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OPERATION OF MACHINE TOOLS

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GRINDING AND GRINDING MACHINES

CONTENTS

CHAPTER I

CYLINDRICAL GRINDING MACHINES

Grinding machines were originally used almost exclusively for truing tool steel parts which had been distorted by hardening, and they are still indispensable for work of this class. The great improvements which have been made, both in grinding machines and abrasive wheels, however, have resulted in the application of the grinding process to the finishing of a great many unhardened parts. In either case, the work, as a rule, is first reduced to within a few thousandths inch of the required size by turning in some form of lathe, and then it is ground to the finished dimension. After a part has been hardened, grinding is the only practicable method of truing it. On the other hand, unhardened pieces can be finished by other means, but grinding is preferable for most cylindrical work, because it enables parts to be finished accurately to a given diameter, in less time than would be required by any other known method.

Several different types of grinding machines have been developed for handling the various kinds of work to which the grinding process is applicable. The machines used for grinding cylindrical parts such as shafts, piston-rods, etc., are called cylindrical grinders whereas the type used for grinding holes in bushings, gears, milling cutters, etc., are known as internal grinders. There are also surface grinders for finishing flat or plane surfaces. and, in addition, types that are specially designed for sharpening cutters, reamers, etc. As cylindrical grinders are the type most commonly used, they will be considered first.

When grinding a cylindrical part such as a rod or shaft, it is mounted between the conical centers of the grinder (as shown by the diagrams, Fig. 1), just as it would be placed between the centers of a lathe for turning; in fact, the same center holes upon which the shaft was rough turned are used when grinding. The work is rotated rather slowly upon these centers c and c_1 by a driving dog d, which engages a pin in the driver plate at the left, and the surface is ground cylindrical by a disk-shaped wheel g. This wheel rotates rapidly (a 14-inch wheel would run about 1600 revolutions per minute), and the grinding is done either by traversing the rotating part past the face of the wheel or by traversing the wheel along the work. Some cylindrical grinders operate in one way, and some the other. The diagram A, Fig. 1, illustrates the method of grinding by traversing the work, the reciprocating movement past the wheel face being indicated by the full and dotted lines which show the position of the shaft at each end of the stroke. The revolving wheel g is fed inward a slight amount at each end of the work and the latter is accurately ground to the required diameter. The wheel can be fed by hand or automatically, the latter method being generally employed, except when adjusting the wheel or starting a cut. The amount that the shaft moves endwise while making one revolution, is always somewhat less than the full width of the grinding wheel face in order to secure a smooth surface free from ridges. This side traverse, as well as the rotative speed of the work, is varied to suit conditions. The operation of a machine having a traversing wheel is shown by diagram *B*. In this case, the work, instead of moving back and forth past the wheel, rotates in one position while the grinding wheel, which is mounted on a suitable carriage, moves from one end to the other, as indicated by the full and dotted lines.

The grinding wheels are composed of innumerable grains of some hard abrasive material which is held together by an adhesive bond. These grains or cutters, as they might properly be called, have sharp

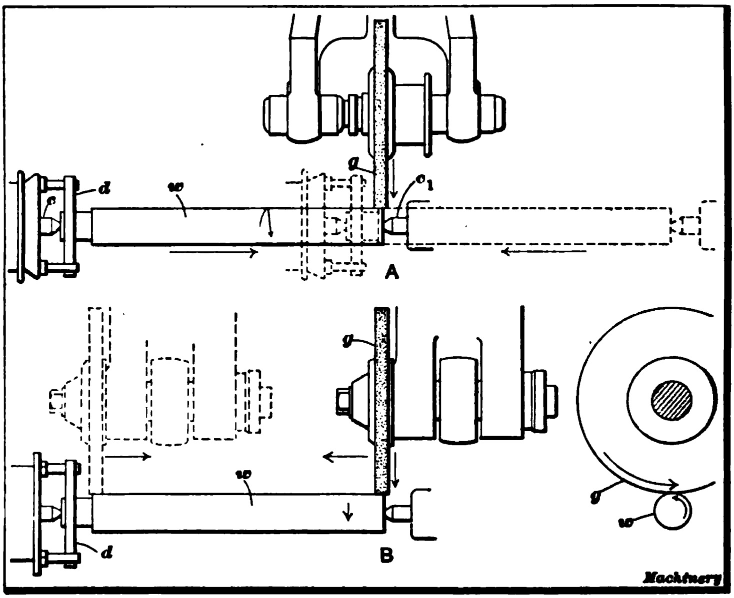

Fig. 1. (A) Diagram illustrating Method of Grinding by traversing Work past Face of Grinding Wheel. (B) Grinding by Traversing the Wheel

