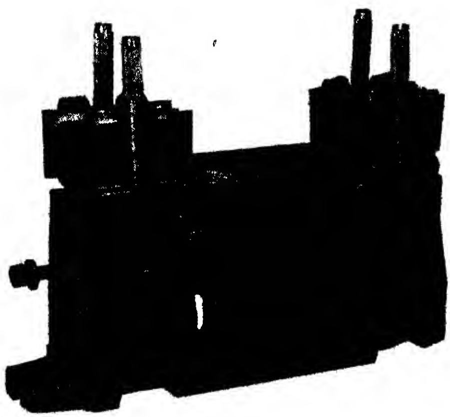


FIG. 45.—Work support for through feeding.

work-support blade and four adjustable high-speed steel work guides. Each guide can be adjusted independently by means of thumb knob or screw driver slot. Changing from one diameter work to another is quickly accomplished without dismantling the machine. Accurately machined hinges on the guides insure accurate alignment of the guides with the line of contact of the work with the face of the regulating wheel.

Two or more angular top blades are recommended with each through-feed work rest, so that, while one is in use, the other can be reground and held ready for replacement. Wearing surfaces of blades are of special alloy to provide a durable wearing surface. In some cases flat top blades are used, principally for long bar grinding. Blades are lined up parallel to the grinding wheel spindle. Work-support blades are supplied as required.

The regulating wheel is carried in a bracket which can be swiveled about a horizontal axis and clamped in any angular position required by the work being ground.

The amount of stock to be removed, the condition of the work as to roundness and straightness, the kind of material and the limits of accuracy required, determine the number of passes.

Sizing is accomplished by moving the housing carrying the regulating wheel and work rest forward on its slide to compensate for wheel wear. The work rest which carries the work-support blade is adjustable to take care of different diameter work. Very convenient means have been provided for truing both the grinding and regulating wheels accurately and quickly. Straight hydraulic truing for the grinding wheel and straight screw type truing for regulating wheel are provided as standard equipment.

Infeed Grinding Method.—*Work having shoulders or heads,* such as shackle bolts, yoke pins, king bolts, valve tappets, etc., is ground by the infeed method. With this method, an infeed work rest with either hand or automatic ejector, is usually employed. The work is laid upon the angular support blade and located endwise by an adjustable end stop which also acts as the ejector rod. A 90-deg. downward movement of the infeed lever moves the infeed slide carrying the work rest and regulating wheel forward a distance of 0.038 in. Thus work is pushed against the grinding wheel. The desired size is secured when the lever is completely down. Coincident with the withdrawal of the regulating wheel by raising the lever, the operator pushes an ejecting knob with his left hand, if this type of rest is used. The finished piece is ejected into receiving pan. However, as the automatic ejector is usually employed, its operating being controlled by the hand infeed lever, the operator uses his left hand only for loading. Figure 46 shows the infeed grinding operation being performed on valve tappets, using the infeed work rest equipped with automatic ejector.

This highly productive method produces work of accurate size and to the required finish. One of the elements contributing to the successful operation of this method is the fact that the *work* during the grinding process is *carried upon a fixed rest,* there being no nonrigid elements anywhere in the setup.

Work having a *slight taper* can be ground by this method; it being only necessary to true the grinding wheel or regulating wheel or both, by means of the adjustable grinding-wheel truing fixture, to the desired angle. Where very high finish or very close limits are required, it is often desirable to perform the operations in two settings, roughing and finishing. Still further refinements of finish can be obtained by using the reciprocating spindle attachment.

FIG. 46.—Infeeding of valve tappets.

The Grinding Wheel Spindle. In order to produce good work, the spindle mounting must be solid enough to absorb any tendency toward vibration and the bearings must be so designed that they can be kept in proper adjustment at all times, as regards both radial and end play.

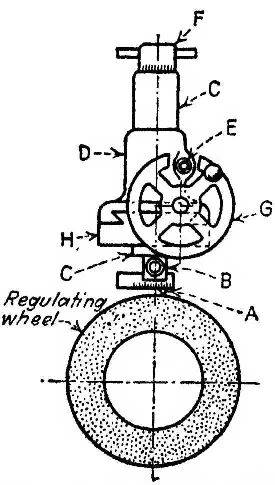


FIG. 47.—Screw-type wheel truing device.

The grinding wheel spindle of the Cincinnati centerless grinder is a heat-treated chrome nickel steel forging. It is mounted in the main frame of the machine, a casting weighing about 4,000 pounds. The spindle bearings are of the three piece plain bronze type, the lower part constituting half of the bearing. The lower half is anchored in place on the machine by means of clamping screws. The top bearing sections are full floating and are adjustable. The spindle itself is held down in these bearings by the downward pull of the multiple "V" belt, as the drive is from a constant speed shaft directly under the spindle.

End thrust is taken up by double row self-aligning ball bearings and it is possible to adjust the spindle accurately while running by means of the knurled thrust collar on the end of the spindle bearing.

Truing Wheels.—Straight screw-type diamond truing is standard equipment for the regulating wheel as illustrated in Fig. 47. The truing tool is usually a diamond *A*. The nib holding the diamond is secured in a bar *B* which slides in a long, adjustable sleeve *C* that is clamped to the housing *D* by a screw *E*. Accurate adjustment of the diamond is obtained by a micrometer dial *F* located on the end of the sleeve. Traverse of the diamond across the wheel is performed by turning a small hand wheel *G* on a fine-threaded screw which fits into the traverse slide *H*.

Fig 48 —Hydraulic diamond-truing device.

Provision is made for keeping an ample stream of coolant on the diamond while truing the wheel. The highest speed, 300 r.p.m., is used for truing.

Straight hydraulic diamond truing is standard equipment for the grinding wheel. This hydraulic truing for the grinding wheel positively insures an evenly trued wheel face. High-quality work results, time is saved, and the work of the operator is easier.

Truing by this method is very simple. Setting and infeeding of the diamond are accomplished in the usual way. A single, directional control lever (shown in Fig. 48) regulates the direction of diamond travel. A needle valve regulates the rate of travel. The pump in the feed box is used for operating the truing unit.

Proper positioning of swivel plate for a desired taper or straight face of wheel is obtained by means of an indicator attachment.

Profile-hydraulic-diamond-truing equipment for the regulating and grinding wheels is used in connection with multiple diameter, taper, or form grinding and is supplied at extra cost. The wheel face can be trued to any desired shape by a diamond, the movement of which, relative to the center line of the wheel, is controlled by means of a cam, an exact reproduction of the outline of the piece to be ground.

Wheel-dressing Attachments.—Rotary-type dressers of metallic type are a low-cost means of truing the grinding wheel. The

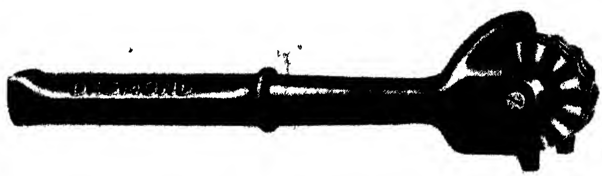


FIG. 49 Rotary-type wheel dressers

dresser is arranged to give a rough finish to the wheel which makes it extremely fast in removing metal, or fine finish for high-finish grinding (see Fig. 49). Or an abrasive rotary-type dresser with abrasive wheel in place of the metal can be used in place of the corrugated-metal disk. The action on the grinding wheel is obtained by setting the spindle of the dresser at an angle of 5 to 7 deg. to the axis of the grinding wheel, the difference in speed of the dresser periphery being sufficient to set up an abrasive action on the face of the wheel and reduce it rapidly to a truly cylindrical form.

The rotary-type dresser, of course, cannot be used for other than a cylindrical shape for the wheel. Form grinding requires the use of a diamond- and profile-truing attachment.

Typical Classes of Grinding.—A few illustrations which follow show typical jobs as ground in the centerless. In Fig. 50 the setup is shown for grinding the outside diameter of the cup or race for antifriction bearings, square with the previously machined faces. Traverse of the work across the face of the grinding wheel is performed in the usual way and the feed of the work to the wheels is obtained by means of a weight-operated carriage. Several bearings must go through at once for good results. High

Fig 50 —Grinding ball races in lots.

production and high finish and precision are essential with such work.

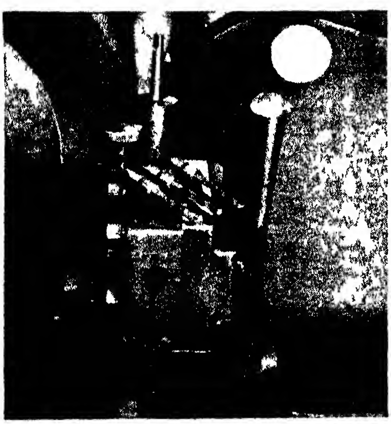


Fig. 51.—Grinding taper shanks on drills.

Figure 51 represents the successful method of concentric taper-shank-drill grinding. The essential feature is that the fluted barrel either straight or with a slight back taper, and the taper shank are ground independently and concentric with each other by means of special fixtures, thus allowing an infinite number of combinations of tapers and diameters of drills. Straight-shank drills are centerless ground automatically, using a magazine feed. The No. 3 centerless grinder is set up for grinding large-sized rivets (Fig. 52).

The standard machine with the infeed work rest and automatic ejector is all that is required. The rivets shown here are $1\frac{1}{2}$ in. in diameter by 8 in. long and are ground direct from the forged stock. The face under the head is also squared up at the same time. Other examples of centerless grinding are shown in Chap. XI on Grinding Crankshafts and Motor Work.

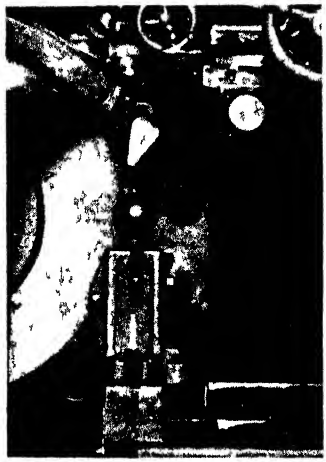


Fig. 52.—Grinding large rivets.

Automatic Hoppers and Feeds.—Reference has been made to the automatic feeds used for different classes of parts. "Feedmatic" through-feed and infeed hoppers applied to these machines eliminate manual feeding operations and one man can care for a battery of three or four centerless grinders. These hoppers are of advanced design and with a low work basin. They are individually motor-driven and easily removable and adjustable for different sizes of work.

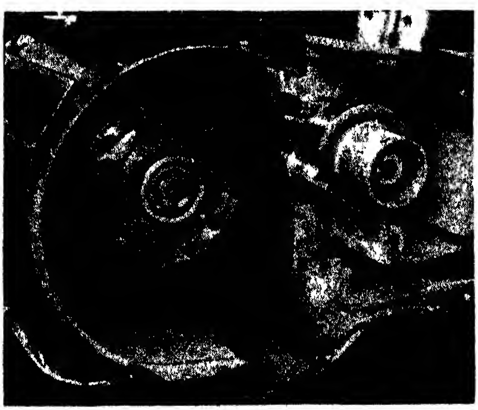


Fig. 53.—Grinding elliptical relief on pistons.

Grinding Elliptical Piston Relief on the Centerless Machine.—This operation is performed on a Cincinnati machine (Fig. 53) in the Amplex plant of Chrysler Corporation as follows:

The regulating wheel has been replaced with a nitrided six-lobe cam having between its high and low point the desired difference to give the right elliptical shape to the piston. The machine is arranged with an automatic infeed attachment. After the operator has inserted a pin through the piston pinhole of the piston and engaged it with the driver, he presses the starting button which moves the regulating slide forward; simultaneously the work driver begins to turn in synchronism with the regulating-wheel cam, so that the piston is ground elliptically in the proper relation to the piston pinhole. After the grinding cycle is completed, the regulating-wheel slide returns to its starting position and the work driver stops. This permits the operator to load and unload the work while it is not rotating.

This method of grinding is principally a generating method, the shape of the piston being generated by its movement to and from the grinding wheel, which is influenced by the multiple-lobe regulating-wheel cam pushing it to and from the grinding wheel over the top of the angular top work-rest blade. From this description it can be seen that the grinding is done entirely by the centerless method, and accuracy of shape and size is obtained owing to the exceptionally rigid support of the piston during the grinding operation.

An ellipse having a difference of 0.011 between the major and minor diameters is ground by the above method removing a maximum of 0.015 stock. A production of 300 pieces per hour is obtained.

This setup is duplicated for the finish grind except that only 0.005 in. of metal is removed in this operation. The piston is ground with a taper of 0.0005 in., with the greatest diameter at the open end of the skirt. Inspection is done with amplifying gages.

CHAPTER VI

EXTERNAL AND INTERNAL GRINDING

Among the important features relating to general grinding operations there are a number of points to be considered carefully. One of these is the effect of coolants, for example, the effects of temperature changes of work under process of finishing; changes in work axis owing to various conditions, etc.

The Brown & Sharpe Mfg. Co. make a number of important statements regarding the *use of coolants*, as follows.

Use of Coolant.—Coolant is used in grinding principally to keep the work cool and to prevent distortion which results if the temperature of a piece is allowed to change while it is being ground. It also serves to wash the particles of metal and abrasive from the surface of the wheel, keeping it clean and free cutting.

A very slight change in temperature will sometimes cause serious inaccuracy in a finished piece of work; especially is this so in cylindrical work when a long slender piece is being ground. If coolant is not used here, the heat generated is often sufficient to cause the piece to expand and bow toward the wheel, so that more stock will be removed than is intended, and the finished work will not be exactly round. Furthermore, its diameter will be smaller in the middle than at the ends. If cylindrical pieces of comparatively large diameter are ground dry, they are apt to be under size when allowed to stand for a little while.

Coolant should be used whenever possible on cylindrical work. In surface grinding it should be used whenever there is much hardened work to be ground, although often it can be dispensed with in grinding cast iron. Internal grinding is usually done dry, owing to the liability of error in gaging holes from which all of the coolant cannot be easily removed.

To prevent rusting of the machine and work, just enough salsoda (sodium carbonate) should be used in the water to show a slight deposit on the machine and finished work when dry.

For wet grinding Brown and Sharpe recommend a solution composed of ½ lb. sal-soda to every gallon of water. Various soluble oils are on the market and are usually more satisfactory.

The amount of coolant is also important. One expert advises 2 gal. per minute for each actual horsepower used. For continuous work the tank should hold from 2 to 2½ times the total flow per minute. For intermittent work, a tank holding 1½ times the total flow per minute is sufficient.

Other details regarding wheels and their selection will come to an operator as the result of observation and experience. Manufacturers of grinding machines and of grinding wheels, however, are in a position to give excellent advice as to the correct wheel to use where the material and conditions required are known, and until an operator becomes proficient in selecting them, it is a good plan to rely upon the judgment of the manufacturer and study carefully the characteristics of the wheels recommended.

Change of Axis of Work.—Any change of axis of work with resultant errors is caused by poor centers, carelessness in cleaning the centers, or from changes of temperature produced by the action of the wheel.

Inaccurate and, sometimes, spoiled work is the result of poorly fitting centers and, as it costs as much to produce poor centers as it does good ones, there is apparently no excuse for poor work from this cause. Care should be taken to have all of the centers of the standard 60-deg. angle and large enough to give good bearing surfaces. The centers of both lathes and grinding machines should accurately fit the centers of the work and should be kept clean and well oiled.

Change of axis of the work makes the wheel, after cutting uniformly around the entire circumference, cut more upon one side of the work than the other, which is something beyond the control of the machine operator. If the cut on one side is uniform from end to end, it is caused by the wear of both centers to the same side or by some foreign substance on the same side in each center, but these cases will seldom, if ever, occur. The cutting on one side may occur at one end, and still be concentric at the other; this is caused either by the wear of one center or by the introduction of some foreign substance.

When the change of axis is caused by a change of temperature, the cut is always deepest at a point midway between the centers, but trouble from this cause will not arise until all of the turning marks are ground out and the wheel has cut entirely around the piece.

Change in Temperature.—One should not think that when there is a change in temperature the change is necessarily sufficient to be detected by the hand. It is probable that very few pieces of steel are so uniform in texture that they will not change their outline with a very slight change of temperature, even though it be the same throughout the piece. It is also well known that the slightest increase of temperature, unevenly distributed, of a piece of steel will cause a change in outline.

For example, if the finger is placed upon one side of a bar, it will cause an elongation of the metal directly under it and the heat of the finger will be absorbed by the bar, leaving as the warmest part that portion where the heat enters.

The amount of expansion is necessarily very small, but when one considers that a "clean-cutting" wheel shows sparks with a cut less than 1/100 part of 1/1000 in., it is readily understood how a very slight change of outline can be detected by the grinding machine.

As a rule, the bar will not bend with perfect uniformity, owing to the tension within itself.

The wheel cuts more deeply in the side which is drawing toward it. This side becomes hotter as the wheel bites deeper and remains heated inasmuch as the bar does not equalize fast enough to cool between revolutions. The heat is increased at each succeeding revolution of the bar until the expansion on that side increases enough to noticeably bend it. The work is then ground only on one side of the circumference as the heating and consequent bending increase.

The heating being almost instantly equalized upon the removal of the wheel, the bar will return to its normal position and leave the other side of greater radius, so that on the next traverse of the table the wheel will cut on the opposite side, and cause the bar to bend this side toward the wheel, thus leaving it elliptical in form. If, as sometimes happens, these two bends have been exactly opposite, the next cut of the wheel will be on two points, and if the bar is of perfectly even tension on these two sides it will continue to cut both sides, but usually the bar will not bend exactly opposite at first. The successive cuts will, therefore, be somewhat as follows: first, completely around the circumference; second, on one side; third, the opposite side; fourth, at right angles; fifth, opposite again, and so on.

In grinding tubing the change due to expansion is increased, as the hollowness of the piece does not permit of such a rapid conduction of the heat to the opposite side of the axis.

It has been stated in section headed Change of Axis of Work that a bar is not affected by change in temperature until the turning marks are ground out. One reason for this is that the ridges act as a file on the surface of the wheel, causing it to cut more freely. Furthermore, there is less stock to remove when cutting the ridges and less heat is generated, and, as the surface is not continuous, there is no longitudinal expansion of the warm side of the bar.

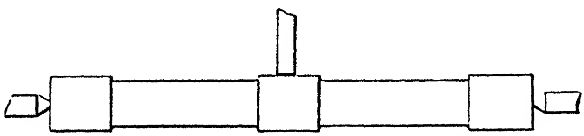


Fig. 54.—Test bar for temperature effect

For example, a test bar was made similar to that shown in Fig. 54. It was found that dry grinding would cause the bar to grind first on one side and then on the other. A bar was then made similar to that shown in Fig. 55. Grinding dry on this showed that when grinding over the surface *B* no change of outline occurred, although the heat was sufficient to turn the surface blue, but the instant the wheel cut upon the surface *C*, the piece changed its axis and ground upon one side only, cutting upon the opposite side on the return cut and grinding the whole circumference when again on the portion *B*.

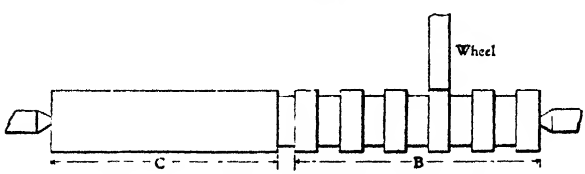


Fig. 55.—Testing in a different manner.

By using a suitable wheel and plenty of water running directly upon the work at the grinding point this change of axis will never occur.

Amount of Error in Grinding.—It is easy to be deceived as to the amount of error in roundness when judging by the sparks from the wheel. For example, a piece 36 in. long and 3½ in. in diameter was being ground showing sparks from one side only. Without correcting the error the piece was measured with a micrometer. Its error was so slight that it could not be detected and an indicator held against it while revolving showed no motion.

Another experiment was made with a hardened plug, 1 in. in diameter. It was first ground round and straight, then carefully measured, replaced in the machine, and the wheel advanced until sparks were just visible. When this amount was ground, it was again measured and found to have been reduced about 1/100 part of 1/1000 in.

Application of Wheel to Work.—When the red-hot sparks of steel pour from the bar, it is easily seen that there is considerable heat at the point of contact and, since the heat is necessarily greater at that point than elsewhere, the bar will constantly bend toward the wheel. In such cases the workman speaks of the wheel as "drawing in" when in reality it is the work that approaches the wheel by revolving with a greater expansion under the wheel than at any other point.

Necessity for Accuracy.—To obtain good results when grinding on centers, care should be taken that the center holes in the work are round and fit the centers accurately, that the centers are true, and that both are free from dirt.

Faceplates should be kept true. When necessary, they can be readily ground in place on the machine.

The graduations on a grinding machine are a great help to the operator, as they enable him to set the headstock swivel and the swivel table approximately correct, but it is seldom that the two lines can be made to exactly coincide, even with the use of a magnifying glass. Accuracy, therefore, must be secured by the use of the adjusting screw.

Error in Setting.—The grinding machine is one of the most sensitive indicators of error known. A small error in the position of the headstock swivel zero will increase the error when setting the table. Any error in setting the machine is doubled on the work.

For example, an error of 1/20 of 1/1000 in the setting of the headstock zero will give an error in the work of 1/10 of 1/1000 or more, as the point of the center is usually on a larger radius than the graduations. This alone would be sufficient to spoil the majority of work. If the point of the center is out $\frac{1}{20}$ of $\frac{1}{1000}$ in the same direction as the headstock zero, then something over $\frac{2}{10}$ of $\frac{1}{1000}$ is the error of the work, and when the same error is made in setting the swivel table the total error is still more. There is also the possibility that the footstock center is out.

Live and Dead Centers.—Work to be ground can be mounted in various ways, as follows: on the live spindle of the headstock, on the two centers, being driven by the headstock pulley; or on two dead centers, the work in this case being revolved by the dead-center pulley furnished with the machine.

The headstock pulley is frequently used for driving large work on centers. Most work, however, when ground on centers is driven by the dead-center pulley. Pieces ground internally are generally driven by the headstock pulleys. The advantage of grinding on two dead centers is that any possible error that may be in the spindle bearing does not affect the work.

In grinding straight work both ends of the work should be calipered. If one end measures more than the other, the error may be corrected by swinging the table a trifle, using the adjusting screw.

Grinding Slight Tapers.—When slight tapers are desired for either external or internal grinding the adjustment is obtained by setting the swivel table to the proper angle.

The graduations on the table scale for setting the table for grinding the taper to "degrees" indicate one-half of the included angle. The graduations for "taper per foot" and "per cent" indicate the included angle. "Per cent" of taper means 1 in 100 regardless of the unit of measurement used.

Selection of Coolants.—In connection with internal grinding the Heald Machine Company suggest that; In selecting grinding lubricants, the following conditions should be carefully considered:

The compounds used must meet these conditions if satisfactory results are to be obtained. We cannot too strongly recommend the use of only high-grade grinding compounds.

The lubricant must assist the wheel to cut free and remove stock with the least amount of effort. When grinding steel, either hard or soft, manganese, glass, or other similar hard materials, a lubricant should always be used. Cast iron is commonly ground dry, but lubricants are used depending on the kind of iron.

To obtain the best results on the grinding of steels (and certain cast irons) use the lubricant composed of soaps that wet out and spread over the work rather than the type that tend to coagulate and draw together in emulsion form. The greater wetting action creates freedom to the wheel in grinding and allows more stock to be removed.

A lubricant should be used to keep the wheel and work washed clean of grinding chips and allow the hardest wheels possible to be used. Be sure the lubricant is provided at the point of cutting between the wheel and the work, not only to assist in the cutting action, but to keep the particles of stock removed from loading onto the wheel.

When grinding bronze, brass, aluminum, and other nonferrous metals, or bakelite, fiber, and similar compositions, the grinding wheel fills or loads with chips easily, and a lubricant is required to keep the wheel clean. This, at times, eliminates the necessity of reducing speeds and permits the user to obtain the highest efficiency from the wheel.

The question of aluminum, however, is somewhat of a question in itself. The lubricant for this work must possess a very keen action of penetration, because this material being soft, tends to drag and tear rather than grind in the small-particle action as would be the case with steel. The wheel, therefore, must be saturated with a penetrant which will overcome this difficulty. Alkalies, of course, must not be used on aluminum as they tend to decompose the structure of the metal.

Kerosene and turpentine have been found beneficial in grinding aluminum and kerosene for some cast irons. As constant use of kerosene may be injurious to the operator's hand, a small amount of disinfectant can be mixed with the kerosene. To prevent fire hazard, carbon tetrachloride, amounting to 2 per cent of mixture, may be used.

Temperature Control.—One of the main objects in using a lubricant is to keep the temperature of the work lowered and uniform. Heat expands and distorts work. If the piece of work being ground is expanded at the time it is measured in the machine, the size will change when the work is removed from the machine and cools off and contracts.

Water is a cooling agent and when mixed with the compound, provides an abundance of cooling for the work. Always use plenty of coolant and see that the temperature of the work is kept as near room temperature as possible. On large installations special cooling systems are used to control the temperature of the coolant.

If the section around a hole is thin, heat, which is always generated in any material by the wheel when grinding, becomes excessive. This is due to the small amount of material which is unable to absorb and distribute the heat. It results in distortion or shrinking of the part ground which causes rejection of the finished parts held to a close tolerance.

A coolant must be used where it is necessary to maintain proper temperature and prevent distortion. Although a better finish may be obtained on cast iron without a lubricant, a coolant may be required to prevent heat distortion and keep the work within the size tolerances.

A correct lubricant will ordinarily assist the wheel to produce the desired finish, with the exception of cast iron where dry grinding finishes are mostly preferred. The lubricant must be kept clean, and where very fine finishes are required, the lubricant should be carefully strained to prevent scratches on the finished ground surface. The lubricant should also possess the ability to settle the grinding chips in the tank, keep the system as free as possible from collecting sediment, and be capable of being properly strained. It is necessary that the particles washed from the operation are settled in the tank and not returned into the system. Constantly washing the work clean helps in producing a satisfactory finish. The grinding lubricant should also prevent the work from rusting when it is left standing around after being ground.

The lubricant must stay permanently mixed with the water and keep the machine clean as well as the pipes in the cooling system to prevent any interruption of the flow of the lubricant from the tank to the work.

The lubricant should remain free from any objectionable odors to maintain the comfort of the man using lubricant. Lubricants that will not infect cuts are preferable for the health of the operator.

Proper lubricants will permit gages to enter work freely without sticking. This decreases gage cost by lengthening the life of the gages. A high grade *grinding compound meets* the conditions outlined in this section.

When grinding laminated irons or steels used in motor stators, it becomes necessary to grind dry because of the danger of any lubricant getting in between the laminations and later causing electrical difficulties in the user's product.

EXAMPLES OF GENERAL WORK

Illustrations of important grinding operations could be presented in practically unlimited numbers if space would permit. The object of certain views which are included in the following engravings is to give suggestions in a general manner of the principles under which a variety of work is handled in the grinding operation. These views are presented as showing different makes of grinders and different ways of doing the work.

For example, in Fig. 56 a railroad-shop job is illustrated, the grinding of a 5-in. piston rod (with 27-in. piston in place) in a Cincinnati machine. This grinding operation has become a

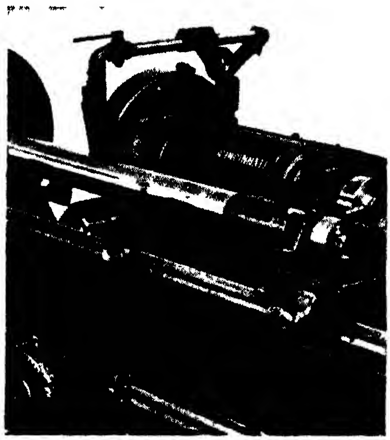


Fig. 56.—Grinding a 5-in. piston rod.

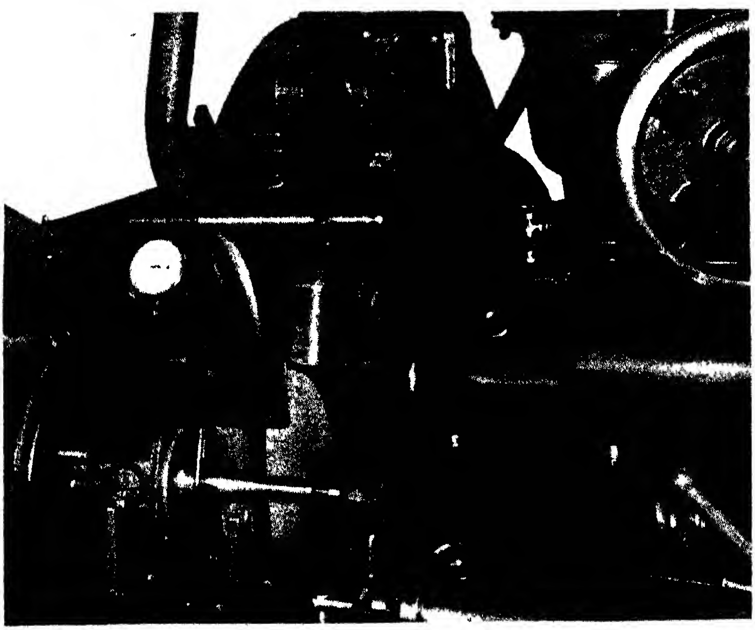


Fig. 57.—Two wheels at work on steering knuckles.

typical one in railroad shops and does much to advance the work of piston overhauling.

Various Illustrations.—Grinding of steering knuckles with two bearings finished simultaneously on a Landis machine is shown in Fig. 57. Figure 58 suggests many grinding cuts that can be made in the universal machine, in this instance a hydraulic type of the above make. For manufacture, for toolroom work, or for repair the facilities of the grinder are of universal adaptability.

A Time Chart.—Figure 59 is a chart for cylindrical-grinding time. This chart is laid out for hardened steel, for which an economical work speed of 30 to 35 ft. per minute is best for

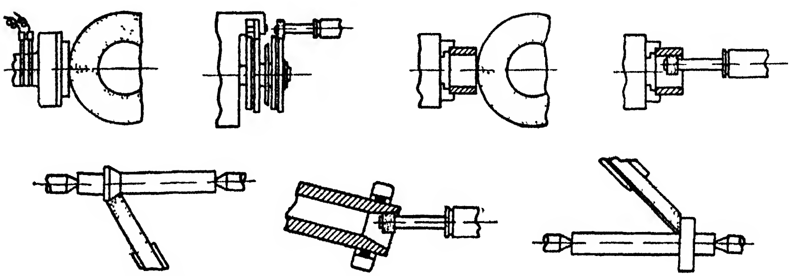


Fig 58.—Diagrams of work on the universal grinder

roughing and 50 to 60 ft. per minute for finishing. Similar charts for soft steel and cast iron can be made by resetting lines "Work Speed—Roughing" and "Work Speed—Finishing." Both lines are slightly inclined because with increase in work diameter a slightly higher work speed should be used. Lines marked "Table Speed—Roughing" and "Table Speed—Finishing" are laid out for a table feed of $\frac{3}{4}$-in. wheel width for roughing and $\frac{1}{8}$ in. for finishing.

Example.—Hardened-steel pin: 1.5 in. in diameter; 6 in. long; grinding allowance, 0.015 in.; stock removal, 0.010 in. for roughing, 0.005 in. for finishing; feeds roughing, 0.001 in.; finishing, 0.00025 in.

On the lower half of the chart find the work diameter and follow the dash line to "Work Speed—Roughing" and "Work Speed—Finishing." Values are 85 and 145 r.p.m. The dash line divides at "Table Speed—Roughing" and "Table Speed—Finishing," because of the different table speeds. Values are 63 and 18 ft. per minute. Going to the upper half of the chart and taking into account the different wheel feeds for roughing and finishing and selecting a table travel of 8 in., it will be found that roughing time is 0.64 min. and finishing time is 4.4 min., not including setting up or handling.

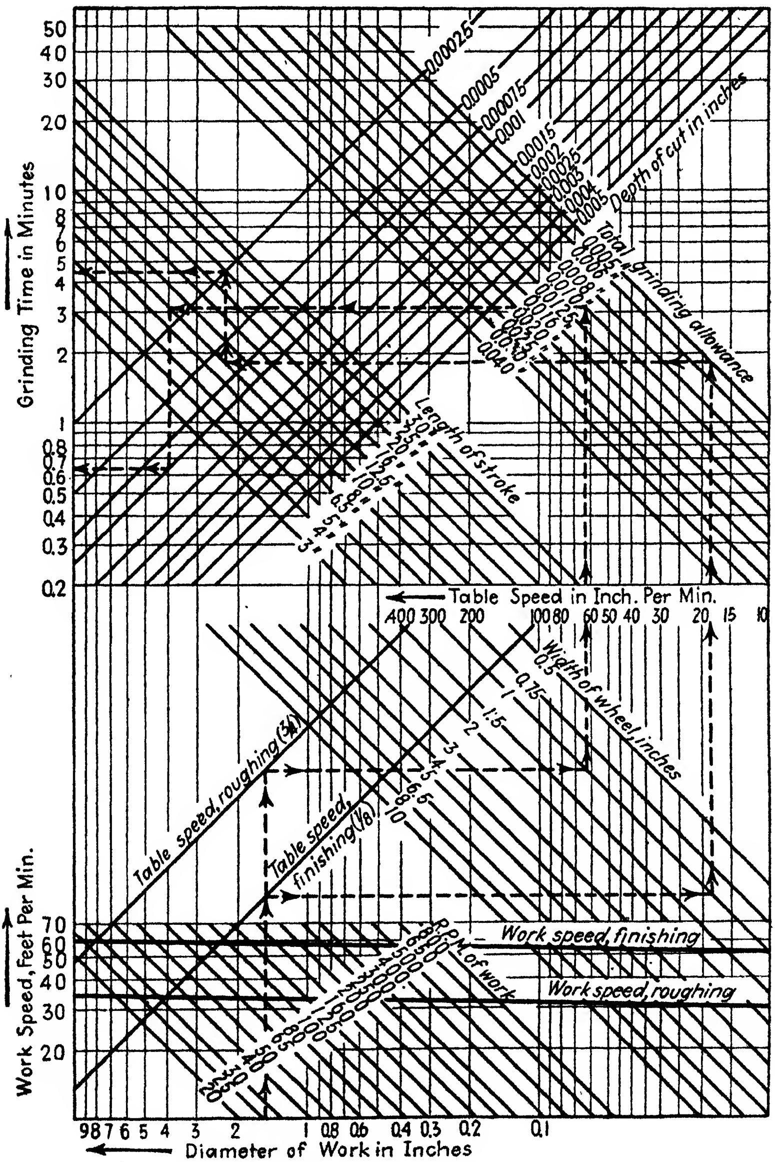
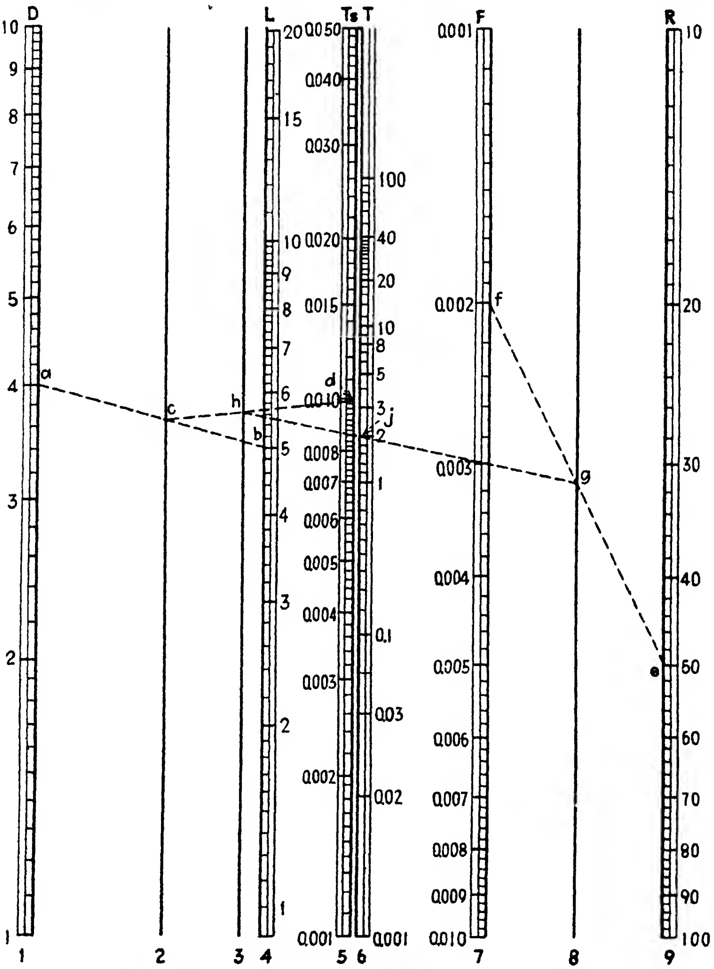


FIG. 59.—Chart for cylindrical-grinding time.

Another Chart for Straight Shafts.—Grinding time in minutes for straight shafts may be determined from the accompanying



Formula $T = \frac{D \times L \times T_s}{F \times R}$

Example $T = \frac{4 \times 5 \times 0.010}{0.002 \times 50} = 2$ *min.*

Where T = *Time in minutes*
D = *Shaft diameter in inches*
L = *Length of shaft in inches*
T_s = *Grinding stock allowance in inches*
F = *Feed per revolution of the work*
R = *R.p.m. of the work*

Fig. 60.—Grinding time for straight shafts.

chart (Fig. 60). To ascertain the time of the complete cycle, an allowance for handling time must be added to the result thus obtained.

Example.—Let

$$D = 4 \text{ in.} \qquad F = 0.002 \text{ in.}$$
$$L = 5 \text{ in.} \qquad R = 50 \text{ r.p.m.}$$
$$T_s = 0.010 \text{ in.}$$

Connect value of D—Point a, Scale 1—with value of L—Point b, Scale 4. From the intersection of ab with Scale 2 at Point c, draw a line to the value of T_s—Point d, Scale 5. Join the value of R—Point e, Scale 9—with the value of F—Point f, Scale 7. From the intersection of ef with Scale 8 at Point g, draw a line to the intersection of cd with Scale 3, at Point h. Where gh cuts Scale 6 at j will be found the value of T—in this case 2 min.

Power Required for Grinding.—Tests by an experienced engineer give interesting results as to the power required to remove metal by grinding. The power as given is the actual horsepower that it is necessary to apply to the spindle of the grinding machine to remove various amounts of metal. The metal removed is given in cubic inches per minute. It averages 10 hp. per cubic inch as follows:

Grinding horsepower applied to spindle to remove

Cu. In. Cast or Steel per Minute	Hp.
½	5
1	10
1½	15
2	20
2½	25
3	30
3½	35
4	40

Some Internal Operations.—A few illustrations here will show the versatility of the internal grinder in finishing bores of cylinders, gears, bushings, collars, and a host of other lines of work. An airplane-cylinder grinder is shown in Fig. 61. This is a precision development of the first order. The makers (Heald) are builders of a number of other types of internal machines, several of which are included in different sections of this book.

Examples of internal grinding in such machines are presented in the group (Fig. 62). Different setups for typical jobs are shown in Figs. 63 to 66. The first is for a double spur gear held in a Heald sliding-jaw collet chuck. The "runout" of both steps of this double gear was held to within 0.002 in. by means of this chuck. In Fig. 64, perfectly constant wall thickness was

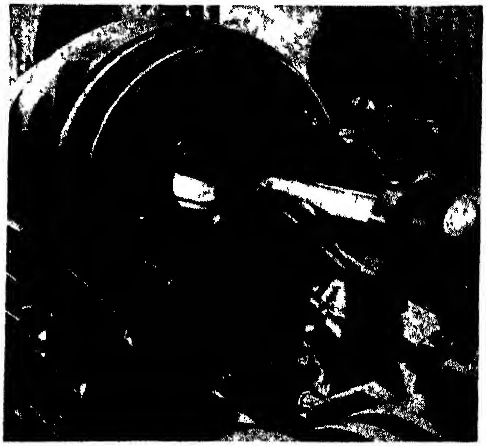


FIG. 61.—Heald internal grinder on cylinder work

FIG. 62.—Examples of internal grinding.

obtained on this sleeve with the type of fixture designed by the grinder builders for this job. The fixture is a snug fit for the sleeve and the work is drawn into place hydraulically and removed by ejector pins.

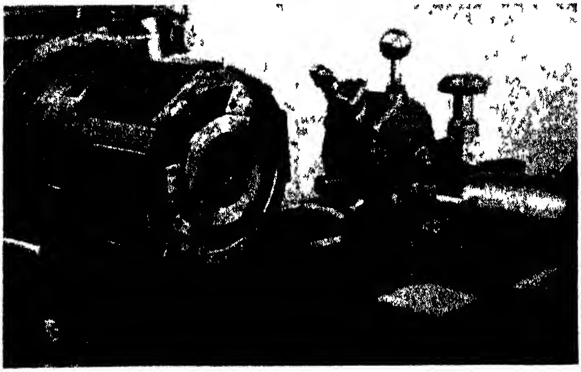


FIG. 63. Fixture for grinding holes in gears

The refrigerator cylinders (Fig. 65) required a degree of interchangeability under conditions where an error of 0.0002 in. in location would be sufficient for rejection. A Heald finger

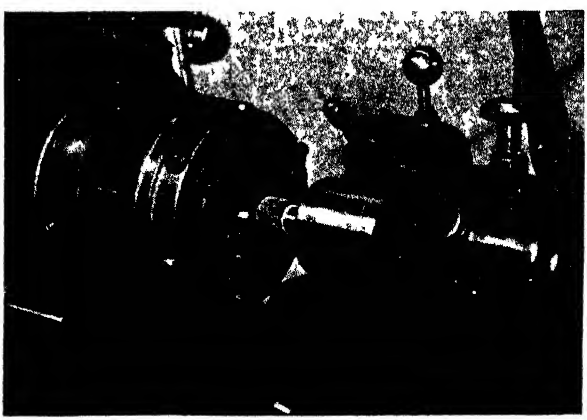


FIG. 64.—Chuck for grinding small cylinders.

combination fixture was used making it possible to manufacture these parts commercially on an improved standard of quality. The built-up index fixture (Fig. 66) is used for obtaining absolute concentricity of the four chaser cam holes with the center line of the die head, as well as uniformity of chordal distance between them. These views show typical jobs in this internal machine.

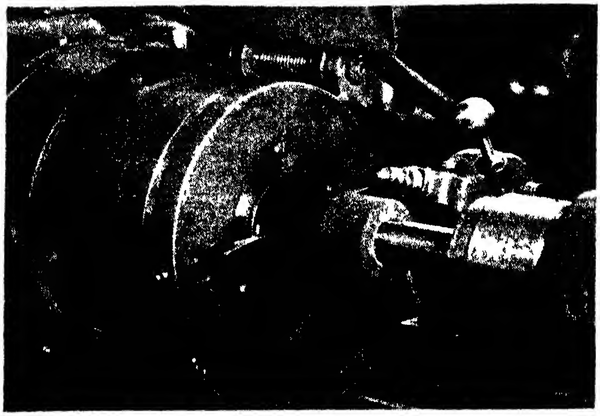


Fig. 65.—Holding bushings and sleeves for grinding.

Spindle Speed for Small Holes.—One of the problems in securing efficient metal removal in small-hole grindings is to obtain spindle speeds sufficiently high to enable the wheel to cut to best advantage. The reason for this problem can be seen in the accompanying table which has been worked out by an engineer

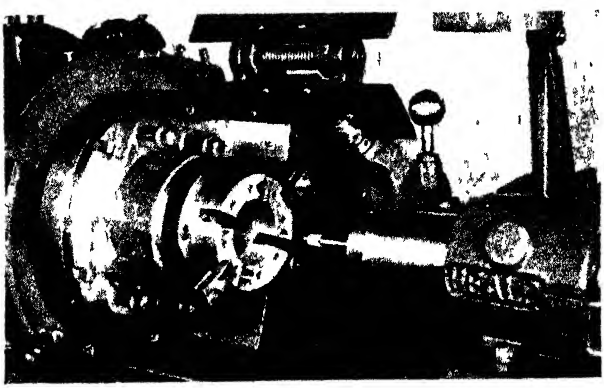


Fig. 66.—Grinding small holes in dies and tools.

experienced in the grinding of small holes. For speeds of even 20,000 r.p.m., as recommended for ¼-in. holes, are not available on all machines. The table follows:

GRINDING SMALL HOLES

Diameter, In.	Spindle Run at R.p.m.
1/16	59,000
3/32	37,000
1/8	29,000
3/16	23,000
1/4	20,000
3/8	17,500
1/2	15,000
3/4	11,000
1	7,500
1 1/2	5,000

Data on Internal Grinding.—Tables 4, 5, and 6 represent the practice of the Heald Machine Co. and are the result of many years of active experience in the field of internal grinding. Table 4 gives the amount of stock which should be left for internal grinding, this it will be noted, depending on the length of the holes to be ground. Table 5 shows the amount of stock to be removed in the roughing and finishing cuts. Table 6 contains suggestions for selecting the length of wheelhead spindle nose necessary for the work to be done. Spindles should, of course, be

TABLE 4.—APPROXIMATE STOCK DISTRIBUTION—HEALD AUTOMATIC INTERNAL GRINDERS

(Based on uniform stock condition)

For No. 72*a* machines				For No. 81 machines			
Total	Rough	Semi-finish	Finish	Total	Rough	Semi-finish	Finish
0.005	0.003	0.001	0.001	0.005	0.0032	0.001	0.0008
0.006	0.004	0.001	0.001	0.006	0.0042	0.001	0.0008
0.008	0.006	0.001	0.001	0.008	0.0062	0.001	0.0008
0.010	0.007	0.0015	0.0015	0.010	0.0075–0.0077	0.0015	0.0008–0.001
0.012	0.009	0.0015	0.0015	0.012	0.0095–0.0097	0.0015	0.0008–0.001
0.015	0.0115	0.002	0.0015	0.015	0.0118–0.012	0.002	0.001 –0.0012
0.018	0.014	0.0025	0.0015	0.018	0.0143–0.0145	0.0025	0.001 –0.0012
0.020	0.016	0.0025	0.0015	0.020	0.016 –0.0165	0.0025	0.001 –0.0015
0.025	0.0205	0.003	0.0015	0.025	0.0205–0.021	0.003	0.001 –0.0015
0.030	0.025	0.0035	0.0015				
0.035	0.0295	0.004	0.0015				
0.040	0.034	0.0045	0.0015				
0.050	0.0435	0.005	0.0015				

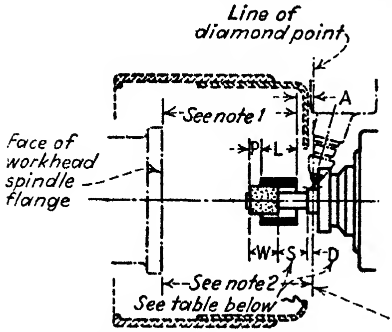
kept as short as possible to secure maximum stiffness. While this refers directly to the Heald No. 81 machine, the suggestions will be helpful on any machine.

Table 5.—Suggested Stock Required for Internal Grinding under Average Conditions and Rigid Wall Thickness

(For Hardened Steel. Stock is Given for Diameter of Hole and Excludes Runout of Hole Due to Improper Centralization of Work in Fixture)

Diam. of hole, in.	Length of hole, in.													
	5/16	1/2	3/4	1	1 1/2	2	2 1/2	3	3 1/2	4	5	6	7	8
1/8	0.004	0.004												
	0.005	0.005												
1/4	0.005	0.005	0.006	0.006										
	0.006	0.006	0.008	0.008										
1/2	0.005	0.005	0.006	0.006	0.008	0.008								
	0.006	0.006	0.008	0.008	0.010	0.010								
3/4	0.006	0.006	0.008	0.008	0.010	0.010	0.010	0.010						
	0.008	0.008	0.010	0.010	0.012	0.012	0.012	0.012						
1	0.008	0.008	0.008	0.008	0.010	0.010	0.010	0.010	0.010	0.010				
	0.010	0.010	0.010	0.010	0.012	0.012	0.012	0.012	0.012	0.012				
1 1/2	0.008	0.008	0.010	0.010	0.010	0.012	0.012	0.012	0.012	0.012	0.012			
	0.010	0.010	0.012	0.012	0.012	0.015	0.015	0.015	0.015	0.015	0.015			
2	0.010	0.010	0.010	0.012	0.012	0.012	0.015	0.015	0.015	0.015	0.015	0.015	0.015	
	0.012	0.012	0.012	0.015	0.015	0.015	0.018	0.018	0.018	0.018	0.018	0.018	0.018	
2 1/2	0.012	0.012	0.012	0.012	0.015	0.015	0.015	0.015	0.018	0.018	0.018	0.018	0.018	0.018
	0.015	0.015	0.015	0.015	0.018	0.018	0.018	0.018	0.020	0.020	0.020	0.020	0.020	0.020
3	0.012	0.012	0.012	0.015	0.015	0.015	0.015	0.018	0.018	0.018	0.018	0.018	0.018	0.018
	0.015	0.015	0.015	0.018	0.018	0.018	0.018	0.020	0.020	0.020	0.020	0.020	0.020	0.020
4	0.015	0.015	0.015	0.015	0.015	0.018	0.018	0.018	0.018	0.020	0.020	0.020	0.020	0.020
	0.018	0.018	0.018	0.018	0.018	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.025	0.025
5	0.018	0.018	0.018	0.018	0.018	0.018	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025
	0.020	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030
6	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.025	0.025	0.030	0.030
	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030	0.035	0.035
7	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030
	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.035	0.035	0.035	0.035	0.035
8	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030
	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.035	0.035	0.035	0.035	0.035

Method of Determining Length of wheelhead Spindle Noses. Heald No. 81 Internal Grinding Machine-chucking Type



$S = (A-D) + ([L+P] - W)$

Example

When:	Then:
A = 1"	A = 1"
D = 9/16"	D = 9/16"
L = 1 3/8"	(A−D) = 7/16"
P = 5/16"	L+P = 1 11/16"
W = 3/4"	W = 3/4"
S = ?	([L+P]−W) = 15/16"

Length, spindle nose = S = 1 3/8"

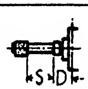
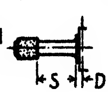
The diamond point should be located as near to the hole as possible but not closer than W + 1/4" on average holes or W + 1/8" on very small holes.

Note 1: The outer edge of the hole cannot be more than 7 1/8" from the face of workhead spindle flange and the inner edge of the hole not less than 3 1/4"

Note 2: The minimum and maximum distance of the diamond point from the spindle flange is limited to 4 1/16" and 7 13/16" respectively.

Important: Length of spindle nose "S" cannot under any condition be less than the minimum length specified in the table below.

Table 6

Style of wheelheads	Max. distance D wheelhead extension projects beyond diamond point				Minimum length S of wheel spindle			
	181	183	185	187	181	183	185	187
Quill style 	1/2	3/8	9/16	3/4	3/4	3/4	7/8	1
Naked style 	1/4	1/16	3/16	3/8	1	1	1 1/4	1 3/8
Collet style 	1 1/8	1 5/16	~	~	Minimum length S is not limited. When mounted wheel requires a smaller diameter (than the shank) next to the wheel, the length R of the reduced diameter should be equal to $(L + P + \frac{1}{16}'') - W$.			

CHAPTER VII

SIZE CONTROL IN PRECISION GRINDING

It is generally accepted by experienced manufacturers that accuracy in machine work must be controlled within close limits to assist in assembly. Improvements in methods of designing and building tools bring definite steps in advance and a still more insistent demand from tool users for even a higher grade of product from the tools. New systems of controlling quality of work and more critical systems of inspection have resulted in a degree of precision in the product from many plants that would have been impossible a few years ago. With the advances in the degree of accuracy as in the work produced there has also been an increase in output, as the methods developed for purposes of precision frequently lead to a speedier rate of operation. This may be due in some cases to the saving of time brought about by automatic gaging of work as it approaches the desired size. Undoubtedly, as in the case of certain cylindrical and internal grinding machines, the automatic sizing of the work, either outside or bore diameter, effects a considerable economy in the operator's time in gaging and testing the job as it comes down toward specified dimensions.

However, at any given period in our development there is usually a set limit for degree of precision of definite classes of work, and finer work than may be required at the time may mean extra expense to the producer, and an unnecessary cost to the customer, if the job does not necessitate actual holding to very fine tolerances. Judgment should prevail in this as in all other important matters of shop management.

To insure cheap manufacture, tolerances should always be at the maximum permissible, consistent with the correct functioning of the piece of work under consideration. It is true that there will always be a certain amount of wear to contend with, and this must invariably be taken into account when fixing the tolerances. However, every piece of equipment has a certain projected economic life, and it is a futile waste of money to build something into this piece of equipment in the way of accuracy, durability, or functions of any kind, designed to endure for a long period of time after the economic life of the equipment has been expended.

It is an extremely costly matter to attempt to produce work which approximates perfection. On this subject R. E. W. Harrison has pointed out in a paper before the A.S.M.E., that actually there is no such thing as perfection in this world. Perfection can only be attained at infinite cost and is, therefore, something which represents an unattainable ideal, but nevertheless a focal point in our observations.

Control over the limits of accuracy must be paid for in a proportionate way, not only in the time of the workman, but in the capital investment in the machine, gaging equipment, the type of factory in which the equipment is housed, the engineering, the supervision, and, in fact, every factor which goes to make up the manufacturing cost. Hence, any well-balanced manufacturing scheme should be predicated on the idea that in no single instance will a limit of accuracy be prescribed for any particular piece, which is finer than that piece need have to fulfill its functions satisfactorily and to last the anticipated economic life.

The Grinder a Sizing Tool.—It might be said that the precision grinding machine in its various forms is the sizing tool of industry, permitting us to manufacture within close limits of accuracy to degrees of finish which limit wear and, therefore, impart to the piece an economic life consistent with the capital value involved.

Closely coupled with the problem of manufacturing accuracy is the control of the finish of the piece as it leaves the grinding machine. It has been definitely proved that, according to the roughness or smoothness of the finish involved, so is the extent of the inevitable initial wear. There is a quite appreciable margin of wear on even a smoothly ground surface, and it is necessary, if correct functioning is to be obtained over the maximum period of time, that this initial wear be taken into account when fixing the limits of accuracy to which the piece should be manufactured. For instance, a running fit on a shaft which normally would have 0.0035 in. clearance between the maximum diameter of the shaft and the minimum diameter of the hole, would be automatically opened out to, say, 0.015 in. of maximum clearance after running in, if the shaft or the bore or both be ground roughly. In some classes of mechanism such clearance would be fatal to correct functioning

Close Limits Not Always Desirable.—It has been realized by those in control of the most precise manufacturing schemes, that it is futile to specify close limits of accuracy on parts which are finished with a rough surface, inasmuch as the initial wear will take the dimensions of the piece out of the prescribed tolerance area. To quote an example, it would be extremely irrational to make a 1-in. plug gage with, say, a No. 3 finish, as it is obvious that this plug gage could not retain its size and, therefore, its ability to gage correctly beyond the first few hours usage.

To quote another example, we have the modern automobile. In some classes of cars it is customary to caution the driver of a new car not to exceed a speed of thirty miles per hour for the first 500 miles. Such precaution is not necessary with most high priced cars. The difference between the two automobiles is that in some the finishes are relatively rougher and any undue pressure or load applied to them will cause a ragging of the surfaces which will lead to permanent injury. The car with more refined finishes presents no such danger, hence there is not the same necessity for speed restriction when putting the car to work.

From the foregoing, therefore, it will be obvious that in those mechanisms where accuracy within fine limits is a necessity, with this also goes the responsibility for producing those surfaces to an extremely fine finish, thereby limiting the initial wear and conserving the original limits of accuracy.

In both internal and external operations, eccentricity must first be removed before sizing accuracy can be imparted. Also lack of parallelism, chatter marks, and other imperfections must first be removed before an attempt is made to secure an accurate dimension on a given diameter.

Internal Grinding.—In the case of the internal grinding machine with the grinding wheel carried on the end of a relatively small diameter spindle overhung, and necessarily operated in a condition and a place where the maximum rigidity is difficult to attain, the previous inaccuracies of the work prior to grinding exercise a tremendous influence over the amount of time taken to secure accuracy in size, concentricity, finish, parallelism, and freedom from periodic errors.

A nice balance must be maintained between the accuracies demanded from the operations preceding grinding and the grinding operation. Sometimes this is the cause of departmental disputes. However, this matter should never be permitted to become the subject of even departmental discussion. The work processing department should invariably set down the limits of accuracy for each operation, not only for the grinding, but for the turning, the boring, the milling, and in fact for the surfacing of any portion of the piece during the operations immediately preceding grinding. In many cases it is desirable and, in fact, economically necessary to specify limits of distortion to which the piece is permitted to go during heat treatment, as it is quite conceivable that careless or ultra-rapid heat treatment, while being cheap in itself, can inject a production cost increase into the grinding operation out of all proportion to the saving effected by the speed of heat treatment or other operation, and, in fact, this one factor alone can jeopardize the efficiency of the whole manufacturing problem.

Establishing Limits.—It therefore follows that in any well-balanced manufacturing scheme, the work processing department must set up limits of accuracy and deformation for all operations preceding grinding, and this is particularly true in regard to internal grinding where the ability of the machine to remove imperfections at a fast rate is low, and the correction can only be obtained at the expense of time due to the necessarily light characteristics of the spindle construction common to all such grinding machines.

External Operations.—In the case of external grinding, as in that of internal grinding, the increased use of automatic grinding machines has brought to light many factors affecting production which hitherto had not been given that degree of consideration which their importance deserves.

Automatic-grinding-machine operations entail a consistency in preceding conditions far in excess of that required for individual or manual production, and this condition has thrown a searchlight onto such factors as excessive stock, variation in stock, lack of parallelism, eccentricity, faulty centering, excessive burrs, lack of consistency in the metallurgical make-up of the material, and a host of other minor things, all of which exact their toll from the possible profit in the grinding operation. In the case of external grinding, as in internal grinding, there is a definite responsibility on the processing department to specify the limits of accuracy to which the work should be turned, bored, and centered prior to the grinding operation. The practice of making inspections between operations is as good today as when it was first inaugurated. It pays dividends, obviates departmental disputes, and above all it results in the location of a fair amount of burden to all machines involved in the manufacturing scheme.

Surface Grinding.—There has been a phenomenal growth in the application of surface grinding during the last 15 years, and while this has entailed closer attention to details on the part of the foundry, the practice has been found economical and the results satisfactory.

The one factor which on occasion most adversely affects the economics of cheap surface grinding is the wide variation in the thickness of the pieces presented to the grinding wheel. Particularly is this true in the case of horizontal- and vertical-spindle surface-grinding operations where work is bulky and much time is lost when it is necessary to short-stroke the machine or rotate the chuck while one piece only is being ground.

It is as true of the grinding machine, as of any other machine tool, that the tool is only a productive unit when the cutting element is buried in the work. Variation in the amount of stock involves free traversing or cutting air rather than metal, and this is costly and wasteful. In this case also, the matter must be taken care of by the work processing department, and definite limits set which will insure that, while not imposing too heavy a burden on the foundry or machine shop, the stock for removal by the surface-grinding machine is not excessive in regard to amount or variety between pieces.

With internal work, drilling, boring, and heat-treatment operations are slowed down if work is held to too close limits.

With external work, center lathe, turret lathe, and screw machine production are limited by too close adherence to size.

With surface work, foundry and machining costs are inflated by too exacting demands by grinding department.

Balance Required.—While it is true that excessive accuracy demands upon the grinding machine will increase production costs, it is equally true, and even more apparent, that excessive accuracy demands on drilling machines, boring machines, lathes, milling machines, and gear cutters will boost the cost of items produced on these machines beyond the economic limit.

Here again there is necessity for good judgment and production balance on the part of the production engineering department. This responsibility, however, does not end with this department, but goes right back to the engineering department and carries the implication that the engineers assigning limits of accuracy to which parts must be manufactured be familiar with the possibilities of the machine tools on which these parts are to be made.

It is an unfortunate fact that some designing engineers are not accurately informed regarding the accuracy and producing possibilities of modern machine tools, hence the frequent assignment of limits which, if adhered to, would inflate the costs and the frequent result that limits are taken by the shops as a guide only and ignored, with consequent increase in the cost of assembly and occasionally faulty functioning. The difficulty is especially pronounced in those cases where the very nature of the product is such that components have to be replaced fairly frequently, and it is not unknown, of manufacturing concerns actually being driven out of business by the excessive costs of installing and maintaining repairs once the original installation has been sold and put to work. Nothing can emphasize more clearly the need for a sane and accurate control over the limits of accuracy to which the component parts of a mechanism are to be made.

The Design Angle.—The design angle on this problem is of paramount importance. To quote an example, within the last few years an article of general household use was designed with over 20 component parts calling for limits of accuracy within a total tolerance of $2/10$ of $1/1000$ in. The experimental models were made in a toolroom where no accurate record of the costs was obtained, furthermore there was undue optimism regarding the capabilities of machine-tool equipment to produce the components rapidly to the prescribed limits of accuracy and at a low cost. This optimism was based on inexperience and lack of knowledge, also a lack of investigation. The consequence was that a corporation of many million dollars capitalization was floated on the assumption that this article of general use could be put on the market at a low competitive figure. Seven million dollars' worth of machine-tool equipment was bought and the whole scheme of production was put into motion. A vast quantity of work was put into progress, but when it was in its final stages of manufacture then the real difficulties began.

As is usual in a manufacturing scheme of this kind, the inspection department reported direct to the management and the inspectors demanded from the production lines limits of accuracy in accordance with the figures set down by the engineering department. The whole scheme reached deadlock conditions and the tangle was eventually only solved by a redesign of the major units, whereby proper functioning was obtained with two parts only made to the fine tolerances and the remainder of the parts to commercial limits with a total tolerance of 0.0005 in. on each piece.

Engineering Capacity.—Generally speaking, engineers can be hired capable of designing mechanisms which will perform any reasonable function under almost any condition, but the real engineer is the man who can design equipment which will achieve the desired results, with the minimum number of parts, made to maximum tolerances.

The article referred to in the foregoing paragraphs is now on the market performing satisfactorily and yielding a profit to the capital interests at the back of it. However, these people have had to write off many hundreds of thousands of dollars which they can directly charge to lack of engineering experience, and lack of appreciation of the costs of manufacturing to within close tolerances.

Centerless Grinding.—With the advent of the centerless grinder in the cylindrical grinding field, a new technique as regards sizing as a part of mass production program has grown up.

To quote an example take the automobile wrist pin, an article usually ranging up to 1 in. in diameter by approximately 3 in. long, and produced to limits of accuracy of plus 0 minus 0.0002. The process by which the extreme accuracy of this component is built up is a method whose characteristics are a gradual decrease in the inaccuracies of the work. Concurrent with this is the building up of the finish until we reach the point where the work has reached its nominal size within a prescribed tolerance and the results obtained are so uniform that inspection is greatly simplified and the hazard of rejection is almost eliminated.

The grinding of work such as electric motor armature shafts when handled on center-type grinding machines, presents a somewhat similar problem, but of somewhat greater complication, inasmuch as varying degrees of accuracy are required on the different portions of the shaft. Dependent on the quantities involved and the capital expenditure which each job will stand, so must the method of sizing and gaging be evolved.

PRECISION GRINDING WITH DUPLEX WHEELS

Since the introduction of heavier and more rigid machines by builders of precision cylindrical grinders, the use of duplex grinding wheels has increased rapidly, especially in automobile manufacture. Up to eight or nine years ago, grinding machines seldom carried wheels with more than a 4-in. face. Changes in design of cylindrical grinders to give increased rigidity in the general construction now makes possible, however, the use of wheels with faces up to 10 and 12 in. in width. Particular attention was paid to the grinding wheelhead when the machines were changing in design. More rugged castings, wider sliding bearings, larger spindles, and heavier spindle bearings were provided to withstand the stresses of the larger grinding wheels. Formerly 10 to 15 horsepower was applied to grinding machines. Now this has been increased to 20 and 30 horsepower, giving increased cutting capacity. With sturdier designs to carry heavier wheels, adaptations of duplex grinding wheels naturally followed.

The duplex-grinding-wheel method has been adopted by many because of the increase in production and savings which are the result of this system of grinding. By grinding two diameters at the same time the production is doubled, as, of course, no more time is required to grind two diameters than to grind one. Typical examples of work being ground by double grinding wheels are shafts with multiple bearings of the same diameter, and short shafts and parts having two diameters of different sizes. Long shafts with bearings of the same diameter require a plunge cut for each set of bearings being ground, while small parts with two surfaces to be ground are finished in one cut.

On components with diameters of an unequal size, from which different amounts of stock are removed, it is important to select the correct grades of abrasive so that there is equal wear on both wheels. The diameter from which the greater amount of stock removal is to be made should have a tougher bonded wheel, if possible, to resist the greater degree of wear caused by the heavier cut. If such a selection of wheels is made, the necessity of frequent truings will be eliminated, and increased accuracy will result. This factor exists only when the stock removal on diameters is different, since if the diameters are the same and the same grit and grade of wheels are used the wear will be equal.

Usually when grinding with double wheels it is impossible to traverse the work so as to provide a high finish because of the interfering arms or shoulders. Where a high finish is absolutely essential, however, grinding machines are equipped with a spindle reciprocating attachment. This moves the grinding-wheel spindle slowly backward and forward in its journal bearings, and when the grinding wheel is given this movement, the diamond lines do not show on the work and the quality of finish is greatly improved. Ordinary reciprocating attachments provide for spindle movement of $\frac{1}{16}$, $\frac{3}{16}$, or $\frac{3}{8}$ in., provision being occasionally made for starting or stopping this movement by means of a lever.

Users of the duplex-grinding-wheel arrangement are agreed that each set of wheels should be mounted separately on its own collet and kept on this collet as definite economies result from this procedure. If the wheel were dismounted from its collet when changing to a different job, it would run out of balance when remounted. This would necessitate a great amount of balancing time, additional wheel dressing for rematching wheels, and increased diamond wear.

In addition to the application of duplex grinding wheels on center-type grinding machines, this method of grinding has been recently adapted successfully to centerless grinders. The development of the hydraulic loading and unloading attachment has been directly responsible for the increasing use of double-wheel mounts on centerless grinders. Prior to this development it was impossible to load work with interfering arms or shoulders between the grinding and regulating wheels with safety. Now, however, hydraulic loading attachments handle work faster so that it can be ground more economically with double wheels, deposit the work in exact relation to the wheels, and eliminate the danger to the operator during loading, which was previously encountered.

Some of the applications of this method of grinding and the economies derived from it are to be seen in the accompanying illustrations of both center-type and centerless grinders. Figure

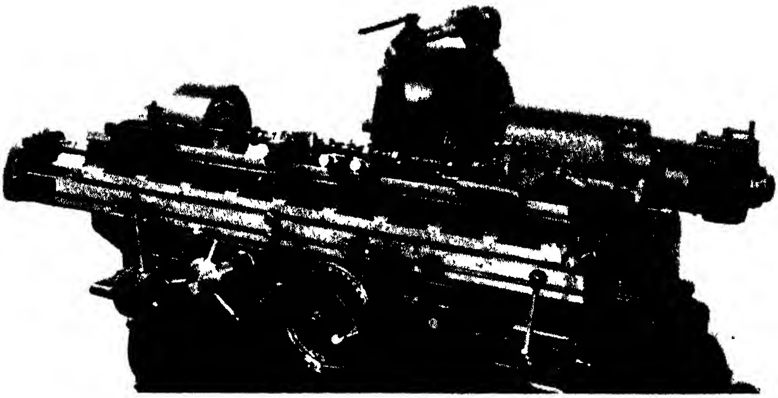


FIG. 67.—Using duplex wheels on camshafts.

67 shows a setup for grinding four bearings of an automobile engine camshaft on a Cincinnati 10- by 36-in. saddle-type grinder equipped with duplex grinding wheels. The production on this operation is 36 shafts per hour, which is more than twice the production obtained on a single-wheel grinder. The accuracy of the work is directly proportionate to the accuracy with which the wheels are sized before grinding. This machine is equipped with the spindle reciprocating attachment which moves the grinding wheels backward and forward and imparts a high finish to the work. Two bearings are ground simultaneously, after which the work is indexed to a new position for grinding the remaining two, making a total of four bearings in one setting of the camshaft.

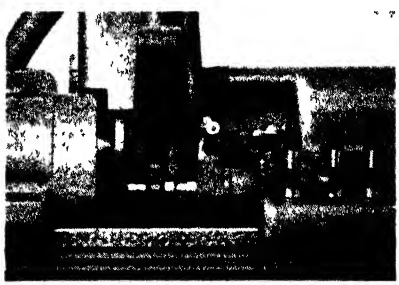


FIG. 68.—Another double-wheel setup.

Figure 68 shows a Cincinnati 10- by 18-in. saddle-type grinder with double grinding wheels for grinding two diameters on hardened-steel hydraulic shock-absorber rocker shafts. Both bearings are of different length and diameter and are separated by the rocker arm, which, as the work is rotated, passes between the two wheels. By grinding these two diameters simultaneously a production of 96 completed shafts per hour is obtained, 0.020 in. of stock being removed by the ¾-in. and 1¼-in. face wheels. Many grinding operations in the transmission parts of automobiles such as steering knuckles, universal joint spiders, gear-box shafts, and so forth, lend themselves to the multiple-wheel method of grinding two or more diameters at one time. In addition to effecting economies in the production of these parts

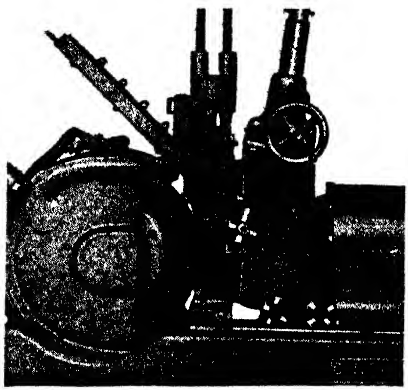


Fig. 69.—Grinding universal-joint spiders.

by duplex grinding on center-type machines, some of them may be even more economically ground on centerless grinders.

The grinding of two arms of a universal-joint spider by duplex wheels on a Cincinnati No. 2 centerless grinder is shown in Fig. 69. Work is placed in the inclining chute of the hydraulic loading and unloading fixture, and the machine works automatically. As the elevator part of the fixture rises, one piece of work is released from the chute and passes by gravity on to the work-carrying fingers and is lowered by action of the hydraulic cylinder on the slotted work-support blade. The automatic infeed attachment immediately brings the duplex regulating wheel forward, thus feeding the arms of the spider to the duplex grinding wheel. The spacer between the wheels allows the rotation of the two arms not being ground. As the regulating wheels back away, fingers carry the piece upward where it is ejected into the receiving chute over the regulating wheels. It is stated that with a stock removal of 0.010 in., the limits for roundness are held within 0.0002 in , and for straightness and

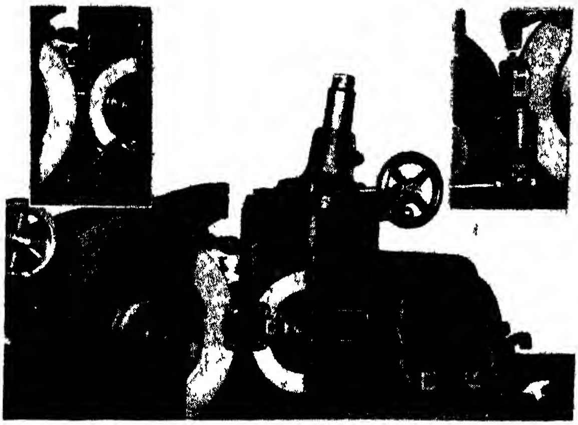


FIG 70 - Setup for automobile stub axles

size within 0.0005 in. and 0.0002 in., respectively. Net production of grinding four arms complete totals 200 pieces per hour. All wheels have a 1-in. face.

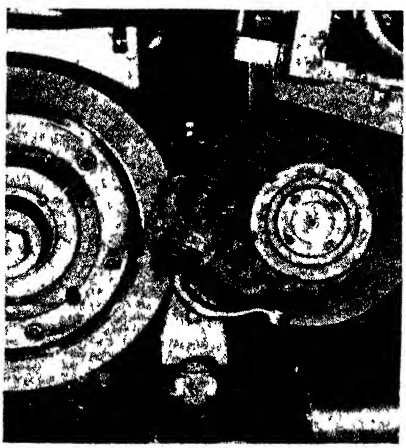


FIG. 71.—Another automobile stub-axle job.

A double-grinding-wheel mount for grinding automobile stub axles on a Cincinnati No. 2 centerless grinder is shown in Fig. 70. The unbalanced axle spindles are firmly held in the grinding position on a stepped work blade by means of an overhead equalizing pressure shoe. Details of the arrangement are shown in Fig. 71.

Although two grinding wheels are used, only one regulating wheel is employed, it being trued with the proper step to provide accurate feeding of work to grinding wheels. It is stated that a net production of these parts with 0.015 in. stock being removed at one cut is 200 an hour, and limits for size are held within 0.0005 in. A spindle-reciprocating attachment is used to assure a high finish to the work.

In Fig. 71 the taper or stub end of a steering knuckle is being ground at both ends in a centerless grinder. The work is inserted with the guide wheel withdrawn, and the movement of this guide wheel toward the grinding wheel gives the desired in-feed.

The foregoing illustrations are typical of the jobs being ground with duplex grinding wheels and with increasing demand among manufacturers for high production and more economical grinding methods, duplex-grinding-wheel arrangements will undoubtedly be applied to many more jobs as their advantages become more generally known.

CHAPTER VIII

EXAMPLES OF PRECISION GRINDING

A few illustrations of various grinding operations are presented in this section showing in certain instances remarkably accurate classes of work. They are typical of requirements as to precision, in the finishing of some classes of machine and tool elements and also illustrate methods of holding different parts that are to be ground to precision limits.

PRECISION WORK ON REFRIGERATOR PARTS

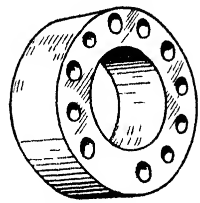


FIG. 72.—A finished cylinder of steel, hardened and ground. It is located from a previously ground dowel hole.

A method of finishing hardened-steel compressor cylinders is by the use of a Bryant machine. Figure 72 shows a finished cylinder. A previous operation has ground a 3/8-in. dowel hole in a small machine. This removes 0.003 in. of stock to a tolerance of 0.0003 in. at the rate of 30 per hour. The second operation is to grind the

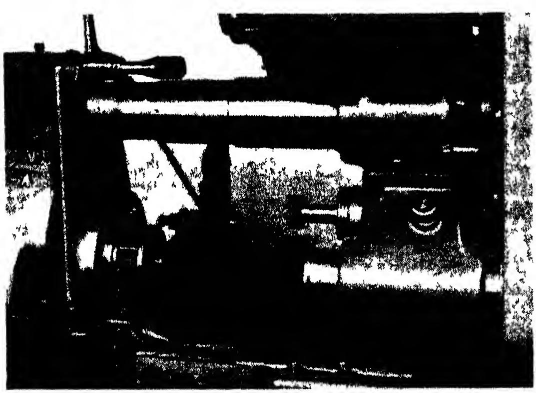


FIG. 73.—The setup used on a Bryant machine for grinding both the central hole and the outer face at one setting.

central bore, 1½ by 1¼ in., and finish the face, which is 3 in. in diameter. Figure 73 shows a similar job set up in a machine.

Locating from the ground dowel hole the piece is held in a draw chuck as in Fig. 74. This chuck is shown in detail in Fig. 75. The hole is ground by one spindle as at *A*, after which

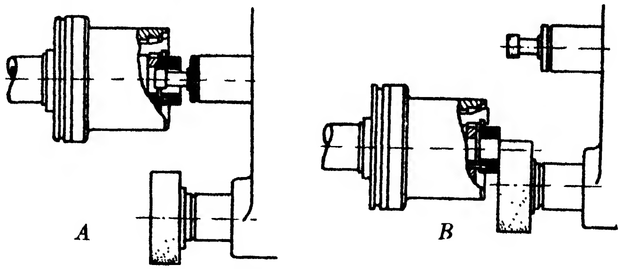


FIG. 74.—Showing how the hole is ground by one spindle and the face by the cup wheel.

the larger cup wheel comes into play as at *B*. Finishing the hole requires the removal of 0.010 in. of stock while the face is cleaned up perfectly square, at the rate of 20 pieces per hour. The hole tolerance is 0.0003 in.

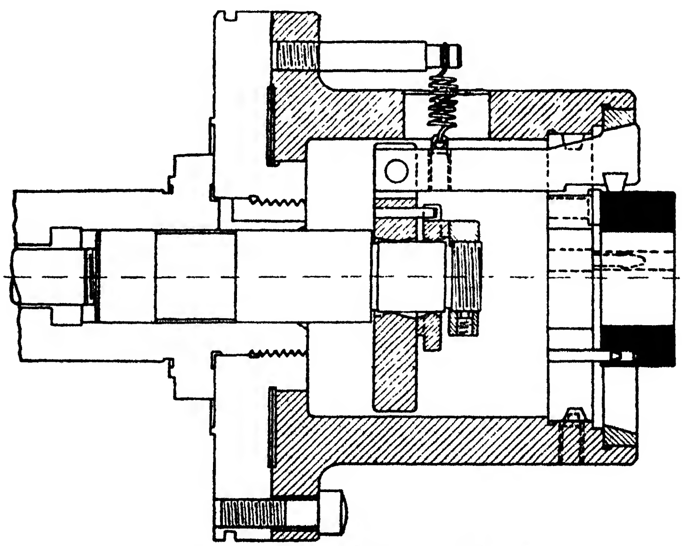


FIG. 75.—Details of chuck or holding fixture and the dowel pin which locates the work.

The hardened-steel bearing plate Fig. 76 fits at the end of Fig. 72. The hole is 5/8 by 3 in. with a 3-in. flange. With 0.006 in. of stock left for grinding the production rate is 20 per hour. The hole tolerance is 0.0004 in. The face of both cylinder and bearing plate must be gastight when bolted metal to metal. The grinding positions of the two wheels are shown in Fig. 77. Details of the draw-in chuck used for holding this piece are shown in Fig. 78.

A somewhat different piece, the field spider, is shown in Fig. 79. It is held in the draw-in chuck shown in detail in Fig. 81. This is of malleable iron and is only ground in the hole and on the recessed face, as indicated by the wheel positions in Fig. 80. The hole is 1¼ in. in diameter, the faced surface being 3 in. The outside diameter is 7 in. About 0.010 in. is removed from the bore, the tolerance being 0.0003 in. There is no special tolerance on the face, but it must be a good finish. Production is 30 per hour.

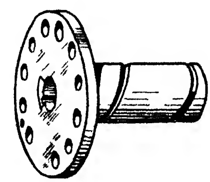


FIG. 76.—The hardened-steel bearing plate which is finished all over and ground on all important surfaces.

Grinding Crankshaft Bearings.—Crankshafts for refrigerating compressors must be very accurate in both bearings and crankpins. Figures 82 and 83 show how a double-throw shaft is ground on a Landis machine. The shaft is held by the main bearings in two hydraulic clamps, being located by a radial arm under the pin not being ground. This arm carries different

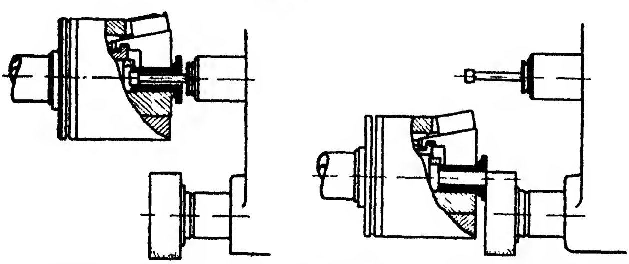


FIG. 77.—Similar layout for hardened-steel bearing plate, showing how the two spindles of the Bryant grinder operate.

shoes for each pin, because when grinding the first pin the pin in the shoes is in the rough. When the shaft is reversed, the shoe must fit the finished pin.

It will be noted that the location of the shaft is made from the short end in both cases. To do this a swinging arm is provided in both the right- and left-hand work heads, as seen in the two illustrations.

The material is case-hardened steel. An aloxite wheel, 30 by $1\frac{1}{16}$ by 12 in. is used. The tolerances are close, being 0.0003 in. for plane alignment, 0.001 in. for throw, 0.0005 in.

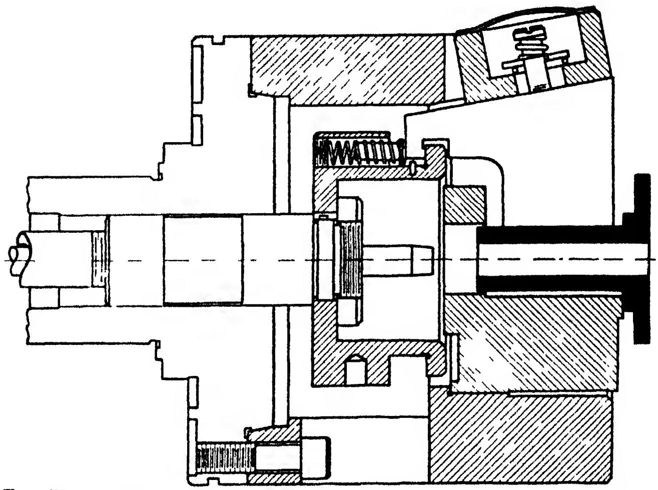


FIG 78.—Special collet chuck which holds the work (See Fig. 77.)

for diameter, 0.005 in. for width of pin, with no figures set for out of round or taper. A high finish is demanded and the bearings are finished by lapping. Production is 25 shafts, or 50 pins per hour, the wheel finishing 80 pins between dressings. Alignment of the work heads is very important as the tolerance is 0.0002 in.

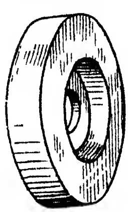


FIG. 79.—Malleable-iron cast spider which is ground only in the bore and on the adjacent face.

SPRING COLLETS FINISHED BY GRINDING

Spring collets for precision lathes have been in use for more than half a century; they probably had their inception in the watch-tool industry. Today, their use in machine shops and toolrooms is almost universal, since they afford a ready means for accurately holding finished bar stock, such as drill rod and round cold-rolled steel. Manufacture of collets, whether in small lots or in large quantities for distribution to the trade, presents several grinding problems that are outlined in this article. Regardless of whether few or many collets are to be made, special grinding appliances are necessary to promote accuracy.

A typical collet of standard design is illustrated in Fig. 84. While the hole is for ½-in. stock, the other dimensions are standard. Thus, in cases where collets are made in quantities, it is an excellent plan to make the blanks in turret lathes. The

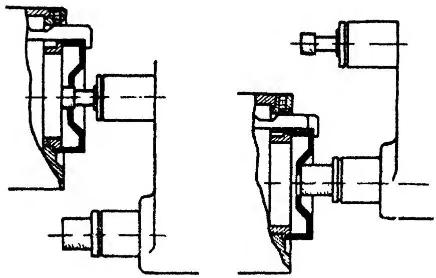


FIG 80.—Another layout of a malleable casting which shows both spindle positions and type of chuck used.

blanks can be stocked as semifinished parts to be finished as occasion requires.

Sequence of Operations.—Spring collets should be made of tool steel, spring tempered. The first grinding operation is to rough-

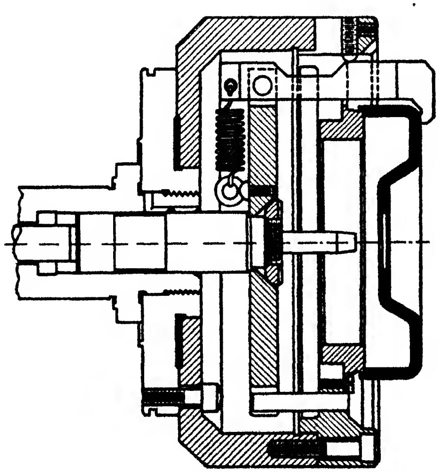


FIG. 81.—Details of chuck used.

grind the bore. A special fixture for the internal grinder is used, as shown in Fig. 85. A production grinder will handle the work nicely, but if such a machine is not available, a universal grinder set up for internal grinding can be used. The fixture consists of the cast-iron body *A*, screwed to the spindle nose; the work locating bushing *B*, which is of hardened steel; and the draw-in rod *C*.

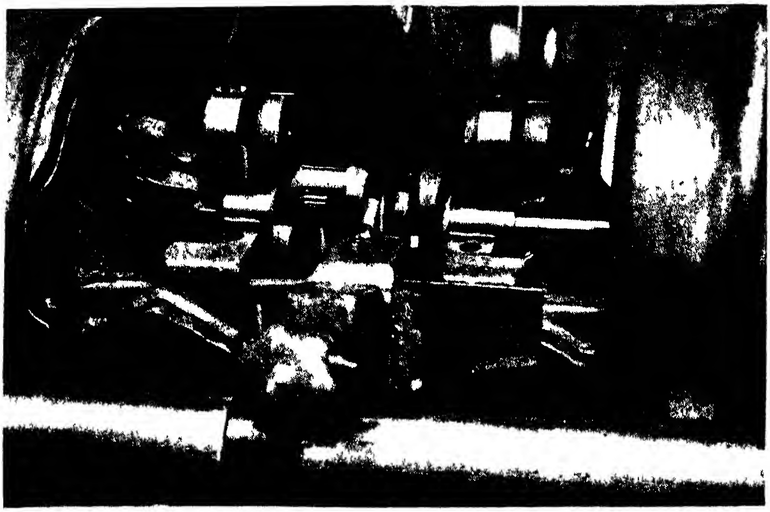


Fig 82 —Grinding double-throw crankshaft

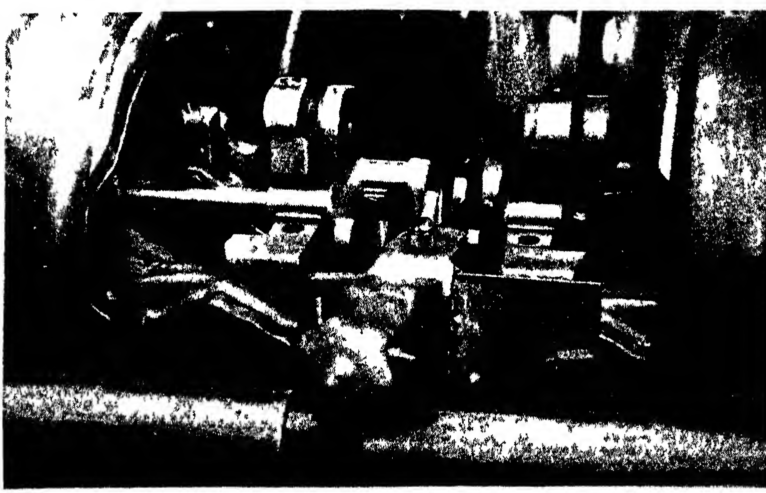


Fig. 83.—Grinding double-throw crankshaft.

As the collet is drawn back, it is obvious that it will contract. To overcome this, a ring should be attached to the outer end by sweating, as at *D*. A number of these rings can be provided and they can be used over and over again. About 0.020 in. should be allowed for grinding a ½-in. hole, and in rough grinding about 0.010 in. should be removed. This will leave 0.010 in. for finish grinding, which may appear liberal, but the reason will be explained later on.

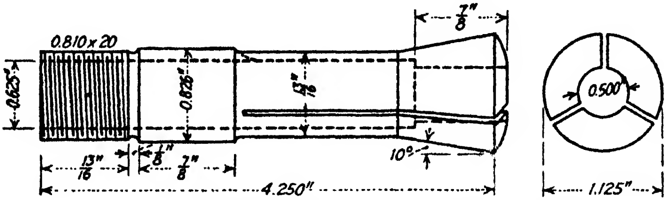


Fig. 84.—A typical spring collet of standard design.

The wheel for this operation should be of manufactured abrasive of a comparatively coarse grit, about 36, while the grade should be from medium to medium soft. It should run at a surface speed of 5,000 ft. per minute. However, such high speed is not always possible to attain with such a small wheel. For example, it would be necessary to run a ½-in. wheel at more than 38,000 r.p.m. to attain a surface speed of 5,000 ft. per minute. For this reason, lower surface speeds must often be used.

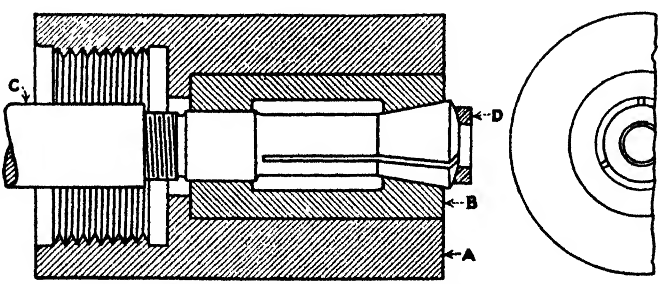


Fig. 85.—Fixture for rough grinding the hole.

Rough grinding the outside diameter is the next operation. This is done in a universal grinder so that both the tapered and the straight portions can be ground at one setting of the work. The collet is mounted on a special mandrel, as shown in Fig. 86. The small diameter of the mandrel is a push fit in the hole previously ground, and the large diameter is tapered slightly to fit snugly in the back end of the collet. Where large quantities of collets are to be finished, it pays to rough-grind with a coarse wheel and to finish with a finer one. In such cases the roughing wheel can be 36 grit, medium-soft grade and operated at 5,000 surface feet per minute. While it is true that higher wheel speeds are used for the general run of production grinding, not all universal grinders can be operated at such a high speed.

Approximately, 0.020 in. should be removed in roughing. The wheel bed is set over to generate the required angle and the angular portion of the collet is ground by feeding the wheel at that angle. The wheel spindle remains parallel with the work and one corner of the wheel is dressed to the angle to be ground. The straight portion of the collet is then ground by traversing the work. Since the two surfaces are ground at one setting, it is obvious that they will be concentric

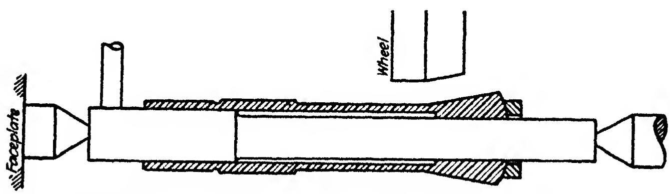


FIG 86 – Rough grinding the outside The taper and the straight portion are ground at the same setting

Ring Prevents Springing.—After the collet has been rough-ground, it should be heated just enough to soften the solder for holding the ring (*D*, Fig. 85) in place. When the solder softens, any strains that have been released by removing the scale will adjust themselves. The collet may either spring open or shut a slight amount. It is for this reason that such a liberal amount of metal is left for finish grinding. When the collet is allowed to cool with the ring in place, it is obvious that it can be finish-ground accurately with assurance that it will not be sprung from either its true shape or from the required dimensions. Since the collet may spring either way, it may be necessary to have several mandrels having diameters varying at the small ends.

Finish grinding the outer diameter is the next operation. If different wheels are to be used for roughing and finishing, the finishing wheel can be 60 grit and medium-soft grade. If, however, one wheel is to be used for both roughing and finishing, it should be as fine as 60 grit. The finishing operation on the outer diameter does not differ from the roughing operation just described.

In Fig. 87 is illustrated the internal grinding fixture for finish grinding the hole. It consists of the faceplate *A*, which is screwed to the spindle nose of the grinder; the outer part *B*, which is secured to the faceplate by three bolts; and the hardened

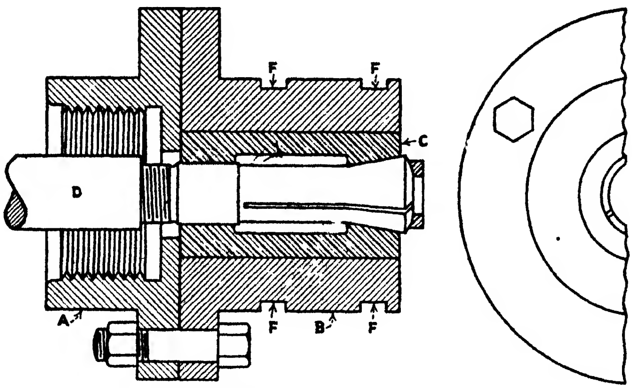


FIG. 87.—Fixture for grinding the hole.

and ground bushing *C* in which the collet is located. The collet is drawn back into position with the draw-in rod *D*, which is screwed over the end.

Insuring Concentricity.—Since both the bore and the outer diameter of the collet must be accurately concentric, it is generally necessary to true up the fixture, using an indicator and taking

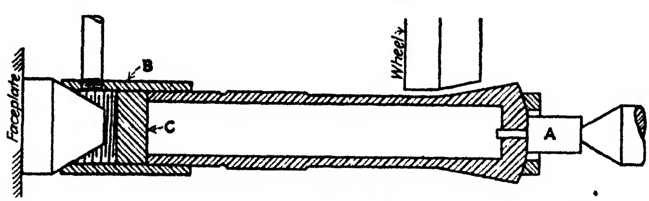


FIG. 88.—Setup for guiding the outside of a collet having a very small hole.

readings from the ground surfaces *F* while the fixture is revolved slowly. If the adjustable part of the fixture does not run true, the bolts are loosened slightly and the fixture is lightly tapped with a lead hammer until a true reading results. If the outer end of the fixture runs out more than does the inner end, it generally means that dirt or burrs are between the hub of the faceplate and its seat against the shoulder of the spindle nose. This must be remedied before grinding. With true indicator readings at both surfaces, the fixture will produce true work.

The wheel for grinding the bore should be about 80 grit in a soft grade and should run at about 5,000 surface feet per minute. If this speed is not possible, then a harder wheel must be used. It is, of course, impossible to grind very small holes by the method outlined above. If the hole is very small, a setup such as is shown in Fig. 88 should be employed for grinding the outer diameter. The hole in the collet is first lapped just enough to remove the hardening scale and a center plug, as at *A*, is inserted. This plug should be a light, drive fit. The collar *B* is screwed over the back end of the collet and is held securely by the screw plug *C*.

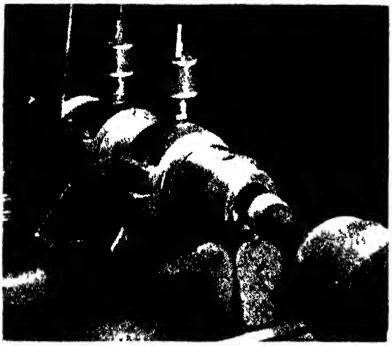


Fig. 89.—Grinding internal taper in collet.

For grinding the hole, the center plug is removed and the grinding is done with either a small wheel mounted on a slim shank, or with a diamond lap. A diamond lap is simply a steel lap charged with medium-grit diamond dust by rolling it between two plates on which the diamond dust has been sprinkled. Care must be exercised in using a diamond lap because too much pressure will tear the abrasive from it. The operation of lapping is necessarily somewhat slow, but for holes ⅛ in. in diameter or smaller it is not always possible to find grinding wheels.

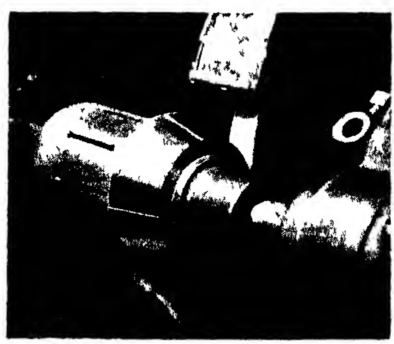


Fig. 90.—Grinding outside of jaws.

After the hole has been ground, or lapped, to size, the last operation consists of removing the ring that has been sweated in place. The nose of the collet is polished with abrasive cloth, the work being performed in a bench lathe in which the collet fits.

Two typical grinding operations on collets are seen in Figs. 89 and 90. In the first the mouth of the collar is being ground to receive the collet while in Fig. 90 a collet is being ground on the outside. This collet has a reverse taper for closing, and is held in a mandrel for grinding.

TRAVERSE SPINDLE GRINDER ON SMALL WORK

The traverse spindle grinder is very useful in the toolroom and on many classes of small work it is a valuable and almost indispensable manufacturing tool. Although primarily designed

FIG. 91.—Simple precision or toolroom grinding spindle.

for watch factory purposes, it has a place in other factories doing high-grade work, and will be found of value along with other bench-lathe equipment.

Two Traverse Spindle Attachments.—Two types of traverse spindle grinders as made by the Pratt & Whitney Company are illustrated in Figs. 91 and 92. The first of these is adapted to be attached to the slide rest by a screw and nut, the latter passing into the tool-post slot. It may be used for grinding or drilling holes, and general work. The slide-rest screw locates the spindle at any desired point and it can be set at any angle.

The traverse motion of the spindle is controlled by a leather washer at the end or, better still, by the fingers engaging the sides of the pulley. The taper hole in the spindle has an included angle of 4 deg. and the largest diameter of the hole is 0.2 in.

Figure 92 shows the other type of traverse spindle which is so mounted on a grinding rest that it may be adjusted vertically, as desired, swung up entirely out of the way to permit gaging of the work, and returned to its proper position as determined by the stop. The spindle is carried in a rectangular frame which is supported at three equidistant points to give it a rigid support on the top of the slide. There is one slide only, which is operated by a screw with friction micrometer. The spindle is set at any desired angle with the axis of the work by means of the graduated circular base of the grinder head.

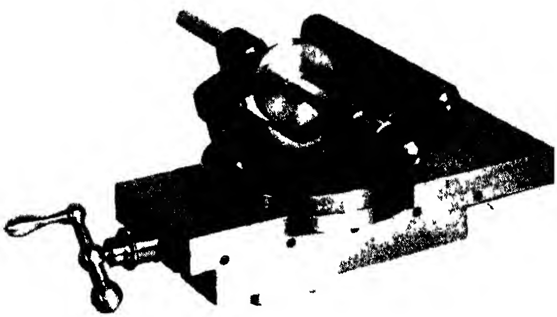


FIG. 92—Universally adjustable grinder (*Pratt & Whitney*)

This attachment is particularly serviceable where precision grinding is to be done on a manufacturing basis.

The spindles in these traverse spindle grinders are ½ in. diameter, and run at speeds from 12,000 to 13,000 r.p.m. Both the bearings and the spindles are of hardened steel, ground and carefully lapped for straightness and fit.

CHAPTER IX

AUTOMATIC AND SEMIAUTOMATIC EQUIPMENT

Along with the general advance in machine-tool design there has been marked development in recent years in the way of automatic or semiautomatic control of grinding operations, both external and internal. These improvements have led to easier and more accurate means of duplicating work with a fine degree of precision and yet without placing any appreciable amount of added responsibility on the operator as to the sizing of the work. The purpose of such facilities is primarily the simplification of operations especially where numbers of parts are to be ground to very close tolerances. This relieves the use of special measuring instruments to a degree and to that extent diminishes the effect of individual elements in connection with the holding of bores and external diameters to extremely close limits of accuracy.

THE BRYANT GRINDERS

The Bryant grinder was developed for finishing chucked work by means of wheels applied to the face and to the bore of the piece. In Fig. 93 is shown a sectional view of the Bryant No. 12-A two-spindle semiautomatic hole and face grinder, including the cross-feed arrangement and auxiliary stop. This is a double-purpose machine used for the finish grinding of two or more different surfaces at a single chucking of the work. The grinding wheels are used successively, the operator swinging either one into working position as desired. The machine is used for both production purposes and toolroom operations. As a production tool it has the same advantages of wheel-slide control as the single-spindle hole grinders of the same make. In addition, the second wheel spindle offers the opportunity of grinding a face square with the ground hole and saves time of rehandling.

As a precision tool the natural result of grinding two or more surfaces at a single holding of the work insures a high degree of accuracy as the surfaces so finished must be true and concentric with each other. This is of especial advantage where certain classes of work are to be finished which cannot be ground on two

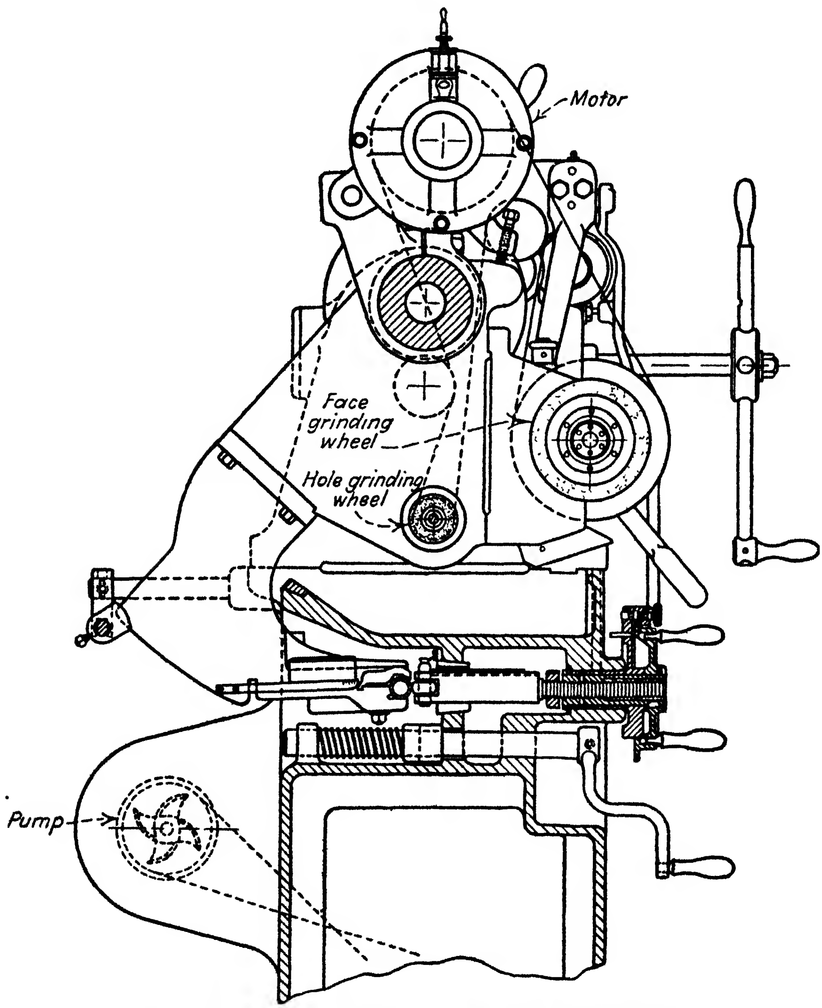


FIG. 93.—Section of Bryant No. 12 A hole-and-face grinder.

surfaces accurately by changing from one setting to another. Where such pieces are chucked in this grinder exact relation of the surfaces is assured by the finishing of the different surfaces at a single holding of the work.

Not only are holes and faces ground on the machine but, in general, the machine is quite universal for chuck work and will grind also short outside diameters with hole and face operations,

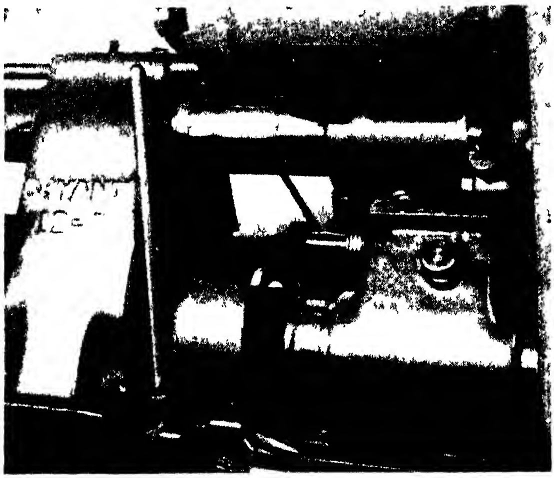


FIG. 94.—Grinding face and hole at one setting.

all at a single holding, whenever the method of chucking permits of reaching the different surfaces with the wheels. When holes only are to be ground the face-grinding wheel bracket may

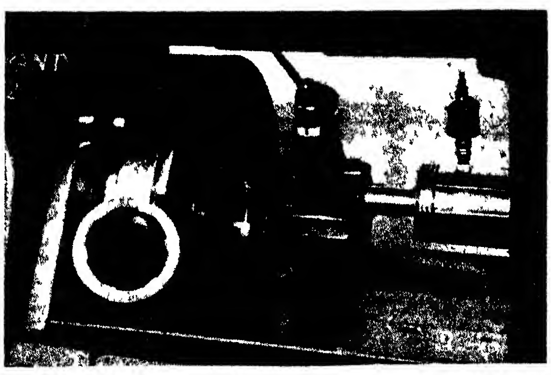


FIG. 95.—Grinding profile for over-running cam.

be removed and the machine operated as a single-spindle hole grinder, although this is not necessary with small lots.

The machine illustrated has a total chuck swing of 15½ in., a maximum wheel-slide traverse of 10½ in., and a maximum grinding length of 8 in. The wheel-slide travel for each revolution of work is from $\frac{1}{16}$ to $\frac{1}{2}$ in. A variety of chucks are available as designed for meeting requirements of accurate and quick chucking of gears, ball- and roller-bearing rings, collar bushings, cylinders, connecting rods, etc.

Typical Operations.—In Fig. 94 a typical job is shown with both internal and face work carried on at a single setting of the piece. Figure 95 illustrates the use of the internal profile-grinding attachment as arranged for grinding over-running clutch rings. The control of the wheel-slide travel is secured through the outside master cam plate and rocker arm seen at the front of the head. Another cam-attachment job is represented by Fig. 96 which illustrates the grinding of the outside face of an irregular cam at one operation. Another special piece of work is shown in Fig. 97. This view shows the use of a fixture for holding a master connecting rod for a radial airplane engine and indexing it for the finishing of eight pivot holes.

FIG. 96—Cam attachment grinding face of cam at one operation. No 12 Bryant grinder

AUTOMATIC SIZING DEVICE

The Bryant Company also build the automatic machine shown in Fig. 98, this view showing the automatic sizing mechanism.

Bryant Automatic Sizing Device.—The object of the Bryant automatic sizing device is to relieve the operator of the necessity of hand plugging or watching a visual gage, and to control the grinding operation without the attention of the operator, by automatically separating the wheel and work when finished. The grinding cycle is divided into four stages or steps; chuck, rough grind, finish grind, and dress wheel. These steps are generally arranged to take place in the order outlined, but the order may be changed if the character of the work makes it desirable to dress before finish grinding.

Assuming that dressing is to follow the finishing cut and that a piece of work has been chucked, the operator brings the grinding wheel into the hole to be ground in the usual manner, turning up the cross feed to bring the wheel in contact with the work. He then starts the cycle by lifting a small lever at the right of and below the cross-feed handwheel. The roughing feed is thereby started and the roughing operation proceeds automatically to a point determined by a rider cam yieldingly mounted on the handwheel. This cam automatically makes a contact which advances the device to the finish grinding step. This causes the rate of feed to be reduced, and releases the sizing indicator finger so that it makes contact with the work.

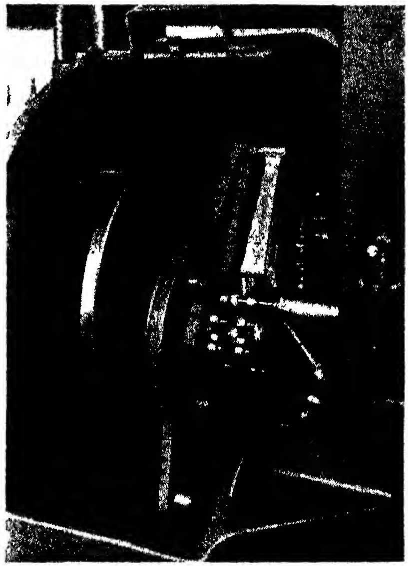


FIG. 97. Indexing fixture for master connecting rod.

The finish grinding proceeds automatically until the finish size as determined by the indicator is reached. Contacts are made by the indicator to advance the device to the dressing position. In coming to the dressing stage the device has caused the feed to stop and the wheel to be backed off from contact with the work, this being done by moving the feed nut axially without turning back the handwheel. At the same time the indicator finger is withdrawn from contact with the work. The wheel continues to traverse the length of the hole, but without grinding since the cross feed has been relieved.

The operator at this point disengages the traverse and withdraws the wheel from the hole. As he does this the air-operated diamond holder is automatically lowered and the wheel is dressed as it is withdrawn. As the dressing is finished and the wheel slide swung back on the lifter to its chucking position, the sizing device advances to its chucking step, the cross feed is further backed off automatically by a half turn of the handwheel, and the indicator head is automatically swung clear for removal of the finished work and chucking of another piece.

FIG. 98.—Bryant automatic grinder showing automatic sizing

For convenience in setting the indicator a pilot light is provided. After grinding the first piece to size manually, the operator can turn a switch which will cause the light to burn when the indicator contacts are closed. He can then easily adjust the indicator so the points just close at the finish size.

The Nortonizer.—The Norton grinder in Fig. 99 is a 10- by 36-in. Type C semiautomatic machine with automatic electric sizing device known as the "Nortonizer" This device stops the

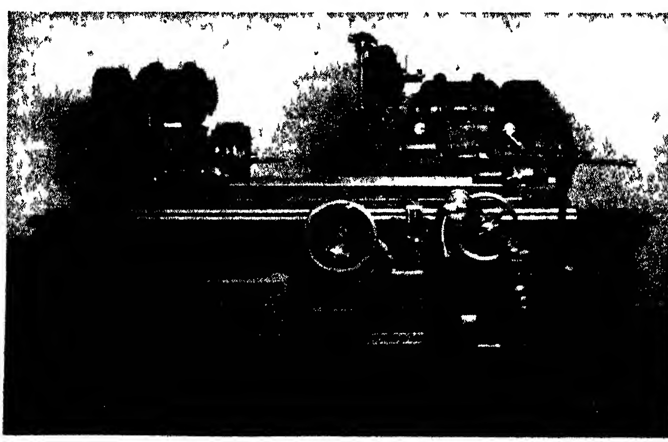


FIG. 99.—Norton semiautomatic grinder.

feed of the grinding wheel automatically directly from the work itself when the correct diameter has been produced. All of the important machine functions are electrically controlled through this device.

A gage rides the work as the grinding wheel feeds in. When the correct diameter is reached, an electrical contact is made which stops the wheel feed and automatically lifts the gage from the work. The wheel remains in contact with the work for a very short but definite period which is controllable within extremely fine limits, and then recedes rapidly to a position which facilitates rapid and safe reloading of the machine.

When used on semiautomatic machines, the starting and stopping of the work revolution, the rapid travel of the wheel up to the work, the feeding during the grinding operation, and the operation of the footstock and steadyrest (if these units are used) are all controlled automatically. All the operator does is place the work in the machine, move a single lever with his right hand and simultaneously place the gage on the work with his left hand. He need not be present when the work is finished and he can operate as many machines with Nortonizers as the nature of the work permits.

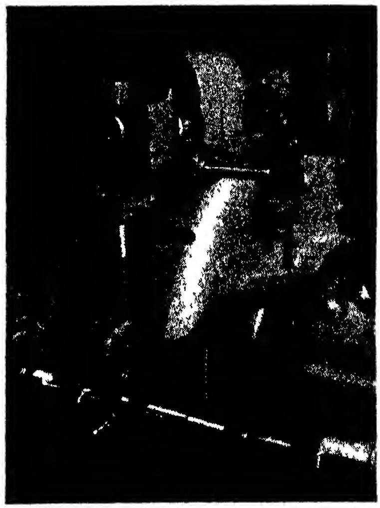


Fig. 100.—Gage portion of Nortonizer device.

Several distinct advantages are claimed for the device. Inspection operations are said to be virtually eliminated, as work can be ground accurately round and well finished to a total limit of 0.0003 in., hour after hour. No compensation for wheel wear is necessary since this factor has no influence on the finished size. The grinding wheel can be replaced and, after truing, the very first piece ground will be an exact duplicate of the last one ground with the old wheel. Furthermore, the work need not be prepared for grinding to such close tolerances as for a machine which functions on a definitely timed cycle.

The Nortonizer can be applied to any new Norton cylindrical grinder and to practically all Type A or BA machines now in service. Round work, splined work, keywayed work, or partial-diameter work can be ground. The two views in Figs. 100 and 101 show the device clearly. In Fig. 100 the automatic sizing device is shown in place on a piece of work. The mechanism which raises the gage from the work when the correct size has been obtained can be seen on top of the wheel guard. The view in Fig. 101 shows the control unit with the cover removed.

The "Gage-matic" and "Size-matic" Grinders.—Another line of grinders with automatic control of work diameter is that of the Heald internal machines known by the above names, The Gage-Matic uses a solid positive plug for testing the size of each piece automatically at very close intervals of time,

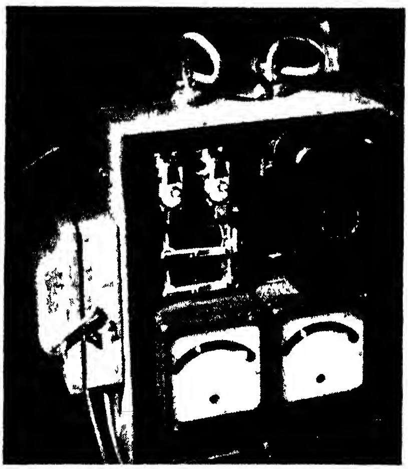
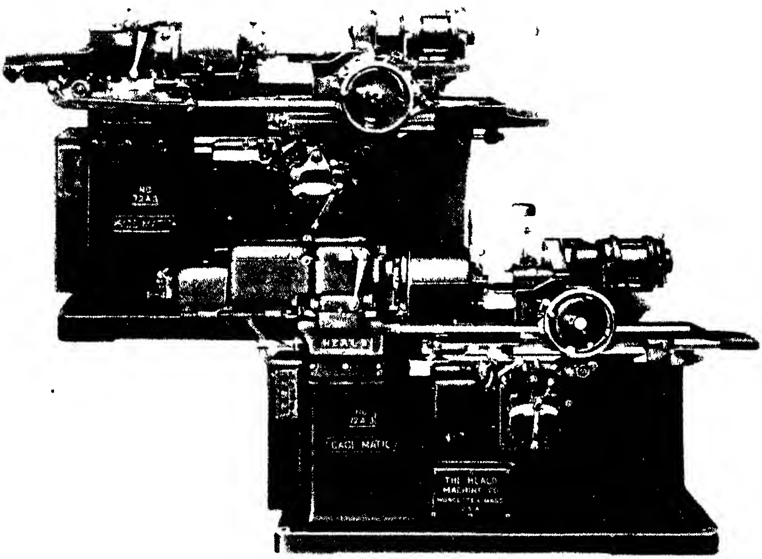


FIG. 101.—Control unit of the Nortonizer.

while the Size-Matic has automatic control for the entire grinding operation. Both machines are shown in Figs. 102 and 103.

In the Gage-Matic machine the gage at the back of the work automatically tests the piece at "split-second" intervals, assuring constant, uniform results, making it unnecessary for either operator or inspector to check each piece.

After the operator has chucked the work and thrown the starting lever to the left, the process of grinding goes on automatically: First, the table moves at full speed until the wheel enters the work, then the table speed changes to roughing speed, the work head starts revolving, and the coolant starts flowing. The roughing feed removes the stock rapidly, the hydraulically operated table reverses automatically between the dogs, and the sizing gages attempt to enter the hole. As the roughing gage enters the hole at predetermined diameter, the dogs act to short-stroke the table, and the table speed changes to truing speed, the diamond automatically drops into place for truing the wheel, and the wheel re-enters the work. The table speed now changes to finishing speed and the wheel feed to finishing feed. At the required finished size the size gage enters the bore and at full speed the table returns to rest position. As



FIGS. 102 and 103 —Heald Gage-matic and Size-matic grinders.

the wheel leaves the work, it is instantly covered and guarded. The size gages retract, eliminating any interference when checking work. All units stop automatically, the operator then removes the work, and the grinding cycle is complete. The movements are shown graphically in Fig. 104.

The Size-Matic automatic features also cover every operation in the complete grinding cycle except loading and throwing over of the starting lever. They include a fast table speed up to the work, then the table slows down to roughing speed, and the wheel cuts with a roughing feed and continues to grind until the hole has nearly reached finished size; when the wheel withdraws from the work, the diamond drops into position, the wheel is trued at truing speed, after which it again grinds, the speed having changed to finishing speed and the feed to finishing feed. When the hole has reached finish size, the wheel automatically withdraws from the work at high speed and all units come to rest position.

The method of sizing is unique and distinctively different from that used on any other grinding machine. Suppose the hole to be finished is 2.000 in. in diameter (see diagram) the wheel is

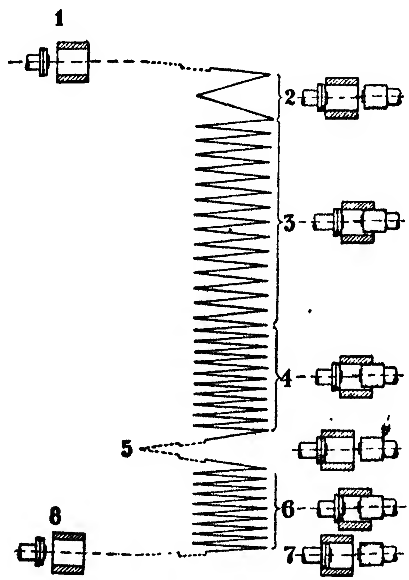


FIG. 104.—Grinding cycle of the Gage-matic.

allowed to rough out the stock until 0.0008 in. is left on the side so that the hole when the wheel withdraws from the work to be trued measures 0.9992 in. from the center. The diamond has been set 0.999 in. from the center allowing 0.0002 in. to be trued off or just enough to clean the wheel. The wheel now starts to grind at a finishing speed and finishing feed of 0.0001 in. per pass with the result that ten passes of 0.0001 in. give the 0.001 in. desired making the hole exactly 2.000 in.

In other words, having roughed the hole to nearly finish size, the diamond is set to true the wheel at this point, then by knowing the amount of stock being removed per pass of the wheel, it is a simple matter to advance the cross slide a definite amount to secure exactly the same-size hole on each successive piece.

There is, however, another factor to be considered and that is the wear of the wheel due to the grinding action and truing. To compensate for this wear, each time the table comes to rest position, there is an arrangement on the cross slide that advances it sufficiently to allow a slight amount of material to be dressed off the wheel each time it is presented to the diamond.

In removing this last amount of stock, the operation is accomplished under ideal conditions, for the wheel has just been trued, presenting a clean, sharp surface to a definite amount of stock to be removed. The feed is fine, the speed is correct, therefore

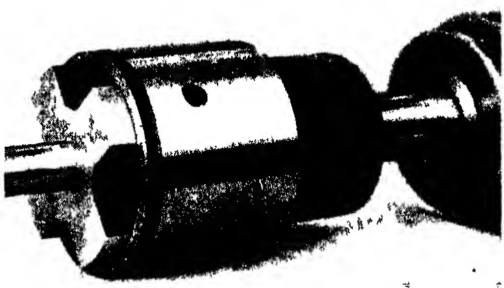


FIG 105 – Work, gage, and grinding wheel in position

under these conditions, the result is exact duplication as long as the relationship of the point of truing and the finish size remain the same. Figure 105 shows a piece of work with a gage at one end and the grinding wheel at the other.

Gages for the Gage-Matic.—These gages are made of selected materials with accurately finished gaging surfaces. On medium lot jobs, gages made of high-carbon high-chrome heat-treated steel give satisfactory life at low cost. Where large quantities of parts are being ground, gages with tungsten carbide inserts give longer life. Although the tungsten carbide gages are higher in price, the additional life obtained from them offers greater economy.

When it is not convenient to obtain gages from the makers, users will find the following information of value.

The gaging surfaces must be smooth, held to close limits of accuracy and of a size not too much under the high limit of the hole being ground. If the gages are not made large enough, they will offer only a small amount of gage wear before the hole being ground becomes undersize and thereby results in high gage cost. On the other hand, if the gage is made too close to the maximum size of the hole, pieces may be ground oversize and become scrap. As finishing gages become worn out, they may be used as roughing gages.

Gages under 5/8 in. diameter require a gage adapter that fits in place of the gage screw. A typical gage-rod adapter is shown in Fig. 106 and complete information on size and shape of both roughing and finishing gages follows. Gages 1/2 in. in diameter and less have solid shanks shown in Fig. 106, and have a press fit into the gage adapter. Gages over 1/2 in. use gage screws and are shown as style *B* in Table 7.

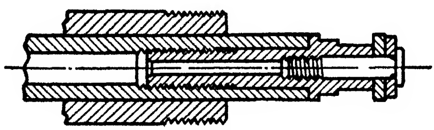

Mounting of a pair of gages on gage rod adapter

Fig. 106.—How go and no-go gages are mounted.

Gage-rod adapters are also required where there is not sufficient gage-rod adjustment to permit the gages to reach the hole in the work.

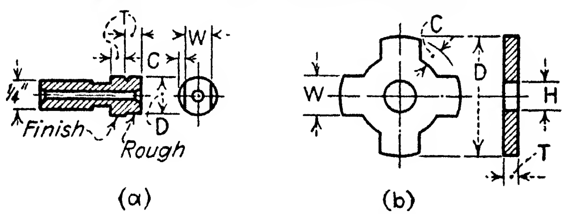
Gages should be ground on an external grinder capable of producing unusual accuracy. The Heald factory gages are ground on a special precision grinder used only for grinding gages. It is equipped with two wheels on the grinding spindle; one for roughing and the other for finishing. The finish wheel is about 100 grain and only about 0.0002 in. left by the roughing wheel for finishing. The finishing wheel is allowed to spark out and really laps to finish size.

When grinding, the gage is held in a mandrel. The gage must not be forced on the mandrel but have only a finger-push fit. The shoulder on the mandrel holds the gage square and care should be taken not to tighten the nut too much or it may buckle the gage. Tightening with the fingers is satisfactory and preferable. Special attention must be given to both the centers in the mandrel and on the grinder. Best results are obtained with lapped centers.

As the finished size of hole in the work is measured by the gage in the Gage-matic when the work is at grinding temperature, it is necessary that the gage itself be measured for final size at a temperature approximating the temperature at which it is used. Many times gages are ground at a temperature less than that of the atmosphere because of the coolant used in their grinding. In such cases, gages measured at the time they are ground will expand after being permitted to take the atmospheric or work temperature and thereby increase their size and when used cause oversize holes to be ground in the work.

If the work being ground has chamfer or radius on end of the hole which the gages contact, sharp corners on the gages are satisfactory as the chamfer or radius in the work guides the gages into the hole. If the hole has a square corner, chamfer the outer edges of both roughing and finishing gages to allow gages to enter hole freely.

TABLE 7.—GAGES USED IN GRINDING



Finished size of hole, in.	Average amount to make gage diameter *D* under high limit of hole		Style	*H*	*T*	*C**	*W*
	Rough gage	Finish gage					
⅛–½	0.0010	0.0002	*A*	Solid shank†	1/16–⅛	⅛–¼ diam. of gage	½–¾ diam. of gage
½–⅝	0.0010	0.0002	*B*	¼†	⅛	⅙ diameter, of gage	⅓ diameter, of gage
⅝–1	0.0010	0.0002	*B*	⅜	⅛		
1–1½	0.0012	0.0003	*B*	⅜	⅛		
1½–2½	0.0015	0 0003	*B*	⅜	⅛		
2½–3	0.0018	0.0003	*B*	⅜	⅛		

* Extra clearance is required for automatic bore-centering fixtures.

† Requires adapters on gage rod.

LANDIS AIR-JET METHOD OF SIZING

Another method of automatically controlling the size of cylindrical work in the grinding machine has been adopted by the Landis Tool Company as the result of extended experiments. This method involves the use of back pressure built up in a small air jet as the nozzle approaches the work. Similar experiments in Europe led to a combination of ideas in what is now known in this country as the Landis-Solex sizing device. The same principles are being used inspection gates for various kinds of work.

The device operates on the principle that if air is escaping from a pressure line, the pressure is affected by both the size and shape of the outlet through which it is escaping. As used in connection with cylindrical grinding, the back pressure is also affected by the distance between the nozzle and the work, as well as the size of the nozzle itself.

This change in pressure is used to change the level in a column of mercury, forcing the mercury up into contact with an electric terminal, forming a mercury switch. This contact operates electrical mechanism which controls the feed of the grinding wheel into the work. The operation of the device can be easily followed from the accompanying illustration.

Air pressure of about 2 lb. per square inch is furnished by a small air pump mounted directly on the frame of the machine and driven by the regular coolant pump-drive motor. This air pressure is led to the caliper frame *A* which has two Carboloy-tipped shoes that rest on the work as shown. The air-outlet jet is between these two shoes and blows directly against the work as it revolves.

A light spring tension keeps the shoes in contact with the work, and as the work decreases in diameter, the gap between the air jet and the work is lessened. With the opening decreased, the air pressure builds up in the air line behind the jet, and accumulating in chamber *B*, it forces the mercury up into columns *C* and *D*.

Just before the work reaches the finish, or at the end of the roughing period, the mercury contacts the connection in column *C*. This completes an electric circuit which energizes a solenoid, and cuts down the rate of infeed movement. Grinding continues at the slower rate until the correct diameter of the work is reached, when the increasing air pressure has forced the mercury up into contact with the connection in column *D*. This energizes another solenoid and stops the infeed. At the same time the grinding wheel is moved rapidly away from the work. Provision is made for all necessary adjustments for contacts in

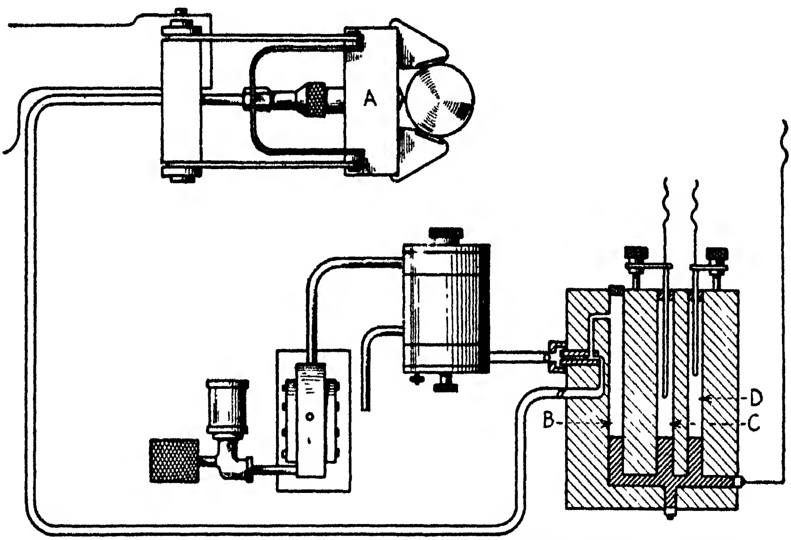


FIG. 143*A*.—Diagrammatic drawing of Landis-Solex sizing device system.

the mercury columns and for the carboloy-tipped shoes that contact the work.

The jaws have a considerable range as to size of work they can cover. The three standard jaws range from 3/8 to 7/8, 7/8 to 1 3/4, and 1 3/4 to 3 in. As the sizing measurements are taken from the diameter of the work itself, the gaging is not affected by wheel wear, wheel dressing, or a variation in the amount of stock removed. Work can be held within 0.0003 to 0.0005 in., depending on the characteristics of the work itself.

Electrically controlled grinding machines are now being used in increasing numbers. They represent a comparatively new development that has great possibilities in production work. Details can be had from several builders of these machines.

CHAPTER X

SURFACE GRINDERS AND THEIR WORK

THE PRATT AND WHITNEY MACHINE

Reference has been made to different types of surface grinders, including the new hydraulic machine brought out in 1935 by the Pratt & Whitney Company. This is shown in Fig. 107. This new model is characterized by increased weight and power, and by the much higher table speeds available.

The drive to the spindle is the same direct geared connection used in Pratt & Whitney vertical surface grinders for many years. The motor is up out of the way, and its full power is transmitted to the wheel through a pair of hardened nickel-steel spiral-bevel gears particularly developed for this drive. The design is such that the drive can handle much more than the standard 30 hp. should the occasion arise. These gears run in oil at all times. The level of oil in the reservoir is maintained at the mark on the round gage on the front of the gear housing. These gears produce a spindle speed of 1,265 r.p.m. Special gear ratios can be supplied if a different spindle speed is required.

The entire spindle and drive mechanism is ball-bearing mounted, using preloaded bearings which are fully protected from dirt and moisture. These are lubricated by a hand pressure pump. The spindle and wheel flange are one piece, and the upper end is splined accurately where it slides through the spiral-bevel gear. The lower spindle bearing absorbs the thrust of the grinding cut. End play in the spindle is prevented by a series of compression springs which support the upper bearing. These springs are of sufficient capacity to carry the dead weight of the spindle and wheel parts, and keep the spindle in automatic adjustment, preventing wheel sag.

The wheel used is 14 in. in diameter, 5 in. high, and 1½ in. thick. It is held in a cast-iron-wheel mount which bolts to the spindle flange. A few minutes is sufficient to change wheels. A strong steel guard surrounds the wheel to prevent damage in case of accident. Wheel truing is accomplished by a built-in device on the end of the table. This is accurately graduated to save needless wheel waste.

The wheel down-feed mechanism is the ratchet wheel and pawl type and produces power feeds ranging from 0.00025 to

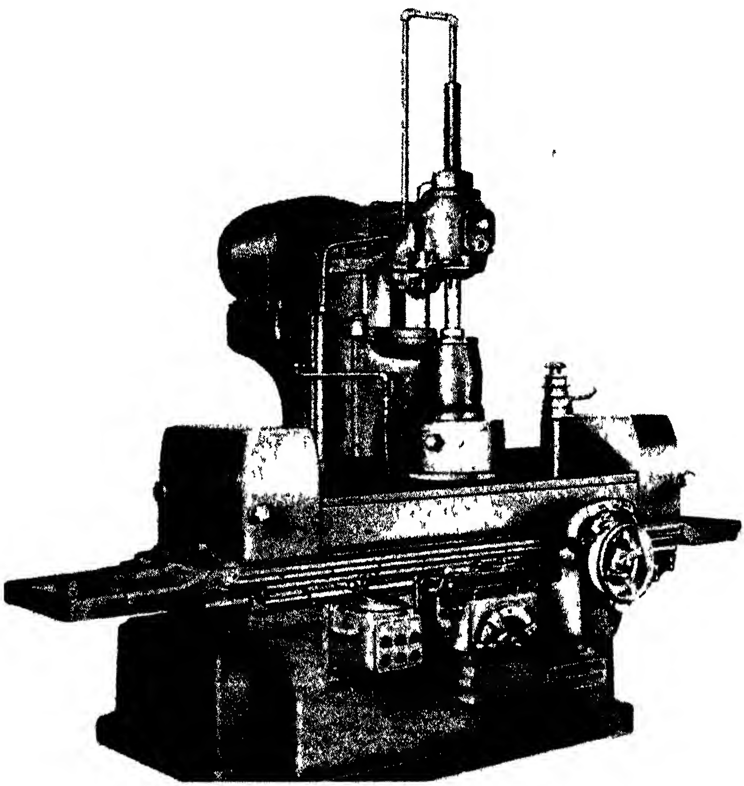


FIG 107 – Pratt and Whitney surface grinder

0.005 in. at each end of the table stroke. In addition either a slow or a fast handwheel feed is engaged by pulling the handwheel in or out. The wheel head is mounted on broad vertical ways, with a narrow guide for accurate alignment.