corners or edges which cut away the metal as the work traverses past the wheel face, or *vice versa*. The relative rotation of the wheel and the part being ground should always be as shown by the end view (diagram *B*), for cylindrical grinding. As the arrows indicate, the grinding side of the wheel *g* moves downward, and that side of the work *w* being ground, moves upward or in the opposite direction.

From the foregoing, it will be seen that a cylindrical grinding machine must be arranged to rotate both the grinding wheel and work. In addition, either the work or the wheel must be traversed longitudinally. The wheel must also be fed in automatically for taking successive cuts, and provision must be made for varying the traversing movement and the rotative speed of the work to suit different conditions. The way these various movements and adjustments are obtained with the type of cylindrical grinder illustrated in Fig. 2, will be explained. It should be understood, however, that the mechanical details vary with grinders of different makes, although all cylindrical grinding machines operate on the same general principle.

Cylindrical Grinding Machine of the Universal Type

The machine shown in Fig. 2 operates by traversing the work past the grinding wheel *G*, as illustrated by the diagram *A*, Fig. 1. The grinding wheel is revolved by a belt that passes over a pulley at the side of the wheel and connects with an overhead countershaft. The table *A*, which moves back and forth when the machine is in operation. carries a headstock *H* and a footstock *F* in which conical centers *C* and

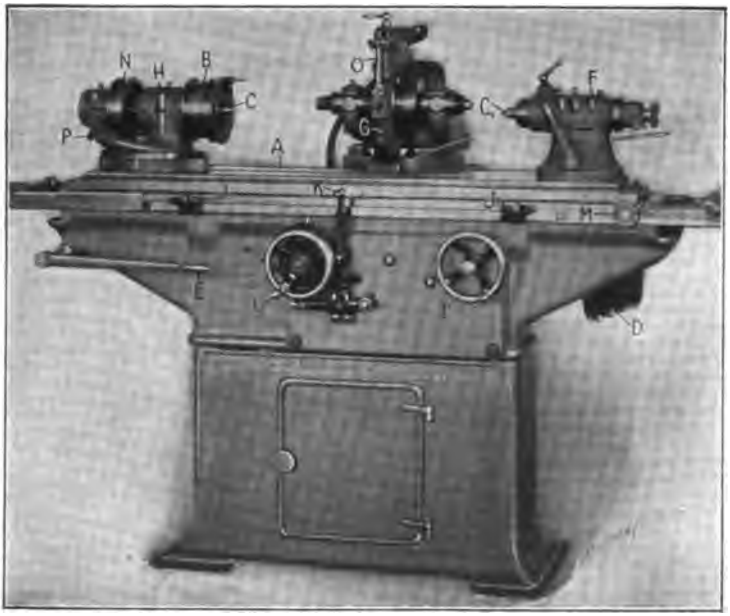

Fig. 2. Brown & Sharpe Universal Cylindrical Grinding Machine

C_1 are inserted. When a cylindrical part such as a shaft or rod is to be ground, it is placed between these centers and is rotated upon them by a belt passing over pulley *B* and connecting with a long cylindrical drum, which forms part of the overhead works for driving the machine. This long drum is used instead of a narrow pulley, so that the belt can shift along as the table moves to and fro.

The power for moving the table along the ways of the bed is obtained from a belt connecting with cone-pulley *D* which transmits motion to the table through suitable shafts and gearing located inside the bed. The traverse of the table and rotation of the work-spindle, can be started or stopped by lever *E* to the left. The wheel *I* to the right is used for moving the table by hand. When operating the table in this way, the knob in the center of this wheel is pushed inward, and when the table is to be traversed automatically, this knob is pulled out. The travel of the table or the length of its stroke is controlled by the position of the adjustable dogs J and J_1 which operate the reversing lever K. Lever K connects with a clutch inside the base and this clutch, through gearing, reverses the movement of the table whenever lever K is thrown to the right or left. The length of the stroke is changed by varying the distance between dogs J. These dogs slide upon a rack attached to the front of the table and are held in position by a spring-latch that engages the rack teeth.