The hydraulic mechanism is driven by a separate 5-hp. motor mounted on a pad on the bed on the right rear side as shown in the illustration. Oil for the hydraulic system is carried in a tank in the base of the column. It is drawn from this tank through a large Cuno filter which keeps all dirt and grit out of the system. The control valve and lever are on the front of the bed under the operator's hand and vary the table speed from zero up to 100 ft. per minute. Two adjustable stops are provided for quick setting of particular speeds if desired. Notice the complete absence of gearing and other mechanism under the table, owing to the simple hydraulic drive. Automatic table reversing takes place at any desired point by dogs which are instantly adjustable along a longitudinal rack on the front of the bed. The table may be reversed easily by hand if desired.

The table is fully enclosed by sheet-metal guards which can be lowered or raised to confine the spray of coolant from the wheel. Coolant is supplied to both the inside and outside of the wheel from a tank cast in the bed at the left rear. A separate ½-hp. motor drives a built-in coolant pump. Coolant is returned through a large opening to the tank. Baffle plates and a strainer are hung in the tank, and can be lifted out for easy cleaning.

All controls are grouped on the front of the machine and are very simple. Push-button control is provided for all three motors, and on top of the same box is the lever for magnetizing or demagnetizing the magnetic chuck. Red lights in the push-button box show which way the current is engaged.

Lubrication is in general by the reservoir system, so that oiling is simple and positive. The machine weighs 12,000 lb. including the three motors, and all castings are heavily ribbed for stiffness. The table working surface is 12 by 36 in. with a maximum longitudinal travel of 45 in. A magnetic chuck is used with a working surface 11 by 34 in.

Work Handled on the Pratt and Whitney Machine.—Typical jobs handled on this machine are shown herewith. For example, Fig. 108 shows the use of the long table for 5½-ft. saws, finished three at a time. There are 160 sq. in. of surface on each side of each saw or a total of 960 sq. in. They are finished flat and parallel, removing 0.006 in. from each side. The actual time given for grinding for all six sides is 80 sec. The grinding-wheel cost is stated as approximately ½ cent per saw. By use of templates, saws which require it can be given the necessary relief.

Figure 109 shows a lot of cast-iron covers finished on one side at the rate of eight pieces in 16 min. Figure 110 represents a

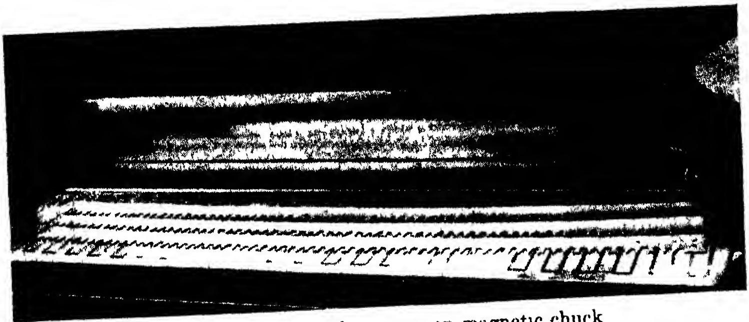


FIG. 108.—Grinding long saws on magnetic chuck

FIG. 109.—Cast-iron covers ground on fitting surface.

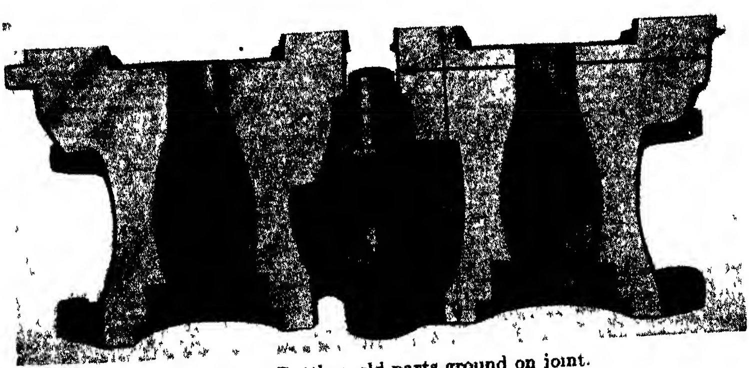


FIG. 110.—Bottle-mold parts ground on joint.

pair of bottle-mold parts, which are commonly finished on the face by shaping. However, some manufacturers are coming to the use of the surface grinder for producing a true smooth surface in a minimum of time. Practically every material which can be held in place can be ground. Steel, iron can be held on magnetic chucks; nonmagnetic materials, of course, require special holding fixtures.

BLANCHARD SURFACE GRINDERS

The Blanchard surface grinder shown in Fig. 111 is a 16-A automatic type. These grinders are part of a line built by the Blanchard Machine Co. for all classes of work requiring accurate

Fig 111 —No 16-A Blanchard grinder

finishing on flat faces. The automatic type referred to grinds one side of the work in one pass under the wheel whose face is automatically kept at a fixed height. The operator has only to load the work on the machine. The chucking, grinding, measuring, unloading, demagnetizing, and cleaning the chuck face are all performed by the machine.

The magnetic chuck rotates slowly but continuously and conveys the workpieces in a continuous stream first under the grinding wheel, then under the wheel control caliper, and finally to the unloader. At this point the pieces leave the chuck and are discharged from the machine. The chuck face is washed and cleaned after unloading, ready for fresh workpieces, and is automatically made strongly magnetic just after receiving fresh work and continues so under the wheel and the caliper. At the unloading point it loses its magnetism and continues so past cleaning and loading points.

The wheel-control caliper controls the feed of the grinding wheel to maintain a uniform thickness of work. It compensates for variations in amount of stock on the work and variable wear of the grinding wheel. On most work, limits of 0.0005 in. are maintained throughout a day's run without readjustment of the caliper. The caliper, Fig. 112, has a vertical spindle mounted in ball bearings and carrying at its lower end an arm which holds a shoe of stellite whose lower edge is parallel to the face of the chuck. The upper end of the caliper spindle carries an arm of insulating material holding a copper disk. Turning the spindle

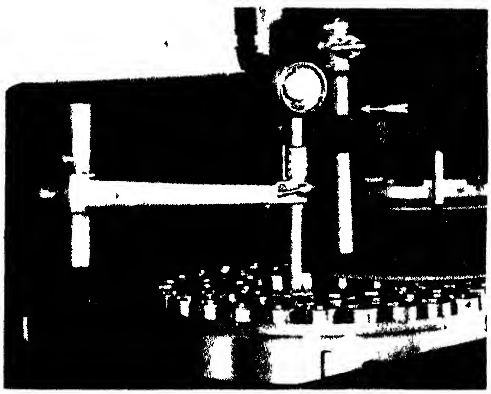


FIG. 112.—Caliper used on these machines

through a small angle brings this disk against two contacts and allows current to flow to a magnet coil on the feed mechanism. The caliper spindle has adjustment vertically by a small crank, one turn of which moves the spindle and shoe 0.005 in. vertically; graduations to 0.0001 in. make it easy to make fine adjustments.

The disk is set so that it will just touch a size block or finished piece of work, and the wheel set to the same height. Pieces of work then sent through the machine, if ground to correct thickness, will just touch the shoe but not with sufficient pressure to move it. As the wheel wears, the thickness of the pieces coming to the caliper will increase. An increase of 0.0001 to 0.0002 in. will give sufficient pressure against the shoe so that the friction of the work passing it will drag the shoe along with the work causing the caliper spindle to turn slightly and close the contacts.

The magnet then receives current through the caliper contacts and withdraws a locking pin from the ratchet-feed mechanism, allowing the feed pawl to operate.

The caliper is so sensitive that it operates on extremely fine changes in thickness of work. This caliper is not available on all sizes of machines.

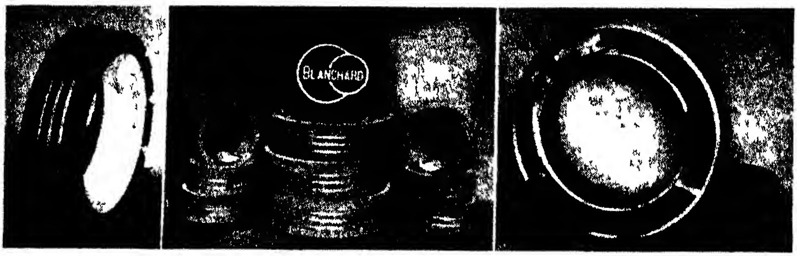


FIG. 113.—Either type of wheel is used on these machines.

Either cylinder or segmental wheels as in Fig. 113 are used on the Blanchard machines. Figure 114 shows the grinding of the face of an eccentric on a high-power machine of this make and Fig. 115 shows an enlarged view of the use of the same continuous-reading caliper. The spindle motor is built in the head. The work to be ground is held on a rotary magnetic

FIG. 114.—Grinding eccentric face on Blanchard.

chuck. This chuck is carried in a table body sliding on the base. The work is simply laid on the chuck, and held magnetically, or in the case of a large ring, it may be merely centered by a plug or stops, and not otherwise held. By means of the pilot wheel the table body, carrying the chuck, is moved along the base to bring the center of the chuck just under the near edge of the wheel. In that position the chuck is rotated by power continuously in one direction, and the wheel head fed gradually

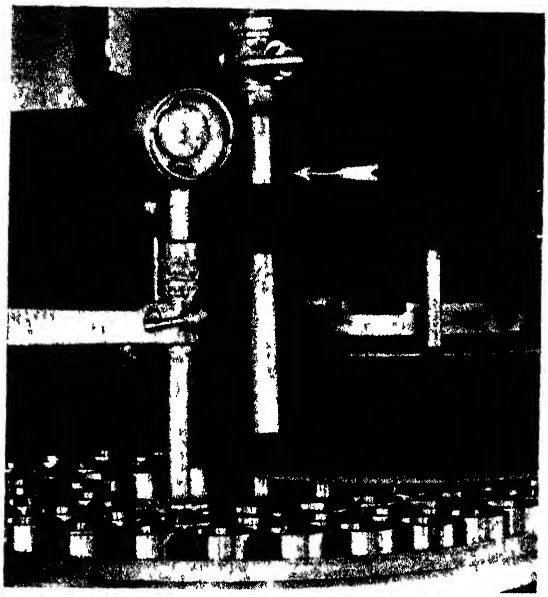


FIG. 115.—Enlarged view of continuous-reading caliper.

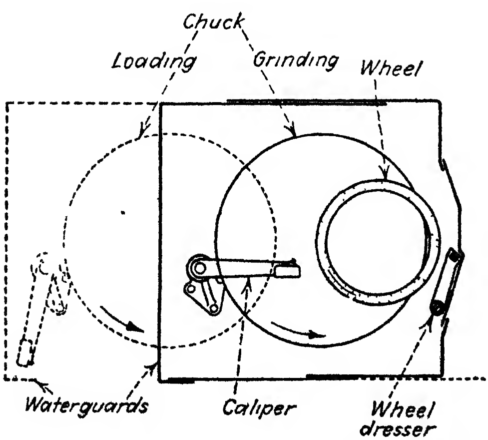


FIG. 116.—Diagram of loading and grinding positions.

downward until the desired amount of metal has been removed The chuck is then moved out again, clear of the wheel, and the work removed. All grinding is done with the chuck rotating in a fixed position—the sliding motion is only for bringing the chuck clear of the wheel for handling work. The grinding and the loading positions are clearly shown in the diagram, Fig. 116.

The chuck can be rotated by power in any of its positions. This permits grinding pieces with a central projection, or small pieces laid radially, with projections above the ground surface at their inner ends, as the chuck need be moved under the wheel only far enough to reach the surface to be ground. A convenient treadle at the end of the base controls the rotation of the chuck as needed for convenience in loading and unloading, and leaves the operator's hands free for handling work.

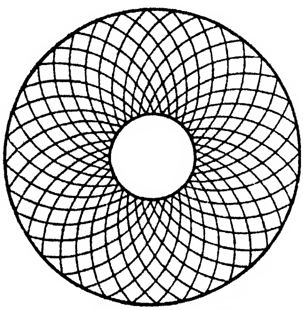


FIG. 117—Grinding marks of vertical cup wheel and rotary table.

The water system applies the water where the heat is being generated, and supplies an ample quantity to absorb all the heat. With a free-cutting wheel, and occasional cleaning of the holes in the faceplate to ensure a full flow of coolant, there need never be any trouble from heating of the work.

Water is delivered both inside the wheel and through an outside nozzle. The inside water passes through a cored opening in the wheel head into an annular recess in the faceplate, thence through straight holes outward and downward to the inside of the wheel. This water, whirling with the wheel, is driven out across the cutting face of the wheel, even passing between wheel and work in the spaces between the grains of abrasive in the wheel face. This application of a large volume of water to the point of cutting effectively removes the heat and makes it not only possible but safe to grind hardened work very rapidly.

Vertical-spindle grinding machines require that the spindle be at exactly right angle with the table or chuck if flat work of uniform thickness is to be secured. When the spindle is set correctly, the wheel cuts in both directions and leaves a characteristic cross marking, as shown in Fig. 117, in which only a portion of the lines are shown. Unless these marks are uniform, the spindle is not exactly square. While the lines shown are from a Blanchard rotary-table machine, similar markings will be found on the straight-table machines, except that they are not radial as in this case.

In chucking work on the rotary type of machine the center of the table should be left open wherever possible. A 5-in. open circle in the center is advised, with steel rings around both outside and inside to prevent sliding of the work. Where magnetic chucks are used, as is common practice, each piece of work must span one or more brass rings in the chuck face. Nonmagnetic work must be securely blocked or clamped.

Medium chuck speed is recommended for most work. Where a single piece is chucked in the center, use the higher speed, but work of large diameter, especially a single large casting, should be run slowly. For extra smooth finish, run the work at 15 r.p.m. for the last few turns.

It is always advisable to use the power feed as it saves time and wheels. An average feed is 0.001 in., but feeds up to 0.003 in. may be used if conditions permit. In most cases the limit is the amount of power available. It is better to use too much feed than too little.

Wheel wear is necessary to cut either fast or accurately; as this exposes new, sharp grains of abrasive to the work. For this reason a soft wheel should be used with sufficient feed to make the wheel cut fast. Power must be provided to carry this feed. If the wheel refuses to cut freely, glazes, or burns the work, the following remedies are recommended by the Blanchard Co.: Use softer or coarse wheels. Use more feed and more power. Reduce the width of the work surface. Use a wheel dresser on the wheel. On broad surfaces omit or at least reduce the amount of oil in the cutting compound.

THE PLANER TYPE OF SURFACE GRINDER

This form of surface grinder, in which the wheel is carried upon a horizontal spindle, is built in several sizes, from small grinders intended for toolroom work, up to machines with a capacity for work 48 in. wide by 10 ft. in length, as in Fig. 118. These grinders are built for a general line of work requiring surfacing. From the shape of the wheel and the nature of the contact, this type of grinder is particularly suited to the handling of work requiring grinding along grooved surfaces or finishing up to a shoulder.

This form of grinder is also built with an oscillating wheel head which is given a lateral movement that is simultaneous with the travel of the work under the wheel; the combination of movements passing the wheel across the work at many different angles to produce a fine finish and preserve the truth of the wheel. A very wide face wheel is used with the type of machine, and in the larger sizes of grinders the space between uprights admits of very wide work being surfaced.

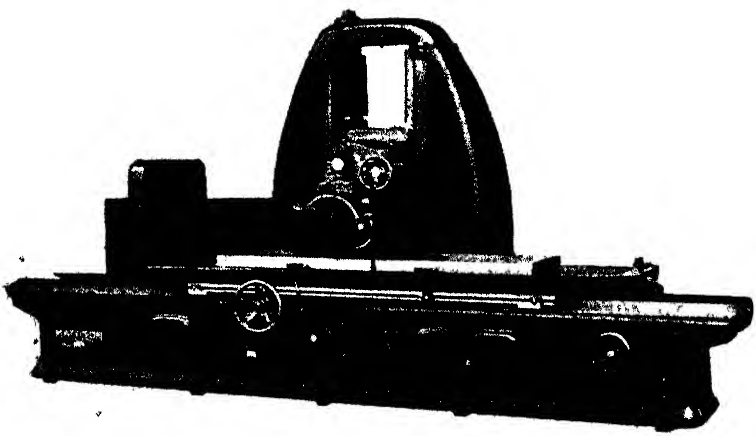


FIG. 118—Planer type of surface grinder. (*Mattison.*)

On all these planer-type machines provision is made for supplying a liberal quantity of water to the work and wheel. The magnetic chuck can, of course, be used for holding work whenever required.

DISK GRINDING

The type of machine known as the disk grinder is being used in a large variety of surfacing work. A grinder of this type was shown in Fig. 18. The disks are made of steel, usually running from 12 to 48 in. in diameter and from ½ to 1 in. in thickness.

The cutting or abrasive disks are cemented to the face of the steel disk, clamped in a press until the cement is set, and then mounted on the spindle of the machine just as a grinding wheel would be. The grinding circles, as the abrasive disks are called, are covered with any abrasive desired, different materials giving best results on different work. These were originally made from sheets of emery or other abrasive cloth, having the grains all over the surface. The small particles of the material being ground clogged the grains of the abrasive and reduced the efficiency. Grooves were cut in the steel disk to form a sort of cushion under the circles and among the latest developments is the spiral circle, in which the abrasive is deposited on the cloth base or foundation in the form of a spiral with a blank space between. This gives a continual shearing action as the grains of abrasives pass by the face of the work being ground and the spaces also serve as a clearance for the chips ground from the work.

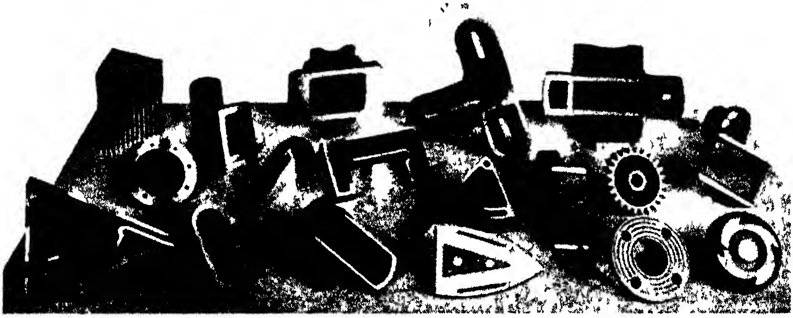


Fig. 119.—Work done on disk type of grinders.

These cut faster than the older forms of circles and give remarkable results in many cases. Another form has the cutting surface divided into small squares or other shaped parts.

The speed varies from about 2,200 to 3,000 ft. per minute at the rim of the disks, according to the work to be ground. The power required varies with the work being done, its surface in contact with the grinding circle having a direct bearing on this point. With motor-driven machines a 12-in. disk machine is fitted with a 2-hp. motor, an 18-in. disk with 5- and a 23- or 26-in. disk with a 10-hp. motor.

Work Done by Disk Grinders.—Figure 119 shows a large variety of flat surfaced work ground on a Besly disk machine. It includes pieces of irregular shape as well as round work such as flanges and gears. Pieces where the surfaces are not continuous offer excellent opportunities for rapid production.

The Besly solution to this grinding problem is this L-type direct-motor-driven base with power-oscillating tables with spring feed and lockout special motor-driven rotary fixtures are mounted on the tables and the machine is equipped with two sets of adapters—the operator may grind the same size seed plates on both ends simultaneously, or a different size on each end. Adapters are easily and quickly changed to meet the needs of the setup.

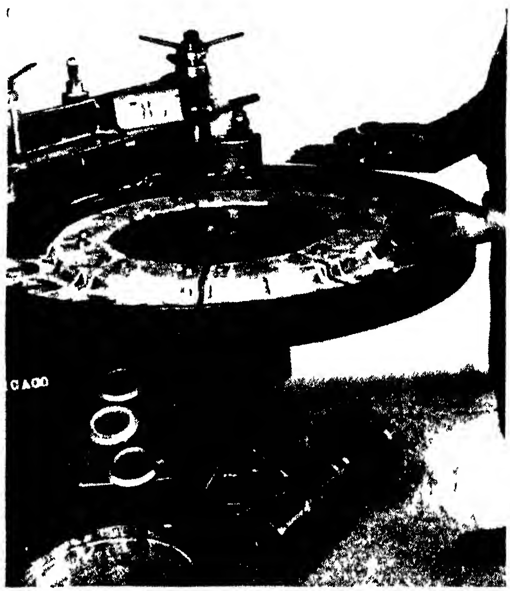


FIG 120—A 30-in Besly grinder with rotary feeding fixture.

Production depends on the type and quantity of the plates being ground—those shown are chucked 22 at a time and ground in 2 min. Production is maintained at the rate of 660 per hour *on one side only* of the machine. Besly Titan Bakelite Steelbacs are used as grinding members.

Figure 120 shows a 30-in. dry direct-connected motor-driven vertical-spindle Besly disk-grinder arranged with rotary feeding fixture for grinding steel barrel spud forgings ranging from ¼ to 2½ in. The amount of stock removed is enough to clean up. The grinding member is 36 St. Besly Titan abrasive disk 30 by 8 in. WP-12.

Production is 1,500 to 2,500 per hour, depending on the size of piece. The work is dropped into holes in the revolving sectional wheel and as it passes over the disk, spring-actuated circular pressure shoes force the piece against the abrasive member. After leaving the abrasive disk, work automatically drops out.

Double-micrometer screws are provided for vertical adjustment on pressure shoes. A suitable dresser is provided as shown.

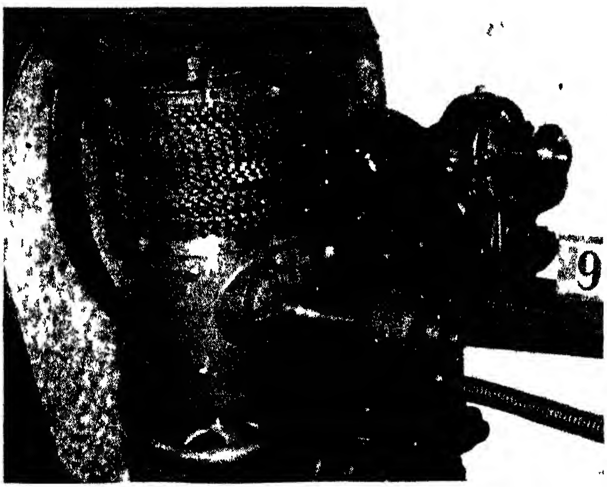


Fig. 121.—Disk grinding a stack of toothed wheels

Another unusual grinding job is seen in Fig. 121, where a stack of toothed disks is ground by rotating them in front of a disk wheel.

General Disk Grinding.—A feature to be considered in disk grinding is to avoid rigid clamping as much as possible. This requires time and often makes the grinding time longer, owing to more metal being removed where it is simply a case of cleaning up a surface. In cases of this kind it is better to let the work float against the disk so that all the high points come in contact first and reduce the total grinding to the simple taking down of the high points to just clean up the low spots.

Where work is small and can be ground all over the surface of the grinding circles, they can be worn out very evenly and economically, but on work which can only use the outer surface, grinding circles are made with an extra large hole and are more economical for this work.

Grinding circles glaze the same as grinding wheels and can be sharpened with a wheel dresser or a stiff wire brush. The brush, such as is used for cleaning castings, is particularly good when grinding carbon, brass, aluminum, or cast iron.

Work should always be moved across the face of the grinding disk both on account of prolonging the life of the circle and for grinding a perfectly flat surface.

Most disk grinding machines are designed to use single belts, the pulleys being made wide enough to allow of this.

Finish Grinding.—For finishing brass for nickel plating or when a specially nice finish is wanted, the disks can be faced with leather disks about 3/16 in. thick and charged with fine abrasive, such as 120 or even finer, alundum, carborundum, or other abrasive material.

Leather disks are also good for fine finish on any kind of work, as it can be made to resemble handwork very closely. An even closer resemblance to handwork can be had by using a felt disk, about 7/16 in. thick, and charged with very fine abrasive.

Generally speaking, the "mile-a-minute" speed, about 5,300 feet per minute, is good for most disk grinding, while for brass-finishing work, 6,500 ft. per minute is good practice.

Summed up in tabular form this gives:

Diameter of disk, in.	R p m. for removing stock	R p.m for brass and burring and finishing
12	2,000	2,600
18	1,400	1,800
20	1,250	1,600
23	1,100	1,300
26	1,000	1,250

Recommended Speeds.—Taking an 18-in. disk as an example, the recommended speed for cast iron is 1,400, for general work such as machine steel 1,650, and for brass work 1,800 r.p.m. This corresponds to about 6,650, 7,840, and 8,550 ft. per minute for rim speed of the disks.

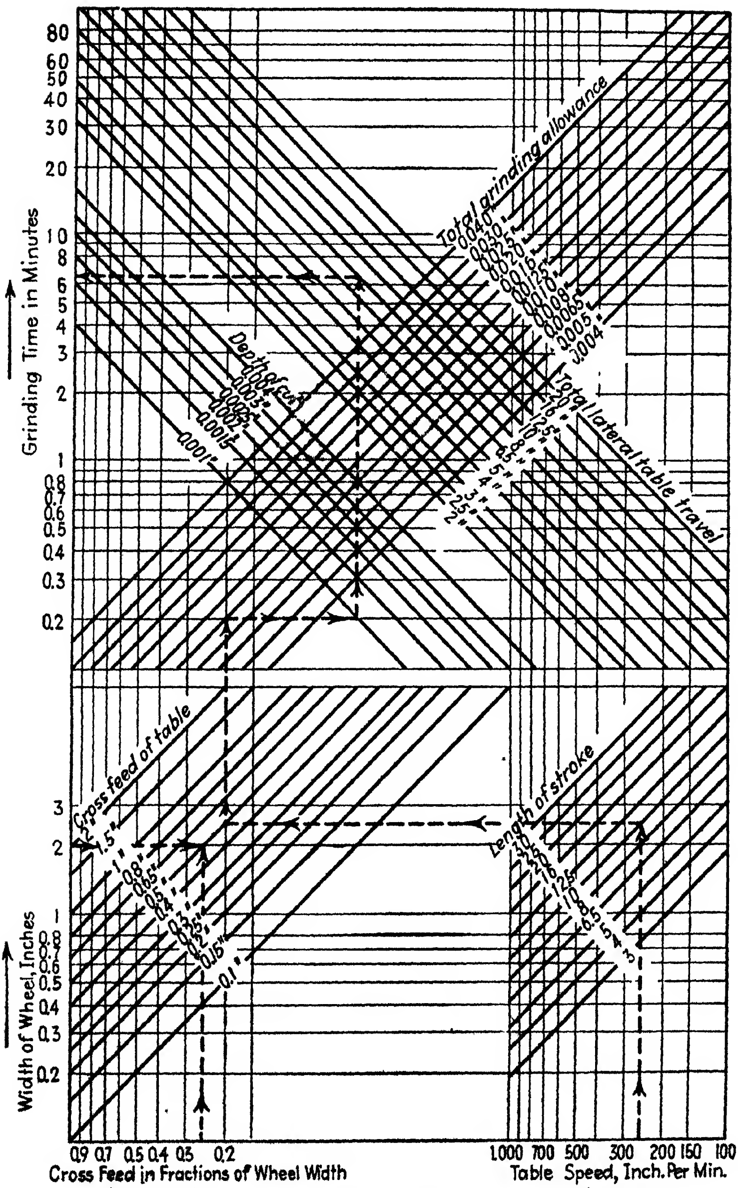


FIG. 122.—Chart for surface-grinding time.

Chart for Surface-grinding Time

As a closing feature for this chapter the chart in Fig. 122 is referred to here as of value in computing times for various classes of surface grinding coming under the usual types of machines, particularly of the reversing-table class.

Many surface grinders have but one table speed, but with others it will be necessary to select the proper table speed for a given condition. Selection of the proper crossfeed at each table reversal depends upon the width of the wheel, whether dry or wet grinding is used, and also upon the nature of the work. Total lateral table travel is the sum of the width of the work plus an amount dependent upon the width of the wheel to allow the latter to clear the work. The same applies to the length of the stroke.

Example.—A plate 8 in long and 5½ in. wide is to be ground, total grinding allowance being 0.010 in. The machine has a table speed of 250 in. per minute and the width of the wheel is 2 in. Allow a moderate crossfeed of ¾ of the wheel width, that is, 1.5 in., set the length of stroke at 10 in. so that the wheel clears the work, and set the total lateral table travel at 8 in. for the same reason and have the wheel take a cut of 0.001 in. per pass. By following the broken line and the arrows on the chart it will be found that the net grinding time for this example is 6.4 min.

Further reference to surface-grinding operations and certain types of machines not covered in this section will be taken up in later pages in this work. There they are shown in operation on certain specific lines of finishing operations.

CHAPTER XI

GRINDING CRANKSHAFTS AND OTHER MOTOR WORK

There is probably no single part in an automobile engine that has received more attention in the development of special machinery for its production than the crankshaft. This is especially true in the case of grinding machines which are responsible for the

FIG. 123—Battery of crankshaft grinders.

final accuracy and finish to surfaces which must withstand the wear occasioned by many thousands of miles of service.

Modern lathes, some of special design, turn the cylindrical surfaces—bearings, crankpins, flange, gear fit, etc.—leaving such amounts of stock as permit the lathes to operate efficiently. The grinding machine must remove the stock left, even though in some cases the amount presents a condition far from ideal for grinding. The crankshaft grinding department of a large automobile plant is seen in Fig. 123.

The grinding operations on a typical light six-cylinder crankshaft (Fig. 124), are given by Howard P. Chace, of Norton Company in Table 8 in their proper sequence. The table refers to Norton grinding machines used as well as data pertaining to

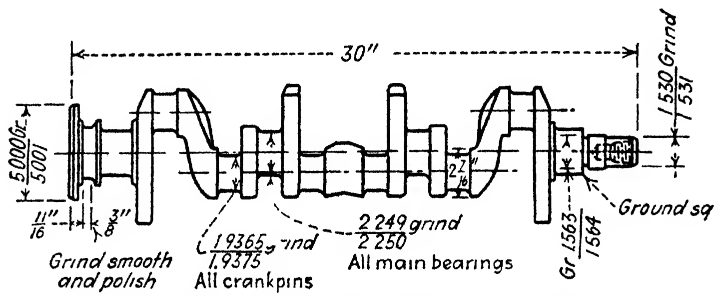


Fig 124 —Details of light six-throw crankshaft

stock removal and production rates. A study of this tabulation will show that two general types of grinding machines are used for the grinding operations.

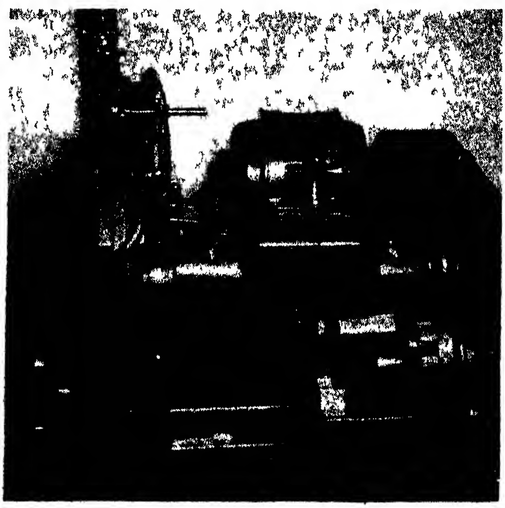


Fig. 125 —Norton grinder for crankpin bearings.

The crankpins are ground in highly specialized machines developed for this particular job. All other grinding is done with standard or special arrangements of plain cylindrical grinders, most of them operated semiautomatically and with such special equipment as has been found most satisfactory for each specific operation.

The Crankpin Grinder.—The Norton D-86 crankpin grinder is a hydraulically operated machine of the double-head type built exclusively for production grinding of crankshaft connecting-rod bearings or crankpins. All the crankpins are finish-ground before the shaft is removed from the machine. The grinding-wheel unit is shown in Fig. 125.

Two levers and one handwheel control all the machine's principal functions. Movement of the main control lever, situated at the operator's left:

1. Opens and closes the workholders.
2. Starts and stops the work rotation.
3. Moves the wheel head in and out rapidly or slowly at the operator's will.
4 Moves the work table to locate each pin opposite the grinding wheel
5. Raises the steadyrest into position or lowers it.

The control of all these functions is so interlocked that the work rotation cannot be started with the workholders open nor can the work table be moved by power while the wheel is grinding between the two cheeks of a crankpin.

The second lever is used for moving the wheel slightly to the right or left in order to "split the spark," that is, grind equal amounts from the shoulders of a crankpin.

A handwheel directly at the operator's right controls the grinding feed of the wheel, the diameter being established by a grinding gage riding on the work and having an indicator before the eyes of the operator. Grinding wheels 42 in. in diameter are used, the width or thickness being the same as the length of the crankpin so that shoulders, fillets, and the body of the crankpin are ground to size in a single cut.

The Main or Line-bearing Grinders.—Bearings are ground in 10-in. Type C cylindrical grinders, Fig. 126, arranged for semi-automatic operation in most instances. Two operations are required, rough grinding and finish grinding.

These machines are hydraulically controlled by a single lever which starts the automatic cycle. The cycle includes starting the work revolution, bringing the wheel head forward rapidly until the shoulders of the bearings are reached, grinding the shoulders at a reduced traverse or feed and then grinding the body

TABLE 8.—OPERATIONS IN GRINDING A TYPICAL SIX-CYLINDER CRANKSHAFT

Operation	Norton grinding machines on crankshaft work	Grinding wheel	Grinding method	Stock removal	Production, cranks per hour
1. Rough grind—diameters Two intermediate bearings	10 × 36 in. Type C semiautomatic	30 × $1\frac{1}{4}$ × 12 in 36 R4BA	Plunge cuts	Diameters 0.030 in.	40 80 bearings
2. Rough grind—width Main-thrust bearing	10 × 36 in. Type C with hydraulic wheel slide	30 × $1\frac{1}{4}$ × 12 in. 36 R4BA	Bump each shoulder	Each side 0.010 in.	40
3. Rough grind—diameter Main-thrust bearing	10 × 36 in. Type C semiautomatic	30 × $1\frac{7}{8}$ × 12 in. 36 R4BA	Plunge cut	Diameter 0.030	80
4. Rough grind—dia. and square Gear-end bearing	10 × 36 in. Type C semiautomatic	30 × 2 × 12 in. 36 R4BA	Plunge cut and bump shoulder	Diameter 0.030	80
5. Grind—complete dia. and shoulders to size in one oper. All crankpins	17 × 42 in. Type D-86 hydraulic crankpin grinder	42 × $1\frac{1}{4}$ × 12 in. 50 P5A	Plunge cuts	Diameters 0.040 in. each side 0.015 in.	15 90 crankpins
6. Finish grind—diameters Two intermediate bearings	10 × 36 in. Type C semiautomatic	30 × $1\frac{1}{4}$ × 12 in. 50 P5A	Plunge cuts	Diameter 0.020 in.	40 80 bearings
7. Finish grind—width Thrust surfaces—main bearing	10 × 36 in. Type C with hydraulic wheel slide	30 × $1\frac{1}{2}$ × 12 in. 50 N5A	Bump shoulders	Each side 0.004 in.	70
8. Rough and finish grind—diameter and shoulder Gear fit	10 × 36 in. Type C semiautomatic	30 × $1\frac{1}{2}$ × 12 in. 50 P5A	Plunge cut and bump shoulder	Diameter 0.050 in. shoulder—clean	70
9. Grind Oil groove	10 × 36 in. Type C semiautomatic	24 × $\frac{7}{8}$ × 12 in 50 O5A	Plunge cut (formed wheel)	Diameter 0.040 in.	80
10. Grind—diameter and face Flange	10 × 36 in. Type C 45° angular wheel slide two-wheel setup	20 × 1 × 12 in. 50 N5BE 20 × 1 × 12 in. 36 J8BE	Traverse cut on large diameter bump face	Diameter 0.035 in. face 0.008 in.	45
11. Finish grind—diameter Extreme gear end (1.530″)	10 × 36 in. Type C semiautomatic	30 × $1\frac{1}{2}$ × 12 in 50 P5A	Plunge cut	Diameter 0.033 in.	80
12. Finish grind—diameter Main-thrust bearing	10 × 36 in. Type C semiautomatic	30 × $1\frac{7}{8}$ × 12 in. 50 P5A	Plunge cut	Diameter 0 020 in.	80
13. Finish grind—diameter and square gear-end bearings	10 × 36 in. Type C semiautomatic	30 × $1\frac{7}{8}$ × 12 in. 50 P5A	Plunge cut and bump shoulder	Diameter 0.020 in.	80
14. Lap all crankpins, main bearings and oil groove	12 × 24 in. Type 30 crankshaft lapping machine	% Abrasive paper		Diameter 0.00025 in.	30

diameter to size at a still further reduced rate of feed. Sizing is accomplished either by a positive stop on the wheel slide or determined by a dial gage. At a touch of a button by the operator the wheel head is rapidly returned to a position allowing the work table to be moved for grinding the next bearing.

In the case of the thrust surfaces on the rear main bearing shoulder grinding to finish size is done by "bumping" or pressing the shoulder against the side of the grinding wheel, working to an indicator gage for sizing to exact width.

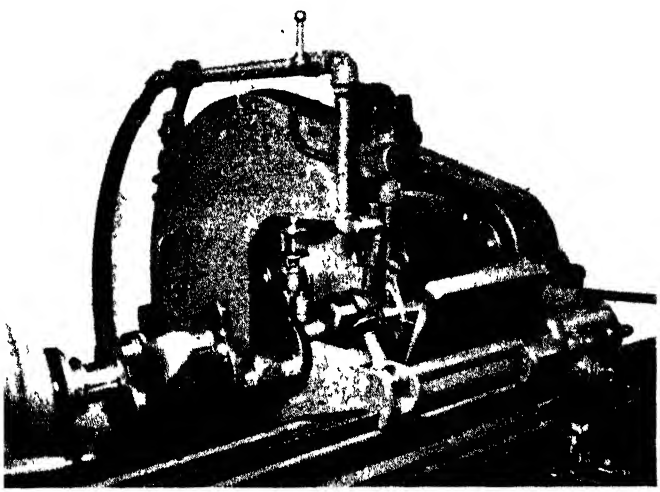


FIG. 126. -Grinding the main bearings.

Flange-face-grinding Machine.—The face of the flange is ground simultaneously with the outside diameter using a two-wheel setup in a special Norton 10- by 36-in. Type C angular wheel-slide machine (Fig. 127). This machine as indicated by its name is built with the wheel-spindle axis at an angle of 45 deg. with the axis of the work center line. The wheels are trued, one for grinding the diameter, parallel with the crankshaft axis, and the other which grinds the face of the flange is trued at 90 deg. to the crank axis. The finish produced on the face using a wheel trued in this manner is far superior to that obtained by contact with the side or edge of a grinding wheel.

Present-day practice in most automobile factories is to polish or lap crankshaft main bearings and crankpins. For this operation a Norton Type 30 crankshaft lapping machine, Fig. 128, is shown.

This machine includes means for rotating a crankshaft on centers and a set of jointed arms carrying rolls of fine abrasive

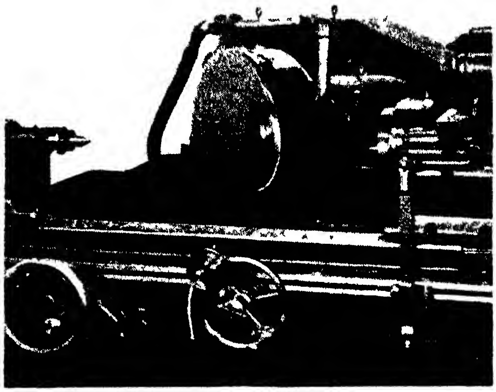


Fig. 127—Face and flange grinding

paper which is partially wrapped about each pin and bearing. A high-luster, smooth bearing surface is produced as the crankshaft is revolved.

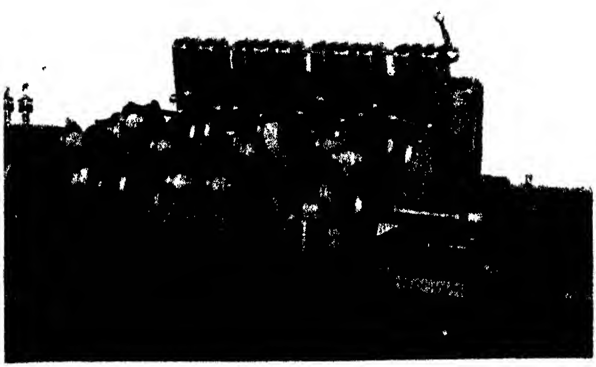


Fig. 128.—Crankpin lapping machine

Automobile Crankpin Operations.—Among the extensive line of grinders by Landis is their hydraulic crankpin grinding machine which is equipped with an indexing fixture for obtaining proper angular relation and a spacing device for the various pins in relation to a fixed locating point on the crankshaft. With this arrangement all the pins of any crankshaft can be ground on the one machine with but a single handling of the work.

Fig. 129.—Crank-carrying fixture with fixed stop plate.

The locating and spacing method on the Type AB machine is described by Landis as naturally depending upon the character of the shaft and the locating points used for previous machining operations. The crank-carrying fixtures (Figs. 129 and 130) are easily removed without interfering with the spindle. They are equipped with hydraulic work clamps through pressure applied through the work-head spindles from a valve controlled at the front of the machine. The heads cannot be rotated until the shaft is safely clamped, the safety device thus preventing possibility of accident. Shafts of different throw are taken care of by extra clamping blocks which are interchangeable.

Fig. 130.—Crank-carrying fixture with indexing plate.

The spacing and locating as provided for are described by the builders as follows:

When the flywheel flange is the locating point, the shaft is located in an endwise direction by bringing the flange against a stud on the side of an indexing plate incorporated into the rear of the left-hand crank-carrying fixture. This plate locates radially from notches 180 deg. apart for four-cylinder shafts, 120 deg. apart for six-cylinder shafts, and 90 deg. apart for eight-cylinder shafts. A plunger, which is released and thrown in position by a convenient lever, holds the plate in position while grinding.

If a milled lug on the extreme left-hand cheek is the locating point, the shaft is located endwise against the side of the clamping block. In this case radial locating is accomplished by means of a fixed stop plate attached to the front of the fixture. The fixed stops are arranged in the same relation to each other as the notches in the previously mentioned indexing plate.

Large Grinding Wheels.—It is of interest here to note the effect of wheel diameters and sizes in general, as they affect crank grinding.

Crankshaft-grinding operations necessarily require large wheels in order to clear crank throws and still reach the surface of the pins. There are reasons, however, for still larger wheels than would be necessary for this reason only. The Landis Tool Co. refers to large-wheel uses as follows:

After continued use by a multitude of users over a period of four years, the large-diameter grinding wheel has proved itself to be highly practical because (*a*) it needs be trued less often--an average of 50 to 65 per cent less—the time saved (about one hour per day) being applied to production work. For example, a 36-in. diameter by 2-in. face wheel has almost 40 per cent more face surface than a 26-in. diameter by 2-in. face wheel. Because 40 per cent more cutting particles are presented to the work at each revolution, the wheel breaks down more slowly and consequently requires truing less often. And less truing means less diamond wear. (*b*) A smaller number of wheels are scrapped. As one large-diameter wheel generally replaces three small-diameter wheels, there are two less wheels scrapped for each large-diameter wheel used. The portion of the wheel that is scrapped cost about $8 when the wheel was purchased; this means a saving of $16 for each large-diameter wheel used. (*c*) There is less changing of wheels. The total time required for balancing a new wheel, changing wheels, and getting into production again averages 3 hr. It follows that for each large-diameter wheel used, about 6 hr. are saved for production work.

In order to enable the operator to handle the wheel without undue effort, a jib crane is supplied as a part of standard equipment. To assist the operator further, a wheel lifter will be supplied if ordered. This lifter is easily and quickly attached to the wheel center and is so proportioned that the wheel will hang straight when it is lifted by the crane.

Occasionally it is necessary to locate endwise from the center main bearing, this being taken care of by placing a locating arm on the left-hand head. The arm is swung down over the work only while locating after which it is swung back so as not to interfere while grinding.

The spacing device consists of a rigid bar on which are securely fastened lugs located in the proper relation to the various pins on the shaft. This bar is immediately beneath the work table in such a position that a stop on the under side of the work table comes against the proper lug on the bar, thus bringing the corresponding pin into grinding position. A lever on the front of the machine brings the desired lug in position to engage the positive stop on the work table.

A hydraulic cushioning device attached to the left-hand end of the bar permits the work carriage to come to a stop slowly, thus eliminating shock from the driving mechanism.

Hydraulic Work Rest.—The stationary hydraulic work rest is rigidly attached to the bed of the machine so that it is directly in front of the grinding wheel, thus being in position always to support the pin to be ground. It consists of two parts—a base and a movable part which is operated hydraulically to bring the work shoes in position. This movable part is held against fixed stops by hydraulic pressure but the final adjustment of the work shoes is made by means of hand adjusting screws. In this way the actual amount of pressure applied to the pin and the actual sizing are done by hand and are under the control of the operator. Stops are provided on the hand adjusting screws so that their position can be duplicated on each pin being ground.

Figure 131 shows a Landis 10- by 36-in. machine used for the grinding of the crankshaft bearings. The equipment varies to some extent, depending upon the characteristics of the shaft and upon the particular bearings to be ground. In order to give some idea as to the procedure we will assume that a seven-bearing six-cylinder crankshaft is the one in question and that the center bearing is the locating point.

The center bearing is ground first and as it is to be the locating point for succeeding operations, the grinding merely follows the turning, a locating arrangement being unnecessary. Hydraulic straight infeed is used, a narrow-pattern work rest at the bearing being ground and a standard rest at the right-hand end to act as a work cradle when changing shafts. A lever-operated foot stock with latch is used for this operation as well as all line-bearing operations. When grinding the intermediate bearings, the equipment consists of an adjustable-stop-spacing bar, a locating arm, two narrow-pattern work rests, and hydraulic straight infeed. In some instances this operation has been materially speeded up by the use of two grinding wheels instead of one for roughing

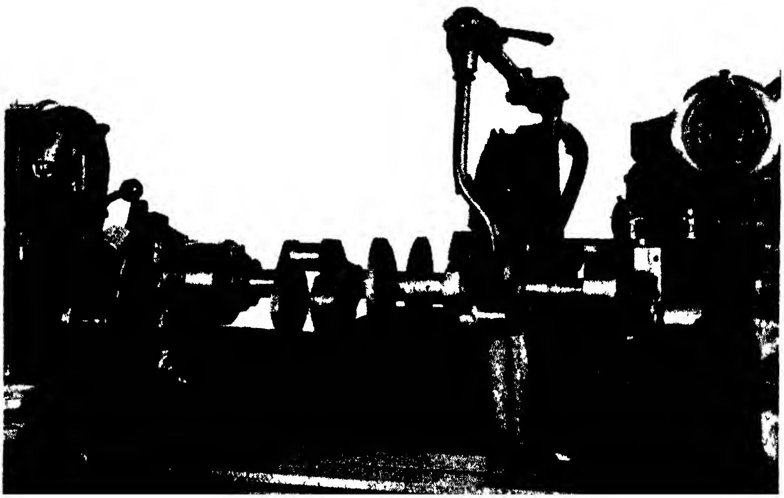


FIG. 131.—Landis crankshaft grinder.

This is accomplished by using an extra wide wheel center and a spacer of the necessary thickness between the wheels, but the maximum distance between the outer sides of the two wheels should never exceed 6 in. An adjustable stop-spacing bar and one narrow-pattern work rest take care of the front bearing. Hydraulic straight infeed is not required because it is unnecessary to move the wheel back any great distance when changing the work. At times a standard work rest is used at the left-hand end to act as a work cradle. The equipment used for the rear bearing consists of an adjustable stop-spacing bar, a narrow-pattern work rest, a standard work rest, to be used as a work cradle, and hydraulic straight infeed.

As mechanical sizing gages are invariably used for line-bearing operations, the narrow-pattern work rest has been recommended regardless of the width of the bearing. This enables either an Arnold or a Pratt gage to be swung down from the wheel guard and snapped over the side of the bearing without interference from the work-rest shoes. The rest may also be arranged to accommodate another type of Arnold gage in the center.

Stock Allowances.—The amount of stock left on main bearings and crankpins for removing in the grinding process varies with different types of shafts and with different plants. However, in some places a fair average is indicated as being from 0.050 to 0.060 stock as ordinarily removed from the pins during the rough-grinding operation. Then from 0.030 to 0.045 in. is removed in finish grinding in some shops. In one plant both rough and finish turning is done, eliminating the rough-grinding operation. About 0.035 in. is then removed as a finish-grinding operation.

Reconditioning Equipment.—It is also of interest to note some of the features of grinding machines built for the use of automotive repair and maintenance shops where regrinding of crankshafts and other parts are essentials of the day's work. The above firm of grinder builders makes several machines which are of special service in reconditioning operations, where precision requirements must be maintained and time and labor expense reduced. Thus Fig. 131 shows a setup in their special automotive grinder where a crankshaft is seen ready for grinding the pins. It will be noticed that the work is held by the ends in chuck fixtures, an aligning bar being provided in the work-head base for bringing the fixtures in line. The left-hand fixture carries a 6-in. three-jaw universal chuck, the right-hand head carries a similar chuck of 5-in. size. The builder's instructions for grinding crankshafts on this machine are:

First determine throw of crank and set fixtures to correspond by means of scale and dial. Fixtures are placed in vertical position, locating plugs inserted and crankshaft placed in machine. The chuck jaws are then adjusted as close as possible but allowing the crank to be turned freely in the chucks, and the centering gage is placed on the pin. Revolve crank in chucks until gage touches on both sides; then tighten in chucks. Withdraw locating plugs and turn heads 90 deg.; again place gage on the pin and test throw. If found to be out, adjust fixtures on slide until gage touches on both sides, after which throw will be true for grinding. If pins could be reduced in diameter an amount sufficient to true them, it would be unnecessary to change throws. However, it is often desirable in regrinding to remove as little as possible from the pins, which necessitates making them true on throw within the amount to be removed. Care should be taken to insure fixtures being parallel; for example, if, in truing the end pin, it was found necessary to move the fixture $^1/_{64}$ in. on the slide, the other fixture should be moved a corresponding amount. When starting to grind the pin, do not use rest shoes until the pin is trued. When the pin is trued, the shoes should be brought firmly against the work as a good support is necessary for obtaining round pins. Do not force the shoes against the work too hard as this will raise the crank and result in the pins not being parallel. This is particularly true of slender shafts.

Although the line bearings are generally ground between centers, this is not always necessary nor is it always done. Removing the crank-carrying fixtures and inserting the centers take about 10 min., but the fixtures may be run down on center and the balance weights removed in about 5 min. In fact, it is often desirable not to remove the fixtures especially when the centers in the crankshaft are bad. An ordinary six-cylinder crankshaft may be ground complete, that is, including both pin and line bearings in $1\frac{3}{4}$ hr.

Regrinding Large Shafts.—Since the advent of the gas-electric car and locomotive with their far-reaching economies, many railroads throughout this country and abroad have been replacing their steam power on short hauls, and in some instances the main-line hauls, with this new power.

With the new power have come new problems to the railroad repair shop, which in the past handled nothing but steam-driven locomotives. Entirely new setups have been necessary for overhauling Diesel engines. In many cases this has been accomplished by the purchase of new machine tools designed for the work; by rebuilding machine tools in the shop, with the addition of such small tools as necessary; and by sending some of the parts back to the manufacturer for refinishing.

One of the most difficult and costly of these parts to refinish without the use of special equipment is the crankshaft. The gas-electric engines run from approximately 100,000 to 125,000 miles, after which it is usually necessary to give them a general overhauling. All worn parts such as pistons, cylinder liners, bushings, etc., are replaced and all bearing surfaces refinished to round them up and impart a good bearing surface. Crankshafts will usually permit at least two regrindings, but in some instances this has been increased to three and four, increasing the life of the crank proportionately. Owing to the equipment required for refinishing the cranks, the greater majority of the roads are sending them back to the original manufacturers, which may seem to be the most economical method of solving the problem. Yet a careful analysis does not always prove this to be true, for besides the actual cost of refinishing there are several allied expenses which must be taken into consideration:

1. There are the transportation charges to and from the crank-refinishing shop. This will, of course, vary depending upon the distance the cranks must be shipped, for some railroad shops are located comparatively near to a crank-refinishing plant, while others must ship long distances.

2. The loss of time during which the crank is being transported and while it is in the refinishing shop must be compensated by maintaining a reserve supply of cranks so that the locomotives can be put back on the tracks without waiting the return of the original cranks. Most roads make a practice of carrying these reserve cranks, but it must be taken into consideration that the locomotive is not earning dividends in the repair shop.

3. The expense of having the cranks reground by an outside source usually varies between one-fourth and one-third the cost of a new crank, and although the customer is returned an excellently conditioned crank, the cost item can be greatly reduced by refinishing in the railroad shop.

For example, one of the large railroad companies installed in its shop a machine for regrinding worn cranks. By eliminating transportation charges and the lost time that the crank is away from the plant, this shop has been able to eliminate one expense and reduce its reserve stock of cranks. The crank requiring regrinding can be taken from an engine and in less than 7 hr. can be reground and ready for assembling, and the total cost of refinishing the crank has been reduced to approximately oneeighth of what it was before the installation of the grinder. Although there is not sufficient crank regrinding to keep the machine busy, it is available for such work as regrinding steam-locomotive piston-rods, car-axle journals, air-compressor pistons and rods, and the many other cylindrical grinding jobs found in the repair shops.

The machine, a Cincinnati 28- by 120-in. plain self-contained grinder, besides being supplied with standard equipment for regrinding main bearings and straight cylindrical work, is equipped with throw blocks for 6 and 8 throw cranks, and also the necessary back rests for the crankpin and main bearing diameters. A 44-in. diameter grinding wheel with 4-in. face is used for obtaining maximum wheel wear and permitting ample clearance between the crank and the grinding-wheel head.

The throw blocks are designed so that they can be quickly located on the crank. Once the crank is between centers, it is unnecessary to remove it in order to index from one set of pin bearings to the next. In this way are offered all the advantages of the more expensive cradle fixtures requiring a live spindle headstock which cannot be used with entire satisfaction for regrinding the main bearings or other cylindrical work requiring dead centers. In operation of regrinding the pin bearings of a 6-throw crank, the total regrinding time for both the pin and main bearings is approximately 6½ hr.

Other interesting details of this machine and equipment include pressure-feed lubricating system to the table ways, which not only increases the life of the machine by reducing wear on these surfaces, but insures a very smooth operation of the table with the resultant freedom from chatter marks and easy and accurate reversal. The oil is fed at approximately 4 lb. pressure to the underside of the table and is carried from the main reservoir by a small gear pump through an industrial-type purolator onto the ways of the machine, thereby insuring correct lubricating conditions.

The grinding wheel can be quickly withdrawn at the rate of approximately 10 in. per minute when changing from one pin bearing to the next. This rapid traverse is entirely free from the standard infeed and is operated by a hand lever on the front of the machine. A 1-hp. reversible-type motor supplies the necessary power.

A 30-hp. main-drive motor driving the grinding-wheel spindle through the multiple strand V belt supplies the power for the table reciprocation when this is used. This motor mounted on the outside of the machine drives through a flexible coupling to the main jackshaft which is mounted on antifriction bearings and contained in the rear bed of the grinder. Twelve table speeds, controlled from the operator's position on the front bed, are available through heat-treated alloy-steel gears mounted on multiple integral splined shafts.

The headstock is driven by a 3-hp. 230-volt variable-speed direct-current motor which is mounted at right angles to the axis

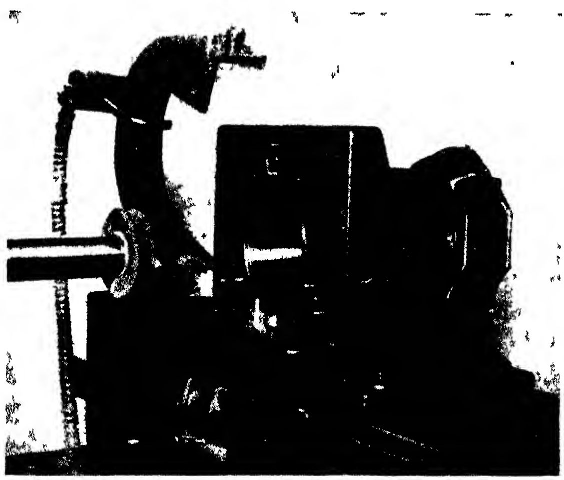


FIG. 132.—Grinding an airplane motor cylinder.

of the faceplate. Power is supplied through a silent chain to a heat-treated steel worm gear and a heavy bronze worm wheel approximately the full size of the faceplate. The various headstock speeds are obtained through a hand rheostat while the machine-clutch lever stops and starts the table traverse and headstock through a dynamic braking panel.

Cylinder Grinding.—The cylinder grinder made by different firms is used for various internal jobs as well as for grinding and regrinding automobile-cylinder blocks. A typical operation on a Heald No. 55 cylinder-grinding machine is shown in Fig. 132. The machine is built for finishing bores in large workpieces, which, owing to their size or shape, cannot be revolved when the

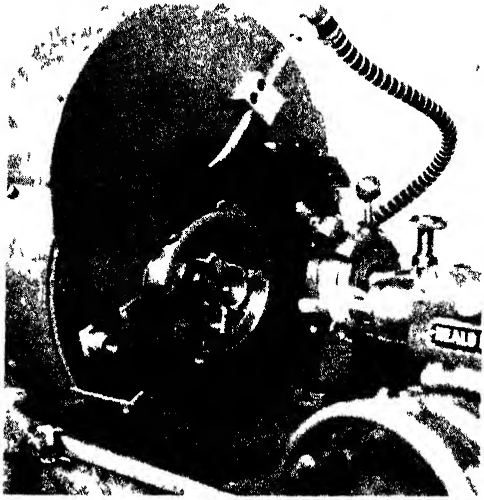


FIG. 133 —Gagematic grinder at work on connecting rods

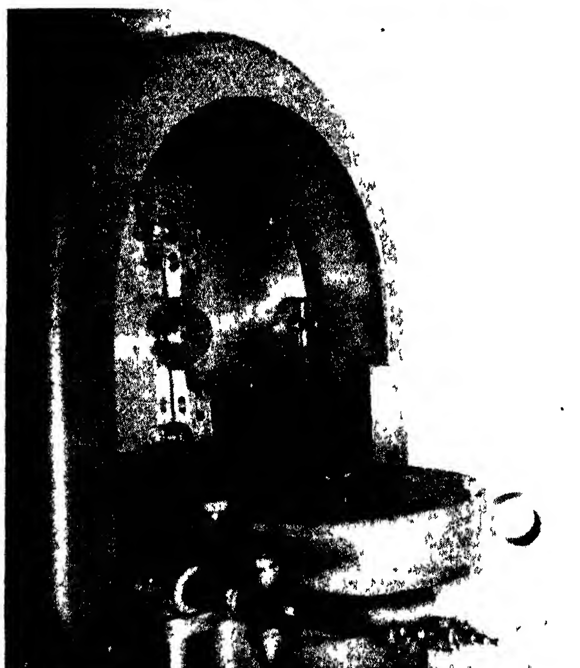


FIG. 134.—Fixture for grinding the side of connecting rod.

grinding operation is being performed. Owing to the large vertical adjustment and crosswise movement the machine is particularly adapted to the shops where there is a miscellaneous class of work as is found in airplane, automobile, or railroad repair shop.

As illustrated, the machine is as well adapted to reconditioning worn airplane cylinders as it is in regrinding not only the wrist

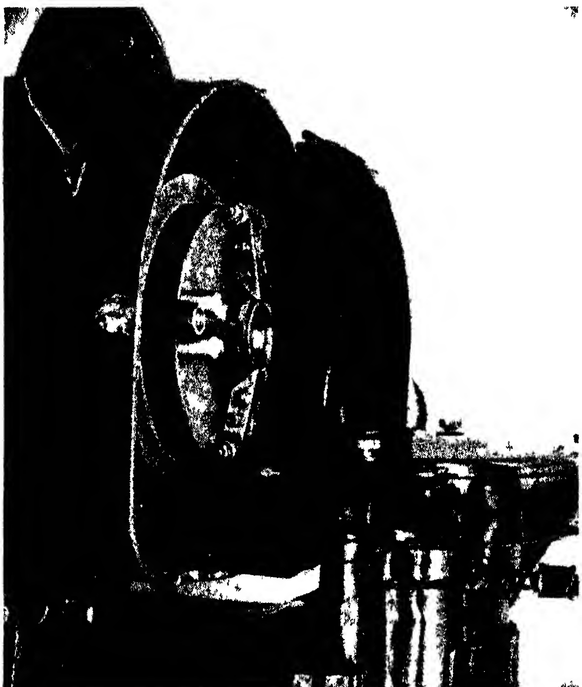


FIG. 135 —Finish grinding the other side of the rod

pinhole in a radial-engine master rod but also the articulating pinholes.

Production Work in Heald Machine.—In connection with the above references to the use of this make of grinding equipment the views in Figs. 133, 134, and 135 will be of interest; the first of these showing a Heald Gage-Matic grinder used in manufacture of connecting rods with the same company's rotary-table surface grinders used for finishing the sides of the rod. The Gage-Matic is applied to the grinding of bores in the rods at the rate of 70 to

85 pieces per hour, the automatic and precision sizing features being of special advantage on this refined class of work.

The surface grinders, Figs. 134 and 135, are shown at work finishing the sides of connecting rods. In grinding the first side (Fig. 134) the rod is located from the centers as indicated in the fixture. The grinding of the second side of the rod is done with the work located from the first side. With these surface grinders the rods are ground on both sides at the rate of 100 to 120 rods per hour.

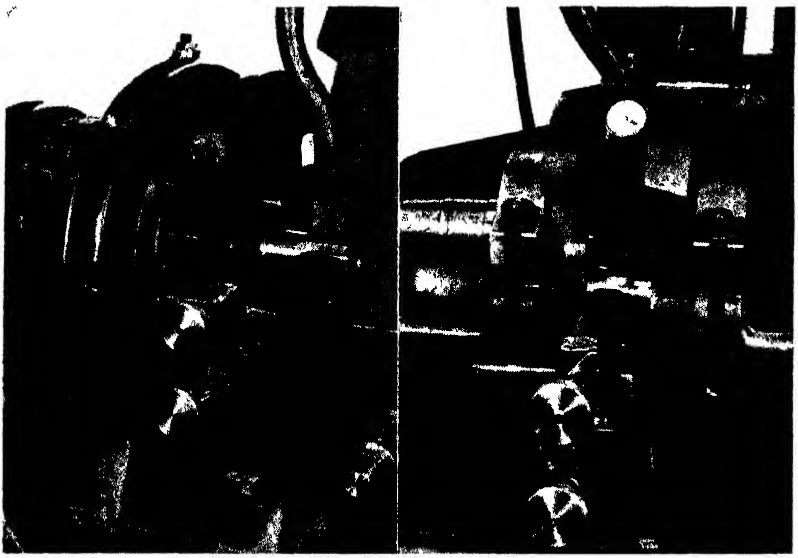


Fig. 136.—Airplane crankshaft being ground on the front end at left. Finish grinding of assembled shaft at right.

An airplane-engine crankshaft, with the counterweight forged in place, is seen in Fig. 136 being finished in a Landis crankpin grinder. This is a two-part shaft. Both the pin bearing and the end surface that fits the mating part of the crankshaft are ground at the same setting with the work held as shown at the left.

The two sections of the crank are then assembled and the crankpin finished with the main bearings held in the fixture shown at the right, Fig. 136. This also shows the dial gage in place. With suitable fixtures of this type the machine can handle a variety of crankshafts.

Internal Grinding of Gears.—Methods used in holding gears for grinding will be found in the volume on Gearing.

Grinding a Diesel-engine Shaft.—A very different type of shaft, for a good-sized six-cylinder Diesel engine, is seen in Fig. 137. This is for an Atlas engine with a 5½-in. crankshaft, for a 200-hp. engine. It is ground in the average time of 3 hr. on a Cincinnati 24- by 168-in. plain self-contained grinder for the seven main bearings, time given floor to floor. Stock removal is 0.060 to 0.070 in. and limits for size held within 0.0005 in.

Features of this grinder are rapid traverse to wheel head, automatic grinding wheel infeed, force-feed lubrication to table ways,

FIG. 137.—Crankshaft for Atlas diesel engine.

antifriction spindle mounting, centralized control, multiple-speed headstock, sliding gears for table-feed changes, powerful drive with flexible coupling, 44-in. diameter by 3-in. face-grinding wheel, and motor-driven coolant pump.

MISCELLANEOUS OPERATIONS

The Gardner double grinder in Fig. 138 is shown in operation on the job of finishing the ends of big springs for knee-action units. The fixtures for holding the springs are shown clearly and naturally are of the quick-acting type operated by simple lever action. The setting of the grinder elements gives the right length to the springs both ends of which are squared to length at the one pass through the machine.

Grinding Production on Cylinder Heads.—An operator grinds 75 or more aluminum cylinder heads per hour on this Besly

No. 6—20-in. wet-direct-connected motor-driven grinder equipped with this specially designed quick-clamping work holder.

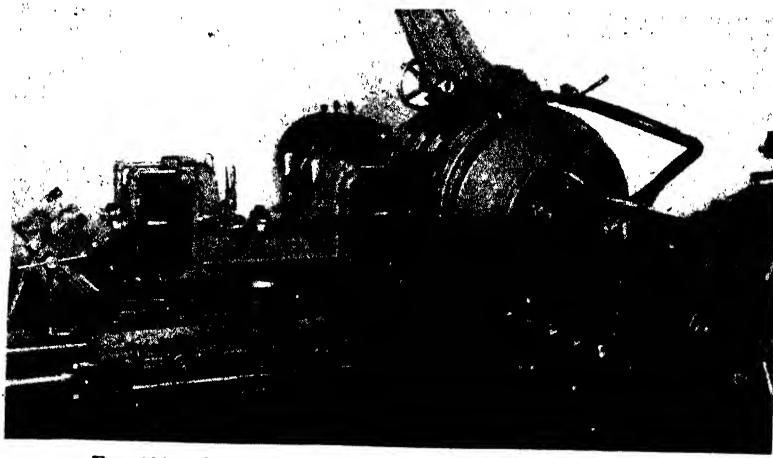


Fig. 138.—Gardner grinder finishing both ends of coil springs.

The cylinder head is placed in the work holder (Fig. 139) with the fins to be ground standing in a vertical position, locating in a hardened-steel V block at the bottom and top by means of a spring plunger in the exhaust-chamber hole. The end of the

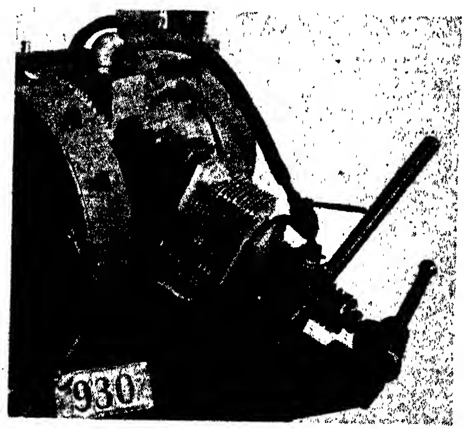


Fig. 139.—Besley grinder finishing cylinder fins.

clamp engaging the work is fitted with a hardened-steel plug which centers the cylinder head in the work holder from the dome opening. There are two hardened-steel pins in the face of the clamp which bear against the face of the cylinder head when the quick-acting lever is pulled back, actuating a cam against the end of the clamp. This in turn securely clamps the work in the hardened-steel V block at bottom and against a hardened-steel pin at top. To unload, the operator pushes the cam lever ahead and lifts the work out. The grinding members are Besly Titan Bakelite Steelbacs, 1 in. thick—abrasive-bonded with bakelite—very efficient for grinding aluminum.

Grinding Splined Shafts.—Splined shafts have become a regular part of machine production in many lines, and where accuracy between the shaft and whatever is mounted on it is desired, the splines are ground in much the same way as gear teeth. Using the formed-wheel method, as in Fig. 140, it is necessary only to have a wheel of proper shape and traverse the splined shaft under it to secure accuracy that avoids the necessity of hand fitting. The shaping of the wheel is done with diamonds, suitably mounted and controlled by formers or cams.

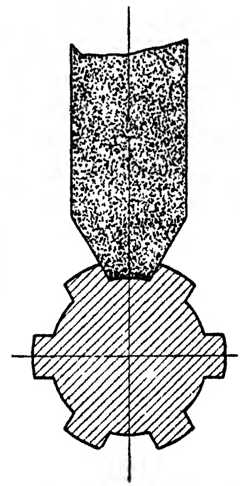


FIG. 140.—Grinding splines with a formed wheel.

Broaches used in finishing the holes in gear hubs and similar work can also be ground in the same way. In both cases, the shaft or the broach must be held accurately between centers and must be correctly indexed between the different splines. Special machines are made for this work, although it can be done on a regular surface grinder with a traversing table and suitable fixtures for holding and indexing the work.

Crankshaft Grinding.—In machining the Ford V 8 cast crankshaft the first operation after centering is to rough-grind the center bearing to establish a steadyrest surface for future operations. A 24- by 1$\frac{7}{16}$-in. wheel is used. The next grinding operation is the rear main bearing, which is ground to length to establish a master face from which to space future operations. These are ground 40 per hour.

Pin bearings are finish-ground on hydraulically operated grinders with 42-in. wheels. Dimensions are held to within 0.001 in. on diameter and 0.002 in. on width at 11 shafts per hour.

The three main bearings are ground in the following order: center, rear, and front, using a 24-in. wheel and removing 0.025 in. of stock, at the rate of 30 per hour.

The cranks are finished in a hydraulically clamped polishing machine using ribbon-type polishing paper with 320 grain abrasive. Approximately 90-lb. pressure is exerted on the paper, a new section being used for each bearing. The shaft runs 120 r.p.m. for 45 sec., which gives a highly polished surface. The shaft is rotated in the direction that it will run when in operation in the car to make the grain of the polished surface run in the right direction.

The quality of the finish is determined by the color of the bearing. A light or white bearing indicates insufficient polish. Brown spots indicate too much polish or a burning effect. The best finish is a dark bearing, almost black, this giving an extremely smooth finish.

Cast Camshafts.—Proferall cast camshafts (Proferall being made up of the first syllables of "processed ferrous alloyed iron"), as made by the Campbell, Wyant & Cannon Foundry Co., are finished by grinding wherever finish is necessary. Only $1/16$ in. of metal is left on the radius of all bearings for rough turning and finish grinding. Cams and eccentric faces have an allowance of $1/32$ in. and are finished entirely by grinding. There is no finish on the sides of bearings or cams in most designs. Special grinding wheels have been developed for these shafts and the wheel makers should be consulted as to their selection.

CHAPTER XII

GRINDING HEAVY ROLLS

Reference has already been made in these pages to the grinding of big rolls for steel mills, paper-mill calenders, rubber mills, and other lines where smooth cylindrical members are essential to the production of sheet metal, paper, asbestos sheeting, and other materials essential to our industrial activities and our personal affairs. For such rolls are required not only for preparing the materials of manufacture, but for paper of all kinds, rubber, linoleum, and many other sheet products, for flour mills, for cereal preparation, and many other purposes. Where rolls are very small and light enough to be considered in the class of shafts and machine-tool spindles so far as dimensions are concerned, the grinding operations employed for finishing them are comparable to the high-grade cylindrical-grinding undertakings, such as are to be witnessed in the best organized production plants in the country. When we come to the heavy class of rolls, with typical forms and dimensions as characterized by sheet-mill and paper-calender units, a somewhat different set of conditions are set up for the finishing of the roll surfaces.

Heavy-roll grinding may involve the imparting of a mirror finish to a solid chilled-iron, steel, or alloy cylinder measuring in diameter perhaps 60 in. and having a length of 20 ft. or more. In fact, a giant roll grinder built by the Farrel-Birmingham Company takes work up to 34 ft. in length. What is perhaps the largest calender roll ever built was ground in this machine. The roll had a diameter of 36 in. and a length overall of 405 in. The gross weight of the roll before finishing amounted to about 110,000 lb.

Yet on the massive rolls machined on such grinders precision requirements are met and limits of error are reduced to a degree, which up to a short time ago, at least, would have presented a problem in grinding even small, light work.

Roll Requirements.—There are a number of reasons for the exacting requirements which are set up in roll-grinding procedure.

Consider rolled sheets for example; everyone today recognizes the demand for smooth, finely finished sheets and strips, which has been brought about by the requirements of the automobile builders, and the manufacturers of metal furniture, desks, cabinets, ranges, and hosts of industrial and household articles. Such products in their most satisfactory form are possible only by the use of highest grade of metal sheets—sheets which are uniform in thickness, free from buckled appearance, and as smooth as a perfectly ground set of rolls with mirror-finished surfaces can produce.

The rolling of superfinished surfaces admits of no surface imperfections in the faces of the rolls. Slightest degrees of irregularity in the rolls or the most minute tool marks (as from a lathe tool), will make their reappearance upon the otherwise perfectly smooth and polished area of steel or other sheet metal. A slight degree of taper in the rolls may result in imperfectly gaged material. Rolls which are either crowned or concaved must be finished to an exact degree of curvature, depending—according to their special requirements—upon the size and width of roll face, diameter, and hence weight of roll, often position of roll—whether lower or upper, whether rolls are for roughing or finishing sets, whether for hot or cold mills, and so on. As with many other special lines of mechanical work, the making and servicing of mill rolls are something of a tradition with certain groups of men long engaged in the handling of such operations for the different industries where rolling equipment is employed. However, the modern roll grinder with its massive construction and precision performance has practically put the servicing of rolls on a precision basis. That is, definite results in respect to time and labor are arrived at for each class of roll and the work is placed in the machine and removed with the same facility with which any class of heavy work is handled about the plant. For given face widths and diameters of rolls in any mill where adequate grinding equipment is installed and where many hundreds of rolls are serviced annually there is an average time value for roll grinding which is little short of astonishing to anyone unfamiliar with the progress made during the many years of roll-grinding history.

If rolls for sheet mills represent certain very definite problems, so do rolls for paper calender stacks present others. Also, certain special considerations are to be found in connection with rolls for asbestos sheeting, linoleum, and other nonmetallic materials. With all rolls, however, some factors are common to the lot: The rolls must be true—whether straight cylinders, crowned, or concave—they must be truly round at any cross section; if crowned or concaved, the curvature must be finished, as already stated, according to accurately determined amount of crown or concavity; and lastly, the rolls must rotate truly concentric upon their journals. In regard to amount of crown or concavity, there are theoretical values for such departures from truly cylindrical forms, yet on various occasions deviation from theory is necessary, and the grinding process must accomplish the production of whatever convex or concave form is requisite to the case in hand.

The Shape of the Rolls.—The paper calender is a set of heavy rolls which stands at the end of the long paper-making machine. Between these rolls passes the paper which is to be given a smooth, glossy, or glazed surface texture. In modern mills the calender rolls extend to great widths and are extremely heavy objects. Reference has already been made to the largest calender roll yet constructed, this having a face width, or length, of 288 in. or 24 ft. and an overall length of nearly 34 ft.

While this 36-in.-diameter roll represents a rare construction in size and weight, still the more conventional rolls are heavy enough to be of interest as machine elements requiring very close workmanship in the process of turning and finishing in the grinder. The crowning of a roll is based upon class of work, conditions of load, length of face, and distance between bearings, section, and other factors related to operation. The crown is to compensate for deflection under load, and its curve is established to correspond to the deflection curve of a beam uniformly loaded. The roll-grinder builders referred to have based their determination of correct roll shapes upon calculations made and checked in the grinding of thousands of paper-mill rolls over a period of many years, during which time they have also built a great number of heavy roll-grinding machines.

Take an illustration of a typical roll crowned to 0.020 in., with a length of face of 188 in. It is known from the extended experience of the firm referred to above that the measurements of the roll diameters at different points should be as follows: Divide half the length into 5 parts, then $\frac{1}{10}$ of the roll face or $\frac{1}{5}$ of the half length would be 18.5 in. Two-tenths would be 37 in., and so on. Thus a table constructed from such data would be:

Diameter at 1/10 of face or 18.5 in. from starting point is 0.0055 in.
Diameter of 2/10 of face or 37.0 in. from starting point is 0.0100 in.
Diameter at 3/10 of face or 55.5 in. from starting point is 0.0155 in.
Diameter at 4/10 of face or 74.0 in. from starting point is 0.01825 in.
Diameter at 5/10 of face or 92.5 in. from starting point is 0.200 in.

These diameters are to be adhered to in grinding the roll with proper crowning for the case in hand. The grinder-crowning and -concaving device is set to produce a mathematically accurate curve, exactly symmetrical on both halves of the curve. The setting may be for any exact curvature desired without manipulation on the part of the operator.

The checking of calculated dimensions during the grinding operation, the measuring of the diameters at any of the points, established as in the foregoing table, may be accomplished with the most precise determination by means of a special type of roll grinder for the purpose of gaging roll dimensions with exactitude. This caliper checks roll accuracy to within 1/4 thousandth to 1/10,000 in. (0.00025 to 0.0001 in.) and eliminates the necessity for correcting errors in rolls after they have been put in place.

Roll-caliper Advantages.—Features of the Farrel caliper (Fig. 141) are worthy of note. Although developed especially for roll-grinding tests, it is obviously well adapted to a wide usage in calipering many classes of large work besides mill rolls. This caliper is an indicating instrument with a dial graduated to read 0.001 in., or for extremely fine work, to 0.0001 in. The caliper is constructed with a light but rigid saddle which is placed on top of the roll and is rolled easily along without effort and without chattering. Readings of the dial may be taken at any intermediate point, or for any or every fraction of an inch of the roll face as the operator walks along the length of the roll. Knowing the desired diameter for any roll, whether straight, convex, concave, or tapered, the operator can quickly check the calculations against the dial reading.

Errors and variances from the calculations are disclosed with exactness; with the regular dial reading directly in thousandths, measurements can be made with accuracy to 0.001, quite accurately to 0.0005, and with a fair degree of accuracy to 0.00025. With the special dial reading to tenths the operator can measure quite accurately to 0.00005, or one-half of one ten-thousandth, of an inch. This dial is, of course, required for extremely fine work. The regular dial is sufficiently accurate for most purposes.

The makers call attention to the fact that the indicating caliper does not replace the so-called "light test" used in paper calender stacks. The caliper checks the accuracy of the rolls against previously made calculations, but naturally cannot check the accuracy of the calculations themselves, this being the purpose of the light test. However, if the calculations are known to be correct, the indicating caliper assures that the majority of the rolls will pass the test without having to be put back in the grinder for correction of errors. This results in important economies in time, and reduction in shut-down delays, spoiled material, and loss of production.

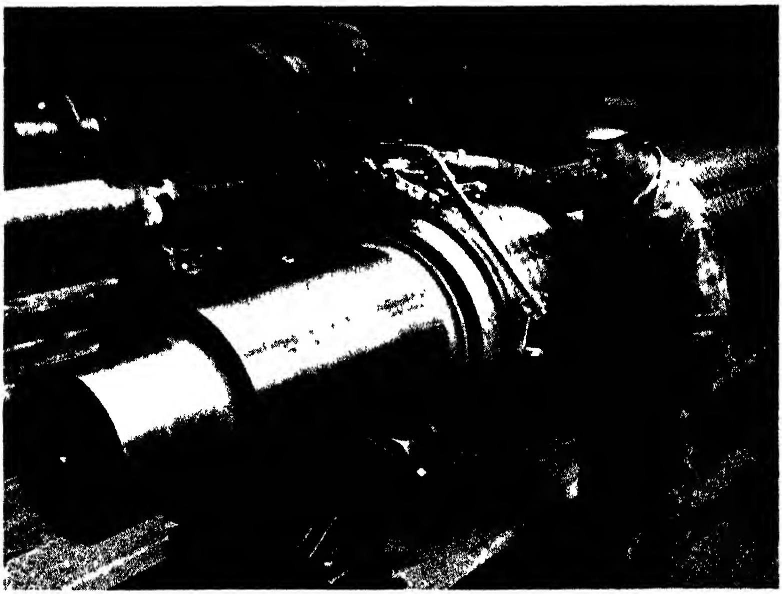


FIG. 141.—Using the Farrel indicating caliper

Other Roll Shapes.—Although the schedule of calculated values for a typical roll, as given for definite diameters at certain intervals along the roll face, is presented as applying specifically to a crowned roll, a corresponding process is followed in establishing curvatures of concave rolls, and the accuracy of such rolls is checked by the indicating caliper in the same manner as in the case of the rolls which are crowned, measurements being made as before, at predetermined points along the face, where diametral calculations have already been performed.

Concave rolls vary in regard to amount of curvature, according to their purpose. The concaved contour is required to compensate for the increased expansion at the center of the roll length over the expansion at the ends. For hot rolling of sheets a concaved roll of about 30 in. diameter may have a depth of concave from a few thousandths to a very appreciable amount, depending upon a number of factors. But while a crowned roll, as explained, takes a curve corresponding to the deflection curve of a beam under uniform load, the concaved roll, it is stated by authorities, has been found through years of demonstration to give best results when ground to a different shape of curve.

Formulas developed by the above company's engineers cover adequately the shapes of roll curves and the reproduction of such curves is mechanically carried out with mathematical accuracy by the crowning and concaving device incorporated in the design of its grinder.

The chilled-iron roll has long been used for paper mills, steel mills, and other classes of plants employing rolling processes. Gray iron and alloy-iron rolls are made for different purposes, and forged-steel and alloy-steel rolls are also used. Rolls are further made of rubber-covered construction, both hard and soft rubber; and brass, bronze, and copper form still other classes of rolls. All of these materials are ground with wheels selected for the purpose, as are also the rolls made of wood. Formerly certain paper-machine rolls were made of paper, though recent efforts to locate information regarding present use (if used at all) have proved unavailing. Cartridge paper, so called, was used for these rolls. It was blanked out with dinking dies and the hole blanked through the center was, say, 5 in. in diameter to fit over the central core or spindle, a steel shaft with heavy nut and plates at the end to screw up on the paper disks and hold them like a solid roll. The paper disks were hard-surfaced stock, about 0.012 in. thick. Squeezed tightly on their core, the assembly was placed in the lathe and the paper disk edges turned down to a size suitable for grinding. The finished surface was as smooth as glass when ground to diameter.

The grinding of chilled rolls for paper calenders was probably the first use made of cylindrical grinding as a regular shop practice. The roll-grinding machine dates back two generations or more, and its use was then confined practically to the plants of the early builders of paper-mill equipment. Steel mills producing sheet and strip materials did not face the finishing requirements at the time comparable to the real problems for paper manufacturers who were engaged in making a superior product. Steadily since that day the demand for newer materials has grown, just as in more recent years there has been a tremendous increase in the requirements for steels of all kinds with all classes of finishes. The exacting demands of the paper mill with its innovations of production created a necessity of refinement in roll finishing that was answered by the builder of roll grinders who developed in his machines a capacity for preparing rolls of any size within extreme limits of accuracy and of unsurpassed surface qualities. With such machines the paper industry met the fresh problems arising with the introduction of newer processes of printing and engraving, the novel desires arising with advanced advertising and publishing practice, and, in brief, the requirements new at one time or another involved in the manufacture of hundreds of different classes of papers.

The Steel-mill Roll.—It was not so many years ago that steel mills commonly began the practice of grinding their rolls, the lathe being generally used for the redressing purposes. The shaping of the rolls was largely a matter of skill of hand and long experience combined with the judgment developed during the long practice on similar operations.

With the use of the heavy steel-mill roll grinder many advantages have been derived aside from the accuracy obtained mechanically for all kinds of sheet-mill rolls whether cylindrical, tapered, concave, or crowned. Precision of form, smoothness of surface, concentricity, and truth of revolution are of first consideration; but there are other factors involved in the mill-roll problem relating directly to the economy of redressing or regrinding in the modern machine as compared with operations of turning and polishing.

The time element involved either in machining new rolls or redressing old ones is of importance, and obviously the effect resulting from mechanically controlled means of grinding scientifically predetermined degree of curvature in the work surface is to reduce the necessary working time to a marked extent. As with many other grinding operations of a more general character, the finishing of roll surfaces by grinding has been found to result in combined improvement in the character of the work and increased speed in the undertaking.

Toward promoting the ultimate working life of the roll, the grinder has been a valuable factor. Chilled rolls, for example, have a limited depth of "shell" ranging perhaps from 5/8 to 3/4 in.; or at least the depth by which such rolls may be dressed and still kept in service will average approximately 3/4 in. under usual conditions. Steel rolls of ordinary proportions may be reduced by, say, 2 in. on a side before they are discarded. In either case, with frequent redressings the rolls wear out rapidly enough.

Suppose a mill follows the practice of dressing a roll after a week's service. Suppose, also, that the amount of metal removed on each occasion is 1/16 in. on a side, or 1/8 in. on the diameter. It will only take a few operations of this kind to use the roll down to a diameter where it is no longer serviceable. If the process of grinding will make it feasible to reduce the roll surface to a lesser degree at each regrinding, then the ultimate life of the roll will be correspondingly extended.

Vibration, Chatter, Etc.—Suitable wheels, well-balanced wheels, and smooth drive of work and wheel are important if highly finished sheet-metal surfaces are to be expected. Irregularities anywhere in the finishing operation are likely to be displayed in the rolled product itself. Unremoved tool marks hardly discernible in the roll may cause trouble in the sheet which is being rolled. The direction of the tool marks if run opposite to the passage of the sheet may result in an aggravated surface blemish which may again be minimized if the roll is turned around to revolve with the tool marks running in the direction of the sheet. The complete removal of all tool marks by the grinding operation sometimes simplifies the placing of rolls for suitable action on the sheet metal.

Ordinarily a reasonable division of work is established between lathe and grinder when new rolls are being machined. A chilled-iron roll cast, say, 1/2 in. over finish diameter would ordinarily be turned to within say 1/32 in. on a side in the heavy-roll lathe and then taken to the grinder for completion.

The truing is not like the usual class of lathe operations. Instead of feeding a turning tool along the face of the roll, a wide faced tool is fed directly into the chilled surface and then the carriage is moved along and another wide cut taken. High-speed tools are commonly employed and the surface speed of the

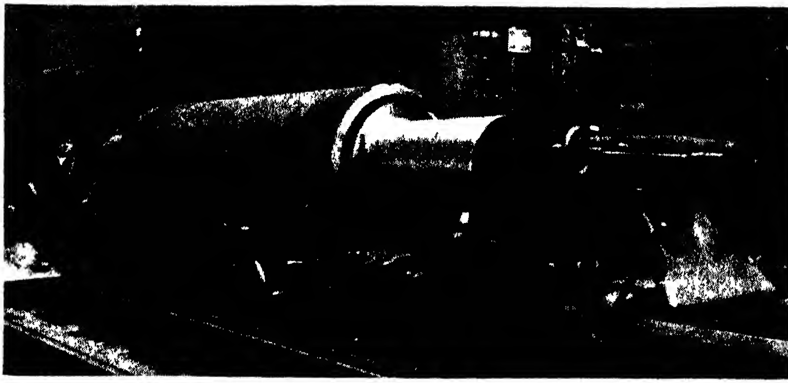


FIG 142.—Turning journal of a 42-inch roll.

roll is held to a low figure—only a few feet per minute. The metal comes off the roll line in long, sharp needles rather than in the form of the usual curled chips.

Figure 142 shows turning of necks in a 42-in. roll.

The grinding, if the job is to be an accurate one, is divided into roughing and finishing with about 0.002 in. left for the latter

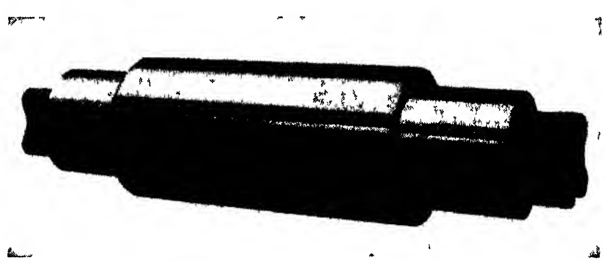


FIG. 143.—Farrel roll for high-brass

operation. It may be even desired to take a final finishing cut in the grinder after the roll has been allowed to stand for a considerable time, in this case only a minute amount being removed in the finishing process. Figure 143 shows a finished roll, a Farrel-Ni-Hard unit for fine finish of sheet brass.

It is necessary that the journals be finished true and even before the turning of the roll face occurs and every step in the operation from roughing down to final grinding must be attended with due care and judgment. Selection of wheels is important, and wheels whether for rough grinding or finishing are to be kept evenly and smoothly dressed.

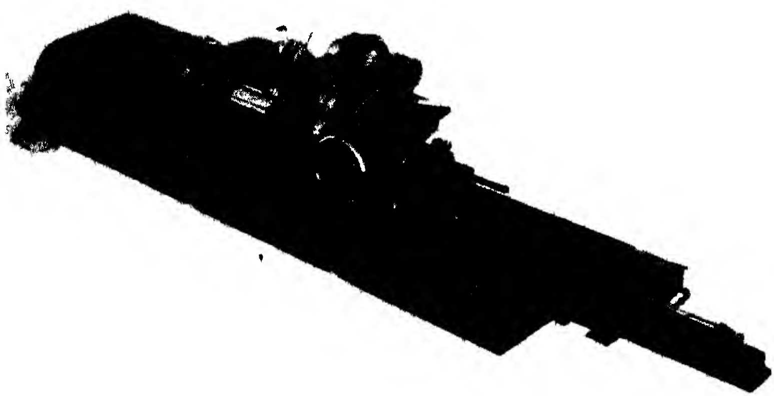


FIG 144 —Cincinnati roll grinder

There is a wide range in work speed employed, depending largely upon the material being ground and the proportions of the rolls themselves. Because of excessive lengths in some cases in proportion to diameters, some smaller rolls are run at considerably slower surface speeds than are used for larger rolls of normal length

Another typical roll grinder is that of the Cincinnati Grinders, Inc , the main portion being shown in Fig. 144.

CHAPTER XIII

CUTTER AND TOOL GRINDING METHODS

PRACTICAL SETUPS FOR SHARPENING INTRICATE CUTTERS[1]

Almost any cutter can be sharpened and still produce as good a finish and as true a form as will a new cutter. In fact, the efficiency of a new cutter may be improved by sharpening before it is used, provided the correct clearance angles for the material to be machined are taken into account.

One of the important points in cutter sharpening is the direction of rotation of the grinding wheel in relation to the teeth of the cutter. If the wheel revolves so that the cut is from the back of the teeth toward their cutting edges, burrs will be formed on the cutting edges and must be removed by an oilstone before the cutter will do good work. About the only advantage of running the wheel in this direction is that the pressure of the cut automatically keeps the tooth being ground in contact with the tool rest.

If, however, the wheel is run so that the grinding cut is from the cutting edge toward the back of the teeth, the cutter has a tendency to rotate with the wheel and the tooth being ground must be held against the tooth rest by hand. Since the pressure required to do this is very slight, this disadvantage is negligible. The advantages of this method outweigh its disadvantages, for there will be no burrs to remove and the cutting edges of the teeth are less likely to be burned.

Special tools and fixtures adapted to a Cincinnati No. 2 cutter grinder give a fast and easy method of sharpening intricate milling cutters. Probably one of the simplest jobs is sharpening the teeth of an end mill. The shank of the mill is held in the taper hole of the headstock and the tooth being ground is held in contact with the tooth rest by hand. A number of the more interesting setups follow:

[1] Herman Isler. Designer, The Cincinnati Milling Machine Company.

A very intricate job is sharpening a dovetail cutter having inserted teeth. The setup for sharpening the teeth of such a right-hand cutter having a diameter of 8 in. and an included angle

FIG. 145.—Sharpening dovetail cutter with inserted teeth.

of 55 deg. is illustrated in Fig. 145. Owing to the large hole for the draw-in rod in the end of the cutter arbor, the stub center *A* is slipped over the regular center in bracket *B*. The tooth-rest finger is set above the tooth being ground and the action of the wheel automatically holds the tooth being ground in contact with the tooth-rest finger. The setup for sharpening a left-hand cutter of the same type is shown in Fig. 146. In this case, the tooth-rest finger is set below the tooth being ground. In both cases a $3\frac{1}{2}$-in. flared cup wheel is used for grinding.

FIG. 146.—Setup for left-handed cutter.

After the swivel table has been set approximately to the correct angle, it is set accurately by a special device. Bracket *C* is attached to the sliding table and carries the swivel stud *D*. One end of a long, fine-thread screw is pivoted in block *F* in the swivel table and the opposite end engages the round nut *H*, which is held in a slot in the swivel stud. The angle of the swivel table is adjusted very finely by turning the nut with a pin inserted in holes drilled for that purpose. A dial indicator mounted on a rod sliding in a holder in the end of bracket *C*, and with its contact point against the side of the swivel table, shows how much that table has been swiveled.

For setting the cutter for tooth clearance, bracket *B* is provided with a clearance-setting gage consisting of a stationary and a pivoted plate. One plate is graduated in degrees and the other one has a zero line that coincides with the graduations on the first plate. The pivoted plate is provided with a locking screw and has a hole to fit the round tail of a dog used for the setting.

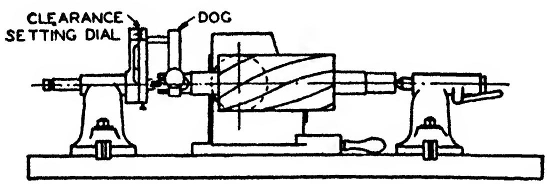


Fig. 147.—Grinding a helical milling cutter.

In use, the cutter is placed on centers with the dog loose on the cutter arbor, and the pivoted plate is locked at zero. The centering gage on top of the wheel head is set in front of the wheel rim, and the slide is moved until the centering gage is opposite the mid-length of the cutter teeth and the cutting edge of one tooth is in contact with the centering gage. The tail of the dog is put into the hole in the pivoted plate and the dog is clamped to the cutter arbor; then the centering gage is removed.

The pivoted plate is unlocked and is rotated with the cutter to the desired clearance angle, after which it is again locked. The table saddle is then moved inward until the tooth to be ground is close to the wheel, the tooth rest is fastened on top of the wheel head, and the tooth-rest finger is placed above the tooth and is clamped. The cutter-setting dog is then removed. The grinding can now be proceeded with. The angle of the cutter is tested by the gage block *H*, which has angular ends. While the diagram in Fig. 147 illustrates the grinding of a helical mill, it shows the relation of the setting dog to the clearance-setting dial.

The setup for sharpening the facing teeth of a pair of combination cutters is illustrated in Fig. 148. The larger cutter is 14 in. in diameter and the diameter of the smaller one is 10 in. Both cutters must run accurately true. The offset of the teeth in one cutter in relation to the teeth in the other must be very accurate and is controlled by the crossfeed screw to which the handwheel and micrometer collar, at left, are attached. The cutters are mounted on an arbor that fits the face-mill grinding attachment. The attachment is very rigid and can be used with either a cup or a disk wheel. The spindle rotates in antifriction bearings. The attachment is set for a clearance angle of 5 deg. and the table is swung halfway round to bring the weight of the cutters and the attachment over the table bearings.

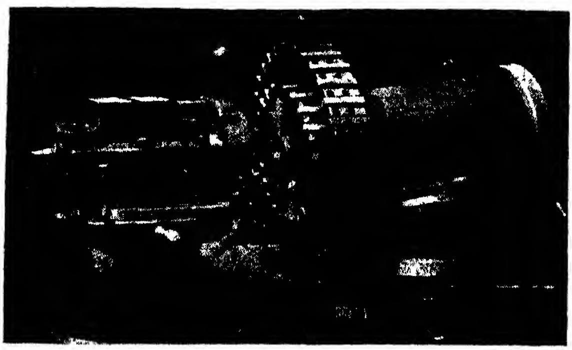


FIG. 148.—Grinding combination cutters.

A 5-in. straight cup wheel is used and the tooth being ground is held by the action of the wheel against the offset finger of the tooth rest. The table is mounted on antifriction bearings and moves very easily. For short movements, a slight twist is given to the knurled knob, bottom center; for longer movements, the handle on the knob is used. The table dog (not shown) has a spring-cushioning device that is very convenient. When the dog is correctly located, and after the operator has let go of the knob, the loaded spring automatically returns the table to the starting position. Before the two cutters were assembled for grinding the faces of the teeth, the outsides and the corners of the teeth in the smaller cutter were ground in the setups shown in Figs. 149 and 150.

Setups illustrating the sharpening of a 16-in. face mill having inserted teeth tipped with tungsten carbide are given in Figs. 151

and 152. The outsides, the corners and the faces of the teeth are being ground in these setups, which were developed in the shop of the Cincinnati Milling Machine Co.

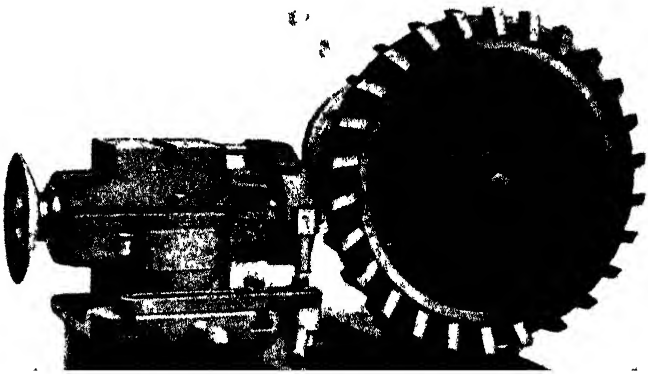


FIG 149 — Grinding outside of teeth.

Formed cutters for milling the teeth in hacksaw blades are ground in the setup in Fig. 153. Since, in use, a number of these cutters are strung in a gang on the cutter arbor, the number depending upon the length of the saw blades, it is essential that

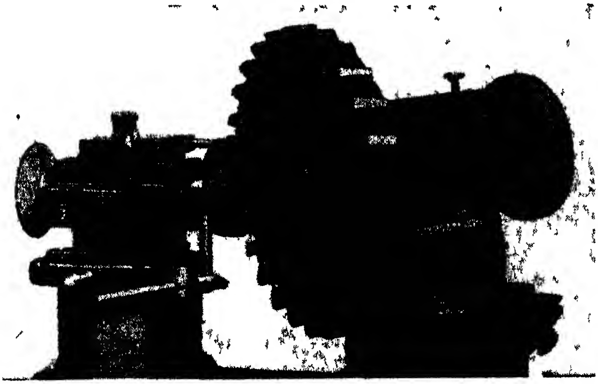


FIG. 150.—Cornering the teeth.

they all be of the same diameter and that the radii of all the cutting faces be alike.

In the taper hole in the spindle of the headstock *A* is fitted a suitable arbor extending beyond the spindle a sufficient distance to allow space for the tooth-rest collar *B*, the cutter *C* to be ground, and the slip collar *D* Through the arbor passes the stud *F*

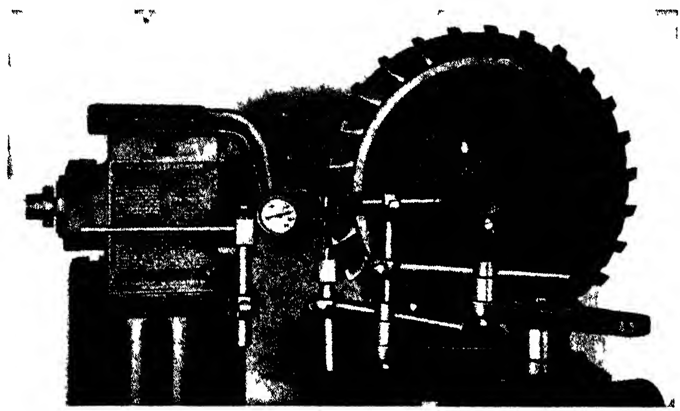


Fig 151 —Grinding carbide-tipped milling cutters

having the clamping-rod stud *H* on the front end making connection with lever *J* at the rear end. This lever fulcrums on block *K* The wheel-truing attachment *L* is mounted on the table in

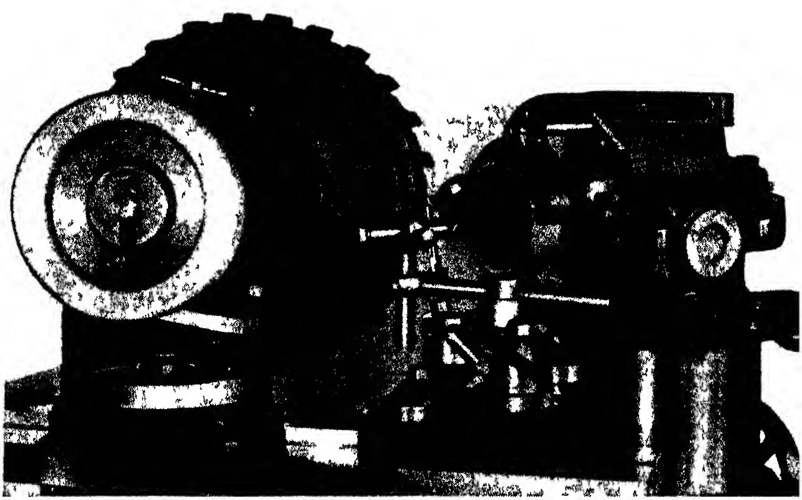


Fig. 152.—Back view of same machine

such a way that the diamond point lines up vertically with the headstock spindle. The tooth-rest finger *M* is rigidly attached to collar *B*, which, in turn, is attached to the work arbor. The offset end of the finger contacts with the relieved part of the cutter about 1/16 in. behind the cutting edges. Also attached to collar *B* is the stud *N*, which carries the thumbscrew *O*, its end being in contact with the table.

The thumbscrew is used for radial adjustment of the cutter to be ground. The operator stands at the left of the table-feed handwheel *P* and holds lever *J* in his right hand. A slight pressure to the left on the lever holds the cutter to be ground firmly against a ground shoulder on the work arbor. Pushing the lever

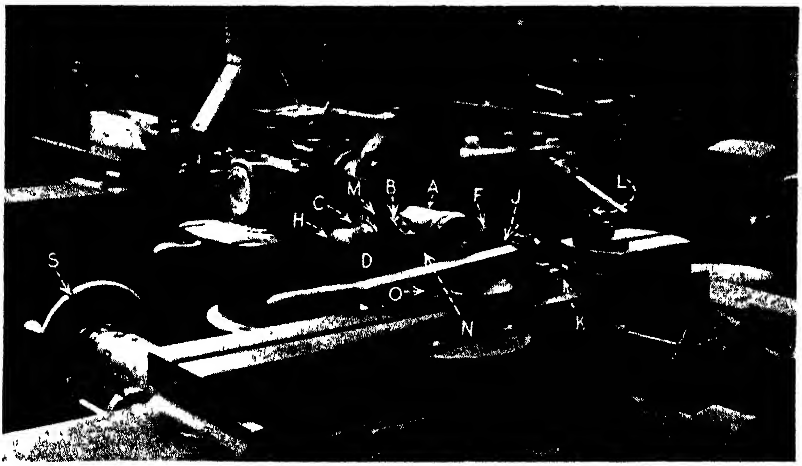


FIG. 153.—Setup for grinding hacksaw blade cutter.

to the right releases the cutter, the slip collar, and the clamping stud, permitting the operator to slide the cutter away from the tooth-rest finger *M* and to index the cutter for grinding the next tooth. By means of a dial indicator (not shown) the highest tooth is located and is turned to the top as the first tooth to be ground. The table is then moved to the left until the diamond point lines up with the grinding wheel. The crossfeed handwheel *S* is then turned to bring the diamond point into contact with the grinding wheel.

After truing the wheel, the table is moved to the right until the cutter to be ground lines up with the grinding wheel. After truing the wheel, the thumbscrew *O* is adjusted, slightly rotating the cutter, and cuts are taken on each tooth in turn. This cycle is repeated until all of the teeth have been sharpened. If the cutter needs grinding several times around to even up the teeth, it is advisable to true the grinding wheel just before taking the final cut. The cutter is placed on a gaging block for inspection after the grinding has been completed.

Sharpening Twist Drills

Drills should be ground so as to cut the right size and with as little power as possible.

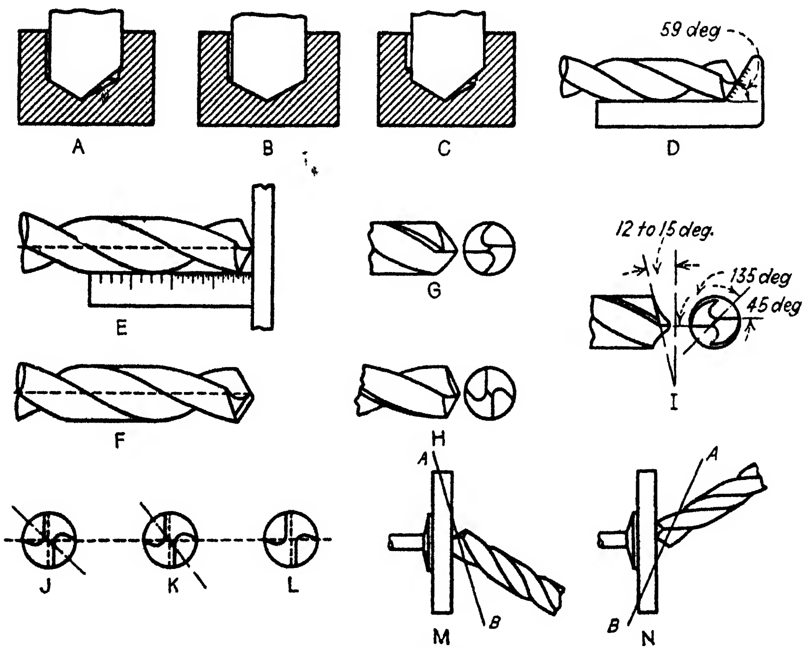


Fig. 154.—Sharpening twist drills.

In order to have the drill in condition to cut the right size, the cutting lips must be of equal length and form equal angles with the axis of the drill. Both of these conditions must be observed or the drill will cut oversize. Thus in *A*, Fig. 154, the point is central but the angles are not alike. In *B*, the angles are equal but lips are not of equal length. In *C*, the angles are unequal and the lips also. In all three cases the drill will cut oversize as indicated, and one lip will do practically all of the work, so that it will dull rapidly and require an extra amount of grinding to keep the drill in condition to cut.

Gaging and Modifying the Lips.—A gage like that shown in *D* will be an aid in getting the angles correct and in grinding the lips central. This gives the usual lip-edge angle of 59 deg. At *E* is shown a method of determining if both of the lips are alike, but it does not give the angle. *F* is a suggestion by Professor Sweet for relieving the drill back of the cutting edge, making it similar to a flat drill in this respect.

For drilling brass, or for any thin stock where the drill goes through, it is best to grind the cutting edge parallel with the axis of the drill. This does away with the tendency for the drill to draw into the work. *G* shows how this is done.

It is sometimes necessary to thin the point of the drill to get best results. This requires care in grinding but it can be done as shown in *H*.

The Proper Clearance.—The best all-round clearance is 12 deg., though for softer metals 15 deg. can be used. The 12-deg. angle referred to is at the cutting edge, but this should increase back of the cutting edge so that the line across the web will be 45 deg. with the cutting edges. This is important as it not only saves power but prevents splitting of the drill in severe service. The point of the drill should look like *G* or *H*. At *I* are the clearance angle and the right angles for the drill point.

The angle of 59 deg. has been mentioned as the usual one for the edge. Twist drills are customarily made so that their cutting edges are straight when ground at this angle. If the drill is ground to a lesser angle, the lips are left hooking and are likely to produce a crooked and irregular hole.

The grinding lines of the drill are placed slightly above center, as in *J*, *K*, and *L*, to allow for the proper angle of the joint which indicates the extent of the clearance. Both *I* and *J* show the proper angle across the point or web, while in *K* the angle is too sharp and will cause the drill to cut rank. The angle in *L* runs backward and shows an entire lack of clearance.

If the drill is placed as at *E* and rotated with its point against the plane surface, the scale will indicate at once the amount of clearance and whether the lips are of the same length.

Some drill grinders give the clearance to the lips as represented by *M* and *N*. Here the axis about which the drill swings in the grinding of the lips is shown at *A-B* and it will be seen that the method results in grinding the lip behind the cutting edge to the form of a truncated cone, the apex of which is at the point of intersection of the axis A-B with the face of the wheel. A gradual increase in clearance from the outside of the drill to the center is thus produced by this grinding principle.

FORM GRINDING

In precision tool and die making, form grinding has helped to produce accurate shapes with a very fine finish on hardened steel, a finish which could not have been duplicated without a great expenditure of money.

It is pointed out by Wm. C. Betz in a description of a form-grinding method, that probably the simplest type of form grinding may be found in the circular and shaving types of form tools used in the automatic screw machine. This class of tool is generally made of high-speed steel and because of the high temperature of heat treating, is liable to distortion, surface defects and soft skin. Any and all of these defects can be corrected by form grinding and the method is not complicated or very expensive.

Mr. Betz states that to form-grind economically, one must get wheels that are suitable for the work. They must be fine-grained, hard enough to hold a form, and free-cutting, so as not to burn the work. For roughing, on machines using wheels from 7- to 12-in. diameter, grains from 80 to 100 and grades from H to J are recommended; for finishing, grains 100 to 150 and grades from J to M. All grinding should be done wet if possible, but dry grinding will produce good work, given reasonable care.

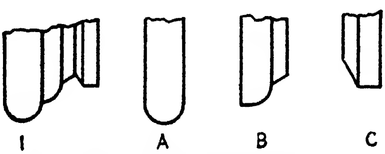


FIG. 155.—Grinding a form tool.

To form-grind, it is not necessary or desirable to finish the form part with a wheel that covers the whole piece. It is better to grind various ribs and projections with narrow wheels, matching one diameter or height with one previously ground. In this way, forms of great width can be ground accurately because the necessary wheel shapes can be easily produced.

Let it be assumed that a form tool is to be ground like that in Fig. 156. It would be possible to true a wide wheel to grind this form by the aid of the radial truing device (Fig. 157), and the angular fixture (Fig. 158), but it would be difficult to find wheels in the smaller diameters which would be wide enough, so that it is better practice to grind this form in three stages; first, the semicircle A (Fig. 155) then quadrant *B* and the first angular section, and last, angle on *C* and the other straight section. The height of the last section can be closely governed by the use of the graduations of the cross-slide dial when truing the wheel.

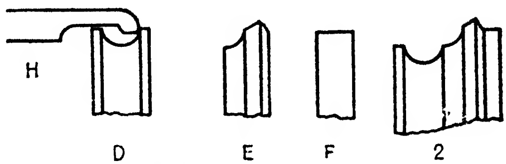


Fig. 156.—Cutters to be ground.

Now suppose we had to true the wheel like that in Fig. 156 to grind a form as at Fig. 155. We would find it a very difficult matter to true the wheel to the center of the radii on both the semicircle and the quadrant, owing to interference of the diamond holder with these radii. The truing device could not be swung through an arc of 180 deg. because of this interference, but by making the form with three wheels as at *D*, *E*, and *F*, the job may be accomplished without trouble.

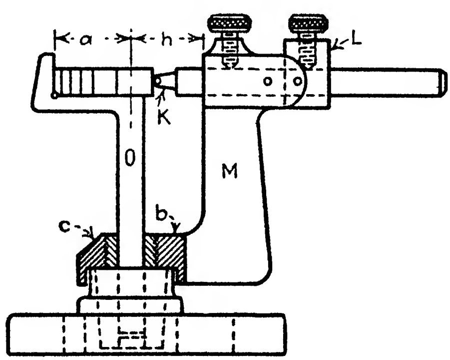


Fig. 157.—Radial wheel truing device.

In using this method of finishing hardened pieces, the wheel-truing devices used fix the measure of success. A radial truing device like that in Fig. 157 is indispensable for truing a wheel to both male and female radii. If the diamond point is back of the center of fulcrum, a male radius is produced; if in front of fulcrum center, a female is produced.

By the aid of bracket *O* (Fig. 157) and a set of accurate-size blocks, radii can be produced on a wheel accurate to 0.0001 in. In making this device care must be exercised to see that the standard is an accurate fit in the base. The taper should not be so slight that it will wedge, nor so obtuse that it might ride on the oil film when being swung from right to left. The taper from 3½ to 5 deg. included angle has been found best. In making bracket *O*, it is best to have the distance *a* long enough to accommodate a number of blocks as then inside and outside radii may be measured with *Jo* blocks to 0.0001 in. from zero to the capacity of the device. Another thing to take into consideration is the height of the frame from the top at *b* to the center of the diamond *K* in relation to the distance *h*. If *h* is deep and height *b-k* is short, large-diameter wheels cannot be trued to the extreme capacity of *h* because of interference of the wheel with the outer portion of the frame at *c*.

Another important part of this fixture is collar *L*, which is used when setting for concave radii. After the diamond is set to the desired inside radius, this collar is slipped onto the diamond-holding rod, the face of the collar is brought into contact with the end of the arm trunnion, and the line on the collar is made to match the line on the trunnion and fastened in place on the rod by the screw in *L*. In order to remove *O* from the fulcrum stud when setting for inside radii, the screw holding the rod in place in the swinging arm *M* is loosened and the rod with collar in place is drawn back. After *O* has been removed, the rod is brought to its original position and the screw is again tightened to hold the rod in place.

The device shown in Fig. 158 may be used on the lathe or on a cylindrical or surface grinder. If used on an external cylindrical grinder, the fixture is held between centers with the rear arm screw adjusted to bring the diamond point of the device to dead center by the aid of a spirit level placed on top of the slide and with the front screw adjusted to take up the slack between front and back.

To use this device on a surface grinder the plates making the pedestal arms are removed, and the fixture is bolted to a hollow angle block or angle iron which in turn is either held by a magnetic chuck or bolted to the machine table. Truing may be done from either bottom or side center of the wheel.

In connection with form grinding, one should have at least a dozen wheel mountings to avoid the necessity of disturbing the wheel setting after each section has been ground. In this way, a wheel trued to a given shape may be used many times without retruing, saving time and wheel life.

Small wheels used on internal grinders must be retrued often to produce exact shapes in the work.

Formed milling cutters and taps may also be successfully ground. For formed milling cutters, comparatively small-diameter wheels must be used, as a large wheel is likely to interfere between clearing the heel of a tooth and the face of the next

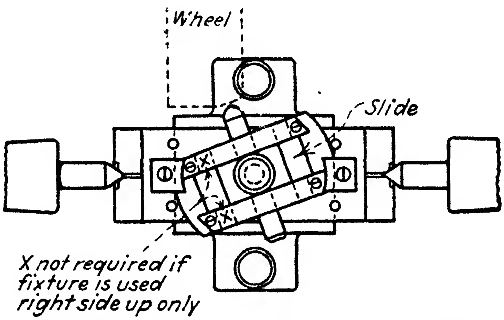


FIG. 158.—Truing fixture for bevel surfaces.

one. This can only be determined by a layout of the work and wheel.

SHARP-CORNER GRINDING[1]

In spite of the aversion that toolmakers seem to have for sharp-corner grinding, there are many instances where this process may be employed profitably. Whether they have a conviction that there is nothing to be gained by it or whether they feel that they cannot get the exact grade and grain wheel from the tool crib, this aversion persists.

Nevertheless, it is a fact that sharp-corner grinding may be done expeditiously and accurately with a rather wide variety of wheel grades, once the principle or knack of preserving the sharp corner on the wheel is understood. When we consider that sectional dies are often designed with a view to eliminate all inside sharp corners by subdividing the sections to extremes and that

[1] Walter Wells.

this could be avoided by allowing for a reasonable amount of sharp-corner grinding, it is obvious that toolmakers must come around to this method sooner or later.

The drawing in Fig. 159 illustrates the above point. Here what would otherwise be five small rectangular sections are combined into one member. The accuracy required on this hinged-cover blanking die, as to both sharp corners and dimensions, may be maintained by grinding this piece integrally fully as well as by grinding the parts individually.

It is generally advisable to do grinding of this sort on a universal grinder. This machine has, first of all, a more sensitive crossfeed than the surface grinder, which is a big advantage. Furthermore, the travel of the table may be paralleled with the plane of the wheel to avoid the slightest drag on the cut, whereas a surface grinder is likely to be out of alignment. The job may be clamped positively to the table. Lastly, it will avoid tying up a machine that is frequently in demand for other shop work.

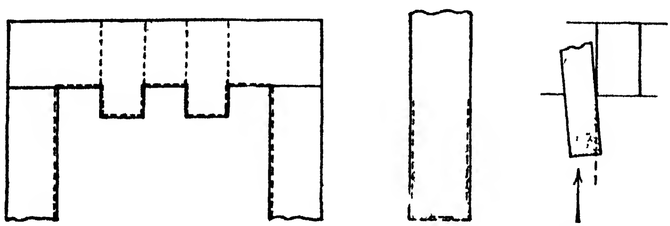


Fig. 159. Fig. 160. Fig. 161.
Fig. 159.—Sharp-corner grinding.
Fig. 160.—How to dress the wheel.
Fig. 161.—How they might drag.

Figure 160 indicates the best way of dressing the wheel, leaving a corner not unlike a diamond tool. This is an enlarged view. In Fig. 161, there is an exaggerated representation of the drag that is likely to occur if care is not used. In Fig. 162 is shown the radius (enlarged about 20 times) that is generally left in inside corners after gashing with the hard-rubber wheel for depth and width. Here the wheel is shown in the wrong position for starting the clearing-out cut. No matter how carefully the grinding is started, or how hard the grade of wheel, the first contact will blunt the keen edge of the wheel. This is because it strikes at the unfavorable 45-deg. angle which concentrates the entire stress of the cut on just a few abrasive grains.

An entirely different sequence of approach and procedure is necessary if the work is to be done to advantage. In Fig. 163, the correct first step is shown. The wheel is positioned to half the width of the radius and fed downward. The next step is to position the wheel at half the depth and feed-in as in Fig. 164. Then, as in Fig. 165, the wheel is fed downward slowly to proper depth. Of course, the first contacts must be made cautiously, even though the angle of approach is flat and saving on the wheel grains.

Allowances are made, of course, for the finishing skim of 0.0015 in., the wheel being redressed beforehand. It is then fed out and up like a facing tool in a lathe. If any suggestion of a radius remains, this may be cleared out readily by touching it up with the wheel after a second redressing. The 45-deg angle

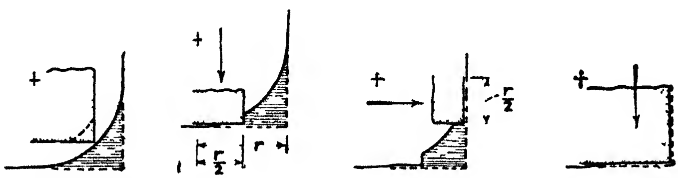


FIG 162 FIG 163 FIG 164 FIG. 165.

FIG 162 —The radius, enlarged 20 times
FIG. 163 —The first step
FIG 164 — The second step
FIG. 165 —Feeding down to depth

approach does not cause any trouble in removing such a tiny bit of stock.

While a P-grade, 60-grain (Norton scale) wheel seems to be the best for this purpose, wheels somewhat harder or softer in bond, or differing slightly in grain, may be used, the principle being that a better job can be made with almost any wheel, provided that the correct sequence of cut is employed. In addition to sectional dies, sharp-corner grinding comes in mighty handy in repair and refitting work. It saves annealing and retempering. It is also recommended for dressing up punches, forming cutters and some types of counterborers. Not only 90-deg., but other sharp angles as well, may be ground in this way.

BORTZ DIAMONDS IN GRINDING WHEELS

The introduction to American industry of the cemented carbides a few years ago started exhaustive research and experimentation in grinding wheel manufacture to produce a means of grinding or sharpening tools of this sensationally hard and durable material. Silicon carbide wheels are being widely used today for the grinding of cemented carbides although a lapping operation is in some instances necessary to obtain desired finishes. It was learned that to eliminate the lapping operation a still harder abrasive substance was necessary.

The first Norton wheels of the bortz type were produced several years ago. They were small internal wheels (sizes 1/4 by 1/4 by 1/8 in. and 3/8 by 1/4 by 1/8 in.) for grinding cemented carbide wire drawing dies.

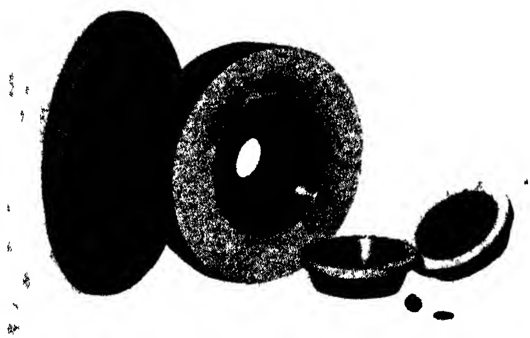


FIG 166 —A group of diamond wheels.

The next development in commercializing the bortz or crushed diamond wheel was with a size 4 by 1/4 by 1/2 in. for producing sharp corners on cemented carbide-tipped tools of special shapes such as used in screw-machine work.

Then came the cup-shape wheels 3 in. in diameter with 3/8-in. rim for lapping small cemented carbide-tipped tools and grinding the clearance on reamers, surface broaches, and milling cutters tipped with cemented carbide. A group of wheels is shown in Fig. 166.

Still another application is in extremely thin cut-off wheels for cutting up cemented carbide shapes.

For the final finish, or lapping job, bortz bakelite wheels are operated on tool and cutter reamers for lapping cutters and reamers containing cemented carbide inserts; mounted on bench grinders for freehand lapping of lathe and planer tools; used in place of lapping plates on tool-grinding machines designed for cemented carbide tools. For actual grinding with the diamond wheel, the coarsest grain size, No. 100, is available and has speeded up jobs for which ordinary grinding wheels are too slow.

In operating the diamond or bortz bakelite wheel, the grinding surface should be lubricated freely with a light machine oil. Water is very satisfactory as a coolant if there is provision for a constant flow. The wheel will last much longer if lubricated with oil or cooled with water during the grinding or lapping operation.

For fast lapping, speeds from 500 to 1,000 r.p.m. are recommended, using a 3-in. wheel. A speed of 2,000 to 3,000 r.p.m. will produce a high finish.

The diamond wheels are of three different grain sizes known by colors, as brown, green, and buff. The brown wheel is stated to be recommended for cemented carbide grinding jobs where speed is most essential. This is the No. 100 grain diamond wheel. For lapping operations to produce keen cutting edges in minimum time the No. 200 grain (green wheel) is being used. For finish lapping where true polished surfaces and microscopically keen cutting edges are called for, the No. 320 grain or buff wheel is recommended.

GRINDING CEMENTED CARBIDE TOOLS

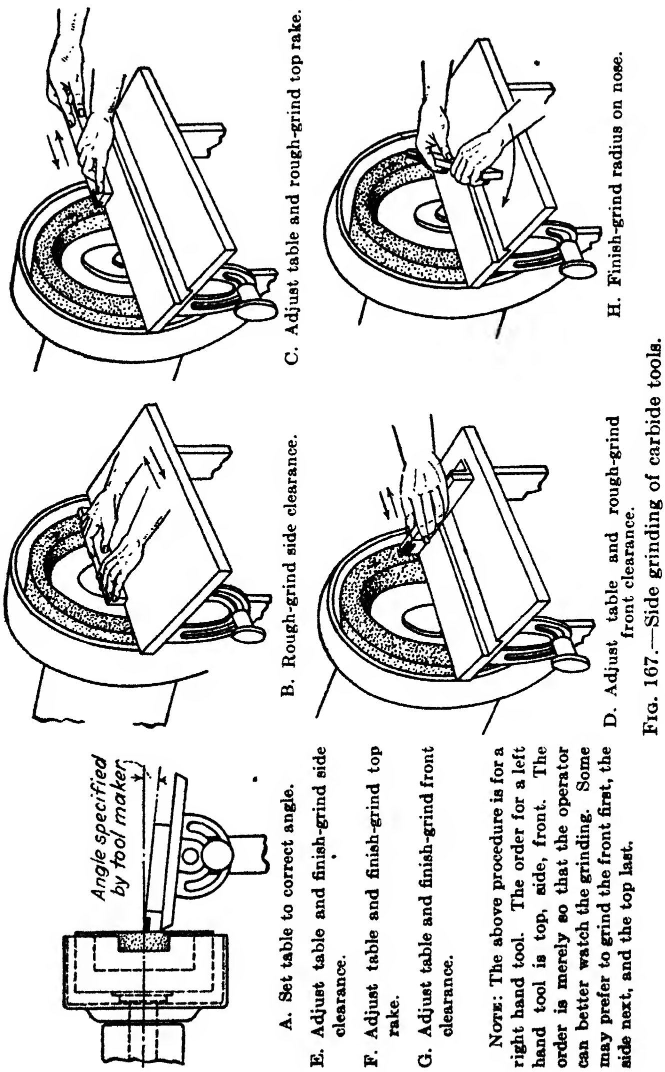
The data in the following pages are supplied from the experience of the Carborundum Company who give the explanation in connection with the sketches for grinding all classes of cemented carbide tools, including forming tools, etc.

Referring to Fig. 167, the order of operations on side grinding of single-point tools is as follows.

A. Set table to correct angle.
B. Rough-grind side clearance.
C. Adjust table and rough-grind top rake.
D. Adjust table and rough-grind front clearance.
E. Adjust table and finish-grind side clearance.
F. Adjust table and finish-grind top rake.
G. Adjust table and finish-grind front clearance.
H. Finish-grind radius on nose.
See setups under Fig. 167.

For rough grinding on periphery of wheel and finish grinding on side of wheel see Fig. 168.

Special wheels are required for grinding cemented carbide tools. Side grinding on cup or ring wheels avoids hollow grinding the clearance angles. Rough grinding on the periphery of a



A. Set table to correct angle.

B. Rough-grind side clearance.

C. Adjust table and rough-grind top rake.

D. Adjust table and rough-grind front clearance.

E. Adjust table and finish-grind side clearance.

F. Adjust table and finish-grind top rake.

G. Adjust table and finish-grind front clearance.

H. Finish-grind radius on nose.

NOTE: The above procedure is for a right hand tool. The order for a left hand tool is top, side, front. The order is merely so that the operator can better watch the grinding. Some may prefer to grind the front first, the side next, and the top last.

FIG. 167.—Side grinding of carbide tools.

plain wheel and finish grinding on the side (see setups in *B, C, D,* and *H,* under side grinding) is faster than side grinding for both operations. Care should be taken to remove all the undercut on the tip, although some undercut may be left on the shank.

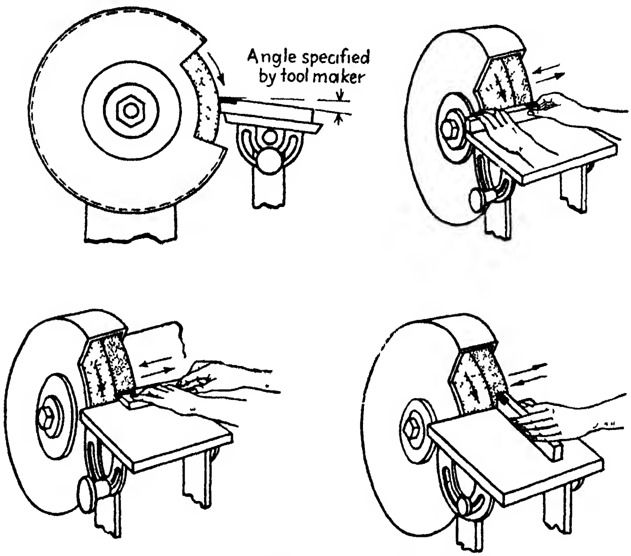


FIG 168 — Rough and finish grinding

Chip breakers may be ground free-hand on the periphery of a grinding wheel, as in Fig. 169. The back rake, or top-side rake if one is ground, must not be too great or weakening of the cutting edge will result. A slight land at the cutting edge may be necessary on some tools for some operations.

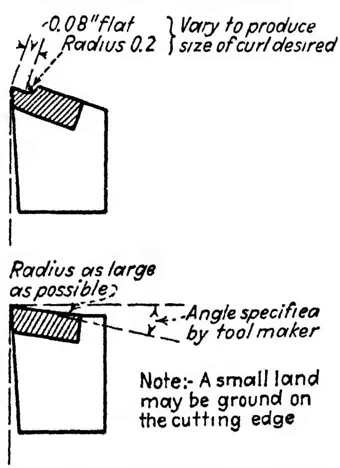
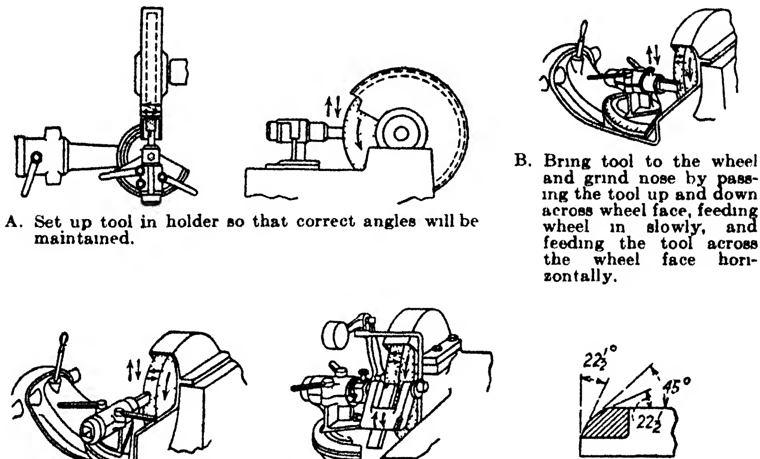


FIG. 169.—Grinding chip breakers.

Form Tools and Saws.—One type of tool grinder uses a plain wheel, as shown in Fig. 170, and grinds on the periphery of the wheel. The plain wheel has the advantage that grinding is done by line contact, but will give a straight line from the heel to toe of the tool. The other machine employs a cup wheel, which has the advantage of constant peripheral speed of the wheel. General instructions are as follows: (*A*) Use light feeds; (*B*) Be sure that the work is flooded with water; (*C*) Large radii may be ground by the use of a special cam in the tool holder; and (*D*) In grinding curved-face tools have the cutting edge as close as possible to the cam.

Tools used for fine finishing cuts and those used on materials having a highly abrasive action should be lapped. By the use of the newly developed diamond wheel in the fine or extra-



A. Set up tool in holder so that correct angles will be maintained.

B. Bring tool to the wheel and grind nose by passing the tool up and down across wheel face, feeding wheel in slowly, and feeding the tool across the wheel face horizontally.

C. Repeat 1, 2 for sides and top.

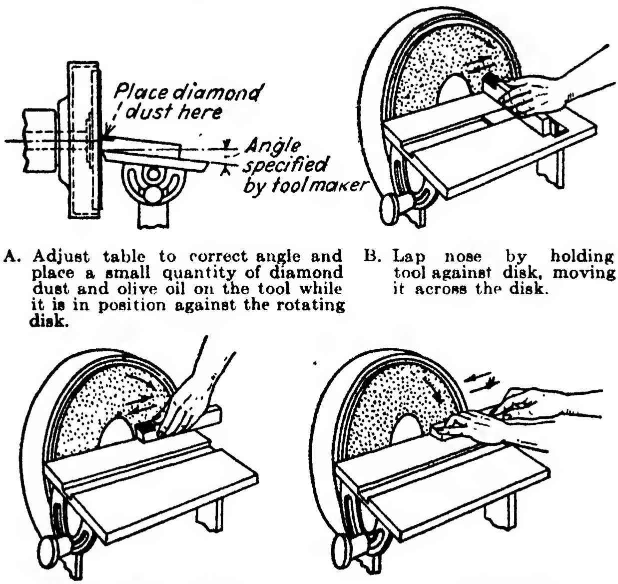
D. Where radius (¼" and over) on nose must be ground, or where radius must be exactly smooth, use special forming attachment with suitable cam to develop correct shape.