The Automatic Cross Feed

The grinding wheel can be moved to or from the work by rotating handwheel L, and it is fed inward automatically by the mechanism

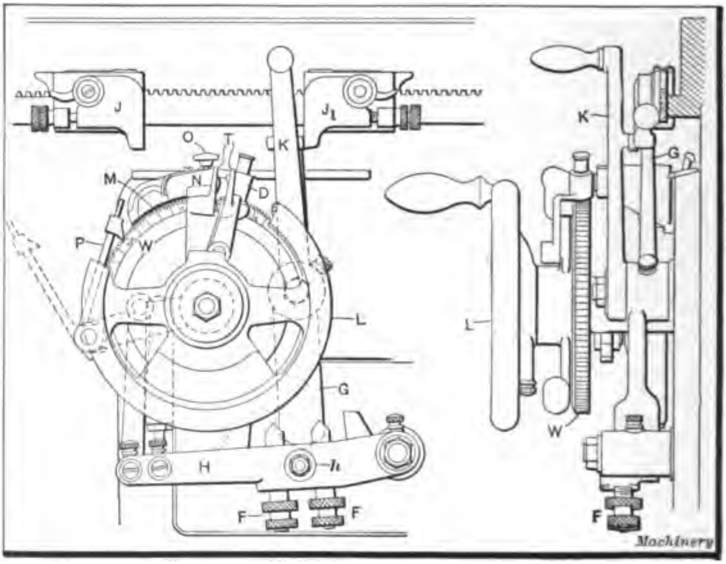

Fig. 3. Mechanism which feeds the Grinding Wheel forward at each Reversal of the Work and automatically disengages the Feed when a Predetermined Amount has been ground away

located just back of this wheel. This mechanism is so arranged that it can be set to stop the feed when the diameter has been ground to a predetermined size. The way in which this automatic feed operates will be more clearly understood by referring to the detail drawing, Fig. 3. When the dogs J strike lever K, thus reversing the table movement, the lever G is also actuated, and it has a V-shaped end which engages roll h, and operates lever H and pawl P. If this pawl is in mesh with the ratchet wheel W, the grinding wheel will be fed forward an amount depending upon the position of the screws F, which come against a surface on lever G, thus regulating the upward movement of lever H and, consequently, the movement of the pawl at the end of each stroke. The automatic feed will continue at each reversal until the shield M (which is attached to head N) intercepts pawl P and prevents it from engaging the ratchet wheel W. The feed then stops automatically.

The amount that the grinding wheel moves inward before the feed is automatically disengaged, depends upon the distance between the end of shield *M* and the tooth of pawl *P*. Each time the table reverses, this pawl rotates ratchet *W* one or more teeth and this feeding movement continues until shield *M* moves around and disengages the pawl, as previously mentioned. As a movement of one tooth represents a reduction in the diameter of the work of 0.00025 inch, the automatic feed can be set for grinding very close to a given size by varying the distance between the disengaging shield and the pawl. The feed can be set to give the full amount at each end of the stroke or any part of the full amount at either end, by adjusting the regulating screws *F*. The feed on this particular machine can be varied from 0.00025 inch to 0.004 inch at each reversal of the table. These feeds seem like very small amounts, especially when compared with the cuts taken on turning or planing machines, but the grinder is a precision machine used for producing fine, accurate surfaces and it is not adapted to taking deep cuts. With a modern high-power machine, however, metal can be removed with considerable rapidity.

The automatic cross feed is a great advantage, especially when grinding a large number of duplicate parts, as it prevents grinding them too small, and makes it unnecessary for the operator to be continually measuring the diameter of the work. The automatic feed is also desirable because it moves the wheel inward an unvarying amount at each reversal. This regularity of the feeding movement increases the "sizing power" of the grinding wheel. In other words, the wheel maintains its size for a longer period and the wear is more uniform. Of course, all grinding operations are accompanied by more or less wheel wear which has to be compensated for (as will be described later), although the amount of wear is surprisingly small when the wheel and work rotate at the proper speeds.