E. For small radii (under ¼") grind 1 flat at 45° and 2 small flats at 22½° and 67½° by means of suitable adjustments of the tool holder.

FIG. 170.—Sharpening tools on machine grinder.

fine grits, the necessity for lapping is eliminated. Lapping can be done with two materials, diamond dust or silicon carbide finishing compound. Machines for the lapping of cemented carbide tools usually have a horizontal or a vertical disk directly connected to a motor and running at quite a high speed. The machines intended for the use of silicon carbide compound should be speeded lower, 900 to 1,200 surface feet per minute being recommended. Higher speeds cause the compound to fly off the disk, resulting in slow cutting. In many cases the disk speed for diamond lapping is also too high for efficient operation.

Set the table of the lapping machine (Fig. 171) ½ deg. less than the angle used for the grind. This will develop the cutting edge and make operation much faster than lapping the entire surface of the tool. General instructions are as follows: Use diamond dust sparingly because the disk is impregnated and diamond dust is expensive; Work should be examined frequently under at least a 10-power magnifying glass to determine the keenness of the cutting edge; The direction of rotation of the



A. Adjust table to correct angle and place a small quantity of diamond dust and olive oil on the tool while it is in position against the rotating disk.

B. Lap nose by holding tool against disk, moving it across the disk.

C. Lap both sides as above.

D. Lap top as above.

FIG. 171.—Machine lapping.

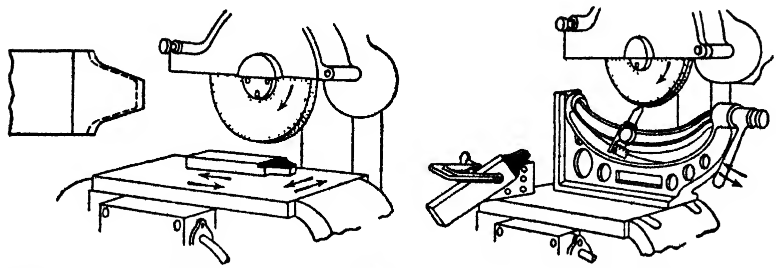
disk should be against the cutting edge of the tool; Lapping should be continued until all grinding marks are out.

The method of lapping with compound is the same as with diamond dust except that: Enough compound should be used to form a film between the tool and the disk; It is not necessary to impregnate the disk with abrasive.

Straight-shank form tools made with the nose the same size and shape at top and bottom as indicated at *A*, Fig. 172, may be sharpened by surface grinding only, since reducing the tool thickness does not change the form.

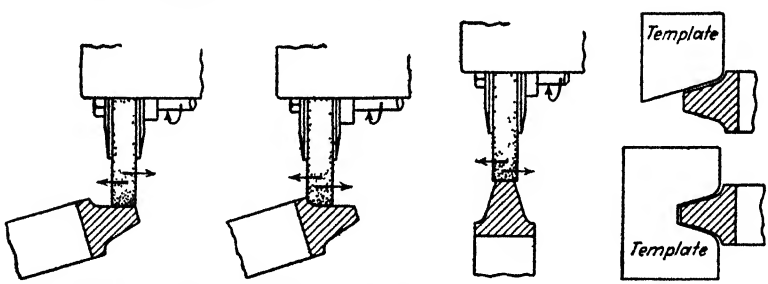
Tools made with side clearance must be ground on the nose to sharpen them, since every reduction in tool thickness causes a change in form. Form tools with side clearance that are used on work not held to close limits may be surface-ground.

Where the nose must be ground, the wheel is trued to the required shape every few passes to compensate for wheel wear and the tool ground a section at a time as shown in *A* to *E*. The work should be checked frequently with templates and a final inspection made with a projectograph



A Set up tool on magnetic chuck or in a vise and surface-grind the top

B Set up of tool and dressing attachment



C True the wheel square, set up tool in a vise and grind the sides, passing the wheel across the work

D True the wheel to correct shape, and grind the radius

E True the wheel square and grind the nose

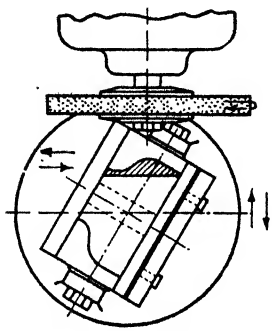
F Using template

FIG 172 —Straight-shank form tool

NOTE The work involved in securing the desired shape consists of alternate dressing and grinding until the correct shape is produced. Usually only a few passes can be taken with the wheel before it requires redressing. The use of sectional templates is advocated during the course of the grinding as a rough check on the work, but the projectograph should be used for the final inspection

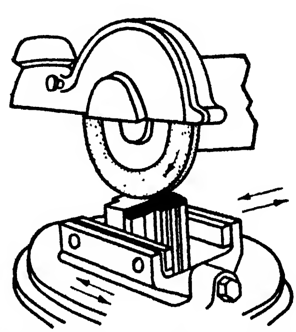
The grinding of curved surfaces is especially time consuming because of the frequent dressings necessary. Usually a magnifying glass held over the point of contact between the wheel and the work will enable the operator to do better grinding and enable him to true the wheel with more accuracy. General instructions: The wheel must be dressed frequently to maintain shape; use light feed and examine the work frequently.

Circular form tools (Fig. 173), like dovetail form tools, are resharpened by grinding on the top of the tooth and not disturbing the form ground on the periphery of the tool by the manufacturer. A surface grinder or tool grinder mounting a plain wheel is recommended. Where the angle between the tip and body of the tool is 90 deg. or more, a straight-faced wheel may be used. Where the angle is less than 90 deg. the wheel face must be trued at an angle, enabling the grinding to be done entirely across the carbide tip. Lapping is recommended. General instructions: (1) Use light feeds; (2) pass the work across and back and forth under the wheel.



1. Set up tool in vise so that correct angle will be produced.
2. Grind, passing the work under the wheel and feeding down the wheel slowly.

FIG. 173.—Circular form tools.



1. Set up tool in vise so that correct angle will be produced on the work.
2. Grind—
   Down feed .001–.002 per pass for roughing; .00025–.0005 per pass for finishing.
   Crossfeed—1/16″
   Table traverse—30–35′ per minute.

FIG. 174.—Dovetail form tools.

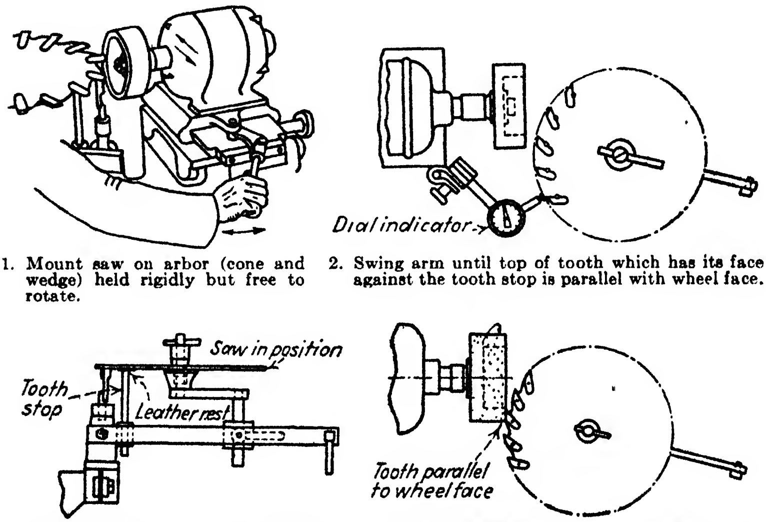
Dovetail form tools, such as illustrated in Fig. 174, will require regrinding only on the end. Offhand grinding is not recommended because of the large area of the carbide involved and the danger of cracking the tip of an expensive tool. Surface grinding on the periphery of a wheel, either on a surface grinder or a tool and cutter grinder mounting a plain wheel, is satisfactory. The direction of rotation of the wheel should be against the cutting as far as possible. The crossfeed and table traverse may be machine- or hand-driven, depending upon the machine. If the center of the ground surface is high take more passes at the lower wheel infeeds. Lapping is recommended. General instructions:

(1) Feed wheel down when starting pass and again when returning across tool; (2) crossfeed may be in both directions

of the table traverse but preferably only in one; (3) crossfeed and table traverse should be at a high rate.

NOTE: Harder wheels will require less down feed. Shop conditions or the operator's skill may necessitate lower wheel feeds. The crossfeed will depend upon the size of the tool, but in general it is good practice to use high crossfeeds rather than low ones.

Cemented carbide-tipped saws (Fig. 175) are made in two general types—solid-tooth and insert-tooth. Solid-tooth saws are supplied with two tooth styles, straight-front and alternate-



1. Mount saw on arbor (cone and wedge) held rigidly but free to rotate.
2. Swing arm until top of tooth which has its face against the tooth stop is parallel with wheel face.
3. Feed wheel to tooth and oscillate across tooth. Do not allow wheel to clear tooth at any time or it will be damaged on return stroke.
4. Back-off wheel, measure tooth with dial indicator.
5. Repeat 2, 3, 4 for rest of teeth.

FIG. 175.—Sharpening circular saws.

bevel, while insert-tooth saws include straight-front, alternate-bevel, and square and advanced type of teeth.

The sharpening of carbide-tipped saws (Fig. 175) is essentially the same for the different classes and types. The outer edge only is ground, without touching the front face of the tooth. Special machines have been developed for saw grinding which mount either a cup wheel or a lapping disk. Where the front of the teeth must be ground, a saucer-shaped wheel may be required, depending upon the number of teeth in the saw and the spacing between teeth.

Where less than 0.002 to 0.003 stock must be removed, the saw may be sharpened by lapping only. In any case the saw should be lapped after grinding. Care must be taken in grinding and in lapping to finish all the teeth to the same height, using a dial indicator for measuring. While allowance must be made for wheel wear in grinding, there is no wear on the lapping disk.

The steps in sharpening a typical saw by grinding are given. For lapping the procedure is the same, since the lapping disk is mounted in place of the grinding wheel. General instructions: (1) Stock to be removed should not exceed 0.002 to 0.003; (2) grind against the cutting edge; (3) use light feeds

The Brown & Sharpe Mfg. Co. supply forming tool grinding equipment as an attachment to their No. 13 universal and tool grinder which aids greatly in keeping farm tools sharp without changing their proper contour.

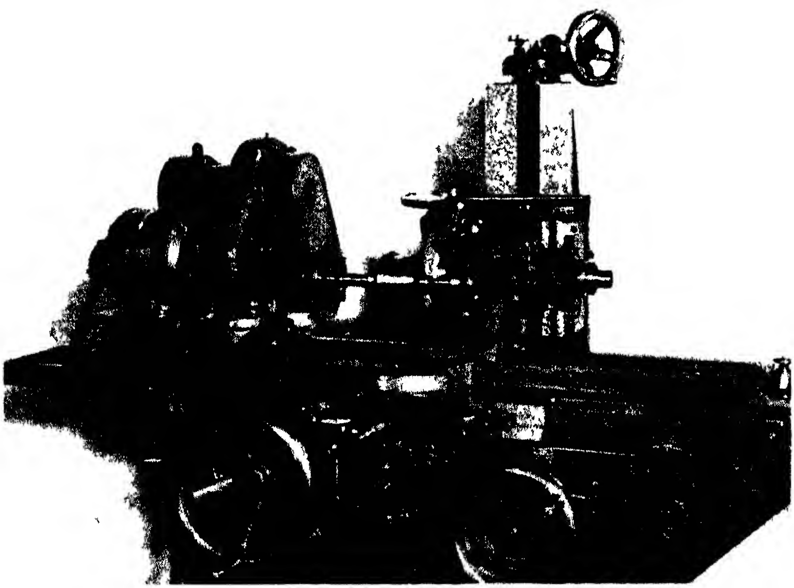


FIG. 175a.—Circular forming tool grinding equipment on universal or tool grinding machine.

There are also numerous attachments now available which add greatly to the versatility of any good grinding machine. Detailed information concerning these attachments, and their advantages, can be secured from the makers of modern grinding machines.

CHAPTER XIV

TYPES AND USES OF GRINDING WHEELS

Grinding wheels are made by three processes, vitrified, silicate (or semivitrified), and elastic.

Wheels are manufactured in a number of shapes and faces, and many sizes, to suit all classes of grinding machinery, as in Figs. 176 and 177. Among the commercial abrasives of which

Standard Types of Grinding Wheels

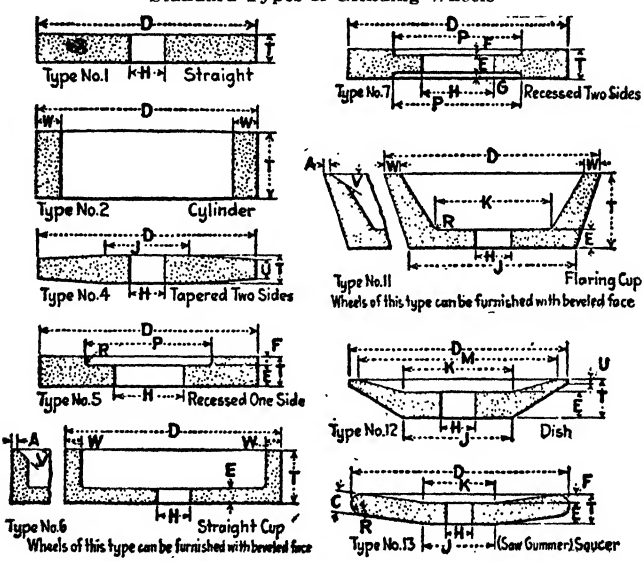


FIG. 176.—Some of the shapes in which grinding wheels are made.

they are composed are emery, corundum, carborundum, alundum, crystolon, carbolite, and carbonite. They vary in hardness, though it does not follow that the hardest grit is the best for all cutting purposes; the shape and form of fracture of the particles must also be taken into consideration. We may imagine a wheel made up from diamonds, the hardest substance in nature, and whose individual kernels were of spherical form; it is quite obvious that it would be of little service as a cutting agent. On the other hand, if these kernels were crystalline or conchoidal in form it would probably be the ideal grinding wheel.

Emery is a form of corundum found with a variable percentage of impurity; it is of a tough consistency and breaks with a conchoidal fracture.

Corundum is an oxide of aluminum of somewhat variable purity according to the neighborhood in which it is mined; its fracture is conchoidal and generally crystalline.

Carborundum is the name given the carbide of silicon as manufactured in the electric furnace by the Carborundum Company.

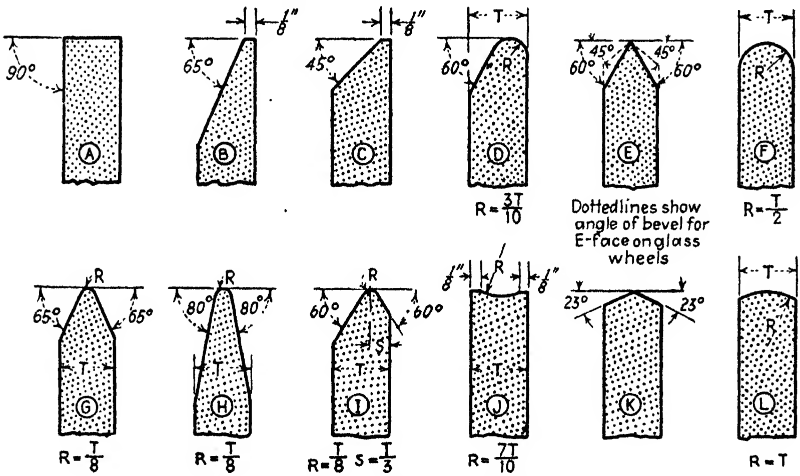


Fig. 177.—Grinding wheel faces.

The principal materials entering into its manufacture are coke, which supplies the element carbon; and sand, supplying the silicon. The mass of coke and sand is raised to a very high temperature which destroys all substances in the coke and sand except the carbon and silicon, the atoms of these two elements then uniting as carborundum, a product that breaks with a sharp, crystalline fracture.

The grade scale of the Carborundum Company and recommendations for selection of wheels for all classes of grinding will be found on page 239.

Alundum is an artificial product, being a fused oxide of alumina. It is of uniform quality, of about 98 per cent of purity. It breaks with a sharp, conchoidal fracture and has the toughness of emery.

The mineral, bauxite, from which alundum is made by fusing in the electric furnace, derives its name from the ruined city and castle of Les Baux, in the southern part of France where it was originally discovered. It is now obtained in higher degree of purity in the United States. The alundum process has been perfected and commercially applied by the Norton Company for their grinding wheels.

Crystolon, which is also used by the Norton Company in the manufacture of wheels, is carbide of silicon, and is one of the most recent abrasive materials put into commercial use. Like alundum, crystolon is an electric furnace product. Its characteristic property of brittleness makes it efficient for polishing and grinding such metals as cast iron, chilled iron, brass, also marble, granite and pearl, in fact such materials in general as possess a low tensile strength.

The tables for selections of grades beginning on page 230 show clearly the different classes of work for which the abrasives, crystolon and alundum, respectively, are recommended.

Aloxite is an aluminum oxide, fused in an electric furnace and one of the later products of the Carborundum Company.

Carbolite (carbide of silicon) is an electrical abrasive forming one of the materials used in the products of the American Emery Wheel Works. Carbolite wheels are recommended by the makers for grinding the softer metals, especially cast iron and brass, and also for grinding such materials as rubber, leather, pearl, etc.

Carbonite is another artificial abrasive made in the electric furnace. It is one of the materials used in the wheels of the Safety Emery Wheel Company.

THE WHEEL-MAKING PROCESSES

The vitrified process produces open texture, free-cutting wheels, which are not affected by weather, time, water, oils, acids, or soda, and are used for both wet and dry grinding.

Silicate wheels are made by the tamping process. Wheels are made of larger diameter and greater thickness by this process than by other methods. These wheels are waterproof and are, therefore, equally serviceable for wet and dry grinding.

Wheels made by the elastic process are the only wheels that can be made very thin and at the same time have the necessary strength and elasticity to make them durable. Elastic wheels are bonded by gums such as rubber, shellac and resins; the mixture of bond and abrasives being heated and pressed in molds. Wheels are made by this process as thin as $1/32$ in. up to 4 in. diameter; $1/16$ in. thick up to 10 in. diameter; $1/8$ in. thick up to 12 in. diameter. Very fine wheels of small diameter have been made as thin as $1/64$ in.

They are used chiefly for saw gumming, grinding between the teeth of gears, sharpening molding cutters, cutting off small stock, etc. They may be run in water, caustic soda, or dry.

In testing the different classes of wheels they are run on a testing machine at a peripheral speed of at least 9,000 ft. per minute, giving a stress of 250 lb. per square inch.

Thus the wheel under test is run at a speed from 50 to 100 per cent higher than that at which it will be operated in practice and is subjected to stresses two or three times as high as are imposed by the usual operating speeds. If a wheel is defective it will break under this test.

THE GRADING OF WHEELS

A grinding wheel is made up of two kinds of material, the "grit" or cutting material, and the bond. The cutting efficiency of a wheel depends largely on the grit; the grade of hardness depends principally on the bonding material used. The efficiency in grinding a given metal is dependent largely upon the "temper," or resistance to fracture, and character of fracture of the grit or cutting grains of the wheel.

Some interesting particulars of the various bonding materials are given by George N. Jeppson:

The function of the bond is not only to hold the cutting particles of the wheel together and to give the wheel the proper factor of safety at the speed it is to be run, but it must also be possible to vary its tensile strength to fit the work it is called upon to do. We often hear the operator say that the wheel is too hard or too soft. He means that the bond retains the cutting teeth so long that they become dulled, and this wheel is inefficient; or, in the case of a soft wheel, the bond has not been strong enough to hold the cutting teeth and they are pulled out of the wheel before they have done the work expected.

The bond to be used for a given operation depends on the wheel and work speeds, area of wheel in contact with the work, vibration in wheel spindle or work, shape and weight of work, and many other like variables.

Wheels are bonded by what are known as the vitrified, silicate, elastic and rubber processes. No one bond makes a superior wheel for all purposes; each one has its field.

The vitrified bond is made of fused clays, is unchanged by heat or cold, and can be made in a greater range of hardness than any other bond. It does not completely fill the voids between the grains, and therefore, a wheel bonded in this way, having more clearance than any other, is adaptable for all kinds of grinding except where the wheel is not thick enough to withstand side pressure. This bond has no elasticity.

The silicate bond is composed of clays fluxed by silicate of soda at low temperatures. It is not so stable as the vitrified bond as regards dampness, gives less clearance between grains, and has a range of hardness below that of the vitrified in the harder grades. This bond has no elasticity and will not make a safe wheel of extreme thinness.

The elastic bond is composed of shellac and other gums. It completely fills the voids of the wheel, has a limited range of grades, has a high tensile strength and elasticity, and can be used for the making of very thin wheels. The rubber or vulcanite bond has the general characteristics of the elastic, but its grades of hardness cannot be varied to the same extent and its uses are limited.

Grain and Grade.—Grinding wheels are made in various combinations of coarseness and hardness to meet the variety of conditions under which they are used. The cutting material is crushed and graded from coarse to fine in many sizes designated by number. Thus the sizes of grain used in the Norton wheels are numbered. By No. 20 grain is meant a size that will pass through a grading sieve having 20 meshes to the linear inch, (400 per square inch), but that will be retained on a screen with 24 openings per linear inch, 576 per square inch.

NORTON WHEELS

Manufacturers of grinding wheels have different grade lists. The Norton grain sizes are as follow:

TABLE 9.—GRAIN SIZES OF NORTON ABRASIVES

Very coarse	Coarse	Medium	Fine	Very fine	Flour sizes
8	12	30	70	150	280
10	14	36	80	180	320
	16	46	90	220	400
	20	60	100	240	500
	24		120		600

The finer flour sizes are classified by hydraulic separation.

Grade (Strength of Bond).—The abrasive grains in a grinding wheel are held in place by posts of bond. If these bond posts are very strong and are capable of holding the grains against the considerable force tending to pry them loose, the wheel is said to be of a hard grade. On the other hand, if only a small force is needed to release the grains, the wheel is said to be of a soft grade.

In the Norton method of marking wheels, as in most methods, the grade letters increase in "hardness" from E to Z.

TABLE 10.—NORTON GRADE LETTERS

Very soft	Soft	Medium	Hard	Very hard
E, F, G	H, I, J, K	L, M, N, O	P, Q, R, S	T, U, W, Z

In a sense, grade alone is not an exact value representing bond strength. It indicates an approximate location in the

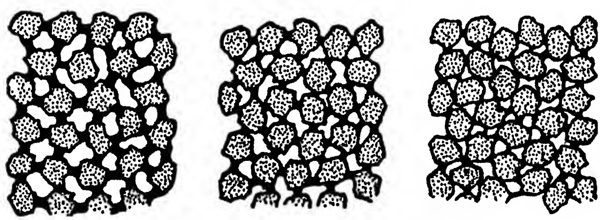


FIG. 178.—Grain spacing or structure.

hardness scale, a position somewhere between two other grades, one of which is harder and the other softer than the grade in question. For example, a grade M wheel lies between a grade N and a grade L, but just where it fits into the hardness picture is determined by another variable in the wheel specifications. This variable is called "structure."

Controlled structure, U. S. Patent No. 1,983,082, is an exclusive Norton feature and is the term used to indicate positive control over the grain spacing in Norton wheels. It is apparent from the sketch, Fig. 178, that grinding action must be affected materially by the spacing of the abrasive grains. Two wheels of the same grain and grade, but differing in this grain spacing, will not grind alike. One will cut much faster than the other.

By means of structure changes, wheel life can often be increased without reducing the cutting rate. As an illustration: A wheel 46-M5B is satisfactory in cutting action but too short in life. A grade change from M to N (46-N5B) produces a marked increase in life but makes the cutting rate unprofitably slow. A *structure* change from 5 to 6 (46-M6B) results in satisfactory life combined with a fast cutting action.

Higher structure numbers represent wider grain spacing. In the same grain and grade, wheels with higher structure numbers will last longer, generally, than those with the lower numbers. In this quality of longer life, they may be considered "harder acting." But in the sense of quality of grinding, which includes heating the work, rate of cut, and finish produced, the higher structure numbered wheels may not be harder acting. Thus the wheel with wider grain spacing may give longer life with no sacrifice in grinding quality.

TABLE 11.—STRUCTURE (GRAIN SPACING)

	Close spacing	Medium spacing	Wide spacing
Structure No.	0, 1, 2, 3	4, 5, 6	7, 8, 9, 10, 11, 12

The five characteristics of a Norton wheel in the order in which they appear in the wheel marking, follow:

1. Abrasive (kind, *i.e.*, alundum, Crystolon, etc.) (Table 12).
2. Grain (size of abrasive particles) (Table 9).
3. Grade (strength of bond) (Table 10).
4. Structure (grain spacing) (Table 11).
5. Bond (kind, *i.e.*, vitrified, bakelite, etc.) (Table 14).

TABLE 12.—ABRASIVE DESIGNATIONS

Kind of Abrasive	Designation
Alundum brand of abrasive.	(Blank)
38 Alundum brand of abrasive.	38
19 Alundum brand of abrasive.	19
98 Alundum brand of abrasive.	98
15 Alundum brand of abrasive.	15
35 Alundum brand of abrasive.	35
Crystolon brand of abrasive.	37

TABLE 13.—ANALYSIS OF WHEEL MARKING 3846-K5B

	Position 1	Position 2	Position 3	Position 4	Position 5
Abrasive......	38				
Grain.... .		46			
Grade			K		
Structure.... ..				5	
Bond.					B

Position No. 1 (*Table* 12)—*Abrasive.*—"Regular" alundum, most commonly used, is indicated by the absence of a numeral in position No. 1. A two-digit numeral has been adopted to designate each of the five other kinds of alundum and the one kind of Crystolon abrasive.

Position 2 (Table 13) gives the grain size; position 3 the grade letter for hardness 9 bond strength); position 4, the structure or grain spacing; position 5, the kind of bond. The long used vitrified bond is indicated by the absence of a letter. Standard Norton bonds are designated as in Table 14.

Sometimes, as in the case of rubber and bakelite bonds, additional symbols are used following the bond letter. These refer to certain modifications of the bond to cover special requirements. Examples are as follows:

14-R2R-1B (rubber)
20-R4T-3A (bakelite)

TABLE 14.—SYMBOLS FOR BONDS

Kind of Bond	Symbol
Vitrified bond..............................	(Blank)
"B" vitrified bond..............................	B
Silicate bond..............................	S
Bakelite bond..............................	T
Rubber bond..............................	R
Shellac bond..............................	L
"V" shellac bond..............................	V

Essential factors to be considered in choosing grinding-wheel specifications that will do a given job most efficiently are:

1. Material to be ground.
2. Amount of stock removed, accuracy, and finish required.
3. Area of contact.
4. Type of grinding machine.

1. Material to Be Ground.—The kind of abrasive to be used in a grinding wheel is largely determined by the properties of the material to be ground. Alundum wheels are recommended by Norton where the material is neither very brittle nor very easily penetrated, or when the material to be ground is of high tensile strength. Such materials include a wide range of substances from hard, tough alloy steels to the tougher varieties of alloy bronze and some of the newer aluminum alloys.

For materials that are very easily penetrated, such as wood and leather and those that are hard but very brittle, such as stone, Norton recommends Crystolon wheels. The dense granular structure of cast and chilled iron calls for the hard, sharp grains of Crystolon abrasive. In general, materials of low tensile strength, including soft brasses and bronzes, aluminum, copper, glass, marble, and sandstone, are more efficiently ground with Crystolon grinding wheels.

For variations in hardness, toughness, and ductility in steels alundum abrasives of different tempers, are designated as "alundum," "38 alundum," "98 alundum," "35 alundum" and "15 alundum." These abrasives have been developed to meet, with their special physical properties, the conditions imposed by these special metals.

As a rule, very hard, dense materials require a relatively soft grade of grinding wheel. Hard materials resist the penetration of the abrasive grains and cause them to dull quickly. Softer grades enable the worn, dull grains to break away and expose new, sharp grains.

Hard, brittle materials generally require a large number of cutting points in a grinding wheel, for rapid grinding, because the penetration of each grain is so slight. A finer grain size may accomplish this, but a relatively close spacing of abrasive grains, or a dense structure will provide the necessary action when other considerations make it inadvisable to use a finer grain size. Exceptionally hard materials, like cemented carbides, are best ground with open structured wheels. This is explained by the fact that the material is very nearly of the same hardness as the abrasive itself, and a wide grain spacing permits a more prompt release of worn abrasive grains than would be possible in a relatively dense wheel.

Soft, tough, and ductile materials require a wheel with comparatively wide spacing of abrasive grains. This allows the grains to penetrate to a maximum depth, and also provides sufficient clearance for the relatively large chips which are removed.

2. Amount of Stock Removed.—The amount of stock removed by the grinding wheel, and the accuracy and finish required, influence the selection of the grain size and also the structure of the grinding wheel. Where stock removal is large, such as on offhand operations like snagging, coarse-grain size and wide-grain spacing (open structure) are needed. Where stock removal is less, better results can be obtained with a finer grain size and closer grain spacing.

Accuracy and finish can be governed by grain size and structure. Finer grains, closely spaced, will "spark out" more quickly and will "spring" the work (in cylindrical grinding) less than will coarser grains widely spaced. The force on each individual grain is less in the finer, more dense structured wheels. Better finishes can be obtained with fine grains closely spaced than with coarse grains widely spaced, although with proper truing facilities on machine grinding operations, it is possible to produce fine finishes with relatively coarse wheels.

3. Area of Contact.—The area of contact between the wheel and the work influences the selection of the grain size, grade, and structure.

Cylindrical grinding offers an example of relatively small area of contact. The total force between wheel and work may not be very great, as compared to other grinding operations, but the force per unit area is high. Relatively fine grain, closely spaced, distributes the large force over a large number of cutting edges. A grade corresponding to "medium hard" is chosen to prevent too rapid wheel wear, inasmuch as the forces tending to tear the grains out of the wheel are large.

Surface grinding with the rim of a cylinder-shaped wheel is an example of large contact area resulting from the contact of the flat cylinder rim with a flat piece of work. Although the total force between wheel and work may be high, the force per unit area of contact is relatively small. Grain size and structure are adjusted to meet this condition by the choice of coarse grain, widely spaced, to distribute the small force over a small number of cutting edges. A grade in the "soft" end of the range is chosen to permit the grains to be released after they have become dull, as the forces which tend to tear them out of the wheel are light.

4. Type of Grinding Machine.—Heavy, rigidly constructed machines take softer and more open structured wheels than lighter, more flexible types. Some machines set up greater vibrations than others, calling for finer and harder and denser structured wheels. The combination of speeds and feeds on some precision machines makes the use of different kinds of wheels necessary. Plane-surface grinding machines making use of the rim of a cup or cylinder wheel require much softer wheels having a wider spacing of abrasive grains than do plane-surface grinding machines using the periphery of a straight or disk wheel.

Wheel Speed.—The speed at which a grinding wheel revolves is important. Too slow a speed means wastage of abrasive without much useful work in return, whereas an excessive speed may result in hard grinding action and may introduce the danger of breakage. The grain, grade, and structure usually recommended for a certain grinding operation are based on the assumption that approximately the recommended speeds will be employed. If for some reason they cannot be, then the grade at least must usually be changed to suit this condition.

TABLE 15.—RECOMMENDED WHEEL SPEEDS IN SURFACE FEET PER MINUTE (*Norton*)

Tool and cutter grinding	4,500– 6,000
Cylindrical grinding	5,500– 6,500
Internal grinding	2,000– 6,000
Snagging, offhand grinding (vitrified wheels)	5,000– 6,000
Snagging (rubber and bakelite wheels)	7,000– 9,500
Surface grinding	4,000– 6,000
Knife grinding	3,500– 4,500
Wet tool grinding	5,000– 6,000
Cutlery wheels	4,000– 5,000
Rubber, shellac, and bakelite cutting-off wheels	9,000–16,000*

* This higher speed is recommended only where bearings, protection devices and machine rigidity are adequate.

Work Speed.—In machine grinding, speed of work exerts a very pronounced effect on the grinding wheel and hence has to be allowed for in grinding-wheel selection. In general, fast work speed—whether the operation be cylindrical, surface or internal grinding—tends to wear the wheel faster than slower work speed. This is not necessarily a drawback to good grinding practice, but it must be understood to be properly controlled.

Wheel wear is dependent upon the ratio of the work speed in surface feet per minute to the wheel speed in surface feet per minute. The higher the ratio, the more work the wheel is required to do in a given amount of time; hence the wheel has a tendency to wear at a faster rate. If the ratio is decreased by decreasing the work speed, the wheel will be required to do less work in a given time and will have a tendency to wear more slowly.

In general, the longer the arc or the larger the area of contact in precision grinding operations, the faster should be the speed of the work, in order to have the wheel cut properly.

Table 16 covers Norton wheel recommendation for all classes of work.

CARBORUNDUM AND ALOXITE GRADE SCALE

Tables 17 and 18 give respectively the grain and grade scales for the Carborundum Company's "Carborundum" and "Aloxite" brand wheels. The grains of Carborundum, the company points out, are considerably harder than those of Aloxite and more brittle in nature, and the grains of Aloxite while not so hard are tougher and therefore do not fracture so readily. On such materials of low tensile strength as cast iron, brass, bronze, aluminum, and for the grinding of rubber, marble, pearl, and stone Carborundum brand wheels are recommended. For the grinding of high tensile materials such as simple and alloy steels, and malleables, Aloxite brand wheels are recommended by the makers.

Combinations or grain mixtures are also used in compounding wheel mixes. The common combinations in use (chiefly in the cylindrical-grinding field) are 241, 301, 361, 401, 246, 366. The first two numbers signify the grit or grain size on which the mixture is based, and the third number establishes the definite percentage relation between the base-grit size and the finer numbers contained in the combination. All of these combination grits should be classified as "medium."

It will be seen from Table 18 that these wheels are made not only with silicate and vitrified processes but also with rubber

TABLE 16.—NORTON-GRINDING-WHEEL RECOMMENDATIONS

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
Agate:								
Offhand roughing	37	80	K	7		Crystolon	Vitrified	
Offhand finishing	37	240	J	9		Crystolon	Vitrified	
Cutting-off	37	60	N	4	L	Crystolon	Shellac	
Aluminum:								
Cylindrical	37	30	J	8		Crystolon	Vitrified	
Surfacing (cups or cylinders)	38	24	K	8	B	Alundum	Vitrified	
Surfacing (straight wheels)	38	46	H	8	B	Alundum	Vitrified	
Internal	37	46	K			Crystolon	Vitrified	
Snagging (low speed)	37	24	O	6		Crystolon	Vitrified	#12 Tr.
Snagging (high speed)		30	N	4	T2	Alundum	Bakelite	#12 Tr.
Cutting-off		24	S	8	T2	Alundum	Bakelite	
Armatures (laminations):								
Cylindrical		36	L	5	B	Alundum	Vitrified	
Internal		36	J	5	B	Alundum	Vitrified	
Artificial stone (see Stone)								
Ascoloy shafts, cylindrical	37	46	M	5		Crystolon	Vitrified	
Axes (soft steel):								
Siding		36	T	5	B	Alundum	Vitrified	
Edging (scribing)		20	R			Alundum	Vitrified	
Edging (high speed)		30	Q	4	T2	Alundum	Bakelite	
Axles (automobile):								
Centerless		46	M	5	B	Alundum	Vitrified	
Cylindrical		46	L	5	B	Alundum	Vitrified	
Axles (railway and automobile), cylindrical		46	L	5	B	Alundum	Vitrified	
Ball bearings:								
Surfacing cups and cones—soft	38	46	G		S	Alundum	Silicate	
Surfacing cups and cones—hard	38	80	F		S	Alundum	Silicate	
Grind O.D. cups—rough and finish		80	M	6	B	Alundum	Vitrified	
Grind outer race		80	R	6	R	Alundum	Rubber	
Grind inner race		120	P	2	R	Alundum	Rubber	
Internal grain bore		60	M	4	B	Alundum	Vitrified	
Balls steel (soft—large), rough		46	Z1	7		Alundum	Vitrified	
Balls (soft—small), rough		60	Z2	8		Alundum	Vitrified	
Balls (soft—large), semifinish		80	Z2	9		Alundum	Vitrified	
Balls (soft—small), semifinish		180	Z4	10		Alundum	Vitrified	
Balls (hard—large), final finish	37	320F	X	9A		Crystolon	Vitrified	
Balls (hard—small), final finish	37	XF	Z4	11		Crystolon	Vitrified	

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
Buhrstones:								
Grooving (narrow)	37	60	R	2	R1B	Crystolon	Rubber	
	37	46	S		T	Crystolon	Bakelite	.001908*
Grooving (wide)	37	24	M	5		Crystolon	Vitrified	
Bushings (hardened steel):								
Cylindrical		60	L	5	B	Alundum	Vitrified	
Internal	38	60	K	5	B	Alundum	Vitrified	
Centerless (rough)		60/2	M	5	B	Alundum	Vitrified	
Centerless (finish)		120	N	0	R	Alundum	Rubber	
Bushings (cast iron):								
Cylindrical	37	46	K	5		Crystolon	Vitrified	
	38	46	J	5	B	Alundum	Vitrified	
Internal	37	46	I	8		Crystolon	Vitrified	
Cam rollers (hardened steel):								
Cylindrical	38	60	N	6	B	Alundum	Vitrified	
Internal	38	60	L			Alundum	Vitrified	
Cams (hardened steel):								
Rough		60	L	5	B	Alundum	Vitrified	
Finish		60	L	1	R	Alundum	Rubber	
Rough and finish								
Hand machines		70	P	8	T2	Alundum	Bakelite	
Automatic		70	O	8	T2	Alundum	Bakelite	
Cams (cast alloy):								
Rough		46	M	5	B	Alundum	Vitrified	
Rough and finish (hand machines)	37	70	P	8	T2	Alundum	Bakelite	
		60	Q	6	T2	Crystolon	Bakelite	
Rough and finish (automatic machines)	37	70	O	8	T2	Alundum	Bakelite	
		60	P	6	T2	Crystolon	Bakelite	
Camshaft bearings, cylindrical		46	N	5	B	Alundum	Vitrified	
Car wheels (chilled iron), cylindrical		16C	N			Alundum	Vitrified	
Car wheels (steel), cylindrical		20	P	5	B	Alundum	Vitrified	
Car wheels (manganese steel), cylindrical		16	Q	8	B	Alundum	Vitrified	
Carboloy (see Tungsten Carbide Alloys)								
Carbon (soft), cutting-off	37	16	R		R	Crystolon	Rubber	
Carbon (hard-round-small):								
Centerless	37	36	N	5		Crystolon	Vitrified	
Cutting-off	37	46	R	6	T2	Crystolon	Bakelite	

Bathtubs:								
Snagging surfacing (segments)		30	R	7	B	Alundum	Vitrified	
Snagging surfacing (offhand)	37	16	T	5		Crystolon	Vitrified	
Snagging edging	37	24	S	5		Crystolon	Vitrified	
Billets (high-carbon and high-speed steels):								
Cleaning (high-speed swing frames)		14	Q	4	T2	Alundum	Bakelite	
Cleaning (low-speed swing frames)		16	Q	5	B	Alundum	Vitrified	
Cleaning (flexible shaft)		20	Q	5	B	Alundum	Vitrified	
Billets (stainless and alloy steels):								
Cleaning (high-speed swing frames)		12	S	4	T3A	Alundum	Bakelite	
Cleaning (low-speed swing frames)	15	14	S	6		Alundum	Vitrified	
		14	R	7	B	Alundum	Vitrified	
Cleaning (flexible shaft)		20	R	7	B	Alundum	Vitrified	
Bits (auger):								
Grinding throats		36	R		R	Alundum	Rubber	
Fluting		70	R		R	Alundum	Rubber	
Bolts (case-hardened steel):								
Cylindrical		60	L	5	B	Alundum	Vitrified	
Centerless		60	N	5	B	Alundum	Vitrified	
Brake shoes (chilled iron), snagging	37	20	S	5		Crystolon	Vitrified	
Brass:								
Centerless	37	36	N	5		Crystolon	Vitrified	
Cylindrical	37	36	K	5		Crystolon	Vitrified	
Internal	37	36	J	6		Crystolon	Vitrified	
Surfacing (cups and cylinders)	37	24	H	8		Crystolon	Vitrified	
Snagging (slow speed)	37	24	Q	6		Crystolon	Vitrified	#12 Tr.
Snagging (high speed)	37	20	O	2	T2	Crystolon	Bakelite	#12 Tr.
Cutting-off		30	W	7	T3	Alundum	Bakelite	
Brick (vitrified):								
Cutting-off (coping)	37	16	P		V	Crystolon	Shellac	
	37	24	Q	5	T4	Crystolon	Bakelite	
Snagging	37	16	P	5		Crystolon	Vitrified	
Surfacing (cups and cylinders)	37	20	M	5		Crystolon	Vitrified	
Broaches, sharpening	38	46	K	5	B	Alundum	Vitrified	
Bronze (soft) use same wheels as for brass								
Bronze (hard):								
Centerless	37	50	K	5		Crystolon	Vitrified	
Cylindrical		46	K	5	B	Alundum	Vitrified	
Internal	38	60	J	5	B	Alundum	Vitrified	
Snagging		20	Q	8	B	Alundum	Vitrified	
Cutting-off		30	W	7	T3	Alundum	Bakelite	

Carbon (hard-round-large), cutting-off	37	46	R	6	T2	Crystolon	Bakelite
Carbon (hard-plate), stripping	37	30	O	6	T2	Crystolon	Bakelite
Carbon (metallic), cutting-off)	37	46	Q	6	T2	Crystolon	Bakelite
Carbon, surfacing	37	30	J	8		Crystolon	Vitrified
Card clothing:							
Pointing tips	35	100	S		R	Alundum	Rubber
Cylindrical		16	Q	5	B	Alundum	Vitrified
Casein:							
Cutting-off	37	46	P	6	T2	Crystolon	Bakelite
Cylindrical	37	46	J	5		Crystolon	Vitrified
Cylindrical (form grinding)	37	100	M			Crystolon	Vitrified
Surfacing	37	36	H	6		Crystolon	Vitrified
Cast iron:							
Centerless	37	46	L	5		Crystolon	Vitrified
Cutting-off	37	36	R	8	T2	Crystolon	Bakelite
Cylindrical	37	36	J			Crystolon	Vitrified
Internal	37	46	J			Crystolon	Vitrified
Surfacing (cups and cylinders)	37	16	H	7		Crystolon	Vitrified
Surfacing (straight wheels)	37	*	J	8		Crystolon	Vitrified
Snagging (low speed)	37	16	S	5		Crystolon	Vitrified
		30	R	7	B	Alundum	Vitrified
Snagging (low speed portable)	37	16	S	5		Crystolon	Vitrified
Snagging (high speed)	37	16	S	2	T3	Crystolon	Bakelite
Chain links (annealed malleable iron and steel):							
Snagging (low speed)		20	Q	8	B	Alundum	Vitrified
Snagging (high speed)		16	P	4	T2	Alundum	Bakelite
Chain links (unannealed malleable iron):							
Snagging (low speed)	37	16	S	5		Crystolon	Vitrified
Snagging (high speed)	37	16	S	2	T3	Crystolon	Bakelite
	37	16	R	2	R	Crystolon	Rubber
Chasers (thread):							
Surfacing	38	46	J	5	B	Alundum	Vitrified
Grinding throats		60	M	4	L	Alundum	Shellac
Chilled iron:							
Snagging (high speed)	37	16	Q	2	T2	Crystolon	Bakelite
Snagging (low speed)	37	16	R	5		Crystolon	Vitrified
Surfacing (cups and cylinders)	38	24	I	8	B	Alundum	Vitrified
Surfacing (straight wheels)	37	36	I	8		Crystolon	Vitrified
Cylindrical (see Rolls)							
Chisels (air-driven):		24	Q			Alundum	Vitrified
Chisels (woodworking):							
Surfacing (cups and cylinders)		46	O	3	L	Alundum	Shellac

* Special Bond.

TABLE 16.—NORTON-GRINDING-WHEEL RECOMMENDATIONS.—(*Continued*)

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
Chisels (woodworking) *Cont*:								
Edging (cups and cylinders)		60	M	8	B	Alundum	Vitrified	
Sharpening		46	M	5	B	Alundum	Vitrified	
Chromium plating:								
Good commercial finish	38	60	L	5	B	Alundum	Vitrified	
Excellent commercial finish		80	K	5	L	Alundum	Shellac	
High finish		500	I	9	L	Alundum	Shellac	
Clay (blocks):								
Surfacing (cups and cylinders)	37	14	N	8		Crystolon	Vitrified	
Surfacing (segments)	37	16	L	7		Crystolon	Vitrified	
Commutators:								
Rough (resurfacing stones)	37	50	K	3	L	Crystolon	Shellac	
Finish (resurfacing stones)	37	100	K	5	L	Crystolon	Shellac	
Rough and finish (wheel)	37	60	M	4	L	Crystolon	Shellac	
Concrete:								
Cutting-off (coping) solid wheel	37	20	R		R	Crystolon	Rubber	
Steel-center wheel	37	16	Q		V	Crystolon	Shellac	
Surfacing (bricks by hand)	37	24	R			Crystolon	Vitrified	
Surfacing (bricks by machine)	37	24	Q			Crystolon	Vitrified	
Surface (cup wheels)	37	30	K			Crystolon	Vitrified	
Connecting rods:								
Internal	38	60	K			Alundum	Vitrified	
Surfacing (cups and cylinders)	38	24	J	8	B	Alundum	Vitrified	
Copper:								
Tubes (cylindrical)	37	70	J	5	L	Crystolon	Shellac	
Cylindrical (also see Rolls)		60	L	4	L	Alundum	Shellac	
Cutting-off (low speed)	37	24	R		R	Crystolon	Rubber	
Surfacing (cups and cylinders)	37	14	I	7		Crystolon	Vitrified	
Cork	38	46	H	8	B	Alundum	Vitrified	
Couplers and draw bars:								
Snagging (slow speed)		10	U			Alundum	Vitrified	.0115T
Snagging (high speed)		12	R	4	T2	Alundum	Bakelite	
Crankshafts:								
Airplane	38	60	K	5	B	Alundum	Vitrified	
Diesel		46	L	5	B	Alundum	Vitrified	
Crankshafts, automotive: (pins and bearings)								
Rough—heavy-side removal		36	Q	3		Alundum	Vitrified	
light-side removal		46	P	5		Alundum	Vitrified	

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
Dies (drawing):								
Cleaning		60	L	5	B	Alundum	Vitrified	
Surfacing (cups and cylinders)	38	24	J	8	B	Alundum	Vitrified	
Surfacing (straight wheels)	38	46	I	8	B	Alundum	Vitrified	
Drills:								
Cutting-off (high speed)		36	R	8	T2	Alundum	Bakelite	
Cutting-off (low speed)		60	P	7	T2	Alundum	Bakelite	
Cylindrical		50	N	5	B	Alundum	Vitrified	
Centerless (soft) through feed		60	M	5	B	Alundum	Vitrified	
Centerless (hard) in feed		80	N	6	B	Alundum	Vitrified	
Precision sharpening	38	46	M	5	B	Alundum	Vitrified	
Point thinning		60	N	5	B	Alundum	Vitrified	
Drills (small):								
Fluting		46	R	0	R	Alundum	Rubber	
Offhand sharpening		60	N	5	B	Alundum	Vitrified	
Offhand sharpening		60	R	0	R	Alundum	Rubber	
Drills (large):								
Fluting		46	P	5	B	Alundum	Vitrified	
Offhand sharpening (wet)		36	P	5	B	Alundum	Vitrified	
Files, surfacing		36	O	5	B	Alundum	Vitrified	
Firthite (see Tungsten Carbide Alloys)								
Forgings:								
Centerless		60	M	5	B	Alundum	Vitrified	
Cylindrical		46	M	5	B	Alundum	Vitrified	
Snagging (high speed)		16	P	4	T2	Alundum	Bakelite	
(low speed)		20	Q	8	B	Alundum	Vitrified	
Fork tines, offhand		30	R	7	B	Alundum	Vitrified	
Frogs and switches (manganese steel):								
Offhand grooving (portable machines)		14	Q	5	B	Alundum	Vitrified	
Semi-precision grooving (planer-type machines)		16	Q	5	B	Alundum	Vitrified	
Snagging		14	R	4	T3A	Alundum	Bakelite	
Surfacing		14	Q	6		Alundum	Vitrified	
Gages (plug), cylindrical	38	80	K	6	B	Alundum	Vitrified	
Gages (U. S. thread, coarse pitch), grinding threads	38	120	K			Alundum	Vitrified	

Finish		50	N	5		Alundum	Vitrified
Rough and finish		46	O	5		Alundum	Vitrified
Snagging (for balancing) slow-speed		20	O	5	B	Alundum	Vitrified
Snagging (for balancing) high-speed		20	P	4	T2	Alundum	Bakelite
Cut glass (see Glass)							
Cutlery:							
Knives—butcher							
Hemming							
Carbon steel		46	M	4	L	Alundum	Shellac
Stainless steel		46	L	4	L	Alundum	Shellac
Offhand							
Surfacing sides		150	I		S	Alundum	Silicate
Knives—paring							
Hemming							
Carbon steel		100	P	6	V	Alundum	Shellac
Stainless steel		100	O	6	V	Alundum	Shellac
Knives—pocket							
Hemming							
Carbon steel		100	P	6	V	Alundum	Shellac
Offhand—rough		100	N		S	Alundum	Silicate
finish		220	O		S	Alundum	Silicate
Swaging		60	Q	5	B	Alundum	Vitrified
Backs		46	P	5	B	Alundum	Vitrified
Tangs		60	P	5	B	Alundum	Vitrified
Edging	37	400	O			Crystolon	Vitrified
Knives—table							
Hemming							
Carbon steel		60	M	4	L	Alundum	Shellac
Stainless steel		60	L	4	L	Alundum	Shellac
Cutters, sharpening (machines)	38	46	K	5	B	Alundum	Vitrified
Cutters (moulding), sharpening (offhand)		60	N	5	B	Alundum	Vitrified
Cylinders, automotive (cast iron):							
Internal (wheels)	37	36	H	9		Crystolon	Vitrified
Honing (new cylinders, sticks)							
Commercial finish	37	150	M	7		Crystolon	Vitrified
Honing (new cylinders, sticks)							
Mirror finish	37	500	J			Crystolon	Vitrified
Rehoning (sticks, roughing)	37	60	N	5		Crystolon	Vitrified
Rehoning (sticks, finishing)	37	120	L	6		Crystolon	Vitrified
Dies (forging), cleaning		60	P			Alundum	Vitrified
Dies (threading), chamfering (cone wheel)		80	Q	5	B	Alundum	Vitrified

Gages (U. S. thread, medium pitch), grinding threads	38	220	M			Alundum	Vitrified	
Gages (N. S. thread, fine pitch), grinding threads	38	220	M			Alundum	Vitrified	
Gears (cast iron), cleaning between teeth (offhand)	37	36	R	0	R	Crystolon	Rubber	
Gears (hardened steel):								
Form precision grinding	38	60	K	5	B	Alundum	Vitrified	
Generative precision grinding	38	60	J	5	B	Alundum	Vitrified	
Internal	38	46	L			Alundum	Vitrified	
		46	L	5		Alundum	Vitrified	
Surfacing (cups and cylinders)	38	30	I	8	B	Alundum	Vitrified	
Surfacing (straight wheels)	38	46	J	5	B	Alundum	Vitrified	
Gears (untreated)	38	24	M	5	B	Alundum	Vitrified	
Glass (lamp shades), grinding edges	37	80	L	7		Crystolon	Vitrified	
Glass (lenses):								
Edging		220	N	10	B	Alundum	Vitrified	
Surfacing (torics)		100	N			Alundum	Vitrified	
Telescopic (edging)	37	120	K	9		Crystolon	Vitrified	
Glass (tubing):								
Cutting-off (low speed, wet)	37	120	R	0	R	Crystolon	Rubber	Spec.*
Cylindrical	37	36	J	6		Crystolon	Vitrified	
Internal	37	60	H	9		Crystolon	Vitrified	
Nicking	37	180	S			Crystolon	Vitrified	
Glass (tumblers), edging	37	120	P	8		Crystolon	Vitrified	
Glass (circular mirrors):								
Rough beveling (automatic)	37	80	H	6		Crystolon	Vitrified	
Rough and final beveling (automatic)		220	K			Alundum	Vitrified	
Glass (windshield):								
Rounding corners		150	N			Alundum	Vitrified	
Semipolishing edges		150	N			Alundum	Vitrified	
Granite:								
Coping	37	24	Q	3	T4	Crystolon	Bakelite	
Surfacing and moulding	37	40	K			Crystolon	Vitrified	
Surfacing (portable)	37	14	J	5	T2	Crystolon	Bakelite	
Guide bars:								
Surfacing (segments or cylinders)		16	M	8	B	Alundum	Vitrified	
Surfacing (straight wheels)		24	K	8	B	Alundum	Vitrified	
Hammers (claw):								
Grinding between claws		46	R	0	R	Alundum	Rubber	
Neck grinding		24	Q	5	B	Alundum	Vitrified	
Hastellite (see Tungsten Carbide Alloys)								

* Special Bond.

TABLE 16.—NORTON-GRINDING-WHEEL RECOMMENDATIONS.—(*Continued*)

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
Housing (automobile axle):								
Cylindrical		46	N	5	B	Alundum	Vitrified	
Snagging, slow speed		14	R	7	B	Alundum	Vitrified	
Snagging, high speed		14	R	4	T2	Alundum	Bakelite	
Surfacing (segments)		16	O	8	B	Alundum	Vitrified	
Knives (machine):								
Chipper and barker, sharpening		36	K	5	B	Alundum	Vitrified	
Hog, sharpening		36	K	5	B	Alundum	Vitrified	
Leather fleshing, sharpening (bricks)		36	P	5	B	Alundum	Vitrified	
Leather shaving, sharpening—cylindrical		50	P	8	B	Alundum	Vitrified	
Leather splitting, sharpening		30	J	3	L	Alundum	Shellac	
Moulding, offhand sharpening		36	N	5	B	Alundum	Vitrified	
Machine, sharpening		36	J	5	B	Alundum	Vitrified	
Paper, sharpening		36	J	5	B	Alundum	Vitrified	
Section, beveling		36	M	5	B	Alundum	Vitrified	
Surfacing backs		46	J	5	B	Alundum	Vitrified	
Sugar beet, routing		46	O	3	L	Alundum	Shellac	
Veneer, sharpening		36	J	5	B	Alundum	Vitrified	
	19	36	J		S	Alundum	Silicate	
Knives (see Cutlery)								
Leather	37	30	J			Crystolon	Vitrified	
Limestone:								
Coping	37	24	Q		V	Crystolon	Shellac	
	37	30	R	3	T4	Crystolon	Bakelite	
Molding	37	40	K			Crystolon	Vitrified	
Surfacing (drum rubber)	37	24	K			Crystolon	Vitrified	
Links (locomotive), machine grinding		36	Q	5	B	Alundum	Vitrified	
Links (see Chain Links)								
Machine-shop grinding, general offhand		30	P	5	B	Alundum	Vitrified	
Malleable iron, annealed:								
Snagging (slow speed)		16	R	7	B	Alundum	Vitrified	
Snagging (high speed)		16	Q	4	T2	Alundum	Bakelite	
Snagging (unicast wh.)		20	Q	8	B	Alundum	Vitrified	
Malleable iron, unannealed:								
Snagging (slow speed)	37	16	T	5		Crystolon	Vitrified	
Snagging (unicast)	37	16	R	5		Crystolon	Vitrified	

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
Piston rings (cast iron or semisteel):								
Surfacing rough (cylinders)	38	30	H	8	B	Alundum	Vitrified	
Surfacing (straight wheels)		50	L	5	B	Alundum	Vitrified	
Internal (snagging)	37	36	R			Crystolon	Vitrified	
Piston rods (locomotive), cylindrical		46	M	5	B	Alundum	Vitrified	
Pistons (aluminum):								
Cylindrical	37	36	J	7		Crystolon	Vitrified	
Centerless	37	46	I	5		Crystolon	Vitrified	
Regrinding	37	46	K	5		Crystolon	Vitrified	
Pistons (cast iron):								
Cylindrical	37	36	K	7		Crystolon	Vitrified	
Centerless	37	46	J	6		Crystolon	Vitrified	
Regrinding	37	46	K	5		Crystolon	Vitrified	
Plows (steel):								
Surfacing		20	Q	5	B	Alundum	Vitrified	
Fitting		24	R	7	B	Alundum	Vitrified	
Edging and jointing		16	S			Alundum	Vitrified	
Plows (chilled iron), all operations,								
wet		20	R	7	B	Alundum	Vitrified	
dry		20	N	5	B	Alundum	Vitrified	
Porcelain:								
Cutting-off (low speed)	37	46	N	8	T2	Crystolon	Bakelite	
Cylindrical	37	46	J	6		Crystolon	Vitrified	
Removing imperfections (bricks)	38	80	M	6	B	Alundum	Vitrified	
Centerless	37	36	K	5		Crystolon	Vitrified	
Pulleys (cast iron):								
Cylindrical	37	30	J	8		Crystolon	Vitrified	
Rough with pulley grinder (cylinder wheel)	37	24	I	8		Crystolon	Vitrified	
Finish with pulley grinder (cylinder wheel)		50/3	N	0	R	Alundum	Rubber	
Rails (surfacing welds):								
Wheels (slow speed)		24	R	5	B	Alundum	Vitrified	
Wheels (high speed)		16	Q	4	T3A	Alundum	Bakelite	
Bricks		24	M	5	B	Alundum	Vitrified	
		16	N	5	B	Alundum	Vitrified	
Ramet (see Tungsten Carbide Alloys)								
Razors (straight):								
Burring		46	P	5	B	Alundum	Vitrified	

Marble:								
Balusters (rough turning)	37	8	M			Crystolon	Vitrified	
Balusters (finish turning)	37	36	K	5		Crystolon	Vitrified	
Coping	37	24	Q		V	Crystolon	Shellac	
Surfacing (segments)								
1st gritting	37	40	L	6		Crystolon	Vitrified	
2d gritting	37	120	K	7		Crystolon	Vitrified	
3d gritting		220	J			Alundum	Vitrified	
Honing		320	M	8	L	Alundum	Shellac	
Surfacing (wheel)								
Roughing	37	8	L			Crystolon	Vitrified	
Finishing	37	36	J	6		Crystolon	Vitrified	
Moulding								
Roughing	37	8	L			Crystolon	Vitrified	
Finishing	37	36	L	5		Crystolon	Vitrified	
Metallographic specimens:								
1st operation		46	N	3	L	Alundum	Shellac	
2d operation	37	240	N			Crystolon	Vitrified	
3d operation	37	XF	M			Crystolon	Vitrified	
Monel metal:								
Cutting-off		36	P	8	T2	Alundum	Bakelite	
Snagging		24	Q	5	B	Alundum	Vitrified	
Cylindrical		46	L	5	B	Alundum	Vitrified	#7 Tr.
Needles, pointing		70	Q			Alundum	Vitrified	
Nitralloy:								
Before nitriding		36	J			Alundum	Vitrified	
After nitriding	37	100	I			Crystolon	Vitrified	
After nitriding	38	60	H	8	B	Alundum	Vitrified	
Pipe (cast iron), internal	37	14	T	5		Crystolon	Vitrified	
Pipe (cast iron), internal	37	16	R	4	T3	Crystolon	Bakelite	
Pipe (soft steel):								
Cutting-off		36	S	8	T2	Alundum	Bakelite	
Internal		20	P			Alundum	Vitrified	
Pipe balls (manganese steel):								
Cylindrical machine								
Roughing		36	O	5	B	Alundum	Vitrified	
Regrinding		46	M	5	B	Alundum	Vitrified	
Centerless machine								
Roughing		30	T	5	B	Alundum	Vitrified	
Regrinding		24	Q	5	B	Alundum	Vitrified	
Piston pins:								
Centerless machine								
Roughing		60	M	5	B	Alundum	Vitrified	
Semifinishing		80	M	6	B	Alundum	Vitrified	
Finishing	37	320	N	8	L	Crystolon	Shellac	

Side of tang		60	O	5	B	Alundum	Vitrified
Concaving		60	P	8	B	Alundum	Vitrified
Shoulders (cutting in)		80	P			Alundum	Vitrified
Shoulders (shaping after hardening)		120	M			Alundum	Vitrified
Edging (roughing)	38	80	K	6	B	Alundum	Vitrified
Edging (finishing)		220	J	5	L	Alundum	Shellac
Point shaping		46	P	5	B	Alundum	Vitrified
Razors (safety), sharpening		220	N	5	L	Alundum	Shellac
Reamers:							
Backing off	38	46	K	5	B	Alundum	Vitrified
Cylindrical	38	46	M	5	B	Alundum	Vitrified
Fluting	38	46	L	5	B	Alundum	Vitrified
Rifle barrels, cylindrical		46	M	5	B	Alundum	Vitrified
Rims (automobile):							
Removing welds (high speed)		20	R	0	R	Alundum	Rubber
Removing welds (slow speed)		24	Q	5	B	Alundum	Vitrified
Grooving		24	R		R	Alundum	Rubber
Roller bearing cups:							
Centerless O.D.		80	L	7	B	Alundum	Vitrified
Internal		70	N	5	B	Alundum	Vitrified
Rollers for bearings:							
Centerless—roughing		80	O	8	B	Alundum	Vitrified
finishing		90	R		R	Alundum	Rubber
Rolls (brass or copper):							
Cylindrical—roughing	37	46	L	3	L	Crystolon	Shellac
finishing	37	100	I	9		Crystolon	Vitrified
Rolls (granite):							
Roughing	37	16	K	5		Crystolon	Vitrified
Finishing	37	36	J	8		Crystolon	Vitrified
Rolls (cast iron):							
Cylindrical (rough)	37	30	K	5		Crystolon	Vitrified
Cylindrical (finish)	37	80	J	7		Crystolon	Vitrified
Rolls (alloy chilled iron)	37	20	Q	4	T2	Crystolon	Bakelite
Rolls (chilled iron):							
Farrel-type machine							
Roughing	37	30	L	5	L	Crystolon	Shellac
Roughing	37	36	L	5	T2	Crystolon	Bakelite
Finishing	37	70	J	4	L	Crystolon	Shellac
Norton-type machine							
Cylindrical (hot-plate rolls)	37	24	N	5		Crystolon	Vitrified
Cylindrical (dryer rolls)	37	46	J	6		Crystolon	Vitrified
Rolls (hard rubber):							
Cylindrical (rough and finish)	37	36	K	5		Crystolon	Vitrified

TABLE 16.—NORTON-GRINDING-WHEEL RECOMMENDATIONS.—(*Continued*)

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
Rolls (soft rubber):								
Cylindrical (rough)	37	24	K	5	T2	Crystolon	Bakelite	
Cylindrical (rough)	37	24	K	5	L	Crystolon	Shellac	
Cylindrical (finishing)	37	60	K	5	T2	Crystolon	Bakelite	
Cylindrical (finishing)	37	60	K	4	L	Crystolon	Shellac	
Rolls (steel, hardened):								
Farrel-type machine								
Roughing		80	M	5	L	Alundum	Shellac	
Finishing	37	320	I	8	L	Crystolon	Shellac	
Norton-type machine								
Cylindrical	38	46	L	5	B	Alundum	Vitrified	
Cylindrical	38	100	I	6	B	Alundum	Vitrified	
Cylindrical (polishing)	37	500	I	9	L	Crystolon	Shellac	
Roll-scouring bricks:								
Hot rolls	37	80	L	7		Crystolon	Vitrified	
Finishing rolls	37	120	M	7		Crystolon	Vitrified	
Rubber (soft):								
Cylindrical	37	24/1	K	5	T2	Crystolon	Bakelite	
Cylindrical	37	24	K	5	L	Crystolon	Shellac	
Rubber (hard):								
Cutting-off	37	36	Q	6	T2	Crystolon	Bakelite	
Cylindrical	37	30	K	5	T2	Crystolon	Bakelite	
Rubber (inking rolls)	37	60	K	5	T2	Crystolon	Bakelite	
Sad irons:								
Surfacing (cups and cylinders)	38	14	I	8	B	Alundum	Vitrified	
Surfacing (offhand)	37	16	N	5		Crystolon	Vitrified	
Snagging	37	16	Q	5		Crystolon	Vitrified	
Safes:								
Snagging		16	P	5	B	Alundum	Vitrified	
Surfacing		20	O	8	B	Alundum	Vitrified	
Sand cores, cutting off	37	24	P	5	T2	Crystolon	Bakelite	
Saws (band), gumming	19	46	M			Alundum	Vitrified	
		46	M	5	B	Alundum	Vitrified	
		36	O	7	T	Alundum	Bakelite	
		30	O	3	L	Alundum	Shellac	
Saws (circular), gumming	19	46	M			Alundum	Vitrified	
		46	M	5	B	Alundum	Vitrified	
Saws (metal cutting), gumming		60	P			Alundum	Vitrified	

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
High speed		14	Q	4	T2	Alundum	Bakelite	
Snagging (unannealed billets)								
Slow speed		16	P	5	B	Alundum	Vitrified	
High speed		16	M	2	T2	Alundum	Bakelite	
Steel (stainless):								
Centerless	37	50	M	9		Crystolon	Vitrified	
Cylindrical	37	46	M	5		Crystolon	Vitrified	
Surfacing	38	36	H	8	B	Alundum	Vitrified	
Cutting-off		36	Q	8	T2	Alundum	Bakelite	
Snagging (billets, high speed)		12	S	4	T3A	Alundum	Bakelite	
Snagging (billets, low speed)	15	14	S	6		Alundum	Vitrified	
		14	R	7	B	Alundum	Vitrified	
Steel castings (low carbon):								
Swing frame (low speed)		14	Q	5	B	Alundum	Vitrified	
Swing frame (high speed)		14	Q	4	T2	Alundum	Bakelite	
Floor stand (low speed)		20	Q	8	B	Alundum	Vitrified	
Floor stand (high speed)		20	P	4	T2	Alundum	Bakelite	
Steel castings (manganese): (see also Frogs and Switches)								
Snagging (low-speed swing frame)		14	Q	5	B	Alundum	Vitrified	
Snagging (high-speed swing frame)		14	R	4	T2	Alundum	Bakelite	
Snagging (low-speed floor stand)		16	P	5	B	Alundum	Vitrified	
Snagging (high-speed floor stand)		20	Q	4	T2	Alundum	Bakelite	
Stellite:								
Cylindrical		46	M	5	B	Alundum	Vitrified	
Offhand (tools)		46	N	5	B	Alundum	Vitrified	
Surfacing (cups and cylinders)		50	G	8	B	Alundum	Vitrified	
Surfacing (straight wheels)	38	46	H	8	B	Alundum	Vitrified	
Drills (pointing—machine)	38	46	L	5	B	Alundum	Vitrified	
(pointing—hand)		60	M	5	B	Alundum	Vitrified	
Cutting-off (low speed)		60	P	7	T2	Alundum	Bakelite	
Tool and cutter	38	46	J	5	B	Alundum	Vitrified	
Stone (artificial):								
Surfacing	37	46	K	6		Crystolon	Vitrified	
Coping	37	16	Q		V	Crystolon	Shellac	
Stove parts (cast iron):								
Snagging	37	24	T	5		Crystolon	Vitrified	

Scissors and shears (cast iron):								
Surfacing sides of blades	37	100	S			Crystolon	Vitrified	
Scissors and shears (steel):								
Surfacing sides of blades (cyl.)		150	O	5	V	Alundum	Shellac	
Grinding flash from bows		46	P			Alundum	Vitrified	
Pointing and shaping		50	O			Alundum	Vitrified	
Grinding neck or corner		120	N	5	L	Alundum	Shellac	
Strike-cutting edges		120	M			Alundum	Vitrified	
Resharpening (small wheels)	38	100	M	8	B	Alundum	Vitrified	
(large wheels)		100	M		S	Alundum	Silicate	
Shovels, edging		30	R	7	B	Alundum	Vitrified	
Slate:								
Cutting-off (portable)	37	24	R	5	T2	Crystolon	Bakelite	
Coping	37	24	R	3	T4	Crystolon	Bakelite	
Moulding	37	46	K	6		Crystolon	Vitrified	
Spline shafts:								
Centerless		50	N	5	B	Alundum	Vitrified	
Cylindrical		50	O	5	B	Alundum	Vitrified	
Surfacing splines		50	L	5	B	Alundum	Vitrified	
Springs (leaf):								
Grinding eyes		20	P	5	B	Alundum	Vitrified	
Chamfering		20	S			Alundum	Vitrified	#0115Tr.
Springs (coil), squaring ends—small		30	O	5	B	Alundum	Vitrified	
large		16	N	5	B	Alundum	Vitrified	
Steel (hardened):								
Centerless	38	60	M	5	B	Alundum	Vitrified	
Cylindrical	38	46	L	5	B	Alundum	Vitrified	
Surfacing (cups and cylinders)	38	30	G	8	B	Alundum	Vitrified	
Surfacing (straight wheels)	38	36	H	8	B	Alundum	Vitrified	
Cutting-off		46	Q	8	T2	Alundum	Bakelite	
Internal	38	60	J			Alundum	Vitrified	
Steel (soft):								
Centerless		60	M	5	B	Alundum	Vitrified	
Cylindrical		46	N	5	B	Alundum	Vitrified	
Surfacing (cups and cylinders)	38	16	K	8	B	Alundum	Vitrified	
Surfacing (straight wheels)	38	36	L	8	B	Alundum	Vitrified	
Cutting-off		24	S	8	T2	Alundum	Bakelite	
Internal grinding	38	46	L			Alundum	Vitrified	
Steel (high speed):								
Centerless		60	L	5	B	Alundum	Vitrified	
Cylindrical	38	46	L	5	B	Alundum	Vitrified	
Surfacing (cups and cylinders)	38	46	G	8	B	Alundum	Vitrified	
Surfacing (straight wheels)	38	46	H	8	B	Alundum	Vitrified	
Cutting-off		46	Q	8	T2	Alundum	Bakelite	
Internal	38	46	J			Alundum	Vitrified	
Snagging (annealed billets)								
Slow speed		14	Q	5	B	Alundum	Vitrified	

Surfacing tops automatic machine							
Roughing	37	36	P	3		Crystolon	Vitrified
Finishing	37	80	Q	4		Crystolon	Vitrified
Straus metal (see Tungsten Carbide Alloys)							
Tantalum carbide (see Tungsten Carbide Alloys)							
Taps:							
Squaring ends		60	N	5	B	Alundum	Vitrified
Grinding relief	38	80	J	6	B	Alundum	Vitrified
Fluting (small taps)		60	R		R	Alundum	Rubber
(large taps)	38	46	L	5	B	Alundum	Vitrified
Threading	38	150	L			Alundum	Vitrified
Shanks (cylindrical)	38	80	M	6	B	Alundum	Vitrified
Thread gages (see Gages)							
Threads (see Gages)							
Tile, cutting-off (low speed)	37	36	Q	8	T2	Crystolon	Bakelite
Tools (lathe and planer):							
(Carbon and H.S.S.)							
Light (offhand) roughing		36	O	5	B	Alundum	Vitrified
finishing		60	N	5	B	Alundum	Vitrified
Heavy (offhand)		[illegible]	O	5	B	Alundum	Vitrified
Heavy (large wheels)		24	P		S	Alundum	Silicate
Automatic (cup wheel)		24	M	5	B	Alundum	Vitrified
Automatic (straight wheel)		24	M	5	B	Alundum	Vitrified
Fixture grinding	38	46	K	5	B	Alundum	Vitrified
(See also Tungsten Carbide Alloys)							
Tubes (steel):							
Centerless		60	N	5	B	Alundum	Vitrified
Cutting-off		60	R	2	R1D	Alundum	Rubber
Tungsten and tantalum carbide alloys:							
Offhand roughing	37	60	I	9		Crystolon	Vitrified
Offhand semifinishing	37	80	H	9		Crystolon	Vitrified
Offhand finishing	37	100	H	9		Crystolon	Vitrified
Fixture grinding (semi-offhand)							
Rough sellers	37	60	I	9		Crystolon	Vitrified
Gisholt	37	60	I	9		Crystolon	Vitrified
Sundstrand	37	60	F	9		Crystolon	Vitrified
Semifinish sellers	37	80	I	9		Crystolon	Vitrified
Gisholt	37	80	H	9		Crystolon	Vitrified
Sundstrand	37	90	F	9		Crystolon	Vitrified
Surface grinding (B & S type) dry							
Rough (tungsten)	37	80	G	9		Crystolon	Vitrified
	37	60	H	9		Crystolon	Vitrified

TABLE 16.—NORTON-GRINDING-WHEEL RECOMMENDATIONS.—(*Continued*)

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
Tungsten and Tantalum Carbide Alloys *Cont.*:								
Finish (tungsten)	37	100	G	9		Crystolon	Vitrified	
Rough (tantalum)	37	80	G	9		Crystolon	Vitrified	
Finish (tantalum)	37	100	F	9		Crystolon	Vitrified	
Hydraulic (wet)								
Rough	37	60	I	9		Crystolon	Vitrified	
Finish	37	100	H	9		Crystolon	Vitrified	
Form grinding	37	100	H	9		Crystolon	Vitrified	
Sharp angles	37	280	H	9		Crystolon	Vitrified	
Backing-off	37	60	H	9		Crystolon	Vitrified	
Milling cutters (cups)	37	80	G	9		Crystolon	Vitrified	
Milling cutters—straight wheels	37	60	I	9		Crystolon	Vitrified	
Cylindrical								
Rough	37	60	I	9		Crystolon	Vitrified	
Finish	37	100	H	9		Crystolon	Vitrified	
Internal	37	46	K	8		Crystolon	Vitrified	
Lapping (C. I. plate)		280				Norbide* Grain		
Lapping—coarse		100				Diamond	Bakelite	
Lapping—medium		200				Diamond	Bakelite	
Lapping—fine		320				Diamond	Bakelite	
Centerless	37	80	I	9		Crystolon	Vitrified	
Tungsten rods:								
Cutting-off		150	R	7	R1D	Alundum	Rubber	
Centerless	37	60	J	9		Crystolon	Vitrified	

Work—material—operation	Abrasive	Grain	Grade	Structure	Bond	Abrasive (trade mark)	Bonding process	Special treatment
Valve seat inserts:								
Cast iron (roughing)	37	46	M			Crystolon	Vitrified	
Alloy steel (roughing)	38	60	N	6	B	Alundum	Vitrified	
Stellite (roughing)	38	80	I	8	B	Alundum	Vitrified	
All seats (finishing)	37	150	L			Crystolon	Vitrified	
Valve tappets:								
Facing (special tappet grinder)	38	60	L	5	B	Alundum	Vitrified	
Centerless		80	P	8	B	Alundum	Vitrified	
Cylindrical		46	M	5	B	Alundum	Vitrified	
Valves (automobile):								
Grinding seats		80	O	5	B	Alundum	Vitrified	
Cylindrical grinding stems		46	N	5	B	Alundum	Vitrified	
Cutting-off stems		30	W	7	T3	Alundum	Bakelite	
Centerless grind stems		60	O	5	B	Alundum	Vitrified	
Vascoloy ramet (see Tungsten Carbide Alloys)								
Welds:								
Smoothing (high speed)	24	24	R	4	T2	Alundum	Bakelite	
		20	R	0	R	Alundum	Rubber	
Smoothing (slow speed)		24	Q	8	B	Alundum	Vitrified	
Widia (see Tungsten Carbide Alloys):								
Wood (hard), centerless	37	24	K			Crystolon	Vitrified	
Worms, grinding threads	38	36	L	5	B	Alundum	Vitrified	
Wrenches, snagging		24	Q	5	B	Alundum	Vitrified	
Wrought iron, snagging		16	R	7	B	Alundum	Vitrified	

* Trade Mark Reg. U. S. Pat. Off. for Norton Boron Carbide, B_4C.

TABLE 17.—STANDARD GRAIN SIZES FOR CARBORUNDUM AND ALOXITE BRAND WHEELS

Very coarse	Coarse	Medium	Fine	Very fine	
6	12	30	70	150	280
8	14	36	80	180	320
10	16	40	90	220	400
	20	50	100	240	500
	24	60	120		600
				1 F	
				2 F	
				3 F	

bond, and shellac bonded and Redmanol bond. For many operations, carborundum and Aloxite wheels are bonded with rubber. With this bond it is possible to make both extremely thin wheels and wide-faced wheels. The thin wheels are used generally for cutting-off work and the wide-faced wheels in snagging steel and malleable castings. Rubber wheels are also used in cases where a fine finish is required such as on ball races, and are used almost exclusively as regulating wheels on centerless grinders. Rubber-bonded wheels must be run at higher speeds than vitrified to get proper efficiency. Because of the nature of the bond, these wheels can be safely run at the higher speeds.

Shellac-bonded Wheels.—Wheels bonded with shellac come under the head of what are termed elastic wheels. They are principally used in the coping and cutting of marble and granite. These wheels are also used in finishing cast-iron rolls, chilled-iron rolls, and are used in the final finishing of hardened steel such as cams, etc.

Redmanol Bonded Wheels.—Redmanol,[1] a synthetic resin, has after a long period of experimental work been found to be an ideal bonding agent in the manufacture of carborundum and Aloxite-brand wheels. Thin wheels bonded with this material are used for cutting off bar stock of all kinds of steel and other materials. Redmanol cut-off wheels can be made extremely thin and can be run at high speeds (10,000 to 15,000 surface feet per minute) with safety. Redmanol wheels of the wide-face type are used extensively in the snagging of steel castings, malleables, etc., and they have been used with much success

[1] Reg. U.S. Patent Office.

in the finishing of cams and rolls which require a high finish. Redmanol wheels have had a great success in the field of saw gumming, and in the fabrication of stone, marble, and granite.

The Table 18 shows the limit of grades manufactured in each of the five processes. The grades are comparative within the same process only. This table cannot be used to translate vitrified grades into Redmanol or Shellac nor can all sizes of wheels be manufactured in all grades shown. The silicate bonded wheels of the "LL" type grade comparatively with the grade scale shown under "silicate," but are manufactured in grades "M" and softer only.

TABLE 18.—GRADE SCALE OF CARBORUNDUM AND ALOXITE BRAND WHEELS

	Vitrified	Silicate	Shellac	Redmanol	Rubber
Very hard	D E	D E			
Hard	F G H	F G H	1 2	3 4 5	B C D
Medium	I J K L M	I J K L M	3 4 5	6 7 8 9 10	E F
Soft	N O P R S T	N O P R S T	6 7 8 9	11 12 13 14 15 16	
Very soft	U V W	U V W	10	17	

The Different Classes of Grinding.—The Carborundum Company recommends the following speeds and selection of wheels for cylindrical, surface, internal, and snagging grinding operations:

The essential wheel characteristics for each of the four general types of grinding give the broadest and most comprehensive basis for establishing a relation between wheel specifications (grit, grade and bond) and the grinding conditions (working stresses) encountered.

1. *Cylindrical Grinding* (Centerless and Center-type Machines). (Recommended wheel speed 6,000 surface feet per minute)

Grit range—{36 to 80 in regular grits. 24 to 40 in combinations.

Grade range—I to P.

Bond types—vitrified.

Three variables which influence grade and grain selection are work size (diameter), hardness of material being ground, and amount and rate of stock removal.

The larger the work diameter, the softer and coarser the wheel.

The harder the material, the softer the wheel required. The rate of stock removal affects both grade and grit. Light and continuous automatic feeds permit the use of softer and finer wheels.

2. *Surface Grinding.—Vertical-spindle type* (cup and cylinder wheels) recommended wheel speed 4,000 to 5,000 surface feet per minute.

Grit range, 16 to 60.

Grade range, N to V.

Bond type, silicate in aloxite; vitrified in carborundum.

The broader or greater the area of contact, the softer the wheel required. Chip clearance must be provided to avoid excessive heat in this operation. Chip clearance is increased by the use of coarser grits, or where a group of pieces are ground clearance is provided by proper spacing of the work, to cut down the area of contact. Since hardened steel and chilled-iron grain penetration cannot be secured on grits coarser than 24, finer grits are preferable.

Horizontal-spindle type (periphery grind with straight wheels) recommended wheel speed 3,500 to 4,500 surface feet per minute.

Grit range, 30 to 80.

Grade range, M to U.

Bond type, vitrified.

The rotary-table type of surface grinder in general uses harder wheels than the traversing type. Soft steels require the hard grades and hardened stock the softer range. Finer grits operate more satisfactorily on extremely hard stock.

3. *Snagging.*
   A. Wheels operating under 6,500 surface feet per minute. (Recommended wheel speed 6,000 surface feet per minute)
      1. {Floor-stand grinders. Swing-frame grinders.
         Grit range—10 to 24.
         Grade range—F to I.
         Bond type—vitrified.
      2. Portable grinders (air or electric).
         Grit range—16 to 36.
         Grade range—F to I.
         Bond type—vitrified.
   B. Wheels operating over 6,500 surface feet per minute and under 9,500 surface feet per minute. (Recommended wheel speed 9,000 surface feet per minute)
      1. {Floor-stand grinders. Swing-frame grinders.
         Grit range—12 to 20.
         Grade range—8 to 12.
         Bond type—redmanol.
      2. Portable grinders (air or electric).
         Grit range—16 to 24.
         Grade range—8 to 12.
         Bond type—redmanol.

The area and nature of contact and the pressure which can be built up between work and wheel are the two factors affecting grit and grade selection. Wide-contact areas require softer wheels.

Sharp, narrow-contact areas require harder and finer wheels.

In snagging operations the work acts as a dresser to a greater extent than on other types of grinding operations and grit and grade selection is determined by the extent of this dressing action.

4. *Internal Grinding.*
   (Recommended wheel speed 2,000 to 6,500 surface feet per minute)
      Grit range—36 to 80.
      Grade range—J to S.
      Bond type—vitrified.

The grit size is governed to a great extent by the wheel size.

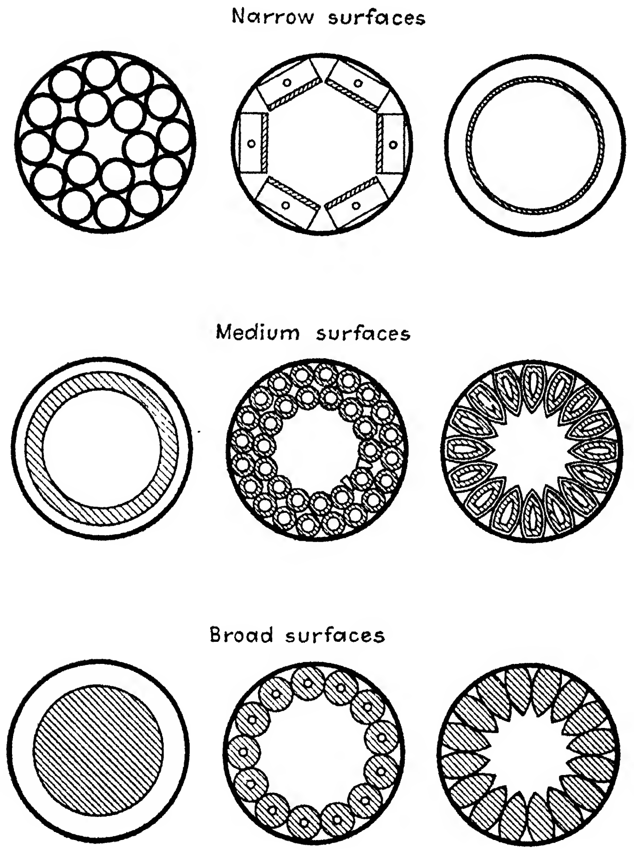


Diagram illustrating "Width of surface" as referred to in table of wheels

TABLE 19.—WHEELS FOR SURFACE GRINDERS

Material	Blanchard			Norton		
	Width of surface			Width of surface		
	Narrow	Medium	Broad	Narrow	Medium	Broad
Cast-iron; bronze	30C30	20C50	20C50	3720-I	3716-I	3716-H
Aluminum	30C40	30C40	20C50	3824-K8B	3824-J8B	3820-J8B
Die castings	30C40	30C40	20C50	3720-I	3720-I	3720-H
Steel castings	24F30	20F40	20F50	3820-J8B	3820-I8B	3816-I8B
Soft-steel; malleable iron	24F30	24F40	20F50	3816-K8B	3816-J8B	3814-J8B
Hardened carbon steel	46L50	46L60	20L60	3824-I8B	3820-I8B	3820-H8B
Hardened high-speed steel	46L60	46L70	24L70	3846-I8B	3836-I8B	3830-H8B
Stellite	46L60	46L70	24L70	3846-I8B	3830-I8B	3830-H8B
Nitralloy	46L60	46L60	46L70	3836-I8B	3830-I8B	3824-I8B
Stainless steel	46L60	46L60	24L70	3836-I8B	3830-I8B	3824-I8B

The grade is determined largely by the rate of traverse. In fact finer grits and harder grades are used on automatic and semiautomatic machines where higher traverse speeds and automatic dressing are available.

Wheels for Blanchard Grinder.—The tables of wheels (19, 19*a*) indicate for each material and width of surface the best wheel for average work, and list also a finer wheel to be used where there is a small amount of stock to be removed and surface is narrow. The tables also list in most cases a coarser wheel suitable for removing metal more rapidly but not usually capable of giving quite as good a finish as the wheel indicated in the middle column.

The tables are only a guide to the selection of wheels and cannot be expected to show the very best wheel for every job.

TABLE 19*a*.—WHEELS FOR BLANCHARD SURFACE GRINDER

Material	American			Carborundum		
	Width of surface			Width of surface		
	Narrow	Medium	Broad	Narrow	Medium	Broad
Cast-iron; bronze...	20-I carbon	20-H carbon	14-H carbon	24-P-L6	24-R-L5	24-S-L4
Aluminum..........	20-I carbon	20-H carbon	20-H carbon	24-R-L5	24-S-L4	24-U-L2
Die castings..........	20-I carbon	20-H carbon	20-H carbon	24-R-L5	24-S-L4	24-U-L2
Steel castings.........	2924-1½	2924-1¼	2924-I	24-N-L8	24-P-L6	24-S-L4
Soft-steel malleable iron...............	2924-1½	2924-1¼	2924-1	24-P-L6	24-R-L5	24-T-L3
Hardened carbon steel	7730-1	7730-¾	7730-½	36A-R-L5AA	30A-S-L4AA	30A-U-L2AA
Hardened high-speed steel...............	7730-¾	7730-½	7724-½	46A-S-SSSAA	36A-T-STSAA	30A-U-SUSAA
Stellite..............	7730-¾	7730-½	7724-½	60-U-SU	60-V-SV	
Nitralloy............	7730-1	7736-¾	7746-½	60-U-1220	40-T-D2L	
Stainless steel.........	7730-¾	7736-½	7730-½	30A-S-SSSAA	24A-T-STSAA	24A-U-SUSAA

They will, however, enable a close approximation to be made in most cases.

The work pictures will help in selecting wheels from Tables 19 and 19*a*.

ECONOMY OF SOFT, FREE-CUTTING WHEELS

It is important to remember in selecting wheels for any work that the wheel must be soft enough to wear away in use, so as to keep itself sharp. The commonest mistake is using too hard a wheel, with the result that the grains of abrasive remain in the wheel face long after they become dulled, leading to glazing of the wheel, reduced output of work, and trouble with burning and checking the work surface. It is false economy to try to use hard, durable wheels.

The wheel cost is a very small fraction of the total cost of grinding. If a small increase in production can be obtained by using a softer wheel, even though the wheel wears out much faster, it will pay to use the soft wheel. Do not judge the value of a wheel by the number of hours it lasts or by the number of pieces ground during its life. Both are misleading. Instead, figure out the total cost per 100 or per 1,000 pieces of work, including labor, overhead, wheel cost, and any burden charged to machine not included in the general overhead expense. You will find, on comparing the costs on the same job, that the softer wheel, that may appear to wear away too fast, will produce the work at lower cost. The gain in production owing to sharpness more than offsets the increased wheel cost.

TRUING AND DRESSING THE WHEEL

Many wheel troubles will be avoided by bearing in mind that there is a most distinct difference between dressing a wheel and truing a wheel. This difference is particularly marked in the case of the Blanchard grinder wheel.

To true a wheel is to remove material from the surface of the wheel so that at grinding speed the grinding face will "run true."

To dress a wheel is to remove the dull abrasive grains from the cutting face or to strip off a loaded or glazed face so that unused and sharp grain edges may cut upon the work.

The Blanchard grinder wheel does not need truing with a diamond or carborundum stick, and if it is done, it will probably only complicate the trouble. Owing to the change in area of contact, the pressure per square inch between the wheel and work increases enormously when a high spot in the wheel face comes in contact with the work; this great increase in pressure per square inch forces the grains of the high spot too far into the work and they are torn out of the wheel, thus dressing off the high spot and truing the wheel.

ONE FEATURE OF GRINDING

One of the greatest advantages accruing from grinding is that it ignores the nonhomogeneity of material and that it machines work with the lightest known method of tool pressure, thus avoiding all those deflections and distortions of material which are a natural result of the more severe machining processes. Yet these objects are too often defeated by the craze for hard and long-lived wheels. A wheel that is too hard or whose bond will not crumble sufficiently under the pressure of cut will displace the work and give rise to many unforeseen troubles. It is also a prolific cause of vibration, which is antagonistic to good and accurate work. The advantage claimed for it, that it gives a better surface finish, is a deceptive one, for it mostly obtains this finish at the expense of accuracy. Quality of finish, that is, accurate finish, is merely a question of arranging of work speed, condition of wheel face, and depth of cut.

Speed and Efficient Cutting.—As already pointed out, the efficient cutting of a wheel depends very much upon the speed of the work, and an absence of knowledge in this respect may often lead to a suitable wheel's rejection. Revolving the wheel at the speed recommended by the maker is the first necessity and if it is found unsuitable after experimenting with various speeds, it should be changed for a softer or harder one as conditions indicate.

If after trying all reasonable work speeds, a wheel should burn the work, or refuse to cut without excessive pressure or persistently glaze the surface of the work, it is too hard for that particular work and material and may be safely rejected. If, after trying reduced work speeds, the wheel should lose its size quickly and show all signs of rapid wear, it is too soft for that particular work and material and may be rejected. These indications refer to ordinary cases and it may be gathered that the most economical wheel is that which acts in such a manner as to be a medium between the two cases. There is still another point to bear in mind with regard to the size of the grit in the wheel, but which refers more especially to very hard materials such as chilled iron. Either a coarse or combination wheel may go on cutting efficiently in roughing cuts because pressure is exerted, but it may begin to glaze when this pressure is much relieved as in finishing cuts. A careful microscopic scrutiny of a wheel that displays this tendency would seem to lead to the following assumption:

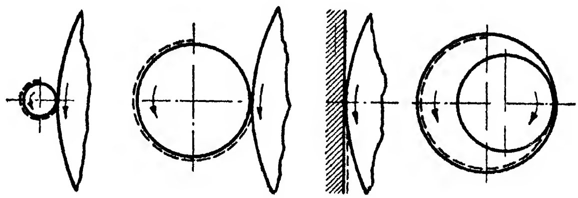


FIG. 179.—Wheel contact with different work.

The Contact Area of Wheel.—Contacts vary with the size of wheel and of work, as shown in Fig. 179. As the contact area increases, more work is required from each individual kernel of grit and it becomes dulled the sooner; this requires that the bond must be more friable both to allow it to escape easily and to minimize the pressure required to make the wheel cut as the cutting area becomes greater. On the basis of this reasoning one grinder operator suggests a list of wheels he found suitable for almost all purposes, and which would be as follows if of Norton grade:

For plain cylindrical grinding, J K L M.

For grinding plane surfaces, H I J K.

For internal grinding, F H I J.

This collection of wheels he found suitable for almost any type of grinding machine, though when the wheels are exceptionally narrow, a grade or one-half grade higher might be possible; it would, of course, be a matter for a little trial and experiment. The wheels for external cylindrical work may preferably be combination wheels, but for plane surfaces and internal work they are better made of single grit, about 36 or 46. The great contact area of wheel in these two classes of work is liable to generate much heat so that an open and porous wheel is preferable.

As the wheel is a disk built up from a numerous assortment of minute cutting tools which are held in position by a more or less friable bond, in using it we must bring it to bear on the work with a pressure that shall not be so great as to tear these minute tools from their setting until their cutting efficiency is exhausted, for if we do so we are wasting the wheel. To gage the exact amount of the pressure required is a matter of judgment and experience, though where automatic feeds are provided on a machine, the right amount of pressure or feed is soon determined. It will also be readily understood that a regular automatic feed is more reliable for the purpose than a possibly erratic hand one. The automatic feed may be set to give a certain depth of cut at each pass of the wheel, and its amount of wear noted; if this wear is found excessive, the depth of cut may be reduced. It must not be here forgotten that work speed also enters into this consideration and that a high work speed will tend to wear the wheel excessively; inversely, a reduced work speed will reduce the amount of wear. Having those points in mind the right combination of depth of cut and work speed is soon arrived at, and an approximate judgment attained for the future.

Grinding Allowances.—The amount of stock left for removal by the grinding wheel and the method of preparing the work have both much bearing on the economic use of grinding wheels; heavy and unnoticed losses often occur through want of a few precautionary measures.

In powerful machines which will remove stock rapidly, the grinding allowance may be anything from 1/32 to 1/16 in. This broad limit allows of expedition in the preparation of work in the way of coarse feeds and does not necessitate the same skill in preparation as would a more refined limit.

There are many cases of an especial character when the grinding allowance stated may be exceeded to advantage so long as discretion is used. Straight shafts may often be ground direct from the black bar of raw material 1/16 in. above finished size, or when shafts of this character must have large reduction on the ends, they can be roughly reduced in the turret lathe while in their black state and finished outright more ceonomically in the grinding machine. Very hard qualities of steels or chilled rolls are other cases where it is often more economical to use the grinding machine without any previous machining process, and though there may be sometimes an alarming waste of abrasive material, its cost is as nothing compared with other savings that are made.

Grinding allowances for hardened work are usually larger than for soft work, to allow for possible distortion. It is sufficient to say that the allowances on case-hardened or carbonized work should not be too excessive; otherwise the hardened surface may be ground away. As far as the actual grinding of hardened work goes, it is indispensable that the whole portion of a piece that is to be ground should be roughed over previous to the final finishing; if it is at all possible to allow some little time to elapse between the two operations so much the better, more especially if it has bent in hardening and been afterward straightened; this will allow of the development of any strain that may be present. Examples of different allowances are given in Chapter III.

GRINDING-WHEEL SPEEDS

At this point it may be well to refer to the matter of speeds for grinding wheels. Cup and cylinder wheels, by cutting on their ends, maintain a constant peripheral velocity irrespective of wear in service. But with disk wheels the wear on the periphery reduces the wheel diameter and as it is desirable that a constant peripheral speed should be maintained, as nearly as possible the speed of the wheel spindle should be increased to compensate for the diminished wheel diameter.

Complaints are sometimes made that wheels appear softer as they wear toward the center. This is caused by the wheel becoming smaller in diameter, and with the same spindle speed the periphery speed is reduced, thus causing the wheel to wear away faster and appear softer, though in reality such is not the case.

The increase of the speed as the wheel wears away can be accomplished by different methods, *i.e.*, variable-speed countershafts, cone pulleys on the spindle of the grinder, or by transferring the wheels from the first grinder to smaller and faster machines as the wheels wear down. This last system has decided advantages, and is recommended where there is sufficient grinding to warrant the use of more than one machine. These grinders should then have but one large pulley on the machine, which removes all the possibility of starting up the new wheel, when full diameter at the highest speed. When the single-pulley system is not employed, great care should always be taken to start up the new wheel on the slow speed.

If on some particular work the wheel does not operate satisfactorily, it can often be made to do so by changing the speed.

If it fills or glazes a slower speed will sometimes give better results, while if the kernels are being loosened by the work, a slight increase in speed (if not already running at the limit surface speed prescribed for that particular size wheel) will

TABLE 20.—GRINDING-WHEEL SPEEDS

Diameter wheel	Rev. per minute for surface speed of 4,000 ft.	Rev. per minute for surface speed of 5,000 ft.	Rev. per minute for surface speed of 5,500 ft.	Rev. per minute for surface speed of 6,000 ft.
1 in.	15.279	19,099	21,000	22,918
2 in.	7,639	9,549	10,500	11,459
3 in.	5,093	6,366	7,350	7,639
4 in.	3,820	4,775	5.250	5,730
5 in.	3,056	3,820	4,200	4,584
6 in.	2,546	3,183	3.500	3,820
7 in.	2,183	2,728	3,000	3,274
8 in.	1,910	2,387	2,600	2,865
10 in.	1.528	1,910	2,100	2,292
12 in.	1,273	1,592	1,750	1,910
14 in.	1,091	1,364	1,500	1,637
16 in.	955	1,194	1,300	1,432
18 in.	849	1,061	1,150	1,273
20 in.	764	955	1,050	1,146
22 in.	694	868	950	1,042
24 in.	637	796	875	955
26 in.	586	733	800	879
28 in.	546	683	750	819
30 in.	509	637	700	764
32 in.	477	591	650	716
34 in.	449	561	620	674
36 in.	424	531	580	637
38 in.	402	503	550	603
40 in.	382	478	525	573
42 in.	364	455	500	546
44 in.	347	434	475	521
46 in.	332	415	455	498
48 in.	318	397	440	477
50 in.	306	383	420	459
52 in.	294	369	405	441
54 in.	283	354	390	425
56 in.	273	341	375	410
58 in.	264	330	360	396
60 in.	255	319	350	383

usually prolong the life of the wheel, and improve its cutting qualities.

Rules for obtaining surface speeds for wheels will be found in Table 20.

Vibration due to frail spindles or machines that are not rigid, is wasteful of both wheel and power. The heavier the machine the softer the wheel can be. In order to use wheels on frail machines they must be made harder. Harder wheels require more power to produce the same work and consequently more pressure against the wheel by the operator.

SPEED TABLES, RULES FOR SURFACE SPEEDS

Table 20 gives the number of revolutions per minute at which grinding wheels of diameters ranging from 1 to 60 in. must be operated to secure peripheral velocities of 4,000, 5,000, 5,500 and 6,000 ft. per minute.

The exact speed at which any specified wheel should be run depends upon several conditions, such as the type of machine, character of work and wheel, quality of finish desired, and various other factors referred to at other places in this book. Wheels are ordinarily run in practice from about 4,000 to 6,000 ft. per minute, though in some cases a speed as high as 7,500 ft. has been employed. An average speed recommended by most wheel makers is 5,000 ft. To allow an ample margin of safety it is recommended that wheel speeds should not exceed 6,000 ft. per minute.

Rules for Obtaining Surface Speeds of Wheels

The table of circumferences (Table 21) will be of service in connection with the finding of surface speeds and spindle revolutions per minute.

Thus, to find the surface speed of a wheel in feet per minute:

Rule.—Multiply the circumference as obtained from the table, by the number of revolutions per minute.

Example.—A wheel 18 in. in diameter makes 1,060 r.p.m. What is the surface speed, in feet per minute?

$$4.712 \times 1{,}060 = 5{,}000 \text{ ft. surface speed.}$$

When the surface speed and wheel diameter are given, to find the number of revolutions of the wheel spindle:

Rule.—Divide the surface speed in feet per minute by the circumference.

Example.—A wheel 24 in. in diameter is to be run at 6,000 ft. surface speed per minute. How many revolutions should the wheel make?

6,000 ÷ 6.283 = 962, number of revolutions per minute the wheel should make.

TABLE 21.—CIRCUMFERENCES OF GRINDING WHEELS

Diam. of wheel, in.	Circum. of wheel, ft.	Diam. of wheel, in.	Circum. of wheel, ft.	Diam. of wheel, in.	Circum. of wheel, ft.
1	0.262	25	6.546	49	12.828
2	0.524	26	6.807	50	13.090
3	0.785	27	7.069	51	13.352
4	1.047	28	7.330	52	13.613
5	1.309	29	7.592	53	13 875
6	1.571	30	7.854	54	14.137
7	1.833	31	8.116	55	14.499
8	2.094	32	8.377	56	14.661
9	2.356	33	8.639	57	14.923
10	2.618	34	8.901	58	15.184
11	2.880	35	9.163	59	15 446
12	3.142	36	9.425	60	15 708
13	3.403	37	9.687	61	15.970
14	3.665	38	9.948	62	16.232
15	3.927	39	10.210	63	16.493
16	4.189	40	10.472	64	16.755
17	4.451	41	10.734	65	17.017
18	4.712	42	10.996	66	17.279
19	4.974	43	11.257	67	17.541
20	5.236	44	11.519	68	17.802
21	5.498	45	11.781	69	18.064
22	5.760	46	12.043	70	18.326
23	6.021	47	12.305	71	18.588
24	6.283	48	12.566	72	18.850

RULES FOR FINDING SPEEDS AND DIAMETERS OF PULLEYS

The proposed speed of the grinding spindle being given, to find the proper speed of the countershaft:

Rule.—Multiply the number of revolutions per minute of the grinding spindle by the diameter of its pulley, and divide the product by the diameter of the driving pulley on the countershaft.

Example.—The driving pulley on the countershaft is 18 in. in diameter, the pulley on the grinding spindle is 10 in. in diameter and makes 1,000 r.p.m. How many revolutions per minute does the countershaft run?

$$\frac{1,000 \times 10}{18} = 555 \text{ r.p.m.}$$

The speed of the countershaft being given, to find the diameter of the pulley to drive the grinding spindle.

Rule.—Multiply the number of revolutions per minute of the grinding spindle by the diameter of its pulley, and divide the product by the number of revolutions per minute of the countershaft.

Example.—The pulley on the wheel spindle is $8\frac{1}{2}$ in. in diameter and should make 1,000 r.p.m. The countershaft runs at a speed of 500 r.p.m. How large should the driving pulley on the countershaft be?

$$\frac{1,000 \times 8\frac{1}{2}}{500} = 17 \text{ in., diameter of driving-pulley countershaft.}$$

The proposed speed of the countershaft being given, to find the diameter of the pulley for the lineshaft:

Rule.—Multiply the number of revolutions per minute of the countershaft by the diameter of the tight and loose pulleys and divide the product by the number of revolutions per minute of the lineshaft.

Example.—A lineshaft running 150 r.p.m. is to drive a countershaft 450 r.p.m. The driven pulley on the countershaft is 9 in. in diameter. What diameter should the driving pulley on the lineshaft be?

$$\frac{9 \times 450}{150} = 27 \text{ in., diameter of pulley on lineshaft.}$$

THE APPLICATION OF HOODS TO WHEELS

Modern machines for cylindrical and surface grinding are equipped with hoods that enclose the major portion of the wheel and which, in case of accident, would stop the broken wheel fragments and prevent injury to the operator. In fact, practically all machines doing wet grinding including tool grinders, drill grinders, knife grinders, etc., require some form of shield to control the water flying away from the surface of the wheel, and most of these machines are therefore so well hooded as to make injury from a broken wheel quite unlikely. It is important that dry grinders, such as are used for "offhand" grinding of castings, steel strips, drop forgings, and other work, so far as possible should be fitted with wheel guards, and in many cases

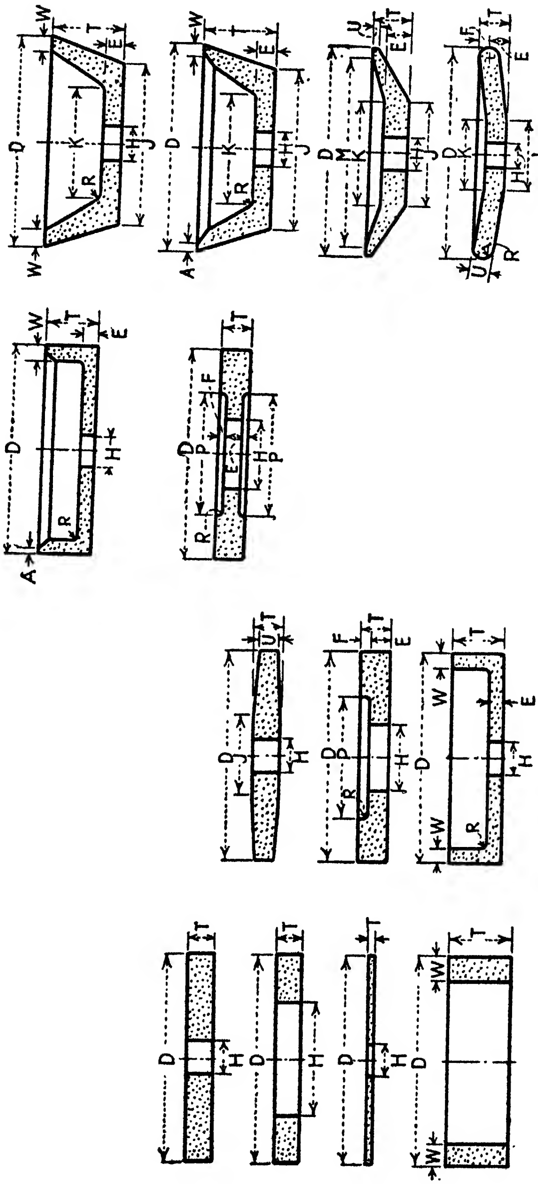


Fig. 180.—Standard types of grinding wheels.

where it has been deemed impossible to put them on, reconsideration of the problem will dislose the fact that suitable hoods actually can be applied with no special trouble.

There is a tendency for workmen at an unhooded wheel to grind castings and such work at the front, top, back, and both sides of the wheel at some time during the course of the day, particularly if the work does not from its weight require resting upon the wheel rest. Usually it will be found that when the wheel is hooded, the restricted area of wheel surface available will still be sufficient for most purposes.

Hoods of some types have transparent shields or flaps at the front to protect the operator's eyes at the same time permitting clear view of the work in operation.

LIMITING THE SPEEDS OF WHEELS

The subject of wheel speeds has already been discussed, and it is pointed out that the peripheral speed of a wheel may be maintained as it wears away in service, by means of a cone pulley on the spindle or by changing to a smaller size of machine with a faster running spindle. In the latter case where there are two or three grinders operated at different speeds there is only one pulley on the spindle and the danger of running the machine at the wrong speed is eliminated. At the same time it is essential that means be provided to prevent wheels over a fixed diameter from being mounted.

A safety stop is sometimes used which makes it impossible to mount an oversize wheel on the grinder spindle. With competent and conscientious supervision these are seldom necessary, however.

The standard types of grinding wheels are seen in Fig. 180.

CHAPTER XV

MOUNTING AND DRESSING WHEELS

One of the most important considerations in connection with the use of grinding wheels is that they shall be properly mounted, upon suitably proportioned spindles and between properly designed flanges. A wheel which is crowded upon a spindle of weak design, or which is cramped between two imperfect flanges that are either too small or take a bearing upon the wheel at the wrong point, is subjected to conditions as likely to cause an accident as is an excessive rate of speed.

The vast number of abrasive wheels in use upon the class of machines commonly known as bench and floor grinders, grinding-wheel stands, emery grinders, etc., and which are so generally in service at various points about the machine shop, blacksmith shop, and foundry, makes it desirable that something should be said here in reference to the best methods of mounting wheels on such apparatus.

In the first place, the machine itself should be of rigid construction, with spindle of ample proportions; the bearings should be well fitted; and kept well oiled so that the arbor will not become overheated and by expanding, break the wheel; and the machine should be securely fastened on substantial foundations not only to insure safety but in order to secure better results with the wheel.

The flanges should be relieved as in Fig. 181, and they should be at least one-half the diameter of the wheel and have a true bearing at the outer edge. The inner flange should never be loose but in all cases should be fixed on the spindle. Under no circumstances should the flanges be allowed to be less than one-third the diameter of the wheel. Wheels must not be allowed to run when held only by a nut in place of a flange, as the nut is liable to crawl and cause accident.

Compressible washers of blotting paper or rubber, slightly larger than the flanges, should be used between the flanges and the wheel. These distribute the pressure evenly when the flanges are tightened, by taking up any imperfections in the wheel or flanges.

The hole in the wheel bushing should be 0.005 in. larger than standard size spindles. This permits the wheel to slide on the spindle without cramping and insures a good fit not only on the spindle but against the inside flange, which is essential.

The flanges should be tightened only enough to hold the wheel firmly, thus avoiding unnecessary strain. The importance of

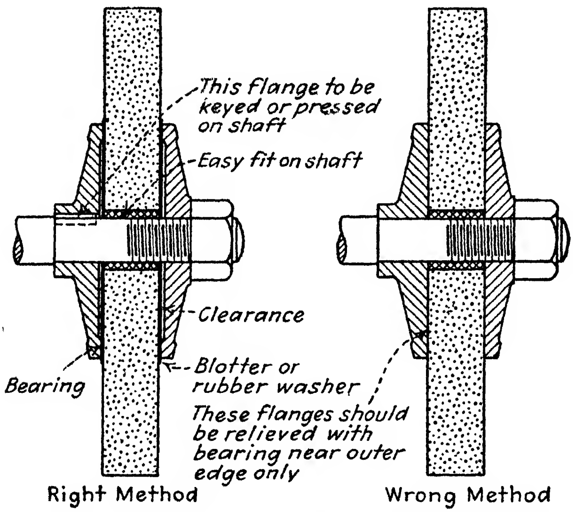


Fig. 181.—Right and wrong method of mounting wheels.

this statement is emphasized by the fact that on a 1½-in. floor grinder equipped with 8-in. standard relieved flanges a man with a 2-ft. wrench can easily exert a crushing pressure between the flanges and wheel of 3,600 lb.

RIGHT AND WRONG WAYS OF MOUNTING

The Norton Company illustrates, by the sketch reproduced in Fig. 181, the right and wrong methods of mounting grinding wheels. In the view to the left relieved flanges are shown with compressible washers between the flanges and the wheel, and a perfect bearing around the outside edge. The view at the right shows the improper method, straight flanges being used, and no washers being applied between flanges and wheel.

The following paragraphs from the Safety Code for use, care and protection of abrasive wheels will be of value to employers and operators. A complete copy of the Code will be available to anyone through application to wheel manufacturers.

Information for the Operator

From Safety Code Approved by American Engineering Standards Committee

Grinding-machine Requirements.—Grinding machines should be sufficiently heavy and rigid to prevent vibration, and should be securely mounted on substantial floors, benches, foundations, or other structures.

Direction of Spindle Thread.—Ends of spindles shall be so threaded that the nuts on both ends will tend to tighten as the spindles revolve. Care should be taken in setting up machines that the spindles are arranged to revolve in the proper direction, else the nuts on the ends will loosen.

Note: To remove the nuts they should both be turned in the direction that the spindle revolves when the wheel is in operation.

Protection Hoods.—Hoods should be used on every operation where the nature of the work will permit, and shall always be used with wheels which are not provided with protection flanges, chucks, or bands.

Work-rest Adjustment.—The work rest should be kept adjusted close to the wheel, with a maximum distance of ⅛ in., to prevent the work from being caught between the wheel and rest, and should be securely clamped after each adjustment.

Cup, Cylinder, and Ring Wheels.—Cups, cylinders, and sectional ring wheels shall be either protected with hoods, enclosed in protection chucks, or surrounded with protection bands. Not more than one quarter (¼) of the height of such grinding wheels shall protrude beyond the provided protection. Where the thickness of the rim of such wheels is less than 2 in., the maximum distance which the wheel may protrude beyond the provided protection shall not exceed 1 in. If the thickness of the rim is 2 in. or more, the wheel may protrude 2 in. beyond the protection, but shall not exceed this amount.

Inspection of Wheels.—Immediately upon receipt, all wheels should be closely inspected to make sure that they have not been injured in transit or otherwise. For added precaution wheels should be tapped gently with a light implement, such as the handle of a screw driver. If they sound cracked, they should not be used. Wheels must be dry, and free from sawdust, when applying the test.

Before mounting, all wheels should again be closely inspected to make sure that they have not been injured in transit, storage, or otherwise.

Storage of Wheels.—Extreme care should be exercised in the storage of wheels. They should be stored in dry places and should be supported on edge in racks. Straight-sided elastic and rubber-bonded wheels of ¼ in. or less in thickness shall be laid flat on a straight surface to prevent warpage.

Spindle Fit.—Grinding wheels shall fit freely on the spindles; they should not be forced on, nor should they be too loose.

Surface Condition.—All surfaces of wheels, washers, and flanges in contact with each other should be free from foreign material.

Bushing.—The soft metal bushing shall not extend beyond the sides of the wheel.

Responsibility.—Competent men should be assigned to the mounting, care, and inspection of grinding wheels and machines.

Starting New Wheels.—All new wheels shall be run at full operating speed for at least one minute before applying work, during which time the operator shall stand at one side.

Applying Work.—Work should not be forced against a cold wheel, but applied gradually, giving the wheel an opportunity to warm and thereby minimize the chance of breakage. This applies to starting work in the morning in cold rooms, and to new wheels which have been stored in a cold place.

Test for Balance.—Wheels should be occasionally tested for balance, and rebalanced if necessary.

Wet-grinding Wheels.—Wheels used in wet grinding should not be allowed to stand partly immersed in the water. The water-soaked portion may throw the wheel dangerously out of balance.

All wet-tool grinders which are not so designed as to provide a constant supply of fresh water shall be thoroughly drained at the end of each day's work and a fresh supply provided just before starting.

Side Grinding.—Grinding on the flat sides of straight wheels is often hazardous and should not be allowed on such operations when the sides of the wheel are appreciably worn thereby or when any considerable or sudden pressure is brought to bear against the sides.

Lubrication.—Care should be exercised so that the spindle will not become sufficiently heated to damage the wheel.

Flanges.—All wheels excepting those which are mounted in chucks shall always be run with flanges.

Recess in Flanges.—Each flange, whether straight or tapered, shall be recessed at the center at least one-sixteenth (1/16) of an inch on the side next to the wheel for a distance as specified in the complete Safety Code in the respective tables of dimensions for straight and tapered flanges.

Flange Fit.—The inner flange shall be keyed, screwed, shrunk, or pressed onto the spindle, and the bearing surface shall run true and at right angles with the spindle. The bore in the outer flange should be not more than 0.002 in. larger than the spindle.

Protection-flange Requirements.—Protection flanges shall always be used with wheels 6 in. and larger which are not provided with protection hoods, chucks, or bands.

Straight-flange and Tapered-flange Dimensions.—A series of tables, in the complete Safety Code referred to, cover all classes of flanges and their dimensions.

Truing and Dressing.—Wheels worn out of round shall be trued by a competent man. Wheels out of balance through wear, which cannot be balanced by truing or dressing, shall be removed from the machine. Truing is best accomplished by the use of a diamond rather than with a wheel dresser, the function of which is dressing only. Truing is not necessarily a sharpening operation but is what its name implies. Dressing rarely trues a wheel.

Truing means the removal of material from the grinding face of a wheel so that the resulting surface runs absolutely true. Dressing is the operation of cleaning or opening up the face of a wheel and does not necessarily leave the surface true.

Wheel dressers except the diamond type shall be equipped with guards over the tops of the cutters to protect the operator from flying pieces of broken cutters or wheel particles.

Washers or Blotters.—Washers or flange facings of compressible material shall be fitted between the wheel and its flanges. If blotting paper is used, it should not be thicker than 0.025 in. If rubber or leather is used, it should not be thicker than 1/8 in. If flanges with babbitt or lead facings are used, the thickness of babbitt or lead should not exceed 1/8 in. The diameter of the washers shall not be smaller than the flanges.

When tightening spindle end nuts, care should be taken to tighten same only enough to hold the wheel firmly; otherwise the clamping strain is liable to damage the wheel or associated parts.

MOUNTING WHEELS ON CYLINDRICAL AND SURFACE GRINDERS

Two methods of mounting wheels on grinding machines are shown herewith. In Figs. 182 and 183 are seen respectively the wheel-spindle detail and the wheel mount for the Cincinnati plain cylindrical grinder.

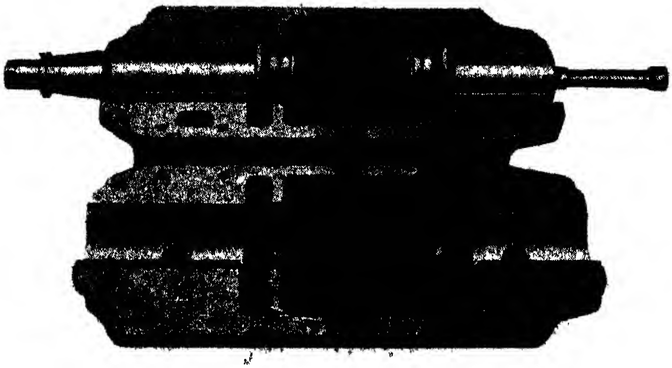


FIG 182 —Cincinnati grinder spindle mounting

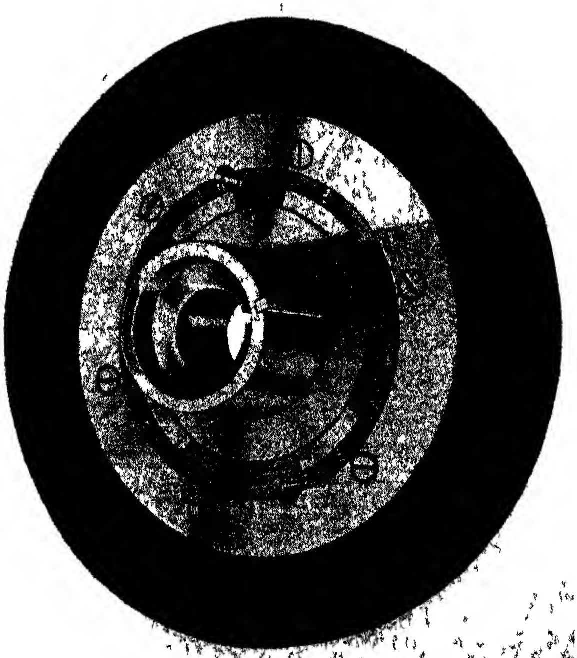


FIG. 183.—Cincinnati wheel mount.

Improved Spindle Mounting.—The grinding-wheel spindle is a heavy, chrome-nickel-steel forging, heat-treated and ground to

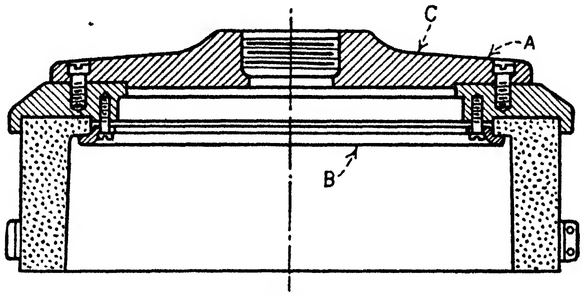


Fig. 184.—Pratt & Whitney wheel mounting.

high finish. It is mounted in half box bearings of special bronze alloy which are scraped to the spindle. Lubrication is automatic; by means of slingers mounted on the spindle the oil is lifted out of reservoirs in the wheel head and carried into distributing

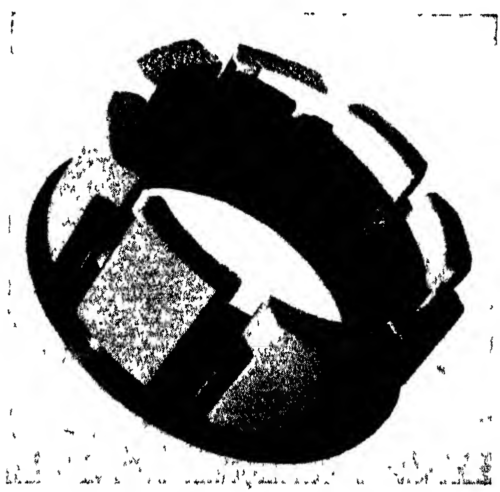


Fig. 185.—A typical segmental chuck.

pockets in the bearing caps. The bronze boxes are milled so that an ample amount of oil remains in the bearings after the spindle is stopped; this supply is used when starting until the machine gets up to speed, insuring ample lubrication at the most critical time. End thrust is taken up by a double-row ball bearing.

Grinding Wheels and Mounts.—The grinding wheels used on this machine are 30 in. in diameter with 16-in. diameter hole which makes for great economy. The wheel mounts (Fig. 183) are made from steel and the outer flange is provided with a circular slot in which are placed balancing weights which can be so positioned as to balance properly the grinding wheel. It is desirable to have several wheel mounts with each machine so that it is not necessary to remove the wheel from the mounts when changing wheels.

The Pratt & Whitney vertical-surface-grinder spindle carries a wheel mount shown in section in Fig. 184. The cylinder wheel in this case is secured in its seat *A* by shellac and by the narrow brass clamping ring *B*.

Another segment chuck for carborundum and aloxite for Pratt & Whitney and Blanchard machines is shown in Fig. 185.

GLAZING AND LOADING OF WHEELS

The difference between glazing and loading, already mentioned, is not always understood clearly. As stated by Norton, a loaded wheel is one whose face has particles of the metal being ground adhering to it—one in which the openings or pores of the wheel face have been filled up with the metal leaving no room for clearance. It is not necessary that all of the pores between the cutting particles on the wheel face be filled up to prevent the wheel from cutting properly. The presence of a number of these pieces of metal on the face of the wheel prevents it from cutting into the work and the loaded pieces will, of course, generate heat.

A glazed wheel is one whose cutting particles have become dull or worn down, even with the bond, the bond being so hard that it does not wear away fast enough to allow spaces between the cutting particles, or the cutting particles to escape when dulled. In a glazed wheel, the cutting particles and the bond at the extreme surface of the wheel are of the same radius.

It will be noted that in many places the space between the cutting particles is filled with bond and the corresponding spaces in the wheel on the left are open and will give room for clearance. Continued work with a wheel that glazes increases the smoothness of the wheel face and decreases the cutting.

A wheel will not load unless the bond is too hard or it is run at a speed very much too slow. The factors that cause loading are, therefore, hard bond and slow speed. Loading may indicate that the wheel is too hard or that it is running too slow, or both.

The factors that cause glazing are hard bond and high speed. Glazing may indicate that the wheel is too hard for the work, or it may be running too fast. A wheel of the right grain and grade may glaze if run too fast, or a wheel run at the right speed may glaze if it is too hard for the work. In short, a wheel loads when it is too hard or when it runs too slow, and a wheel glazes when it is too hard or runs too fast.

One remedy for loading is to increase the speed. A remedy for glazing is to decrease the speed. If the speeds are right, use a softer wheel in either case.

USE OF DRESSERS AND DIAMONDS

The Carborundum Company presents some important data pertaining to the application of dressers and industrial diamonds in the maintaining of proper wheel surfaces. These particulars are covered in the following text accompanied by tables and sketches showing practical application of the points brought out.

Definitions.—Truing may be broadly defined as any operation performed on any part of a wheel to create concentricity or parallelism or to alter the wheel shape, either before or after a grinding period.

Truing may be accomplished with any dressing tool, provided it is rigidly fixed in relation to the point of contact with the wheel.

Dressing may be defined as any operation performed on a wheel face to change the nature of its cutting action.

Wheel Dressers.—The Huntington or star type of dresser has pointed disks loosely mounted on a pin, with solid circular disks as separators. This type is exclusively used for dressing coarse-grit wheels for snagging and offhand grinding, and frequently for dressing segmental-surface grinding wheels.

A corrugated disk (zigzag) dresser (Fig. 186) is similar to the Huntington dresser, except that the disks are cast in a corrugated pattern and mounted without spacers. Intended for use where the work does not require the extreme, open structure produced by the star type, it tends to shear off the grains rather than to tear them from the wheel. Hence, its field is limited to the smoothing of roughing wheels.

The locked-disk type consists of a number of cut steel disks with elongated teeth or a number of cast disks with serrated or zigzag edges, either of which is locked in sets and rigidly mounted without spacers on a pin supported in suitable bearings. The function of this tool is to remove partially the abrasive grains to a common level and slightly to open the bond. Limited in its field to medium roughing wheels it still has a wide range of application, including dressing of wheels for cam and crankshaft grinding, centerless grinding of bar stock and bolts.

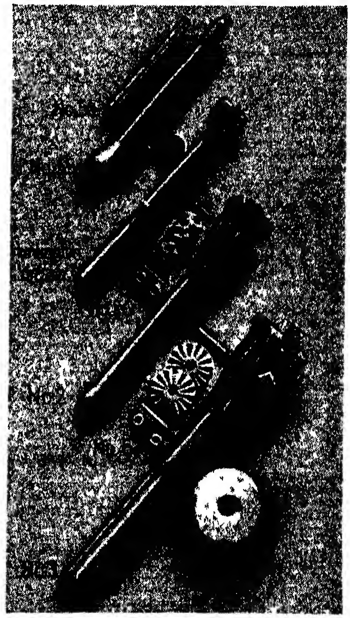


FIG. 186.—Wheel dressers.

The precision-steel type is frequently used in place of diamonds for commercial grinding. It consists of a solid steel shell or cylinder mounted on accurate bearings. These cylinders have diagonal grooves spiraling in one or both directions, or a series of evenly spaced openings. Single-grooved tools are used for the peculiar wheel face required for the fine grinding of cast iron, while the double-grooved and holed types are well suited to the grinding of fine commercial surfaces, finishes on tappets, guides, and general cylindrical work.

Abrasive dresser sticks are of two shapes, square for hand manipulation and round for magazine mounting. The square shape is well adapted to common grits and grades of toolroom wheels for grinding reamers, and mills and miscellaneous cutting tools, Blanchard vertical-surface wheels, and special shaped wheels.

Magazine-mounted sticks are of advantage in the toolroom for forming wheels to various patterns for profile grinding and for dressing or truing wheels of thin section. Either type may be economically used for the truing or dressing of dual-purpose wheels for roughing cuts when a diamond is to be used for subsequent finishing cuts.

Abrasive wheel dressers consist of silicon carbide wheels rotatably mounted in a suitable holder with high-grade bearings. They will in many cases entirely replace the diamond for such grinding operations as on pistons, camshafts, crankshafts, axle-shafts bolts and many commercially fine finishes on the center-

TABLE 22

F rating	Wheel diameter, in.	Wheel face, in.	Grit	Grade	Bond	Abrasive
1	Up to 6	1	40 to 80	Soft	Vit. and sil.	Al. ox.
2	6 to 12	2		Medium	Shellac	
3	12 to 16		90 and finer			
4	16 to 20	3			"Redmanol"	
5	20 to 24					
6	24 to 30	4	12 to 36	Hard	Rubber	Sil. carb.
7	30 to 36					
8	36 to 40	5				
10		6				
12		7		Very hard		
14		8				
16		9				
18		10				

Value of Total Rating, *F*, in Carats

F values	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
Carats	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7 5	8

Example of How to Apply Above Table to Typical Wheels

	Diam.	Th.	Grit	Grade	Bond	Abrasive	Total *F*	Size diamond
F	24	6	50	I	G6	Sil. carb.	(Wheel)	
	5	10	1	2	1	6	25	4 carats
F	12	1	80	R	24	Al. ox.	(Wheel)	
	2	1	1	1	1	1	7	1 carat

less grinder. Their use imparts a smooth, clean cutting face which leaves no dressing marks on the work.

DRESSING AND TRUING OF GRINDING WHEELS

In its practical application, care should be taken to prevent the dressing wheel from passing off or out of contact with the grinding wheel face. This would cause the dressing wheel to gouge the grinding wheel when it again comes into contact at a diminished speed. Another reason for this precaution is that

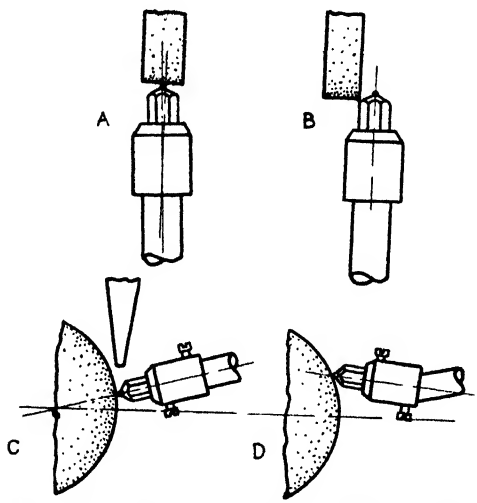


FIG. 187.—Diamond contact in dressing wheels.

as the contact area decreases, the penetration becomes deeper. The angle at which the tool is set (see Fig. 187) bears a very important part in the results desired and obtained. For general use an angle set from 5 to 7 deg. from the vertical.

Industrial Diamonds.—Selection of diamonds for quality for truing and dressing is not properly a shop function. Approximately 85 per cent of the factories use African brown bort, gray bort, and ballas stones. Best quality brown bort stones are recommended for inexperienced operators, because such stones are less brittle and will withstand reasonable wear.

There are six factors to consider in the selection of proper-size diamonds: Wheel diameter, thickness of wheel face, grit, grade, bond, and abrasive. The total rating F, Table 22, gives the key to diamond size. Recommendations for specific applications follow:

Small internal wheels—brown or gray stones in long, natural points, $\frac{1}{16}$ to $\frac{3}{4}$ carat. Reset at least once to obtain advantage of both points.

Small external wheels—octahedron-shaped Brazilian stones from $\frac{1}{4}$ to $1\frac{1}{4}$ carat for hard fine wheels, and octahedron brown or gray for softer wheels. With this shaped stone, the points are of great value. When worn, use for other classes of wheels.

Gear grinding wheels—use only the finest selected brown or Brazilian octahedrons. These stones must be selected by experts for this class of dressing.

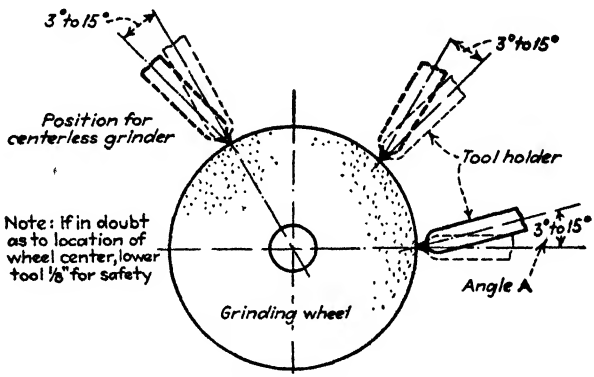


FIG. 188.—How diamond should be held.

Thread and hob grinding wheels—This service requires elongated shapes, natural points or sharp splints, best selected by experts.

Diamond dressing tools should always be used at an angle to the wheel face, and to the direction of wheel rotation. Either one of two angles may be used, depending on the type of tool.

The first and most important angle is one intended to prevent chatter in the tool, gouging the wheel face, and damage to the stone. This is usually referred to as "canting." Refer to Fig. 188. Set the diamond holder on the radial line with its sides parallel to the wheel side. Assuming that the diamond point is in contact with the wheel on this line, raise the rear end of the tool vertically, in the direction opposite the direction of wheel rotation, making an opening between the radial line and the tool axis of from 3 to 15 deg., thus forming angle *A*. If in doubt as to the exact radial line, drop the point to a position not more than ¼ in. below the supposed line. Never have this contact point above the radial line. With this setting it is necessary to rotate the tool point on its own axis to maintain a point on the stone.