Miscellaneous Features

The headstock *H* (Fig. 2) is held to the table by bolts which slide in a T-slot, and the footstock *F* is clamped by the lever shown, so that the distance between the centers can be varied to suit the length of the work. The spindle and upper part of the headstock can be swiveled about a vertical axis for grinding flat disks or taper work, and the angular position is shown by degree graduations on the circular base. The spindle of the footstock is not screwed rigidly against the end of the work, as in the case of a lathe, but it is held in position by a strong spring. By means of this spring, a firm, even pressure is applied to the center, and, in case the work expands from the heat developed in grinding, the center yields and the part being ground is not distorted.

The usual method of grinding a cylindrical part is to rotate it on two "dead centers," both centers remaining stationary. The object of grinding work while it revolves on stationary centers is to secure accuracy, for then any slight error which may be in the spindle bearings is not reproduced in the work. If center *C* were rotated with the work, as in the case of a lathe, any eccentricity of the center would result in inaccurate grinding. Therefore, when grinding cylindrical parts on centers, the spindle is locked by a pin *P* which engages a hole in the flange of pulley *N*. Pulley *B*, which rotates freely around the spindle, carries a driving dog and rotates the work. For some classes of grinding, as, for example, when grinding parts held in a chuck attached to the spindle, it is necessary to rotate the spindle. Lock-pin *P* is then withdrawn and a belt from the overhead driving drum is connected with pulley *N*.

The upper part of the work-table can be set at an angle for taper grinding. This upper swiveling table is normally held to the lower member by bolts at each end. When these are loosened, the table can be turned a limited extent about a central stud, by means of adjusting

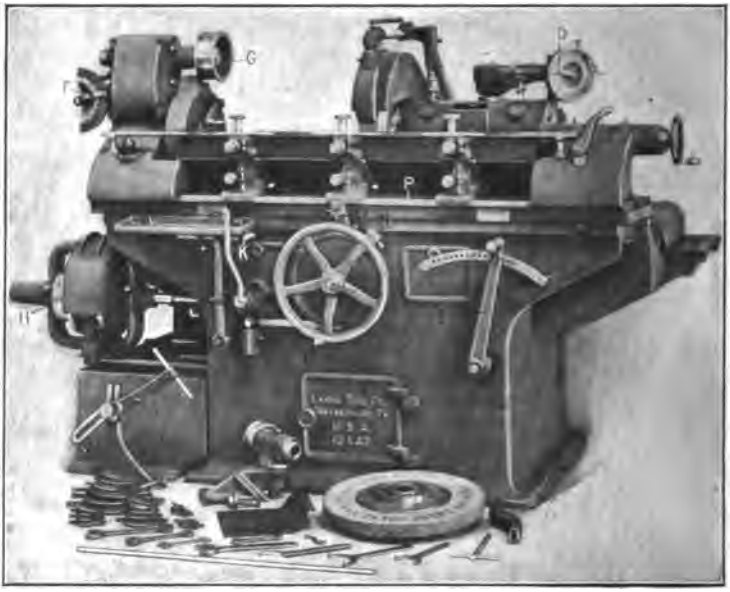

Fig. 4. Landis Plain Grinding Machine

screw *M*. There are two sets of graduations on the end of the swiveling table, one reading to degrees and the other giving the taper in inches per foot. When the swivel table is set at an angle, the headstock and footstock centers remain in line but are at an angle with the ways of the bed or the line of motion. For ordinary cylindrical grinding, the wheel-stand slide is set at right angles to the ways. On a grinder of this type, the wheel slide can also be set at an angle when necessary for grinding parts having a steep or abrupt taper.

Another feature of the cylindrical grinder which should be referred to is the provision made for supplying cooling water to the wheel when grinding. At the point where the wheel is in contact with the work there is considerable heat generated; consequently a cooling medium is very essential when grinding parts which revolve upon the centers, in order to maintain an even temperature. When water is not used, the part being ground tends to bend towards the wheel owing to the higher degree of heat and resulting elongation on the grinding side; in other words, its axis will be continually changing, and, obviously, inaccuracy will be the result. The apparatus for supplying the water consists of a small pump of the fan type which operates in a tank at the rear. The water is conveyed to the grinding wheel through a hose and pipe *O*, and plays on that part of the work being ground.