The second angle, Fig. 189, is intended to make the diamond self-sharpening, and to avoid diamond marks on the wheel face. This angle constitutes a movement out of the vertical plane Again assuming that the diamond point is in contact with the wheel face, move the rear end of the tool horizontally, making an opening of 30 deg., angle *B*, between the tool axis and line, or 60 deg from the wheel face. With this angle the stone assumes and maintains a 60-deg included angle As the stone is rotated, it presents a sharp but broad edge to the wheel, which will dress openly but free of diamond "threads" Here, too, the stone should be slightly below the radial line, rather than above

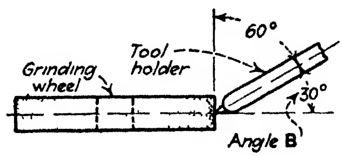


Fig. 189 – To make diamonds self-sharpening

Very frequently the wheel face is worn convex or tapered. It is good practice to contact the stone on the wheel at the highest point before traversing, with infeed, to prevent excessive penetration.

Diamonds Set without Brazing.[1]—While diamonds for dressing abrasive wheels are usually set by brazing, it is not always the best method because expensive stones are frequently injured by being overheated. By the method to be described, a diamond can be set by any toolmaker in less than an hour and at a cost no greater than it could be set by brazing by an expert setter. The method is nothing but a soldering job and a little machining. While the stone will loosen if the solder is heated to 620°F., it will not come out of the setting.

A hole is drilled in one end of the holder, slightly larger than the diamond and deep enough to permit the diamond to project about two-thirds of its length. The end of the holder is then faced so as to leave a nipple having a 1/32-in. wall and projecting about 3/32 in., as shown at *A* in Fig. 190. A small quantity of so-called liquid solder is dropped in the hole and the diamond is

[1] Hector J. Chamberland.

inserted. After waiting for 1 or 2 min. for the liquid solder to stiffen, the diamond point can be adjusted in line with the axis of the holder. This can best be done while revolving the holder in the lathe.

The top of the setting is then covered with ordinary lead solder and is faced to an angle a few degrees steeper than the ordinary drill point. The holder is also turned down for about an inch from the end, as at *B*. A sleeve having a closed end is made by drilling and reaming a piece of drill rod to within 1/16 in. from the end. A hole from 1/32 to 1/16 in., according to the size of the diamond, is drilled in the closed end. When pressed on the holder, the sleeve will contact with the diamond at the intersection of the hole. The holder with the sleeve pressed on may be seen at *C*. It is now necessary only to face the sleeve to an angle of about 70 deg. from the side, as at *D*, continuing the facing until the point of the diamond projects.

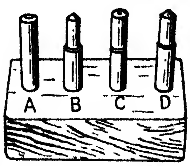


FIG. 190.—Setting diamonds in solder.

The turned-down portion of the holder should be about 0.001 in. larger in diameter than that of the inside of the sleeve, so as to make a tight press fit. The diamond can not come out of the holder and be lost, no matter how carelessly it is used.

DIAMONDS FOR TRUING GRINDING WHEELS

The Heald Machine Company offer the following suggestions:

A diamond used for truing grinding wheels depends for its value chiefly on its physical quality of hardness. Although it varies slightly in this characteristic, the difference between the hardest and softest is negligible for ordinary truing operations, because the material on which it is used is so much softer than even the softest diamond. Stones are graded and priced according to size, origin, color, shape, cleavage, and imperfections.

The industrial buyer's chief concern is to obtain stones which will give him the lowest unit operating expense. It is not uncommon to find inferior stones purchased and used on applications for which they are wholly unfitted, when a stone with a small increase in first cost would not only do the job more efficiently but would last proportionately longer than the small one.

As a rule, the industrial buyer has neither the time nor the opportunity to make a detailed study of diamonds. Because there are so many variable factors in the selection of diamonds for industrial purposes, the buyer's soundest policy is to rely on the recommendations of the machine builder or a diamond expert.

The diamond is a device for correcting the cutting surface of a wheel. When selecting a diamond, it is very important to select a good grade with a sharp point. It should be set tight in its nib and on internal grinders the point should always be lapped concentric with the shank.

As the standard type of conical-point diamond wears, the amount of diamond surface in contact with the wheel increases and offers a greater pressure on the wheel when truing. The diamond holder is arranged in such a manner on the Heald grinders that when the diamond becomes dull, it may be turned in its holder to present a different contact point and be in the best condition to perform the work expected of it. To do this, move the diamond back before truing to eliminate the possibility of it colliding with the wheel, and then adjust it to the proper position for truing.

Heald diamonds have their points lapped concentric with the shanks. Ordinarily on internal grinders, collet-style diamond holders are furnished, but in connection with smaller diameter grinding-wheel spindles having extensions less than 1 in. in length, a narrow, solid holder is used in place of the collet style. The solid holder takes up less space and permits the shortest possible grinding-wheel spindle to be used.

On very small and long slender wheel spindles, the amount of pressure on the wheel when truing is a very important factor, as too much pressure on the wheel causes it to vibrate. This is due to the weak spindle allowing the wheel to bound away from the diamond and so produces a wheel surface unsatisfactory for grinding. On the very small and long holes, it is usually necessary to use long slender diamonds which are very small in diameter. These are known as sliver diamonds, as they are slivers from larger stones. With the sliver diamond, the amount of diamond surface contacting the wheel remains constant as the diamond wears and permits satisfactory truing of wheels with weak spindles.

The unit cost for diamond work depends not only on the initial cost of the stones and settings, but to a very large extent on the degree of care with which the diamonds are handled and the condition of the machine on which they are used.

When a diamond has become dulled, it should be immediately reset. Under no circumstances should the metal of the setting be filed away to expose more of the stone, unless it is a setting especially designed for such handling. The setting has an important function in keeping the stone rigidly fixed. A loose diamond is easily dislodged and will not true a satisfactory surface on the wheel.

When truing a wheel, it is extremely important to take light cuts. A heavy cut increases the heat generated in the stone by its cutting friction and the stone expands before the end of the truing stroke, causing a taper on the face of the wheel. If the diamond does become unduly heated, never cool it with water. When truing wheels on surface grinders, always use water for

TABLE 23.—APPROXIMATE TIME REQUIRED FOR TRUING WHEELS
(72A and 81 Heald Automatic Internal Grinders)

Finish	Hole diameter, in.	Time, sec.
Commercial	Up to ¾	2
	¾ to 1½	2½
	1½ and up	3
Good	Up to ¾	4
	¾ to 1½	5
	1½ and up	6
Fine	Up to ¾	8
	¾ to 1½	10
	1½ and up	12

APPROXIMATE TRUING SPEEDS FOR MEDIUM-SIZE HOLES
(72A and 81 Heald Automatic Internal Grinders)

Commercial Finish	—Approximately 50	per cent of roughing speed
Good	—Approximately 25	per cent of roughing speed
Fine	—Approximately 12.5	per cent of roughing speed

TIME REQUIRED FOR RAPID TRAVERSE OF WHEEL TO AND FROM WORK
(72A and 81 Heald Automatic Internal Grinders)

Automatic rapid traverse (total in and out) 3 sec.

cooling the diamond, as the wheels on this machine, being larger, very easily cause the diamond to overheat and expand.

While the diamond is a very hard substance, it is also brittle. This applies especially to stones with well-defined lines of cleavage. Care should be taken to guard it against shock as a great many diamonds have been cracked by striking the side of a grinding wheel while used by an inexperienced operator.

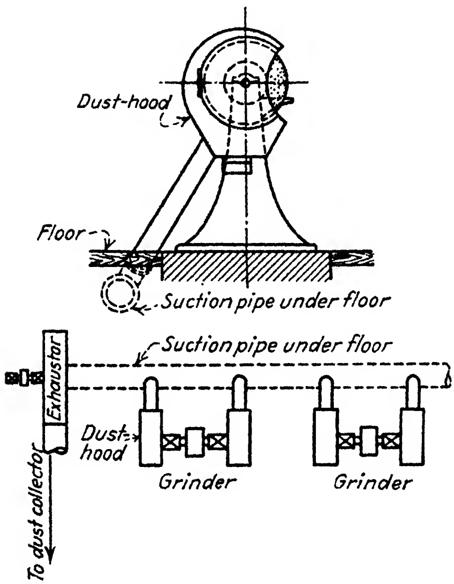


Fig. 191.—Typical exhaust system for grinding room.

The following table gives the approximate diamond sizes for different diameters of wheels:

Diameter of Wheel, In.	Size of Diamond
Up to 3/8	1/4 carat (sliver type)
3/8 to 1	1/2 carat
1 to 6	3/4 to 1 carat
6 to 14	1 3/4 to 2 carats
14 to 18	3 carats

OTHER SUGGESTIONS

Each machine should be marked with the number of revolutions and the size of wheel to be run upon it. In some shops a placard is hung over each machine, giving the machine number, number of spindle revolutions at which it is to be run, the diameter of the wheel in inches, and the diameter at which it is to be taken off. It also bears instructions that the foreman is to be notified when the wheel requires dressing.

All grinding machines in the department should be examined every morning by the foreman or his assistant to determine if the bearings are properly adjusted and oiled and the wheels in good condition. The man in charge should inspect each wheel carefully before it is placed on the arbor.

Competent men should be appointed to mount and true the wheels, adjust the rests, and regulate the speeds.

DUST SYSTEMS

It is highly important that grinding and polishing rooms should be properly ventilated and well lighted and that the machines should be connected to an efficient dust system, not only for the preservation of the health of the workmen, but also to prevent unnecessary wear and tear on the machinery and belts.

Figure 191 shows the system in which the main pipe is put in the ground.

CHAPTER XVI

LAPPING AND HONING MACHINES

LAPPING

Lapping is roughly defined as precision finishing. It is done by movement between the lap and the work with a fine abrasive between the surfaces, and applies to either cylindrical or flat surfaces. Originally done by hand, it is now a well-known machine operation producing very accurate results at low cost. Holes are lapped with plugs of cast iron, brass, copper, lead, or close-grained wood using a fine abrasive. The lap should be considerably softer than the work so that abrasive will imbed itself in the lap and not the work. Holes are lapped with plugs and cylinders were formerly lapped with half-round or round clamps on the outside. Modern lapping machines lap cylindrical work, such as piston pins, between flat surfaces. Crankpin-lapping machines use strips of abrasive cloth or paper but are really more polishing than lapping machines.

Lapping usually removes the high polish left by the fine grinding machine and gives more of a satin finish. It also removes most of the minute hills and hollows left by the grinder. Test on ground and lapped piston pins show a wear of 0.0003 in. after a few hours, while lapped pins run the same time show no appreciable wear. Lapping removes this initial wear before the pins go into service. Similar tests on gage show much greater wear for ground gages than when they are lapped, and approximately three times as much wear on hand-lapped gages than when machine-lapped.

Modern lapping machines, such as the Norton, formerly the Bethel-Player, consist of a mechanically driven disk lap on a vertical spindle. A column carries a swinging overarm which supports the upper lap. This upper lap does not rotate but can float or find its own level when brought in contact with the pieces to be lapped. The laps are made from a soft, close-grained cast iron. The lower lap revolves counterclockwise, at about 60 r.p.m.

The parts to be lapped are driven by plates, thinner than the work, in the same direction as the lap, but at a slightly slower speed. The work holders move in an eccentric path and give an end motion to the work so that it travels across the face of the lap. Some successful users of these machines advocate moving the work across the face of the lap sufficiently to have it project beyond both the inner and outer edges.

The laps on these machines vary from 14 to 24 in. outside diameter and from 8 to 14 in. in the center. It is advised that the center hole be at least half the outside diameter. In some cases it is more. The laps are from 3 to 4 in. thick to prevent distortion. The more accurate the laps the better the work. For the best work they are made in sets of three, as with surface plates. After careful machining they are scraped to a good surface plate and then worked together on a vertical-drill press. By means of a short throw crank in the spindle the upper lap moves in a circular but eccentric path across the face of the lower lap. This causes the upper lap to turn slowly on its own axis. The combined movement, with the use of a fine abrasive and oil, works the laps in to match each other. The first lap is then worked with the third lap and the second with the third, then the third with the first, as with faceplates. After they are once worked into a true lapping surface, any subsequent dressing can be done on the machine, unless the form has been destroyed.

For redressing it is only necessary to let the upper lap rest on the lower one with half its diameter overhanging, and move it back and forth by hand as the lower lap revolves. Use a fine abrasive, not coarser than 220, and oil between the faces of the laps. Frequent inspection with a straight edge, long enough to reach across the laps, will indicate when they are flat.

Very accurate work can be done by lapping and at comparatively low costs if the parts are ground accurately and to close limits. Lapping should not be considered as a stock-removing operation but as a finish. In no case should more than 0.0005 in. be left for lapping and half this is easily possible, and better. This applies to size, parallelism, and roundness or flatness as the case may be. When parts come to the lapping machine as they should, the lapping operation can be timed very accurately to give the desired results. Two lapping operations are frequently advisable.

Hollow work, such as piston pins, is held on spiders as in Fig. 192. They fit loosely on the pins, which are not radial but

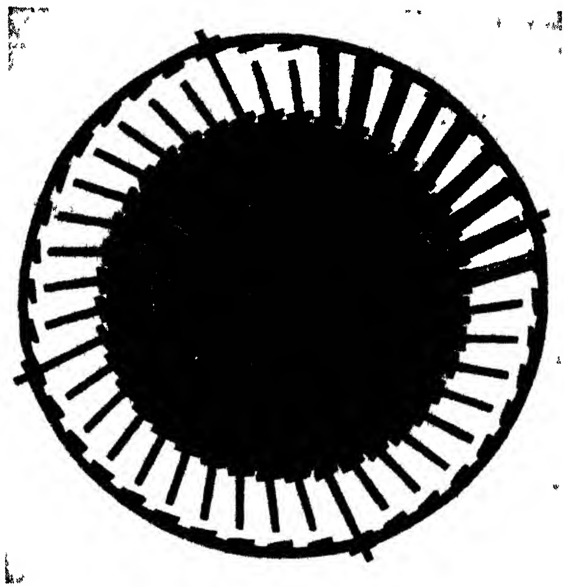


Fig 192 —Lapping holder for hollow piston pins

tangent to a circle of approximately 3 in. in diameter. The pins have end play of perhaps ⅛ in. Solid rollers are held in cages without pins and round or square disks are held in holders which

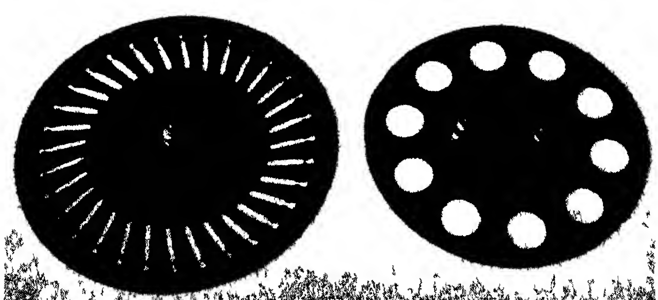


Fig. 193.—Holders for solid pins and disks.

themselves turn in a larger holder, as in Fig. 193. In addition to this the work is removed after a given time, washed free from abrasive, and put back into another holder. In this way thick and thin work is equalized and extreme accuracy obtained. In some of the work the tolerance is but 0.000025 in.

Laps are also made of bonded abrasives which can be dressed with a diamond. Instead of running at high speeds, however, these should not exceed 700 ft. per minute.

For cast-iron laps the abrasive is mixed with kerosene and lard oil to form a paste, but for final finishing only the kerosene is used. Where an abrasive wheel is used as the lap, either kerosene alone or a mixture of Lux and water is used. Standard Oil No. 4116 or No. 1 lapping oil is also good. It gives a bright finish and does not injure the skin. Too heavy oils fill the pores of the lap.

Centerless Lapping.—A late development in machine lapping is the use of machines of the Cincinnati centerless type with abrasive wheels of very fine grit. By using a special feed wheel and a lapping wheel of 500 grit for the finish lapping, a remarkably fine surface is produced and one that has a high finish.

Laps for Finishing Dies

The following suggestions on laps and their use in die work, are by Charles Weslow, a machinist and toolmaker of wide experience. They contain much that will be helpful to any toolmaker, especially those with limited experience. The suggestions are given largely as written by Weslow.

Few young toolmakers have an assortment of laps for small holes in hardened pieces—holes for piercing in a die, holes for dowels, and even laps for screw holes.

Many try to clean out a tapped hole in a hardened die with a tap. Often the tap will stick and break. Then what? Anneal the die just for that—and crack the die when rehardening in the bargain? If a brass screw is made, charged with emery, run in and out, the tapped hole can be cleaned out without running any such risk. If one has an undersize tap, it is practical to use it with a little cotton waste wrapped around the tap, to cause it to "scrape" the thread clean.

Clean Tapped Holes.—In this connection, tapped holes in a die will come out clean if the holes are plugged up with screws before the die is heated. Do not worry about the screws sticking after hardening. They will not stick, simply because a scale forms around the thread of the screw in the heating, which loosens easily by turning the screw. Many tool hardeners stuff the holes with fireproof material, but it is a mean job cleaning such material out of threaded holes, and there is still a tapped hole to be lapped out; whereas if iron screws are used for plugging, all that worry is eliminated.

Screws are used in dowel holes, too, in the process of hardening. Put a washer under the head and a washer and nut on the other end. This method prevents cracking more than does fireproof material, which cools more quickly in water than an iron screw.

Slits in Lap Surface.—Lap No. 1 (Fig. 194) has a pinhole in the arbor, and a screw hole in the end of the lap. A pin is driven into the hole which engages the screw in the lap, as a means for driving without

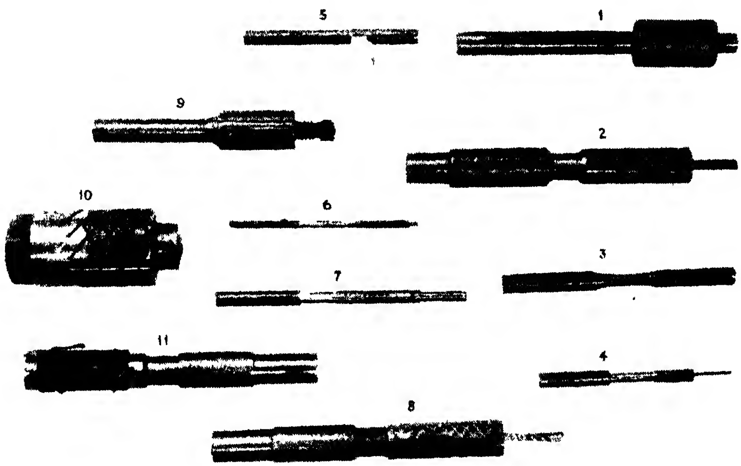


Fig. 194.—Set of toolmaker's laps.

slipping, and because the arbor is tapered, adjusting is feasible. The lapping surface is full of slits, put in with a hacksaw holding the lap in a vise. Mark them off with the naked eye, and they are not cut like a thread; if they were, the lap would possibly screw into the hole being lapped and stick.

No. 2 lap is made of cold-rolled steel and is a common lap depending on a wedge for adjusting. Such a lap is good enough in many cases. The slits in this, too, were cut by hand with a hacksaw.

Numbers 3 and 4 are the same but in smaller sizes, where ordinary toothpicks are used for wedges. Number 5 is another kind of lap, adjusted with a small screw and solid at the end because it is made for jig bushings or for holes that must be straight out to the end and not bell-mouthed which open laps produce.

Numbers 6 and 7 are still of another design. They have three saw slots, solid end, except for the hole into which a taper pin is introduced as a means for adjusting or expansion.

Taper-pin Fit.—The only place where the taper pin fits tight is about in the center. At the end and beyond the center, the pin has clearance. This lap is for jig bushings and piercing holes in a die, providing the piercing hole has been reamed tapered before hardening. Beware, if piercing holes are not tapered for the slug to pass through, as the punches will break due to the pressure of shoving tight-fitting slugs through the holes. That means annealing the die just to taper the holes.

Number 8 lap has the slits filled with solder, which produces a fine smooth surface in a hole, after the hole has been lapped to within two-tenths to size. It is used with fine dry emery (no oil).

Number 9 is adjusted with a setscrew that presses a steel ball against a taper hole at the center.

Number 10 was made for lapping a 1$\frac{3}{16}$-in. piercing hole in a die and is used in a speed lathe. The nut pulls up the head of the screw that is turned taper to about 30 deg. It was very satisfactory, and the glaze around it proves it did the proper duty.

Source of Wedges.—A wooden spoon is suitable material for making wedges for slotted laps for adjusting. These spoons are made of maple and are just about the proper thickness for paring to a taper with a file.

Lap No. 11 is wrapped with emery cloth, and is used for cleaning out the scale in a hole, thus saving a lot of time. Sometimes a three-cornered scraper is used to cut away the scale. With a half dozen three-cornered scrapers of all sizes, the smallest goes into a hole $\frac{1}{8}$ in. in diameter. These scrapers are used for various other purposes; a couple of them have one corner rounded off considerably, so that only two scraping edges are left.

Number 11 lap is also used largely on bakelite molds where dowel pins fit one part of the mold loosely, otherwise known as a slop fit. They must fit that way; otherwise, it would be difficult for the molder to take the hot molds apart. Such laps are also used quite a lot in polishing the corners in small machine parts and models.

Valve-grinding composition is found the best material to charge the laps with. In olden times we had diamond dust for small holes; that used to lap holes in a jiffy. In fact one had to be careful not to lap too much at a time owing to the cutting qualities of the diamond.

I have over 100 of these laps ranging in size from $\frac{1}{16}$ to $\frac{3}{4}$ in. Some that are worn a little are used for roughing out and the newer laps for finishing. "Don't lend out your laps, for others to distort and wear out for you."

HONING

Although the terms honing and lapping are sometimes used interchangeably there is a distinct difference in the operations, both of which now have a place in high-grade manufacturing. The hone, or honing head, consists of abrasive stones or strips held in a metal head or frame. While some of the earlier hones

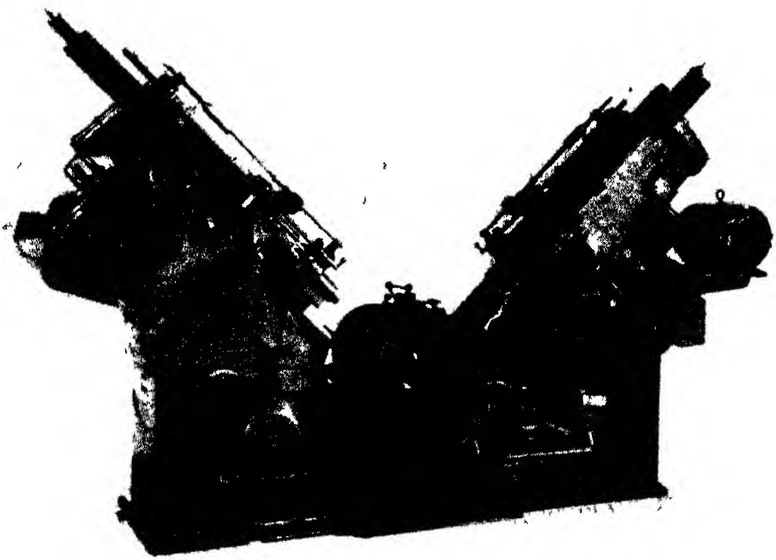


FIG 195 – Honing eight Ford cylinder bores at once.

permitted the abrasive stones to float, and follow the bore of the hole, present practice is to have the hones rigidly held so that they correct inequalities of the bore. The diameter of the hones is adjustable within limits so that the size can be decreased while the hone is being entered in the hole, and then expanded to the desired diameter as the work proceeds.

As with grinding operations of all kinds it pays to get the work out of the abrasive in the shortest possible time. Trying to save the grinding wheel or the abrasive block used in honing is poor economy. Saving the stones increases the grinding time in nearly every case. Abrasive blocks should never be allowed to glaze but should be kept sharp at all times.

The finest grit generally considered as practicable to use is No. 180. It is advisable to reduce the speed of the hone as the surface approaches a full bearing. The finish speed can be 30 per cent slower than at the start. High speed is not always best In one case a test was made on a 6- by 14-in. cylinder. At 240 r.p.m. it took 35 min. to remove 0.016 in. Reducing the speed to 160 r.p.m. also reduced the time to 6 min.

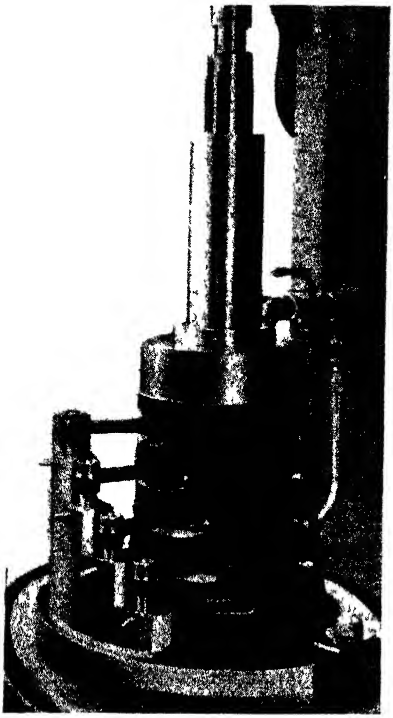


FIG. 196.—Honing four connecting rods at one operation.

On bores less than one and one-half diameters long a fast stroke is recommended, the speed being limited by the shock of reversal. A hole 9 in. in diameter by 1.6 in. long was honed at 60 r.p.m. and with 130 strokes per minute. It is best not to have an exact uniform relationship between speed and stroke.

On nonferrous metals a slightly dull stone gives best results. On aluminum and white metal a 400 grit and lard oil give good results. On steels and irons 180 is about the finest practicable.

The length of the stones rarely exceed two-thirds the length of the bore of hole that is being honed.

A good example of honing is that of two ½-in. holes in the ends of a bearing with 3 in. between them. The bearings were ⅝ in. long. Only 0.0003 to 0.0005 in. of metal is removed while the tolerance is 0.0003 in. The hone was run at approximately 300 r.p.m. and with 140 reciprocations per minute. The production was better than 60 per hour with a single spindle.

Honing Machines.—As nearly all honing machines have been developed for the automotive industry, they are of the vertical type, with few exceptions. Beginning with single-spindle machines that were but little more than drill presses with a reciprocating motion to the spindle, they are now made to hone as many cylinders as there are in the block where production warrants. Eight-spindle machines, both for cylinders in line and for those in V motors, are in common use as in Fig. 195. Their operation is usually automatic both as to the setting of the hones and the number of strokes made before they stop of their own accord. The feed is hydraulic in many machines. Hydraulic honing machines are also made in horizontal types for long holes such as the bores of cannon and of propeller shafts where it is desired to take out even the smallest tool mark that might possibly lead to failure under stress. Connecting rods are honed in lots of four, as in Fig. 196. Each rod floats in an independent holder.

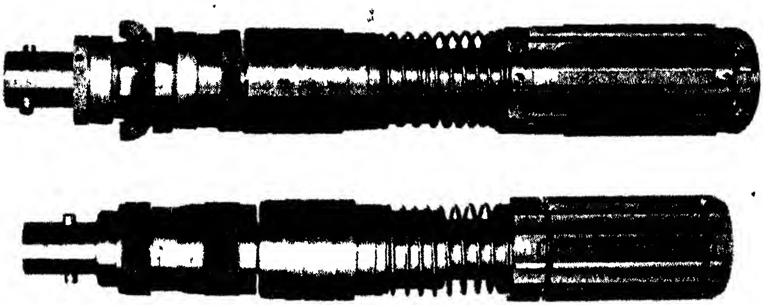


FIG. 197.—Typical micromatic honing heads.

Honing Tools or Heads.—Honing heads consist of a skeleton framework that holds the abrasive sticks or stones which do the work. They are made as light as possible consistent with having sufficient strength and stiffness to support the stones firmly against the walls of the bore. In some of the earlier hones the stones floated and followed the bore if it was out of round. In modern practice, however, the hones are held rigidly in position at the proper diameter after they are set for the work. Two typical heads are shown in Fig. 197. Some are made to be adjusted by hand, while others adjust themselves automatically from the minimum size to that at which the bore is to be finished. With correct stones for the work in hand, and run at the best rate, both as to revolutions and reciprocations, mirror finishes can be secured. Kerosene is generally used as the cutting lubricant.

CHAPTER XVII

POLISHING AND BUFFING

The old strapping machine, consisting of two flanged pulleys carrying a canvas belt loaded with glue and abrasive on the outer side, has long been used for finishing irregular surfaces, especially on brass work. It is often called a strapping or strap-buffing machine.

The straps or grinding belts run at from 2,000 to 2,500 ft. per minute in most cases. The later development of this type of grinding is in the belt grinder. In some of the later types of machines the belt is of emery or other abrasive cloth, carefully cemented into an endless belt and run at about 7,000 ft. per minute.

At the point where the grinding is done, the belt runs over a flat metal plate which supports both the belt and the work and produces remarkably flat surfaces. The belts usually run on top of, or over, a specially prepared leather belt which acts as a cushion.

BAND POLISHING MACHINES

Polishing wheels were formerly of wood with the abrasive carried on a leather strip or band pegged to the wheel. They were covered with glue and rolled in emery or other abrasive.

The later practice is to use a wheel of a steel casting about 12 in. in diameter and 2½-in. face. The face is covered with a strip of cloth carrying the abrasive so that they can be changed from one grade to another or renewed when worn, with very little difficulty.

The grinding bands are graded as follows:

Number of cloth..........	00	0	½	1	1½	2	2½	3	3½
Grade of abrasive.........	Flour	120	90	80	70	60	46	36	24

Polishing machines are made in two styles, one to be used while standing and the other sitting down. Sitting machines have spindles 32 in. from the floor, and standing machines, 42 in. from the floor.

A 12-in. wheel is run about 1,850 r.p.m. making a surface speed of about 5,500 ft. per minute. With an individual motor 3 hp. is allowed for one of these machines.

FACTS ABOUT POLISHING

There are many varieties of polishing wheels in use, the principal kinds being known as wooden wheels, compressed wheels, canvas and muslin, sea horse and felt wheels. To equip a polishing room with the right wheels requires the assistance of a polisher who has had a wide experience in polishing and is familiar with the various methods employed as well as the best abrasives. For good work, and economy in abrasive, glue and labor cost, wheels, and methods must be selected to suit the work.

Wooden Wheels.—A few years ago, the wooden wheel, covered with leather and turned to fit the piece to be polished, was universally used. At the present time, the wooden, leather-covered wheel is used largely on flat surfaces and on work where it is necessary to maintain good edges. When this kind of a wheel is made with a double coating of leather, it makes a first-class finishing wheel.

Compressed Wheels.—Compressed wheels, or wheels having a steel center, are made with surfaces of leather, canvas, or linen. Many tool shops are equipped with these wheels exclusively. They answer all purposes and are safer and more economical than wooden wheels.

They are also used largely on cutlery and for polishing chilled plows. The compressed wheel is of strong construction, is very durable, and easily kept in balance.

Canvas and Muslin Wheels.—Canvas and muslin wheels are used extensively for polishing stoves, shovels, plows, brass, cast iron, and steel. For roughing out and dry fining on irregular pieces, they have proved very satisfactory. They hold the abrasive well and require no washing off, as they can be cleaned with a buff stick or an abrasive brick.

Many concerns, such as plow-, shovel- and hoemakers, buy the canvas and muslin and make their own wheels.

Sea-horse Wheels.—Sea-horse wheels are very expensive, most concerns buying the hides and making their own wheels.

Where a high-grade polish is required, there is probably no wheel which can compare with the wheel made of sea horse. They are largely used on guns, pistols, and cutlery.

Felt Wheels.—Felt wheels are largely used by stovemakers for finishing surfaces. Bull-neck wheels are also used for this purpose.

The felt wheels are made from white Spanish and Mexican felt and are extensively used for finishing on certain classes of work.

Care of Polishing Wheels.—Polishing wheels should be kept in perfect balance and running true at all times. A wheel out of balance wastes time, glue, and abrasive, and will not do such good work.

The most efficient glue and the best abrasive are the cheapest in the long run.

The glue pots should be kept clean and the glue properly cooked before using.

It is also important to heat the abrasive before applying.

The wheels should be kept properly cleaned and thoroughly covered with the abrasive.

The wheels should be selected for the particular work the same as in grinding and only the wheel best adapted should be used at all times.

Polishing Operations.—Polishing operations are usually divided into three classes: roughing, dry fining, and finishing or oiling.

The abrasives used for roughing usually run from Nos. 20 to 80. For dry fining, from Nos. 90 to 120. The numbers used for finishing run from 150 to XF.

For both roughing out and dry fining, the polishing wheels should be used dry. For finishing, the wheels are first worn down a little and then oil, beeswax, tallow, and similar substances are used on the wheel. This, together with the abrasive, brings up a fine finish.

Table 24.—Speed of Buffing Wheels

Material	Feet per Minute
Wood, leather covered	7,000
Walrus	8,000
Rag wheels	7,000
Hair-brush wheels	12,000
Ohio grindstone	2,500
Huron grindstone	3,500

GRINDING, POLISHING AND BUFFING OF MONEL METAL AND PURE NICKEL

Any effect from a sandblast finish to a highly lustrous mirror finish may be obtained on monel metal and pure nickel. The layout of the necessary operations depends upon three considerations: the character of the work to be polished; the desired finish; and the polishing equipment. A base from which all surface defects have been removed must first be produced. The number of operations required depends on the coarseness of the first wheel applied. The pressure must be closely watched, as excessive heat will destroy the true color of the buffed metal and will be likely to warp flat, light-gage articles. Care is especially important in grinding down welds, which might crack. Light welds can be ground with a No. 36 grit, rubber-bond wheel; heavy welds, No. 24 grit. Straight wheels, 6 in. in diameter by 1 in. face, and driven by a portable grinder, are used for the general run of weld grinding. Rubber-bond wheels are operated at approximately 8,000 to 9,000 surface feet per minute.

Polishing.—Wheels for roughing and dry fining should be spirally machine-sewed wheels of tightly woven unbleached cotton fabric. The wheels are made up of sections approximately 1/4 in. thick. A soft or cushioned face is obtained by gluing the sections only to within 1/4 to 3 in. of the periphery. Fine-grit wheels require more cushion than coarse wheels. For the "greasing" operation, a more resilient and flexible wheel is necessary. A suitable wheel is made of 64–68 count unbleached sheeting, with more cushion than required for coarser polishing. Grease coloring may be done on a full disk quilted sheepskin wheel, or a spirally sewed wheel made from fine count (88–88) heavy sheeting. Bobbing done with an emery grout is more on the order of a burnishing operation than a polishing operation, and if done in one operation, the best wheel is a walrus leather type. If two bobbing operations are used, the second should be done with a medium-density felt wheel. The best efficiency is obtained from emery-rolled head wheels at 6,500 to 7,500 ft. per min.

Buffing.—This operation is frequently divided into two operations—"cutting down" and "coloring." The former is done with tripoli. Some polishers prefer a wheel of the same sewing and fabric as recommended for grease coloring, but with loose sections, whereas others like a full disk wheel fabricated from high-count sheeting, the only sewing being around the arbor hole and one or two rows of sewing midway between the arbor hole and the periphery. The coloring operation used for developing a mirror finish is best obtained with a loose-disk canton-flannel wheel at a surface speed of 10,000 ft. per minute. Cutting down with spiral sewed buffs should be done at a surface speed of 8,000 to 9,000 ft. per minute. Less pressure is used than for polishing.

Brushing.—As a final operation brushing produces a smooth even finish, blending in the wheel marks of the previous polishing wheel. When used with emery cake, the tampico brush wheel leaves the surface ideal for buffing, and is supplanting the old bobbing operation when developing a mirror finish. If the grease wheel is well broken in, however, the tampico operation can be avoided. A tampico wheel used with emery paste is also employed as a final operation to produce a satin or scratch brush finish; with pumice and water, or pumice and oil, for a butler finish. Wire brushes do not remove deep scratches or blemishes. Instead, they perform more of a peening operation similar to a very fine sandblast, but resulting in a brighter finish than sand-blasting. Wire brushes are used only in sheet-metal finishing as a final operation for producing a satin finish. Monel-metal wire should be used in wire brushes for finishing monel metal or pure nickel, since small particles of metal from the wire wheels are certain to be embedded in the metal being finished. All brush work is done at slower speeds than polishing operations. The range of brushing speeds is from 3,000 to 6,000 ft. per minute. Bright wire-brush finish requires a fine wire brush (0.004 to 0.008-in. diameter wire) operated at about 4,000 to 6,000 surface feet per minute. If a matte finish is desired, heavier wire and slower speeds are used.

Mill Finishes.—Monel metal and pure nickel may be obtained in cold-rolled or full-finished sheets. Cold-rolled sheets are furnished with either regular cold-rolled finish, or No. 5 mirror finish which reflects a sharp image. Full-finished sheets are furnished in the "as-rolled" condition, which has been annealed, pickled, and given four to six cold passes. It is also furnished in the No. 8 finish of lustrous satin characteristics.

Polishing Cold-rolled Sheets.—Where cold-rolled sheets are used for cabinet work, the surface can usually be polished in a short series of operations. In many cases it is only necessary to buff with tripoli, and then bring out the bright lustrous color with an aluminum oxide (white) or chrome oxide (green) buffing compound. Where it is desired to develop the best possible finish, it is advisable to start the operation by "grease coloring" with fine emery cake (7—see chart), and follow with "cutting down" with tripoli (10). In some cases tripoli can be charged on the same wheel with emery paste. The last is a coloring operation (11 or 12). Pieces that show handling scratches or tool marks should first be cut down locally with emery paper or emery wheels and then polished step by step until prepared for the grease coloring or cutting down operation that covers the entire area of the piece.

Polishing Full-finished Sheets.—The device, well known to polishers, of "crossing" the direction of grinding as each finer grit is started enables the operator to judge when the earlier marks have been cut away. If these marks are not removed early in the grinding operation, they will show up later when buffing is started and require retracing the series of operations. The sequence of operations follows:

180 emery, dry	(5)
180 grease wheel	(5)
200 or 220 grease wheel	(6)
Buff with tripoli	(10)
Color	(11) or (12)
Clean with whiting	(16)

Sometimes it is helpful to use a tampico brush with fine emery cake (8), followed by the final polishing operation.

Finishing Deep-drawn Articles.—The operations are for shells that carry a certain amount of die scratching:

120 emery, dry	(3)
150 grease wheel	(4)
180 grease wheel	(5)
Buff with tripoli	(10)
Color with white finish	(11)
Clean with whiting	(16)

Another method which gives better results at slightly longer time is the following:

Polish on 150 dry wheel	(4)
Polish on 180 grease wheel	(5)
Polish on 200 sheepskin wheel	(6)
Brush on tampico wheel	(8)
Buff with tripoli	(10)
Color with white finish	(11)
Clean with whiting	(16)

Finishing Welded Equipment Made from Full-finished Sheets. The following operations are suggested for finishing light-gage welded equipment, such as used in hotels, hospitals, and canneries, where finish is important:

Grind weld	(1)
80 emery, dry	(2)
	(over welded area)
120 emery, dry	(3)
180 emery, dry	(5)
180 emery, grease	(5)
Brush with tampico and emery cake	(8)
Buff	(11)
	(if bright finish is specified)
Clean with whiting	(16)

If only a commercial finish is required, the procedure may be stopped after the third operation. To develop a fine scratch finish, however, follow the cycle as shown above, omitting the buffing operation. For No. 8 satin-finished sheets, after the No. 180 emery grease, buff lightly, and blend in by hand, using No. 200 worn emery cloth dipped in oil. Rub in the same direction as scratches in the parent metal. Finally, clean with whiting.

Polishing Castings.—After the casting is brought to a reasonably smooth contour, it is polished by using the following operations:

80 emery, dry	(2)
120 emery, dry	(3)
150 emery, dry	(4)
150 emery, grease	(4)
Tripoli buff	(10)
White finish buff	(11)

After the fine emery in grease, the use of a tampico brush wheel with a fine grade of emery cake often permits saving of time on the tripoli buff. Sandblasting or wire brushing is frequently used to brighten recessed areas.

TABLE 25.—GRINDING, POLISHING, BUFFING OF MONEL METAL AND PURE NICKEL[1]

General terms	Name of operation	No. of operation	Grit, No.	Artificial abrasive	Turkish emery	Wheels	Dry	Tallow or emery grease cake	Compound	Speed, surface, feet per minute	Finish
Grinding		1	24 36	X		Rubber-bound grinding wheel	X			8,000 to 9,000	
Polishing	Roughing	2	60 80	X		Cotton fabric sewed sections. Sections glued together to give desired width soft-cushion face	X			6,000 to 7,500	Rough grind
	Dry fining	3	100 120	X			X			6,000 to 7,500	Commercial grind
	Greasing	4	150		X	64–68 unbleached sheeting spiral sewing sections glued together to give desired width—softer cushion face than needed for "roughing" or "dry pinning"		X	Polishing tallow or No. 180 emergy grease cake	6,000 to 7,500	Fine grind
	Greasing	5	180		X			X	Polishing tallow or No. 180 emery grease cake	6,000 to 7,500	Fine grind
	Grease coloring	6	200 220		X	88–88 unbleached sheeting—same construction as for operations No. 4 & No. 5-or-quilted sheepskin wheel		X	Polishing tallow or *F* emery grease cake	6,000 to 7,500	Fine scratch finish
	Grease coloring	7				88–88 unbleached sheeting—loose spiral sewed sections or loose disk wheel			*F* emergy grease cake	6,000 to 7,500	Fine scratch finish
Brushing		8				Tampico wheels			*F* emery grease cake or "grout"	3,000 to 6,000	Scratch brush or satin
Bobbing or sanding		9				Walrus leather wheel. When two operations required, second usually with medium-density felt wheel			"Grout"	5,000	
Buffing	Cutting down	10				Same as operation No. 7			Tripoli	8,000 to 9,000	Bright
	Coloring	11				Same as operation No. 7			Aluminum oxide buffing compound (white)	10,000	Bright
	Coloring	12				Loose-disk buff or 88–88 unbleached sheeting or canton flannel			Chromium oxide buffing compound (green)	10,000	Mirror
Special finishes	Lea method	13				Same as operation No. 7			Lea compound *N*	5,500	Scratch brush or satin
	Wire brush	14				Monel-metal wire brushes			Soap dark solution or water	4,000 to 6,000	Wire brush or satin
	Bobbing	15				Walrus leather wheel			Pumice with oil	5,000	Butler or satin
Cleaning		16				Canton flannel cloth (hand operation)			Venetian lime (whiting)		

[1] Courtesy of the International Nickel Company, Inc.

CHAPTER XVIII

THE MAGNETIC CHUCK

Magnetic chucks have come to be a very necessary part of the equipment of any surface-grinding machine, whether plain or rotary. Credit for these belongs to O. S. Walker of Worcester, whose first patent was granted on July 21, 1896. These are now being made by others.

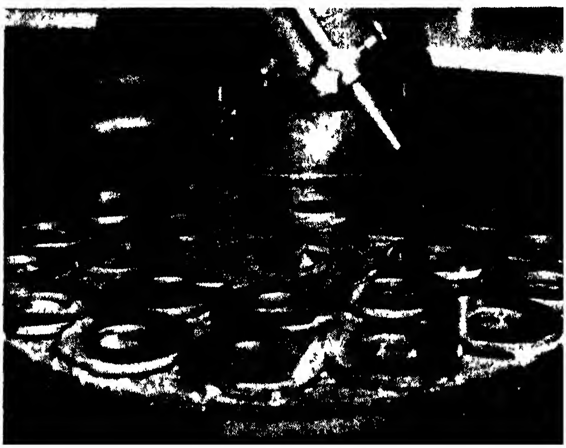


Fig. 198.—Typical magnetic chucks.

Before their coming it was customary to bed thin work in wax on the platen of a grinder in order to finish the flat sides. Other flat work had to be held in "fingers" on special fixtures, and on account of their being very thin and easily sprung, it was difficult to secure really accurate work.

The magnetic chuck holds the thinnest pieces of iron or steel firmly, draws down any slight spring in the work, and prevents springing when strains are released during the grinding operations.

The chuck face is divided into magnet poles, separated by babbitt or other nonmagnetic metals, and coils of insulated wire from these into electromagnets when current is applied. For rotary work, the electric current is supplied by brushes running against insulated contact rings on the outside. Any incandescent lamp socket on a direct-current circuit can supply current.

ALTERNATING CURRENT CANNOT BE USED

A No. 0 chuck having a face 10 by 14 in. uses about one-half as much power as a 16-candle-power lamp. A No. 1¼ with a face 12 by 6 in. takes the same current as a 16-candle-power lamp.

Chucks are made with plain and duplex bases and arranged for straight and taper work. Figure 198 shows two typical chucks.

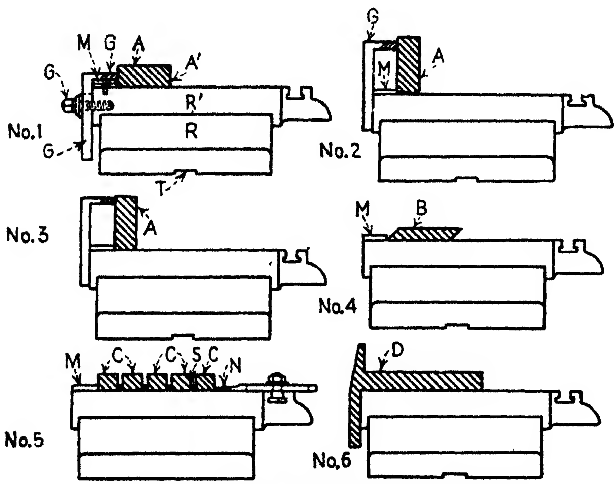


FIG. 199.—Back rests for magnetic chucks.

Figures 199 and 200 show a few adaptations of the magnetic chuck for holding work. The aligning strip *M* in No. 1 is on the back of the chuck for squaring the work against. The edge of *G* just matches this so that the two form a squaring device as shown. Number 1 shows plain work that is easily held. In No. 2 the lower edge is not square and the long side *A* must be out so that the magnetic pull on the angle side holds the piece against the squaring edges.

In No. 5, where a number of pieces are held at one setting, it is sometimes desirable to lay strips of nonmagnetic materials, such as brass, or pasteboard in between them. In this way the magnetism of the chuck seems to get an independent grip on each piece. Sometimes, on heavy work, an adjustable finger, as at *N*, is set against the last piece or row of pieces.

Demagnetizing the Chuck and Work.—Iron and steel in contact with magnets retain some of the magnetism which is sometimes more or less of a nuisance in getting small work off the chucks. To overcome this the chucks are often furnished with a duplex or demagnetizing switch which simply reverses the direction of the current and when this is done a few times, the magnetism will disappear and the work will be easily released.

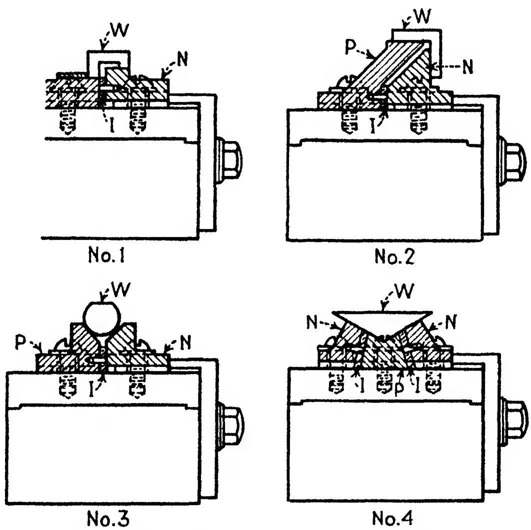


FIG. 200.—Magnetic jigs for special work.

This does not demagnetize the work but demagnetizers are made for the purpose. These are only necessary where the remaining magnetism is objectionable in the work itself. These are sometimes arranged to be worked automatically from the countershaft.

Magnetic chucks are made for use with water but in most cases require a current of air to be blown through the chuck to prevent the entrance of water and the formation of moisture in the interior of the chuck, from the constant heating and cooling of the coil chamber. Some of the later chucks do not require this.

In Fig. 200 is seen an idea of how magnetic jigs can be arranged on the chucks. The work *W* is all outline in this case. The holding pieces are *N* and *P*, negative and positive, separated by nonmagnetic materials *I*, and are air gaps in the case of No. 2 to hold an angular piece by each leg.

A round bar can be held in *V*'s as in No. 3. In No. 4 the central piece is positive and there are two outer, negative poles.

Rotary Magnetic Chucks.—The magnetic chuck is so largely used that the Blanchard Co. now build their own. The suggestion in Table 26 will, however, be useful in chucks of any make.

TABLE 26.—CURRENT AND VOLTAGE FOR BLANCHARD MAGNETIC CHUCKS

Chuck size, in.	Volts	Amperes	Watts
26	110	3 5	385
26	220	1 75	385
30	110	5 2	572
30	220	2 6	572
36	110	7 0	770
36	220	3.5	770

The voltage may be 10 per cent lower or higher without affecting satisfactory and safe operation of Blanchard chucks. In case it is necessary to operate a chuck from a circuit of more than 10 per cent higher voltage, use a resistance in series with chuck that will limit the amperes to the value given in Table 26.

Holding Power of Chucks.—Magnetic chucks hold work down, but do not hold it sideways, except by friction of the work against the chuck face. Therefore, always block every piece sideways and do not condemn the holding power of the chuck when light pieces slide off for lack of stops. Do not expect too much of the chuck, for its ability to hold work depends on the material, cross section, area of contact and surface condition of the work; and if some or all of these factors are unfavorable, special care may be needed.

Testing Chuck Magnetism.—For comparing holding power of different chucks or different places on the same chuck, use a small piece of soft steel, say about ⅝ by ⅛ by 1 in. long, on edge. A small Woodruff key makes a convenient-sized piece. The edge of the piece should be flat and free from burrs. Judge the holding power by pulling the piece vertically off the chuck face, with piece central over a brass ring.

A longer bar, screw driver, or any similar piece is not reliable as a test piece and will give very misleading results in some cases.

The holding power, as shown by small test piece, is not exactly uniform across all the brass rings in the chuck face. It becomes more uniform as more pieces are put on and with the chuck loaded properly for grinding will be sufficiently uniform to hold all the work securely.

As already stated direct current must be used. Where only alternating current is available, it is recommended by the grinder builders that a motor generator be installed.

For one machine use a 1-kw. motor generator, as it costs but little more than a smaller one and has capacity to supply an additional machine.

Failure of Chuck Magnetism.—This may be due to several causes, chief among which are

1. Fuses blown in circuit outside of machine.
2. Low voltage.
3. Loose connections.
4. Broken or short-circuited cable in machine.
5. Worn out or dirty brushes or weak brush springs in table.
6. Short circuit (or ground, if external circuit is grounded) caused by dirt or moisture.

Locating Fault in Chuck Circuit.—Usually in such cases there will be either a short circuit, causing fuses to blow as soon as switch is closed, or an open circuit, so that no current flows when switch is closed and no spark occurs as switch is opened.

The use of this double-throw chuck switch will not completely demagnetize the work, but by it moving from one position to the other after the grinding operation the removal of the pieces will be facilitated.

Electrical troubles in the machine are most likely to occur in the cable or brush holder, rarely occur at chuck terminals, and practically never occur inside the chuck itself.

Before starting to hunt for trouble in machine, test outside circuit up to switch on machine, as the fault may be entirely in the outside circuit. If certain that fault lies in machine, proceed to locate by testing each part of the circuit separately.

Hoist out chuck and inspect brushes and contact rings. New brushes are 5/8 in. diameter by 1 1/2 in. long. The springs should push them up with light but appreciable pressure against contact rings when chuck is in place. The contact rings should be smooth and free from pits or burned spots. If pitted or burned it indicates poor contact caused by either brushes too short, springs too weak, brushes sticking in holder, or in rare instances oily dirt on rings.

If rings and brushes look all right, test with lamp of same voltage as chuck circuit connected across brushes to see if current reaches that point. If lamp fails to light properly, inspect cable from switch to brush holder and inspect brush holder.

If certain there is no fault in circuit up to brushes, then it may be at contact rings or chuck terminals which are reached as directed below.

Look for loose connections or poor contact if trouble is open circuit. Look for dirt and water connecting opposite contacts if trouble is short circuit. The bakelite-molded insulation used for chuck-terminal block, contact-ring holder and brush holder is water and oilproof, but if dirt or water on its surface causes a flashover, the bakelite may be charred so that its insulating quality is destroyed at the place affected, and the piece should then be replaced with a new one.

The compound used to seal spaces around brush holder and around plungers on back of contact rings in No. 16 grinder is an oilproof material. Ordinary insulating compounds are not suitable, as oil softens and thins them.

Stops of some sort must be used to prevent work from sliding. The magnetism holds pieces down but does not hold them sideways, except by the friction between the piece and the chuck free. Except for fairly large and heavy pieces the friction is not sufficient for safe holding, and even with large pieces it is better to use stops as a safeguard in case the magnetism fails through interruption of the current.

The standard way of chucking small flat pieces is to place them close together between inner and outer rings laid on the chuck. These rings are usually of sheet steel of any convenient thickness less than the thickness of the work.

Two rings are furnished with each machine, one fitting on the outside diameter of the chuck and projecting ¼ in. above its face, and the other a flat steel ring to be laid in the center. The diameter of this inner ring is 11 in. for the 26-in., 30-in. and 36-in. chucks, and in each case it represents what experience has shown to be the best size of open space to leave in the center of the chuck.

If this open space were filled in with work, it would increase the area of contact between the wheel and work much more than it would increase the number of pieces chucked; and the result would not be a gain but probably a loss in production.

The outer ring used to retain the pieces should be of such diameter that the pieces next the ring will not project too far outside of the outer brass ring of the 26-in. chuck for good holding. For example, pieces 4 in. diameter, 1/2 in. thick, can be placed out against the outer ring furnished with the chuck. The outermost portion of the pieces next to the ring would receive no magnetism, but the pieces are stiff enough so that the outer portion could not lift or spring from the chuck. On the other hand, pieces of the same diameter but only 3/32 in thick could not be placed so far out, as the outer portions might lift or spring up in grinding, even though held down securely at other points. Pieces of small diameter also require a smaller outer retaining ring in order that the outer row of pieces shall not project too far beyond the outer brass ring of the chuck.

In arranging pieces on chuck, best results will be obtained if the ground surfaces form a complete circle so that the cut is continuous. The inner retaining ring should always be used except for very narrow surface work or work having only a small boss to grind, in which cases it is allowable entirely to fill the chucks.

The 36-in. chuck is intended only for narrow surface work. If used on work of medium or broad surface, best results will be obtained by reducing the width of the group of work to the same that would be held on the 26- or 30-in. chucks. This can be done by using a smaller outer ring, 25 1/4 in. or 30 in. diameter, with the regular 11-in. center ring.

Beveled-edge Pieces.—Pieces having beveled edges must be blocked in such a way that they cannot ride up on each other or on the retaining rings. In some cases square bars of cold-rolled steel laid radially between the pieces may be necessary. Pieces with a single bevel, and to be ground both sides, should be ground on the beveled side first, thus ensuring a good surface for holding when grinding the other side.

Very Small Pieces.—Pieces too small for every one to span one or more rings when placed close together may be securely held by using a perforated brass plate. The holes in the plate should be located directly over the brass rings in the chuck and should be only enough larger than the pieces to allow easy placing of the pieces in the holes. The holes should be smallest near the upper side of the plate, thus giving a bearing as high up as possible on the pieces and reducing their tendency to tip when pushed sideways by the wheel. The thickness of the plate should be about $\frac{1}{64}$ in. less than the thickness of the pieces of work. The plate should be of brass or other nonmagnetic material in order not to absorb any of the magnetism. It should be centered by a central plug or by stops screwed to the chuck but should be left loose so it can be lifted off and cleaned with the work.

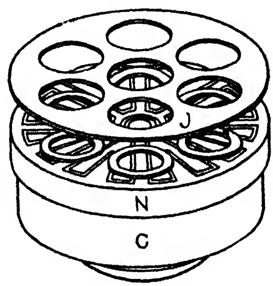


FIG. 201.—Holding small thin work.

Bosses and Projections on Pieces.—Pieces having bosses or projections on the side next the chuck can often be held magnetically by the simple expedient of placing soft-steel blocks under the thinner part to make the piece rest level, the bosses being in contact with the chuck. The success of this method depends on the area of the part in contact with the chuck, the height and area of the blocks required and the location on the chuck. In general the larger the areas of contact and the less the height from the chuck the stronger will be the holding.

Another form of magnetic chuck with means for placing the work is shown in Fig. 201.

Hints for Using Magnetic Chucks.—The chucks should not be taken apart.

Nothing but iron or steel can be held on the chucks.

The holding power depends on the amount of work surface in contact with the chuck.

Work can be held on edge by using adjustable back rest.

Very thin work can be held for grinding on the edges by laying it against the back rest and backing it up with a parallel strip.

Thin work will not hold so well as thick work.

In packing a number of small pieces on a chuck at one setting, it is better to separate them a little with strips of nonmagnetic material.

Do not plug up the vent holes in the chuck.

Keep water away from the switch, the brushes and the interior of the chuck.

Magnetic chucks do not take the place of all other chucks.

Do not use water on chucks except where they are made for it.

Chucks are usually wound for 110 or 220 volts *for direct current only.*

Permanent Magnet Chucks:

A comparatively recent development is the magnetic chuck with permanent magnets that require no electrical connections. This permits them to be used in shops where no direct current is available. Special alloy magnets make them strong enough for grinding operations. A movable chuck face by-passes the magnetic flux when the handle is turned to the "off" position.

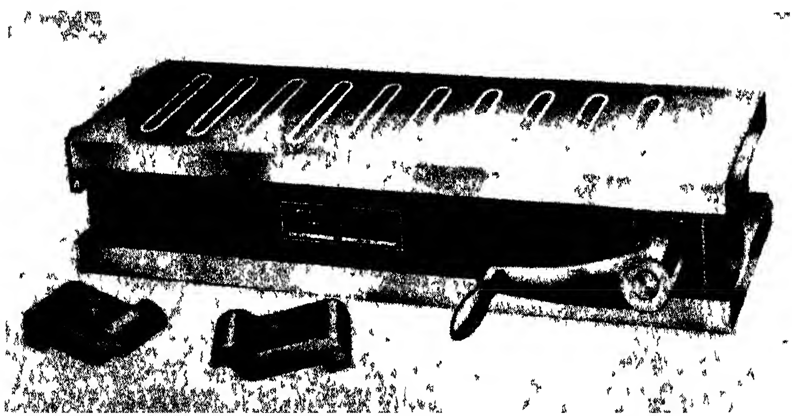


Fig. 201a —Brown & Sharpe magnetic check (permanent magnetic type)

The amount of holding power can be varied by the position of the handle. With the face of the chuck partially energized the work can be easily tapped into exact position, before full magnetism is turned on. These chucks are made by the Brown & Sharpe Mfg. Co.

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D

WARTIME DATA SUPPLEMENT

GRINDING ENGINE CYLINDERS

Cylinder barrels for air-cooled radial engines are ground inside and outside. This is both to secure uniform weight and to remove tool marks, which might make a starting point for cracks when subjected to vibration

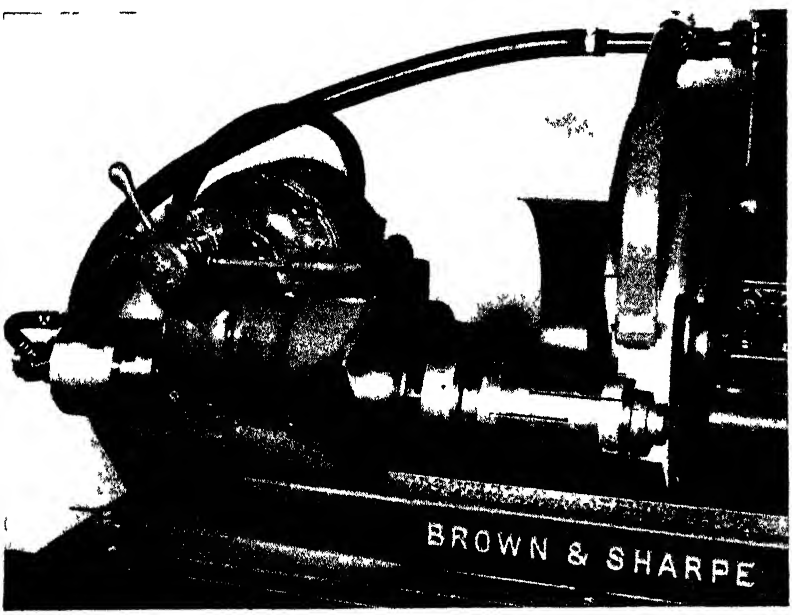


FIG 1A —Expansion mandrel for airplane-engine cylinders

Grinding is a comparatively simple operation The main thing is to have a mandrel that runs true and that will hold the cylinder firmly without distorting it in any way. Such a mandrel is seen in Fig. 1A, mounted on a Brown & Sharpe grinder. As will be seen, this is of the usual split-mandrel type. When the cylinder is put in place, the mandrel is expanded by drawing cones in at each end until the cylinder is held firmly enough for the work to be done.

A cylinder is shown in place on a similar mandrel in Fig. 2*A*, which shows a Cincinnati grinder. The cylinder shown is approximately 6 by 10 in., and about 0.015 in. of stock is removed by grinding. A soluble oil is used as a coolant, and about 18

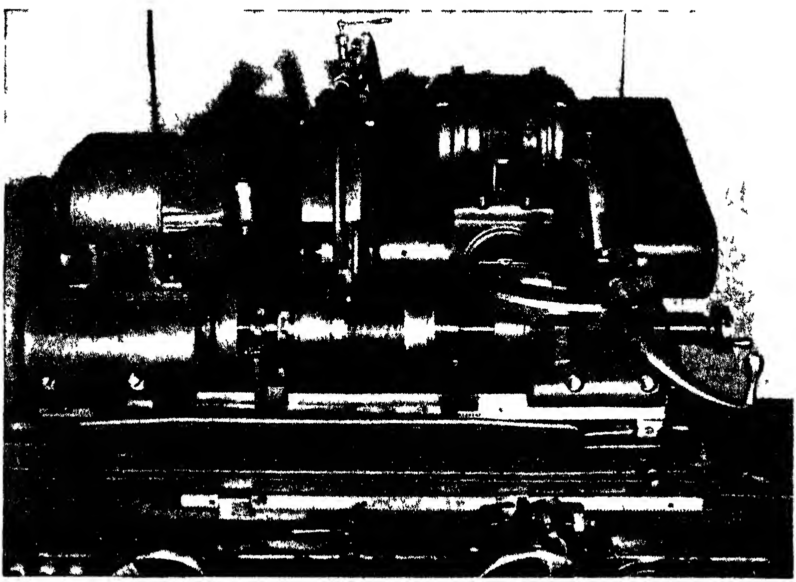


FIG. 2*A*.—The cylinder in place in the machine

pieces per hour can be expected from such a setup. The wheel is a 30 by $1\frac{3}{16}$ by 20 in. of No. E-50-S-100 Alaxite.

CONNECTING-ROD WORK

Connecting rods for radial airplane or tank engines require accurate grinding of crankpin, piston-pin, and link-, or articulated-rod-, pin holes. This means not only accurate machines but also accurate and well-balanced fixtures. Figures 3*A*, 5*A*, and 6*A* show the grinding of all these holes and also give a good idea of the fixtures used in the Bryant machine for this kind of work.

In Fig. 3*A* the rod is positioned by the piston-pin hole and centered by the thumbscrews *A* and *B*. The large end of the rod is clamped to the fixture by straps *C* and *D* while the grinding wheel and the dial gage for checking diameter of bore are clearly seen. Details of a similar fixture are seen in Fig. 4*A*.

The rod is reversed for grinding the small hole by using a fixture somewhat similar to that shown in Fig. 5*A*. Here the small end is centered by screws *A* and *B*, but the clamping is

FIG. 3*A*.—Grinding the large hole in a connecting rod.

done by the plate *C* at the large end. The gaging is done in the same way, and the plug gage is shown on the machine.

For grinding the link-rod-pin holes, the rod must be moved out of center but must also be moved around the large bore to bring all the link-pin holes in line with the grinding wheel, as in Fig. 6*A*. Details of this fixture are shown in Fig. 7*A*. The rod is positioned by the small end that is fitted over the rounded plug shown. The work is located for grinding by centering plug *A* in its bushing *B*. There are eight bushings in this fixture as this is a nine-cylinder engine with one main connecting rod and eight link rods. Each bushing locates a hole to be ground in both cheeks of the main, or master, rod, which some call the

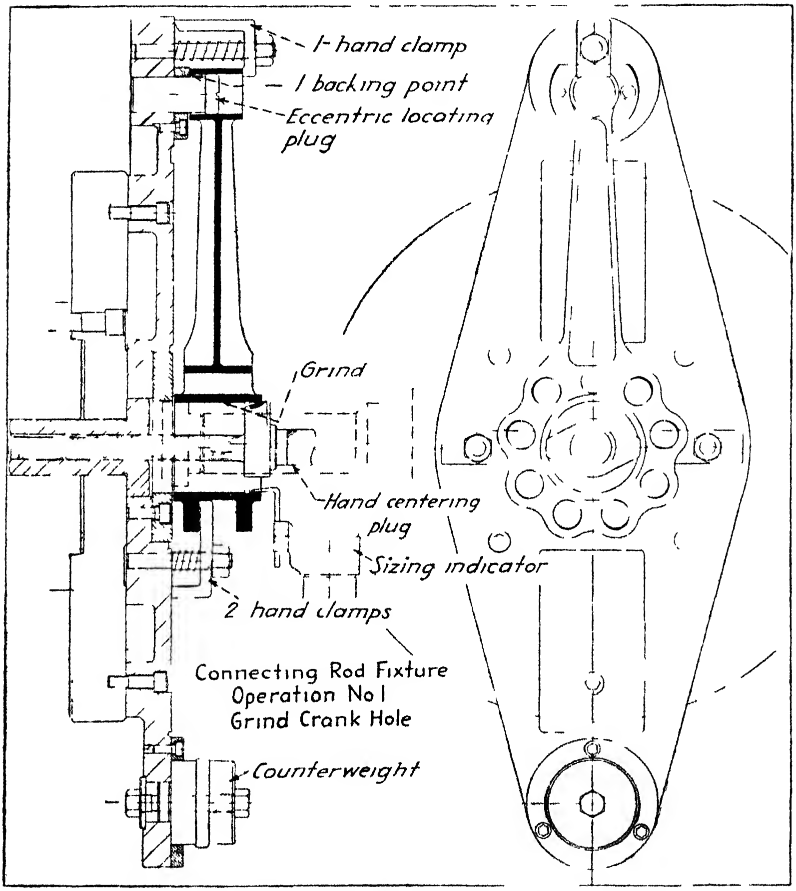


FIG 4A —Details of the fixture for the connecting rod.