Cylindrical Grinding Machine of the Plain Type

Cylindrical grinding machines, like milling machines, are divided into two general classes, known as plain and universal grinders. The first type is used for grinding work in large quantities, which varies comparatively little in form, which means that it is essentially a machine for manufacturing purposes. The general construction of the universal grinder is similar to that of the plain grinder, but it differs

Fig. 5. End View of Landis Grinder, showing Automatic Cross-feed Mechanism

from the latter in having certain special features and auxiliary attachments which adapt it to a more general or universal class of work. The principal difference between the universal and plain types, as far as the construction of the machine itself is concerned, is as follows: The wheel slide of a universal machine can be swiveled with relation to the travel of the table; the headstock can also be set at an angle, and provision is made for revolving the spindle for grinding parts that are held in a chuck or otherwise. With a plain machine the wheel slide is permanently set at right angles to the table travel and the headstock cannot be swiveled. The machine shown in Fig. 2 is a universal type, whereas a plain grinder is shown in Fig. 4. These machines differ considerably in their construction because they are different makes. Plain and universal machines of the same make, however, are practically the same except for the changes referred to, unless one is much larger than the other.

The machine illustrated in Fig. 4 operates by traversing the grinding wheel along the work which rotates in a fixed position, as indicated by the diagram *B*, Fig. 1. The travel of the wheel carriage is regulated,

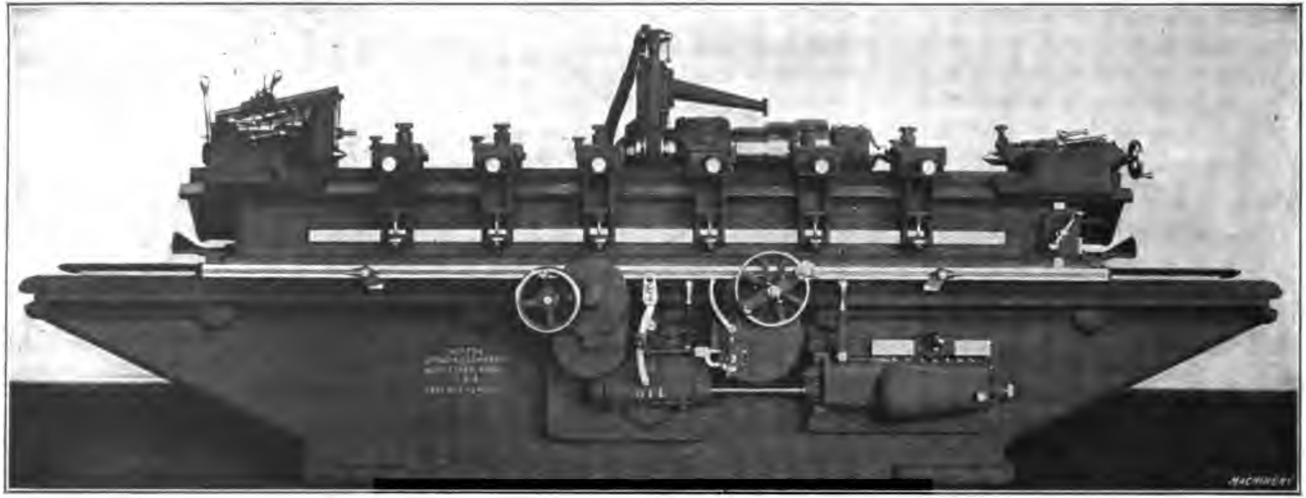

Fig. 6. Norton Cylindrical Grinding Machine of the Plain Type

for work of different lengths, by varying the position of the dogs *N*, which are mounted on a wheel or circular rack. On the periphery of this wheel worm-teeth are cut, and the dogs are held in any desired position by worms which may be lifted out of engagement when the dogs are to be moved a considerable distance. The tappet *O* against which these dogs strike, thus reversing the movement of the carriage, can be swung out of the way when it is desired to let the wheel travel beyond the reversing points. The amount that the wheel carriage moves longitudinally per revolution of the work, or its side traverse, is regulated by changing the position of lever *I*. The lever *J* is used for reversing the carriage travel at any point, by hand, while the traverse movement is started or stopped by lever *K*. When it is desired to move the carriage longitudinally by hand, the wheel *L* is used. The platen *P* can be swiveled for grinding taper work, the same as with a universal machine. The power for traversing the wheel carriage is obtained from a belt operating on pulley *H*, and the work is rotated by a belt connecting with pulley *G*. The work speeds are varied by shifting lever *F*.