"mother" rod. To shift from hole to hole, the plug *A* is withdrawn, the three clamping bolts *C* are loosened, and the part of the fixture that holds the rod is moved to the next hole. Then the bolts are again tightened.

In all these fixtures one of the main problems is to balance them to prevent vibration when the work spindle is revolved at its proper rate. This is done by locating counterweights at the correct points, as can be seen particularly in Fig. 4*A*.

The operation shown in Fig. 8*A* is of interest because it shows how two pieces are ground at one setting by ingeniously arranging them in a chuck to overlap the ends and bring the holes in

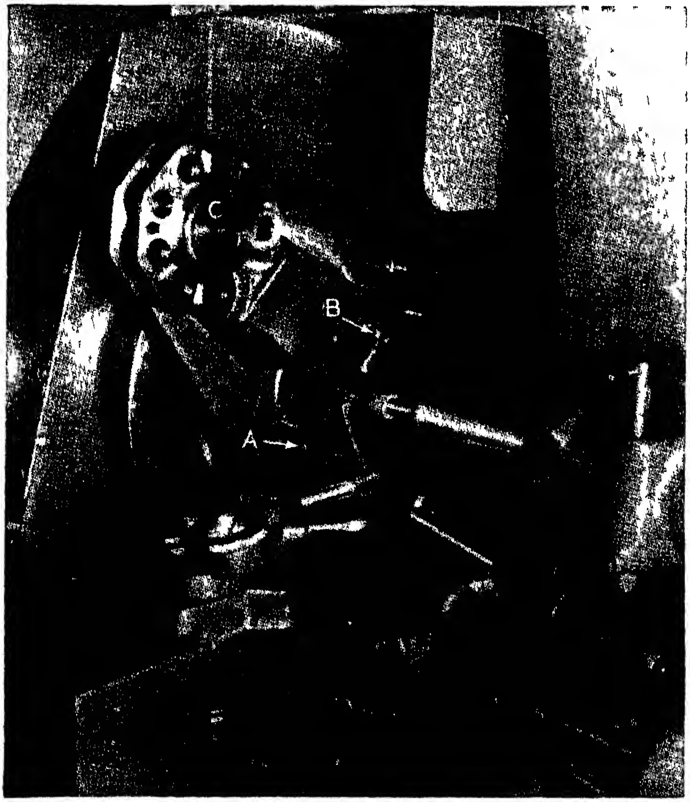


Fig. 5*A*.—Grinding the small hole.

line. With suitably arranged jaws it is an easy matter to locate the two valve tappets in their proper position for grinding.

PROPELLER HUBS

Grinding propeller hubs to receive the ends of the adjustable blades has developed a number of ingenious fixtures. One of these, designed for the Bryant grinder, is shown in Fig. 9*A*. The basic design permits its use for either two- or three-bladed propeller hubs. As shown, it is arranged for three-way hubs with another clamp, at *A*, to hold the second blade opening, *B*. When firmly held at these two points, the third opening is ground as can be seen The hub is easily shifted from one position to another.

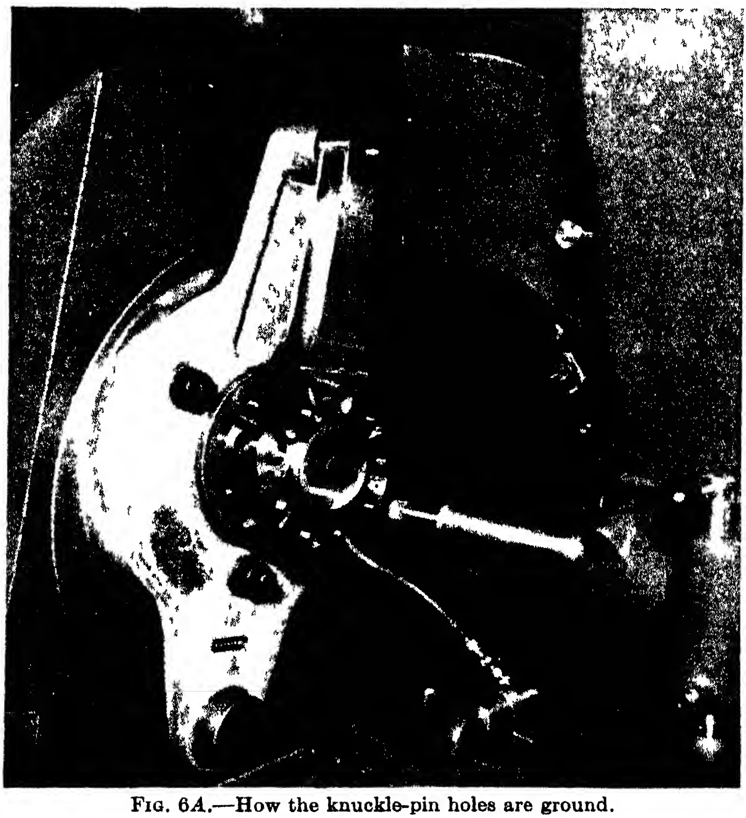


Fig. 6*A*.—How the knuckle-pin holes are ground.

When two-bladed propellers are to be ground, only one centering plug is used, as at *C*. In both cases the hubs are centered and supported by a pin at *D*, which is located in an angle plate that forms part of the chuck.

Details of the centering device are clearly shown. A cone-pointed plunger forces the centering pins against the bore with equal pressure.

GRINDING SUGGESTIONS FOR WAR WORKERS

To assist those who are being or have recently been trained to work on cylindrical grinding, we are presenting a number of suggestions prepared by the Landis Tool Co. for users of their machines. These are divided into several sections, each covering one phase of grinding that affects both the quality and the quantity of work done.

Work Centers.—Both the machine centers and the centers in the work must be clean and of the same angle. The machine center must also be of the same taper as the machine spindle or the work will be moved by the pressure of the grinding wheel. Such movement will prevent work from being round and true.

It is always better to have the centers of the same depth at both ends of the work. And where shoulders are to be ground by straight infeeding, this is absolutely necessary. Centers at each end of the work must be in line if the work is to be accurately ground.

There should also be ample lubricant between the machine center and the work at all times. On light work a good oil is satisfactory, but for heavy work white lead is much better.

Driving the Work.—There are several ways of driving the work in the grinding machine. No matter which is used the driver must be securely fastened to the work. Should the driving dog, or clamp, slip, the wheel may spin the work on the centers and even throw it out of the machine. This will not only damage the work but might kill or seriously injure the operator and others.

The driving dog, or clamp, should be fastened to the largest part of the work if possible. Where the work is driven by an arm bolted to the faceplate of the grinding machine, the arm should *pull* the work instead of pushing it.

The driving pin should not be a tight fit in the clamp on the work. Unless there is a little play between the driving pin and the dog, the work is likely to be crowded off the centers and prevented from being ground true with the centers.

Work Rests.—Proper support of the work by rests is important if a uniform diameter is desired. Practically no one ever used too many rests. On average work of less than 3 in. in diameter the rests should not be more than 12 in. apart; the distance should be less than this on small work. On work over 3 in. in diameter, rests every 24 in. will usually be close enough.

If more than two rests are necessary, put one in the center and use an equal number on each side. Work rests spaced in this

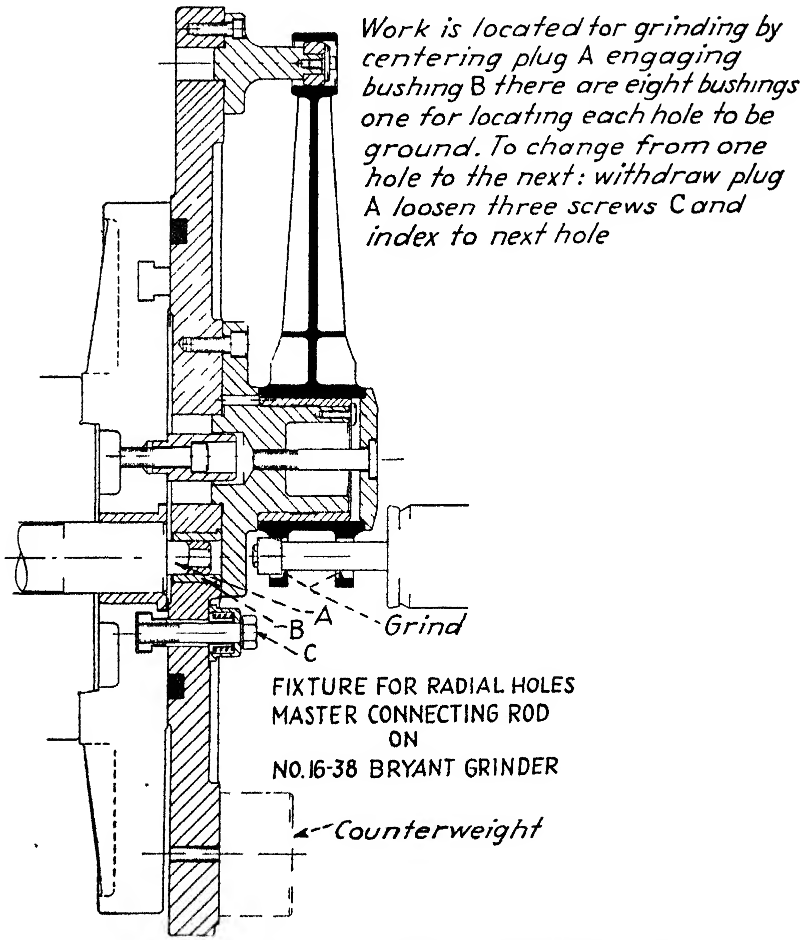


FIG. 7A1.—Section view of fixture for knuckle-pin holes.

way will give uniform support to the work, and greater accuracy will be secured.

After the work rests are located, the work should be "spotted," or ground carefully and without springing, to provide a true surface for the work rests. Then the shoes of the work rest should be carefully adjusted and the work ground from end to end. The lower jaw of the work rest should always bear firmly against the work.

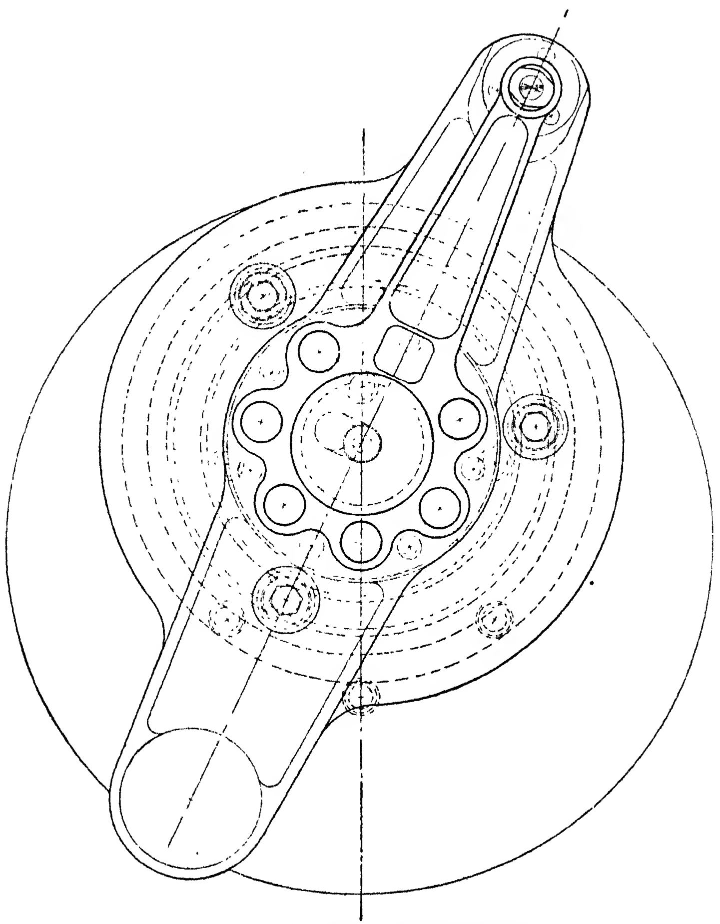


FIG. 7A2.—Face view of the same fixture.

Hardwood makes the most satisfactory material for work-rest shoes in nearly all cases.

Even comparatively short work should have work rests when unusually heavy cuts must be taken.

Mounting and Balancing Grinding Wheels.—Unless grinding wheels are mounted securely and are properly balanced, they are dangerous and do unsatisfactory work. The wheel should fit freely on its center but without too much looseness. If it is forced on, it may develop a crack. Clamping it too tightly may also crack it. Always use washers of some compressible material between the wheel and the flanges to act as a cushion. The washers also tend to prevent slippage of the wheel between the flanges.

Wheels are hard to balance as they may not be of uniform density in all places. Weights are provided so that balance can be secured with care and patience. Wheels may get out of

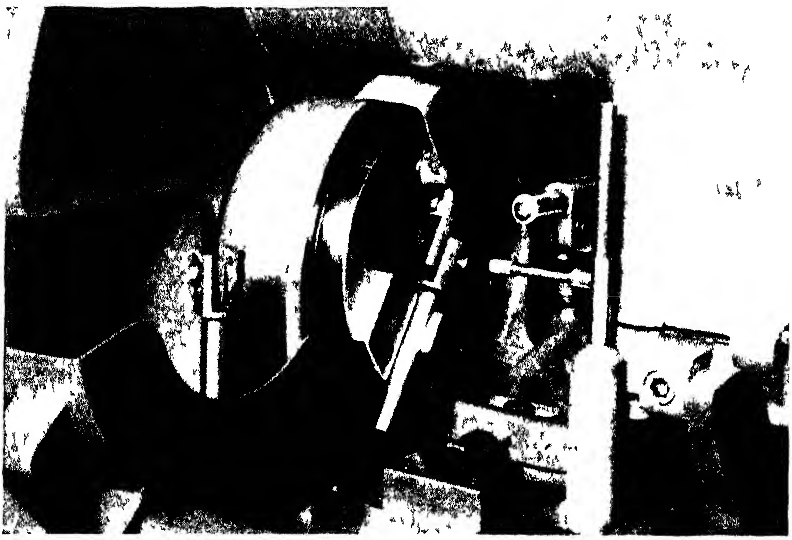


FIG. 8A - Method of grinding two pieces at once.

balance by the wearing away of the heavy part and require rebalancing. It is bad practice to let wheels stand in water as the wet portion becomes heavy and is out of balance. Unless the wheel is balanced, it will not grind a piece perfectly round. After balancing, be sure the balance weights are securely fastened.

While the great majority of new wheels are perfectly sound, it is a good plan to tap them very lightly before mounting. A cracked wheel will give a very noticeable sound.

Speed and Feed of Wheels.—Wheel speed is very important from the point of both work performed and safety to man and machine. A common surface speed is 6,000 to 6,500 ft. per minute. Some plastic-bonded wheels are safe at 9,000 to 10,000 ft. Be sure to stay on the safe side. A wheel *run below* its normal speed will seem to be softer than its grade indicates, while a soft wheel seems harder when speeded up. This fact can be used to advantage when just the right grade of wheel is not available. But no wheel should ever be run above its critical safe speed.

Where wheels of varying diameter are run together to grind different diameters at the same time, the smaller wheel will act

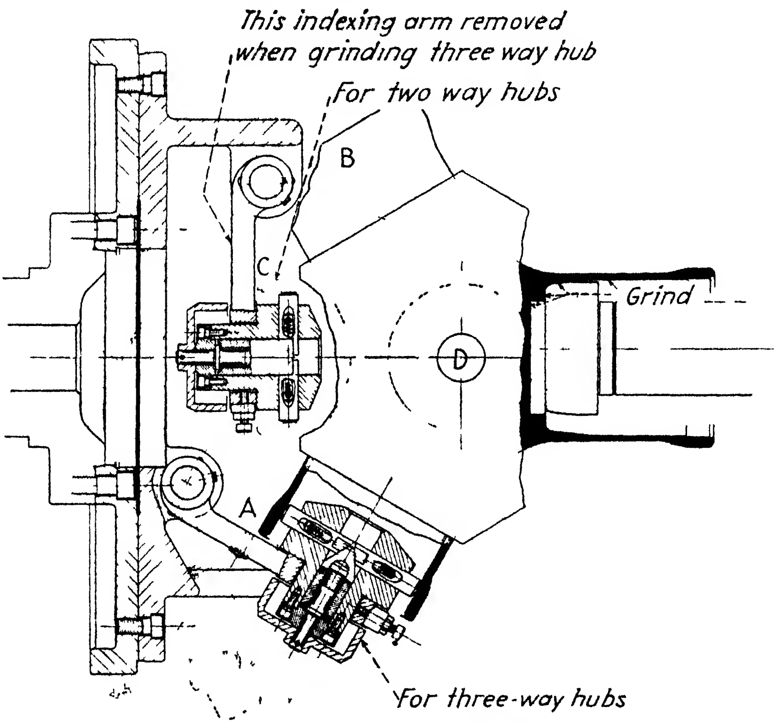


FIG. 9A.—Details of chuck for two- and three-way propeller hubs.

soft. In this case a slightly harder wheel may be advisable. In using different size wheels, limit the speed by that of the largest wheel.

Regular infeeding at a slow rate is best in all grinding. Irregular or too rapid infeed is a cause of wheel breakdown and uneven wear. The best rate of infeed for any particular job can be determined only by experiment. Use the automatic wheel feed along the work whenever possible. It is much more uniform and gives a better finish on the work. Do not be tempted to hog off too much stock at the beginning of the cut. It does not save time. Instead it breaks down the wheel and gives a poor finish.

Speed of the Work.—Work speed is important. A slower work speed permits greater depths of cuts if the traverse feed is also reduced. Where it is necessary to remove stock rapidly, this is a good combination, but this combination does not give the best finish. The kind of work vitally affects the speed. Out-of-balance work such as a crankshaft must be run slower to prevent vibration, which would produce out-of-round bearings.

In most cases of plain grinding the best work speed is between 60 and 100 surface feet per minute for *steel.* For crankshafts use from 35 to 45 surface feet per minute. For camshafts use 15 to 30 surface feet per minute for roughing; about half that for finishing. Changes in work speed also affect the apparent hardness of the grinding wheel. For aluminum and other soft metal the surface speed can be from 150 to 200 surface feet per minute. This permits less wheel feed, less metal is removed at each contact, and there is less tendency to load the wheel.

Low Work Speed and Slow Feed along the Work Also Permits Greater Depth of Cut.—There are so many combinations of wheel and work speeds which affect production that no fixed rules can be given. Experiment and good judgment are always valuable.

In roll grinding where a very high finish is necessary, grinding-wheel speeds are reduced to between 4,500 and 5,000 surface feet per minute. It should be remembered that lower wheel speed, lower work speed, and lower rate of infeed always improve the quality of the finish. There are also special wheels made for high-finish roll grinding that are not safe at the speeds used for vitrified or resinoid wheels.

When a wheel wears down, its speed can be safely increased. But when you put on a new and larger wheel do not forget to reduce the speed of the wheel spindle to the proper point.

GRINDING-MACHINE DRIVES

Nearly all modern grinding machines use V belts for the spindle drive. Whether V or flat belts are used, they should be endless or have carefully cemented joints, as any form of belt lacing can be detected in the surface of the work. The pulleys or sheaves for V belts must be kept in line, and when belts of any kind stretch they should be tightened. Good belts seldom stretch over 10 per cent. Matched V belts should be used so that each belt will do its share of the work. When a belt needs replacing, put new belts on all the pulleys. Keep the older belts to use with other belts that have been stretched the same amount

Do not force belts over a pulley or sheave. Slack up on the adjustment screws before putting on the belt. Keep belt guards in place to prevent water and oil splashing on them, and never use belt dressing on a V belt.

Spindles and Bearings.—Accurate grinding depends on the wheel spindle and its bearings. The spindle must allow just enough lubricant—and no more—between it and the bearing. The proper clearance can be judged to some extent by the temperature. A running temperature of 140°F. is considered about right in most cases. At this temperature the hand can be laid on the bearing for a short time but cannot be held there long without burning. It is safer to use a thermometer, however.

It is for this reason that no expert grinder operator attempts to do precision grinding on a cold machine. He lets it run until the bearings warm up. A cold bearing, or one too cool, indicates too much clearance between spindle and bearing and will not grind to satisfactory precision requirements.

The proper clearance for any grinding-machine bearing can best be obtained from the builder of the machine. His suggestions as to lubricant should also be followed. His experience has taught him how to secure best results with his machine.

CARRIAGE TRAVERSE FEED

Traverse speed, the feed of the work carriage, depends largely on the kind of work and the finish desired. For roughing work, the feed can be almost the width of the face of the grinding wheel. In other words, the face of the wheel should "lap over" the previous cut.

In finishing work, a carriage feed of ½ in. is about as much as can be used satisfactorily. Less than this amount is usually desirable. For real mirror finish, a traverse feed of ⅛ in. for each revolution of the work is frequently used. With this slow rate of traverse feed, the work receives a high polish. There is, however, no fixed rule, and a good operator tries various feeds until he secures the desired finish. It must be remembered, however, that a slow feed means more time must be spent on the job.

Chatter.—Theoretically, no grinding is free from chatter, but in many cases it is invisible to the naked eye and does no harm. Probably the greatest cause of chatter is the use of the wrong wheel for the work and the improper dressing of the wheel.

In general, the cause of fine chatter marks can be found in the wheel head or base, and coarse chatter marks come from the headstock which drives the work. The reason for this is that the r.p.m. of the wheel always exceeds the r.p.m. of the work, and the more frequent the vibrations the finer and closer the chatter marks.

Chatter marks which run lengthwise on the work, usually without a break, and which are evenly spaced come from the headstock. This is why few makers now attempt to drive grinding spindles with gears, chains, or laced belts. Spindles driven with endless belts should have no difficulty of this kind.

There are also other causes of chatter, such as improper truing of the wheel, the wheel's being out of balance, or the wheel center's not fitting the nose of the spindle. Or there may be too much clearance in the wheel spindle or too rapid wheel feed.

Poor work center, points that do not fit, loose work spindles, improper work rests, the work's being out of balance, or motors being out of balance may all cause chatter.

Width of Grinding Wheels.—Selection of wheel width, or thickness, depends on many things. For infeeding, where the work is not fed across the wheel, the face of the wheel should be from 1/8 to 1/4 in. wider than the work is long. This takes care of any normal variation in the depth of the work centers. For a variety of work the wheel width will have to be a compromise to suit best the varied conditions.

TRUING AND DRESSING GRINDING WHEELS

Too many take truing and dressing grinding wheels to mean the same thing.

Truing a wheel means making it run true on the spindle. It should be necessary only when a new wheel is put on the spindle.

After it has been properly trued, it should stay true until it is worn out.

Dressing a wheel might be called sharpening it. Dressing simply removes the grains of abrasive that have become dull from contact with the work. It gives the wheel a new *face*. It is sometimes compared to "face lifting." The motto of a good grinding shop is "True once, dress often."

If all the particles or grit in a wheel would fall when they become dull, there would be no need of dressing. But as they do not, we cut away the dull particles to leave the wheel sharp.

There are two distinct types of wheel dresser. One is mechanical; the other is a diamond. The mechanical dresser has a number of pointed or corrugated metal wheels which revolve when pressed against the dull wheel. These points or wheels break away the dull grains and leave the sharp grains ready for work. Some prefer the mechanical dresser for wheels that are to be used on aluminum or other soft metals. Others like them for truing very large wheels.

For average size work and for steel and similar metals the diamond dresser is used in most cases. The diamond holder should be held firmly, since if the diamond vibrates it will leave marks on the wheel that will in turn show on the work being ground.

Before either truing or dressing a wheel be sure the machine has been run long enough to attain normal temperature in the bearings. Otherwise the wheel may not be really true with the spindle.

Using the Diamond.—Diamonds used in truing grinding wheels are very different from those used in rings and other jewelry. While the diamond is harder than the wheel, it does get ground away and must be turned in the holder to present new facets to the wheel.

Most grinding-machine men use a holder that presents the diamond to the wheel at a slight angle, and arrange it so that the holder can be turned as the diamond wears. As a rule large diamonds are more economical than small ones. They absorb heat better and are not so likely to crack from overheating.

Always start the diamond in the center of the wheel and work toward the edges. Wheels usually wear smaller at the corners, and, if cutting is started at the edges, the diamond may be over-loaded at the center. Reducing the diameter about 0.001 in. at each pass saves the diamond and does not cut the wheel away faster than is necessary.

Use plenty of coolant during both the truing and the dressing of the wheels. This keeps the diamonds cool and should prevent fracturing. When the diamond is partially ground away or when it becomes loose in its setting, it should be reset by a competent man, for not only is the diamond itself expensive but, unless it keeps grinding wheels sharp, the production of the grinding machines is smaller than it should be.

What Size Diamond to Use.—According to Leo Gluck,[1] there is an economical relation between the size of the diamond to be used and the wheel on which it is to be used. This relation takes into account the width of the wheel and the grit of the abrasive. He says:

> The size of grinding wheel grits and the width of the wheel face are the prime factors which control the weight of industrial diamonds used for truing the wheel. The required weight of the diamond increases in geometric ratio with the coarseness of the grits and directly with the face width of the wheel; also, with the number of wheel dressings which are required.
>
> The unit weight of diamonds is the metric karat of 200 milligrams. The unit cost of the diamond increases in geometric ratio with the weight, while its resistance to abrasion is directly proportional to its weight. Therefore, for every grinding wheel or group of wheels there is an economic diamond size for truing operations. Selection of such diamond sizes can be made from the diagram [Fig. 10*A*].

The diagram, Fig. 10*A*, shows the proper size of diamond to use. Thus, a wheel with a 4-in. face and 25 grits per inch should use a 5-carat diamond.

FORMING WHEEL FACES BY CRUSHING

The demand for ground threads of the Whitworth, round top and bottom, form has led to the development of a new method of shaping grinding-wheel faces. This, as might be expected, originated in England, where the Whitworth thread prevails, and has proved very successful.

Wheels of the desired fine grits are shaped by running them in rolling contact with a hardened-steel form of the desired contour. The steel form is fluted much like a hob except that

[1] Leo Gluck, of New York, is an authority on commercial diamonds.

the flutes are usually straight across the face and are not regularly spaced. The irregularities in spacing do not seem to follow any formula but gradually grow farther apart for a few flutes and then return to the narrow spacing and repeat.

Where liquid-cooled airplane-cylinder barrels have shallow ribs on the outside as stiffening ribs, the wheel is formed to grind

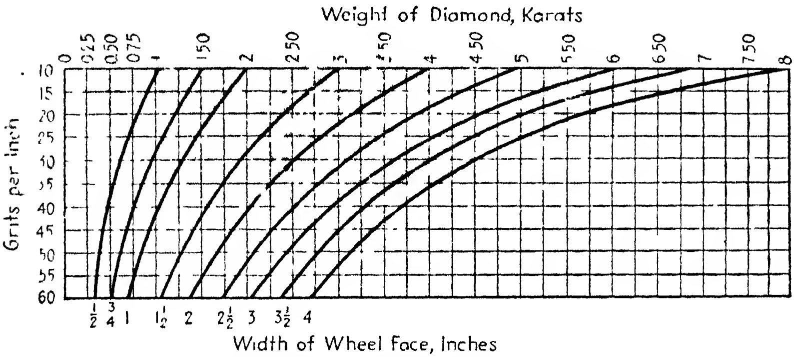


FIG. 10*A*.—Diagram for selecting proper size of diamonds.

the whole length of the barrel at once. The steel form, of proper contour, is forced into the grinding wheel as both form and wheel revolve in contact, and the wheel grit is crushed at the point of contact until it assumes the desired form. Strange to say, the steel form does not seem to be ground away appreciably and can be used repeatedly. The method seems to have possibilities in several directions.

GRINDING NONMAGNETIC RINGS ON A MAGNETIC CHUCK

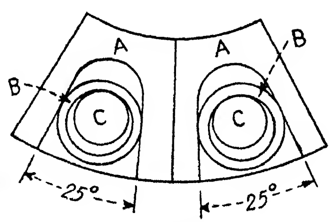


FIG. 11*A*.—Holding nonmagnetic rings for grinding.

Nonmagnetic rings can be ground on a magnetic chuck by providing magnetic holders as shown in Fig. 11*A*. A series of soft-iron V-shaped holders, *A*, *A*, are placed on the rotary table of a Blanchard surface grinder. These have a gap of 25 deg. as shown. The rings to be ground, *B*, *B*, are nonmagnetic. These rings are pushed into the V opening as far as possible and a steel disk, *C*, put inside the ring. This is crowded against the inside of the ring to hold it in the V of the main block. With the ring and blocks in place, the current is turned on the chuck.

This holds the steel V block and the inner ring tight on the chuck, and the nonmagnetic rings are held in place by the steel pieces.

This idea is credited to the Ex-Cell-O Corp. and is being used by Republic Aircraft Products. It can be applied in many other cases by adapting the same idea to the work in hand.

GRINDING AIRCRAFT-ENGINE VALVES

Valves are an important part of an aircraft engine and have more grinding operations than might be supposed. The 10 outline illustrations show the sequence of these operations as

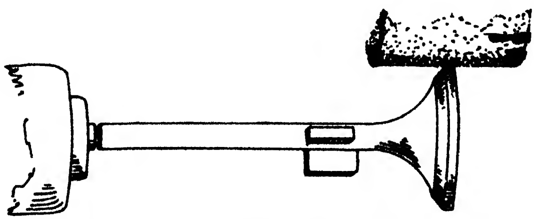


FIG. 12A.—Grinding outside of valve head.

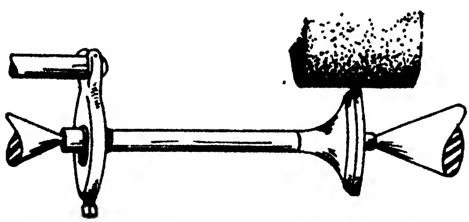


FIG. 13A.—Same operation with valve held between centers.

handled by a Landis grinder. First the outside of the head is ground, as in Fig. 12A. All operations are done in a plain hydraulic machine. Here the end of the stem is held in a chuck and the stem itself supported by two adjustable shoes. Another method is shown in Fig. 13A, where the valve is held between centers.

Next comes the grinding of a 30-deg. angle on the head with the stem held in a chuck and the headstock set at the correct angle, as in Fig. 14A. Where the headstock does not swivel, this level can be made by dressing the wheel itself at 30 deg.

In Fig. 15A the head end of the valve is being ground to remove the center tit, or projection. The stem is held in a chuck and the headstock swiveled 90 deg. Here again this operation can be done without a swiveling head by using the side of a properly dressed wheel. Figure 16*A* shows a head operation being done between centers, and Fig. 17*A* shows the finishing of the head with the end of the valve stem held in a chuck and the stem supported by two adjustable shoes, as in Fig. 18*A*.

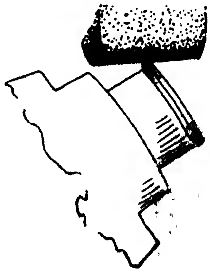


FIG. 14*A*.—Grinding angle on outside of head.

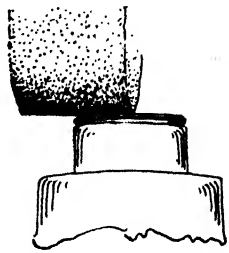


FIG. 15*A*.—Removing center projection.

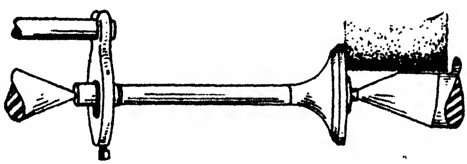


FIG. 16*A*.—Grinding head between centers.

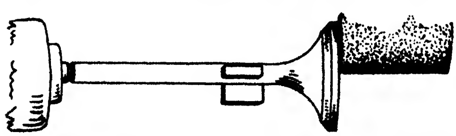


FIG. 17*A*.—Here the head is supported between adjustable guide shoes.

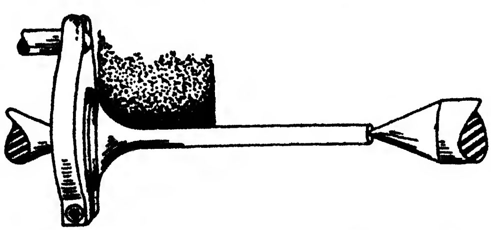


FIG. 18*A*.—Forming the fillet under the head.

The stem and head are rounded together, as in Fig. 18*A*, by driving the valve by a special dog, and by using a wheel formed to the shape of the fillet between the stem and the head. Then, with the same dog as in Fig. 18*A*, the whole length of the stem is ground, as in Fig. 19*A*. A half center is used in the tailstock to let the wheel pass over the end as shown. This figure shows the stem in which centers are used.

Using the 30-deg. beveled end of the valve in a chuck of the same angle, the valve is driven by friction, as in Fig. 20*A*. Here the lower end of the stem is being ground to a smaller diameter, using the same half center as before. Figure 21*A*

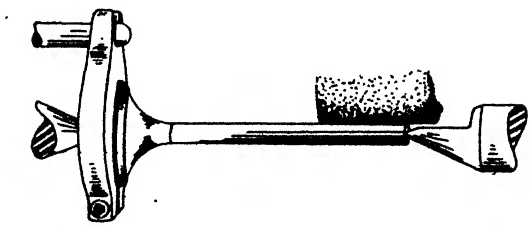


FIG. 19*A*.—Half center lets wheel pass over the end.

FIG. 20*A*. —Driving valve by friction cone against the head.

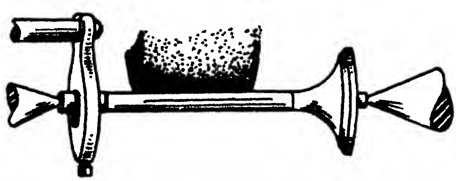


FIG. 21*A*.—Another method of grinding the stem.

shows another method of grinding the stem of the valve, using a dog similar to that in Fig. 19*A*.

CARRIERS FOR CENTERLESS GRINDING OF PROPELLERS

An unusual method of handling work in centerless grinders is shown in Fig. 22*A*. The drums, or carriers, hold a steel American propeller blade for the grinding of the round shank that goes into the hub. The round end can be plainly seen in the carrier that is suspended by the crane.

These carriers are carefully made to hold the blades very accurately in the correct position. The carriers are placed in the centerless grinder, which is equipped to receive them so that the carrier rotates accurately with the round end between the grinding and the guide wheel.

In this way the grinding machine is not tied up while the blade is being adjusted into proper position. Instead, the carrier, with the blade in place, is lowered into place in the grinding machine, and the work of grinding starts with no loss of time.

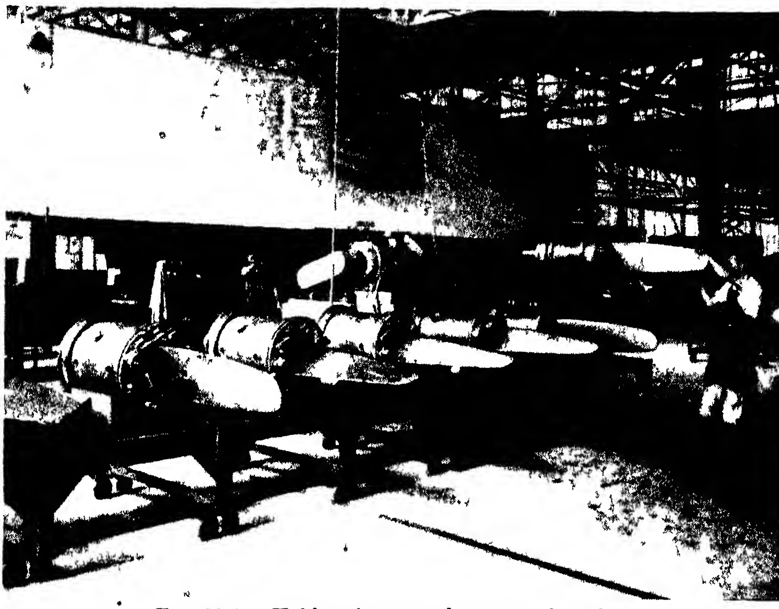


FIG 22A —Holdeis for centerless ground work.

The grinder behind the blades and carriers can handle much more work in this way.

ABRASIVE-BELT MACHINE

Another unusual grinding operation, also in the American propeller shop, is seen in Fig. 23A. Here the tube from which the blade shown in Fig. 22A is made is being ground to uniform thickness by using the abrasive belt shown. The wall thickness of the tube has been carefully measured at close intervals and the thickness marked in the tube at regular points.

With the tube mounted on rollers under the abrasive belt, the operator forces the belt against the tube by means of the block or pad in his right hand. In this way the abrasive belt removes as much or as little metal as desired from the high spots until the wall thickness is remarkably uniform. Going from one end of the tube to the other, the operator can reach all parts of the belt with only a rotary movement of the tube.

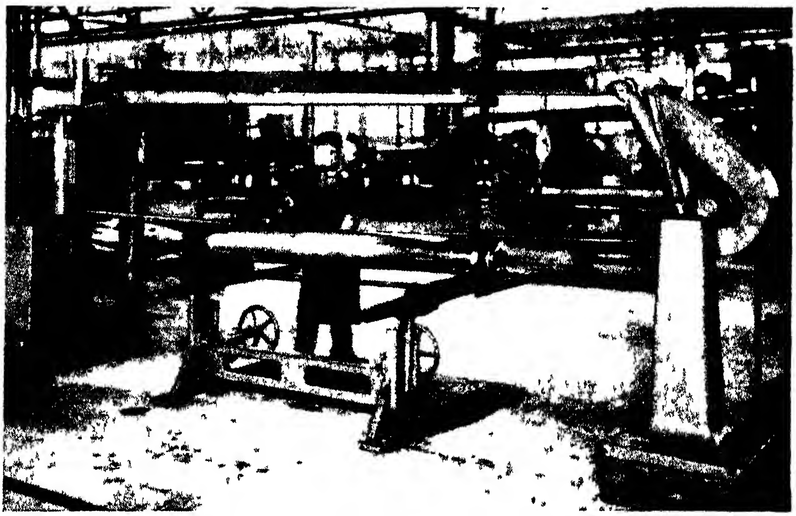


FIG. 23A.—Abrasive belt for reducing thickness of tube of which propeller blade is made.

TOOL GRINDING

Tool grinding plays an important part in machine production, for the best machine tool is dependent on proper tools for its best performance. Without properly ground tools, from the smallest drill to the largest reamer, or from the lathe tool to the largest milling cutter, maximum production is impossible.

For this reason the accompanying suggestions by the Norton Co. as to the best wheels for grinding carbide tools of various kinds are important. The use of carbide tools is growing in nearly all machining operations, and new sharpening methods must be employed. These tools are expensive in first cost but when properly used are a real economy if they are ground to preserve the tool and give best results in cutting. Hand honing or stoning is important in many cases, as a smooth surface on the tool increases its usefulness on many kinds of work.

Grinding-wheel Recommendations for Carbide Tools

Offhand grinding (single-point tools):	
Cup wheels:	
Combination roughing and finishing (wet)	120 Diamond Metal Bonded
Roughing (dry)	3760/1-I7 Crystolon vitrified.
Roughing (wet)	100S Diamond Metal Bonded or 100-B25 Diamond Resinoid or 3760/1-J7 Crystolon vitrified.
Finishing (dry)	37100-H7 Crystolon vitrified.
Finishing (wet)	220 Diamond Metal Bonded or 220-B50 Diamond Resinoid Bonded or 37100-H7 Crystolon vitrified.
Straight wheels:	
Roughing (dry)	3760/1-I7 Crystolon vitrified.
Roughing (wet)	3760/1-J7 Crystolon vitrified.
Machine grinding (single-point tools):	
Cup wheels:	
Roughing (wet)	3760/1-I7 Crystolon vitrified.
Finishing (wet)	3790/1-H7 Crystolon vitrified.
Straight wheels:	
Roughing and finishing (wet)	3780/1-J7 Crystolon vitrified.
Chip breaker grinding:	
Straight wheels:	
Roughing and finishing (wet)	120-B100 Diamond Resinoid Bonded.
Cutter and reamer grinding:	
Cup wheels:	
Blocking off (sharpening)	220-B100 Diamond Resinoid Bonded.
Straight wheels:	
Ingersoll cutter grinder	120-B100 Diamond Resinoid Bonded (10 × ¼ × 1″).
Surface grinding:	
Straight wheels:	
Roughing (wet)	100S or 150 Diamond Resinoid Bonded or 3760/1-J7 Crystolon vitrified.

Roughing (dry)	3760/1-I7 Crystolon vitrified.
Finishing (wet)	220 to 400 Diamond Resinoid Bonded, depending upon finish desired or 37100-I7 Crystolon vitrified.
Finishing (dry)	37100-H7 Crystolon vitrified.
Cylindrical grinding:	
Roughing (wet)	100S Diamond Resinoid or 3760/1-K7 Crystolon vitrified.
Finishing (wet)	100S to 400 Diamond Resinoid Bonded, depending upon finish desired, or 37100-J7 Crystolon vitrified.
Internal grinding:	100 to 400 Diamond Resinoid, depending upon finish desired (available mounted on spindles in smaller sizes).
Hand honing or stoning:	
Rectangular Stick:	220 or 320 Diamond Resinoid hand hone, or 37280-N Crystolon Stick.
Cutting off:	100S or 120 Diamond Metal Bonded for long life; Resinoid Bonded for fast cutting.

GRINDING NARROW SLOTS

Stainless-steel rotor wheels for General Electric superchargers have 142 slots for turbine blades. These slots must be held between 0.065 and 0.0655 in. in width. Every other slot is shallow, about half the depth of the others, as can be seen in Fig. 24*A*.

The slots were formerly milled with slotting saws but gave trouble on the deep slots, since they were good for only eight slots between grinds. So in cooperation with the Norton Co., grinding disks were prepared which have proved very satisfactory. These grinding disks retain their thickness remarkably well and cut much faster than the milling saw.

The machiner is a Thompson surface grinder equipped with duplicate fixtures so that two slots are ground at one table movement. Practically no grinding is done on the return stroke. Indexing is by hand, using a pin which fits into a slot in the

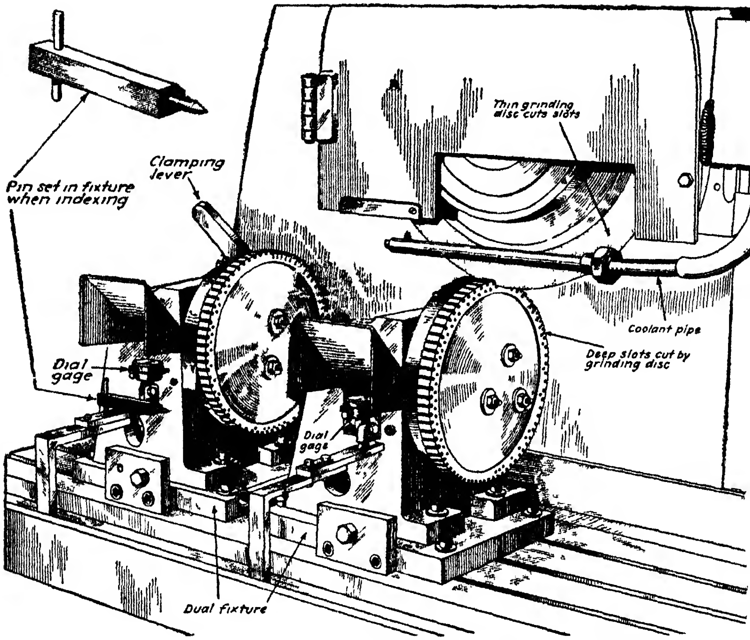


FIG. 24A.—Fixture for grinding narrow slots for turbine blades

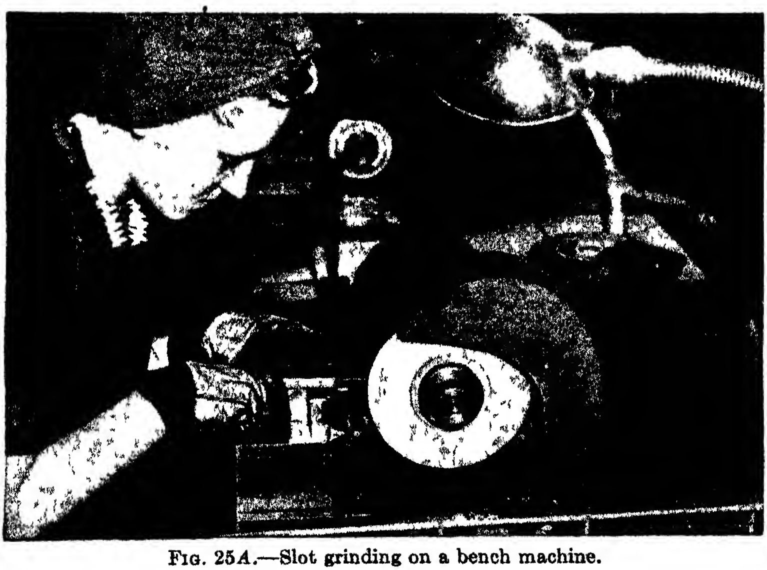


FIG. 25A.—Slot grinding on a bench machine.

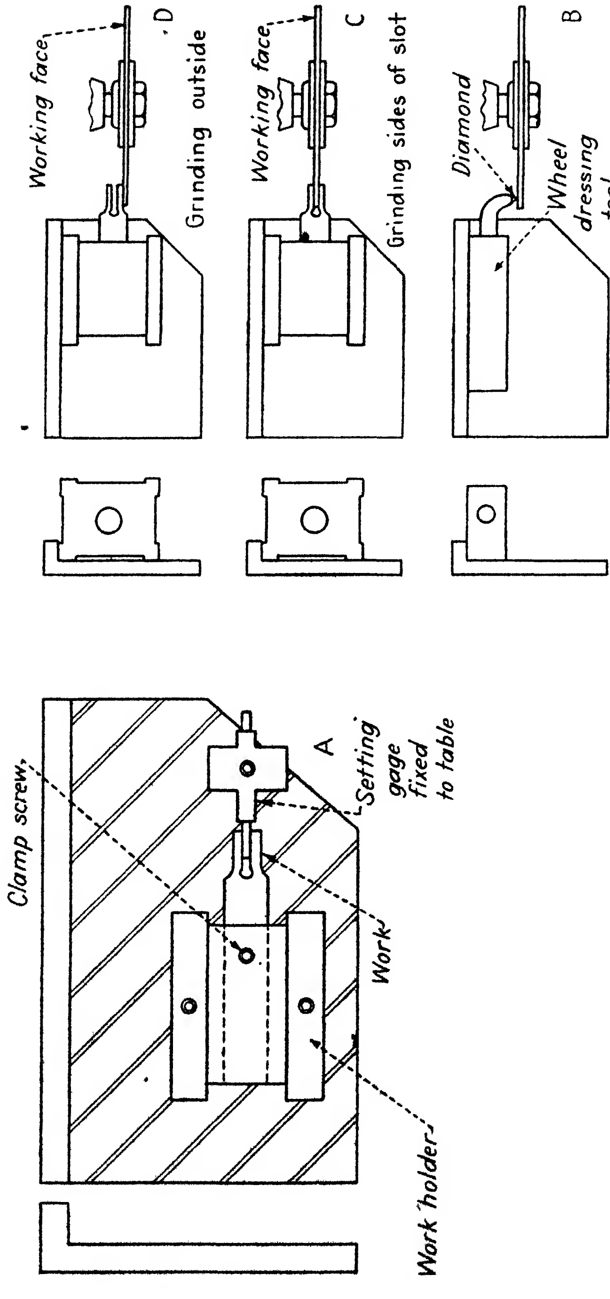


FIG. 26A.—Details of the fixture and of the way it is used.

fixture. The pin is removed after the part is locked in position and before the next cut is made. Details of the fixture are seen in Fig. 24*A*.

Another interesting slot grinding operation is seen in Fig. 25*A*, while details of the work and the fixture are shown in Fig. 26*A*. The work is held in a simple fixture by a clamping screw, as seen at *A*. With the grinding wheel accurately dressed with the diamond, guided by the raised edge of the table, as at *B*, the work is then ground both in the slot and on the sides, as shown at *C* and *D*.

Although these are simple fixtures, they are producing accurate work largely because of care on the part of the operator. With abrasive wheels now available it is possible to perform operations of this kind that would have been impossible without them.

HONING

Honing is being used to a greater extent than ever before, either after a preliminary grinding operation or direct from boring. Its use in war production includes gun barrels up to

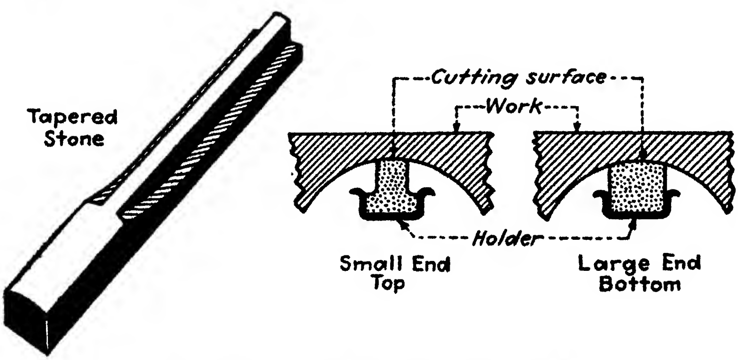


FIG. 27*A*.—Honing stones for blind holes.

large calibers, engine-cylinder bores, and the oleo cylinders of landing gears. Some of the honing machines built by the W. F. and John Barnes Co. have a stroke up to 22 ft., the machine itself being 61 ft. long. These are made with 8-in. and 12-in. diamond honing heads.

Spindle speeds can be varied from 27 to 322 r.p.m. on some machines and from 46 to 600 r.p.m. on others. These machines use 10-hp. motors on the 8-in. head and 15 hp. in the 12-in. heads. The hydraulic unit that reciprocates the honing head from 35 to 60 ft. per minute takes 5 hp. for honing only when head is revolving, or 7.5 hp. when used for straight lapping. The hone expander takes 1/3 hp. and the coolant pump 1 1/2 hp.

The spindle and traversing speeds are arranged to give a "cross-hatch" range of from 30 to 45 deg. This cross-hatching is sometimes referred to as the "figure 8" pattern.

The amount of metal to be left for honing depends on the kind of surface in the bore when honing begins. With a very smooth fine-feed bore, as in automobile cylinders, a common allowance is 0.002 in. on the diameter. The same is true when a cylinder is ground fairly smooth before honing.

Some, however, prefer to leave more metal and a rougher surface. One well-known shop, for example, bores oleo cylinders for landing gears with a single-point tool that leaves tool marks like a fine thread, perhaps 20 to the inch. In this case they leave about 0.020 in. for honing. The hone then cuts down the top of the "threads" very quickly, leaving but little metal to remove. The more metal that is removed, the greater the area of the ridges, which are entirely removed when the cylinder bore is of the right size. It is probable that either method gives equally good results, but some prefer the comparatively rough boring.

MICROFINISH

Cylinders.—Airplane-engine cylinders 350 Brinell hardness. Leave 0.0015 in. in diameter for honing.

Connecting Rods. *Large Bore.*—Grinding leaves 0.0005 to 0.0007 in. in diameter. Bores are then chrome-plated 0.0003 in. thick on each side and rehoned to remove about half this in 8 min.

Small Bore.—Remove about the same amount of stock on the smaller diameter in about 1 min.

Oleo Struts for Airplane Landing Gear.—Chrome-molybdenum steel approximately SAE4130. Cylinder 3 1/16 by 19 1/4 in. Rough honing removes from 0.006 to 0.007 in. on diameter. Finish honing removes about 0.0007 in. on diameter. Roundness to 0.0001 in. and taper to 0.0002 in. in length. The two honings take 7 min. (Data by Micromatic Hone Corp.)

What Honing Stones to Use.—In honing as in grinding, best results are secured by the selection of the abrasive element best suited to the work to be done. A. P. Jackson, director of engineering of the Mid-West Abrasive Co., suggests the honing stones shown in the accompanying list for the types of steels indicated at the left.

HONING-STONE RECOMMENDATIONS

Material	Roughing stones	(Roughing and finish)	Finishing stones
Hardened steels Rockwell C scale 60-70	180 29X 180- 35X		320- 29X 400- 29X 500- 29X
Rockwell C scale 50-60	180- 38X 220- 41X		500- 35X 600- 35X
Rockwell C scale 40-50	180- 65X 220- 62X 320- 55X		500- 52X 500- 59X 600- 41X 600- 59X 600- 64X
Rockwell C scale 30-40	220- 89X 220- 82X	320- 84X 320- 72X	600-120X 600-122X 600-131X 2000-122X 2000-128X
Nickel steels	180- 73X 180-103X		600-122X 2000-122X
Chrome molly	180- 73X 180- 52X	400- 52X	2000- 98X 2000-122X 2000-128X
Gun-barrel steel	180- 73X 180-103X 180-120X	320- 73X 320- 82X 320-103X	500- 73X 500-103X 600- 73X 600-103X

Honing Blind Holes.—It has always been considered necessary to have the hone pass completely through the hole to prevent taper, or a smaller diameter at the bottom of the hole. A. P. Jackson, of the Mid-West Abrasive Co., has developed a new type of stone for honing blind holes which seems to have done away with the taper at the bottom. Mr. Jackson says:

In honing any internal surface, the efficiency of the average stick or stone usually will vary in proportion to the amount of "overhang" allowed in performing the job. If the overhang is sufficient to permit the entire length of the stone to contact the entire area of the work there should be no excuse for taper to develop. There, every fractional portion of the surface to be honed is subjected to the same abrasive contact, the same abrasive speed and the same abrasive pressure. Assuming that the stones within the honing tool are of uniform hardness and assuming that the metal of the work has uniform resistance, the cut and resultant new surface thus effected should be uniform.

In blind hole honing, however, the traverse movement of the stone must end when its lower end reaches the bottom of the hole. Consequently, when stones of conventional design are used, the lower end of the hole cannot be subjected to the same cutting action given the upper area, which is contacted by the entire length of the stone. The inevitable result of such circumstances is a taper in the work.

Meanwhile, the lower end of the stone, being subjected to more work than the upper end, wears away more rapidly and accentuates the taper already in the honed surface.

Abrasive engineers tried a number of innovations. Shorter honing sticks were found to be too slow to cope with modern high production requirements. They did not completely erase the taper although they did reduce the tapered area of the hole to a slight fraction of that caused by long sticks. The use of short sticks had to be discarded although they reduced the tapered area at the bottom of the hole, because they created a concave area above it which was as bad, if not worse, than the original flaw.

Another potential solution tried, without conspicuous success, was the production of composite or segmented stones, the segments being of varying hardness so that the lower segment would cut faster than the upper.

In the end, it was found that taper within the blind hole could be avoided by molding the honing stick with a varying honing surface, thus forcing the lower end of the stick to remove a greater amount of stock than the upper end. This is shown in Fig. 23*A*.

A stone of this type must have greater tensile strength than that of the conventionally designed stone and there has to be a delicate dimensional balance between one end and the other. If the stone's dimensions at the bottom are less than they should be, taper of the hole is not completely eliminated. If, on the other hand, they are more than necessary to eliminate taper, the stone will create taper in the reverse direction.

An extensive system of trial and error has been necessary to find exactly the right amount of dimensional variance so that the increased cutting capacity of the stone at its lower end will offset precisely the loss of abrasive contact due to inaccessibility. An abrasive bond was necessary that would increase their tensile strength so that their taper would not cause them to chip or break under pressure. Such an abrasive bond has been developed and is being used in production of stones today.

At first it was necessary to make each set of stones according to specifications of a particular job, but after a considerable amount of data had been accumulated through experiment and by studying stones of this type used in actual production over a long period of time, it has become possible to specify the exact degree of taper required for a given job.

The elimination of taper in blind hole honing is only one of the problems mastered by abrasive engineers since the day of extremely close tolerances and extremely smooth surfaces dawned upon our industries. Taper difficulties also were encountered in the Superfinishing of bearings and those difficulties have been mastered in the same manner. Both blind holes and bearings can now be produced perfectly straight or, if desired for some special purpose, they can be produced with convex surfaces.

PROPOSED AMERICAN STANDARD MARKINGS FOR GRINDING WHEELS

In order to simplify the ordering of grinding wheels by those who came into the machine industry as a result of the war effort, the manufacturers of grinding cooperated in the arrangement of a new and less complicated system of marking wheels. Although this may perhaps be called a temporary standard which will be replaced at a later postwar date, it is most helpful in the present emergency. It is given here to make it easier for those not familiar with the various markings of different makers to get the wheel they need from any source of supply.

Purpose and Scope

This standard was developed to simplify a complicated condition in industry caused by the diversity of grinding wheel markings used by the various manufacturers of grinding wheels. The necessity for a standard system of wheel markings that would cover all the various types and grades of grinding wheels now used was recognized. Wheels thus marked will simplify the ordering and stocking of wheels wherever a quantity is kept on hand, and will also enable the user to help the grinding-wheel manufacturer in selecting a wheel that would be suitable for the intended work. This standard is more simple, more uniform, and more consistent than all other systems heretofore used for the marking of grinding wheels.

The following is an outline of the standard wheel markings to be used:

Sequence of Markings

Each marking will consist of six parts, placed in the following sequence:

1. Abrasive.
2. Grain size.
3. Hardness, or grade.
4. Structure.
5. Bond, or process.
6. Manufacturer's record.

1. Abrasive.—Each letter represents an abrasive, as follows:

A. Aluminum oxide, regular.
B. Aluminum oxide, refined.

Note: Successively larger suffixes do not necessarily indicate finer finishes. Combinations are used to make wheels stronger, or to give additional pieces per dressing or some other desired characteristic of wheel action.

AB. Mixture of regular and refined aluminum oxide or semi-friable abrasives.
C. Silicon carbide, regular.
CG. Silicon carbide, refined.
D. Corundum.
E. Emery.
F. Garnet.

2. Grain Size.—Each number represents a grain size, as follows:

8, 10, 12, 14, 16, 20, 24, 30, 36, 40, 46,
50, 54, 60, 70, 80, 90, 100, 120, 150, 180,
220, 240, 280, 320, 400, 500, 600, etc.

In addition to nominal grain size, combinations will be indicated by numbers 1 to 4 following the grain size number.

The average grit size in a combination shall be established by averaging the designating numbers of all of the sizes in the combination based on proportions by weight.

All straight-grain wheels and no other shall be designated by the nominal grit size without suffix.

If the average grit size in a combination should exactly coincide with any nominal grit size, the designation shall be that nominal number followed by the suffix 1.

The suffix 2 shall be used to designate all combination wheels, the average grit size of which falls in the coarsest third of the range between the nominal size and the next finer.

The suffix 3 shall be used to designate all combination wheels, the average grit size of which falls in the middle third of the range between the nominal size and the next finer.

The suffix 4 shall be used to designate all combination wheels, the average grit size of which falls in the finest third of the range between the nominal size and the next finer.

3. Hardness, or Grade.—The following symbols represent the hardness, or grade.

STANDARD GRADE SCALE

Soft	Medium	Hard
S1	M1	H1
S2	M2	H2
S3	M3	H3
S4	M4	H4
S5	M5	H5
S6	M6	H6
S7	M7	H7

4. Structure.—The following numbers represent the structure.

Preferred numbers	2		5		8	
Available numbers	1	3	4	6	7	9

Where 1 is the most dense, 5 is medium, and 9 the most open.

5. Bond, or Process.—A bond, or process, is designated by the following letters:

V. Vitrified.

S. Silicate.

E. Shellac or elastic.

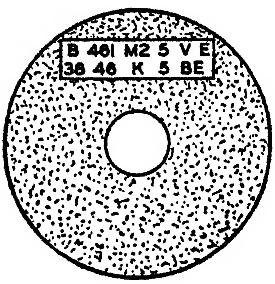
R. Rubber.
B. Resinoid (synthetic resins such as bakelite, etc.).
O. Oxychloride.

6. Manufacturer's Record.—Manufacturer's records are designated by symbols. Each grinding wheel manufacturer is at liberty to use the sixth position for private factory records.

Marking

A dual marking system whereby the adopted standard markings are to have preferred position above the grinding wheel manufacturer's individual markings when the size of the wheel permits (see illustration) is employed.

Wheels too small to permit standard markings shall be wrapped and tagged showing the standard wheel markings above the manufacturer's individual markings. In addition the tag must show the name of the manufacturer and the purchase-order number.



Example

To serve to illustrate the standard wheel markings placed in their proper sequence along with the manufacturer's individual markings, a typical example of a vitrified wheel is shown (see illustration).

Method of Applying Standard Markings to a Grinding Wheel

	Abrasive	Grain size	Hardness or grade	Structure	Bond or process	Manufacturer's records
G.M.	B	461	M2	5	V	E
Mfr.	38	46	K	5	BE	
Mfr.	AA	46	N	5	F	

USING DISTINCTIVE COLORS FOR GRINDING WHEELS

The use of distinctive colors for certain kinds of grinding wheels, particularly for those used on surface grinding operations, is described by Walter Kassebohm.[1] He gives a system of colors of practical service in this kind of work.

[1] Walter Kassebohm is an authority on grinding wheels.

The grinding of die blocks and other work, which is to be done on surface grinders, is, on the other hand, still the job of the toolmaker. As surface grinding includes the rough or finish grinding of soft and hardened tool steels, as well as the grinding of narrow slots, sharp corners and forms, etc., a variety of grinding wheels with different gradings as to the structure, grain size and bond has to be used for greatest efficiency.

Hardened die steels are easily checked and cracked in grinding on a surface grinder by using an unsuitable grinding wheel. Free cutting is impaired, and frictional heat, which results in minute surface cracks, is the consequence when using the wrong wheel.

Incorrectly selected grinding wheels will also become easily "glazed" or "loaded." This is, in most cases, an indication that the bond of the wheel was too strong for the job to be done and the wheel, therefore, did not have the correct self-sharpening characteristics. A "loaded" wheel has a very low cutting efficiency and the imbedded metal chips are a great factor in producing a large amount of heat by rubbing over the surface to be ground, thus forming the main reason for surface cracks.

One of the methods to overcome this difficulty is to give each toolmaker a copy of a standard sheet which describes the type and number of wheel to be used for the different steels and types of jobs to be ground. Such a standard sheet has been proved to be of great help to the toolmaker, but a better method is the selection by color. As soon as the wheel is received in the tool crib, the face of the wheel is painted with a color ring, thus giving the wheel its "personality" according to a large chart which hangs near the surface grinders. The chart shows the correct colors to be used for the different materials to be ground.

The comparatively small number of possible colors for wheels seems to affect the limiting of grinding wheel selection to a few specifications and not always to indicate the best wheel for the job, but general tool room surface grinding can well be standardized with a few wheel specifications without getting inefficient over-simplification of grinding wheel selection.

A color chart for selecting grinding wheels was found to be of great help and a good guide in selecting the correct wheel, but conditions surrounding the job must be considered and might, of course, call for some modifications. Those cases, however, should be considered "special" tool room jobs and should be treated individually.

Fundamentally, the following points should be known and observed by the toolmaker:

Use **hard** wheels for **soft** material.

Use **soft** wheels for **hard** material.

The smaller the area of contact between work and grinding wheel, the harder the wheel should be.

The chart "A," with the encircled areas painted in the respective colors, has been successfully used.

When using "color" identification for selecting grinding wheels, errors as to the selection of a wrong wheel for a certain job are much more easily eliminated. It also has the great advantage that the tool room foreman can easily make an immediate check as to the correct or incorrect selection of the wheel even during the running of the grinding spindle.

The different companies who produce grinding wheels have varying specifications as to number and letter identification of their wheels. Tool room foremen find it is an advantage to have specifications of grinding wheels for identical use, but as supplied by different companies. The foreman should, therefore, be in the possession of a code so as to easily analyze the colored wheels for grinding wheel manufacturers' specifications.

A typical code, which is for reason of simplification only made out for two grinding wheel companies, is as follows:

Chart A for Color Designation of Wheel
Color Selection for Wheels to Be Used for Surface Grinding

Condition of steel	Material to be ground	Wheel color for roughing and finishing	Wheel color for extra-fine finish, narrow slots, and sharp corners
Hardened	All oil hardening tool steels such as: Deward, Utica, Paragon, Ketos, Bethlehem Tool Room Steel, K-46, etc. All high-speed steels such as: L-XX, Rex AA, etc.	Blue	Yellow
	Hardened high-chrome steels such as: Huron, H.Y.C.C., etc. Cast iron Cemented carbides (if diamond wheels are not available)	Red	Green
Soft	All steels	Orange	Brown

CHART B

Chart with Code for Selection of Wheels

Color of wheel	Wheel specification for Carborundum Co. wheels	Wheel specification for Norton Co. wheels
Blue..............	46A-T-172	3846-H8BE
Yellow........ .. .	100A-U-172	38100-H8BE
Red.....	60S-W DG	3760-I7
Green...	120S-WEG	37120-I7
Orange....	36A-P-678	36-J5BE
Brown.......... ..	60A-U 673	60-J5BE

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