The grinding wheel is moved to or from the work by the handwheel *D*. In conjunction with this handwheel there is an automatic cross feed which may be set to advance the wheel at each reversal of the carriage on which the wheel is mounted. This feed is effected by the pawl *A* (Fig. 5) which meshes with ratchet teeth in the periphery of the wheel *D*. Provision is made for automatically disengaging this feed when the wheel has ground any predetermined amount from the work. This is accomplished by a movable ring *B*, mounted on the handwheel and having a knock-out cam *C*, which engages a pin on the feed pawl *A*. When setting this feed to grind a given amount, the wheel is first brought into contact with the work, by turning the handwheel *D*; the ring *B* is then moved around until the cam *C* is against the pin on pawl *A*. When the machine makes its first stroke, the pawl is disengaged from the ratchet. The wheel should then be allowed to pass over the work until it has practically ceased cutting, when the traverse should be stopped, say at the footstock end. The diameter of the work is next measured carefully with a micrometer. The thumb-latch *E* is then pressed against its stop four times for each 0.001 inch reduction in diameter required. As this thumb-latch has attached to it a spring pawl engaging the ratchet teeth on the wheel *D*, the ring *B*, with its knock-out cam, is moved away from the feed pawl *A* an amount equivalent to one ratchet tooth each time the latch is pressed. When the grinding is continued, the cam gradually moves backward and finally disengages the feed pawl. The amount of feed is regulated by adjusting screw *F*.

Large Grinding Machine of the Plain Type

Fig. 6 shows a large grinding machine of the plain type which will grind work up to 96 inches in length. This machine has a moving work-table and the grinding wheel revolves in a fixed position, except for the crosswise feeding movement at each end of the stroke. The wheels used in this machine are 24 inches in diameter and have a width of 2 inches. The wheel slide is fed forward either by a handwheel or automatically, and the automatic feed can be set for grinding a given amount. The rotative speed of the work can be changed by shifting the belt on the driving cone pulley of the headstock. The rate of table traverse can also be regulated to give a coarse feed for removing stock rapidly or a finer feed for finishing. The mechanism seen at the front of the machine includes the automatic cross feed, and the table speed-changing mechanism. There are also hand-wheels for adjusting the table longitudinally and the grinding wheel in a crosswise direction. The particular machine illustrated is equipped with six steadyrests which are used for supporting the work and to prevent vibration. The number of rests used in any case depends upon the length of the part being ground.

CHAPTER II

CYLINDRICAL GRINDING OPERATIONS

As an example of grinding, suppose a rather short shaft is to be ground cylindrical and to a diameter somewhere between 2.050 and 2.0495 inches, there being an allowable variation in size of 0.0005 inch. Before beginning to grind, a wheel should be selected that is suitable for the part to be ground. When grinding, the work must also be rotated at the proper speed in order to minimize the wheel wear and secure a well finished surface. The points to be considered when selecting the wheel and adjusting the work speed, have been referred to separately in Chapter III, to avoid confusion. We shall assume that a wheel of the proper grade and grain has been mounted on the spindle of the grinder and that a machine similar to the one shown in Fig. 2 is to be used. We shall also assume that the work has been rough turned in a lathe to within about 0.010 inch of the required size.

The headstock *H* and footstock *F* are first set the required distance apart and then the work is placed between the centers with a driving dog attached to the headstock end, as illustrated in Fig. 7. The same center holes upon which the part was turned, are also used when grinding, and they should be carefully cleaned before placing the shaft in the machine. The centers should also be oiled, because, as previously mentioned, work of this kind rotates upon the "dead" centers of the machine, which remain stationary in order to secure greater accuracy. When the shaft is in place, the reversing dogs *J* and J_1 are set to give the table the right length of stroke. The travel should be reversed when a small part of the wheel face has passed the end of the piece being ground. If the stroke is too long, more time will be required for taking a cut than is necessary.

As the part is to be ground cylindrical or straight, the swivel table *A* should be set to the zero position. The headstock *H* must also be set to zero, as otherwise the centers will not be in alignment. It should be remembered that the graduations are only intended to give an approximate setting, and when accuracy is required, it is necessary to test the work by using a micrometer or gages. This test is made by first taking a trial cut and then measuring the diameter of the work at each end. If there is any variation, the table is turned slightly in whatever direction may be required to produce a cylindrical surface, by using the fine adjusting screw *M*, Fig. 2.

Setting the Automatic Feed

When starting a cut and setting the automatic feed, the grinding wheel is moved in by hand until it is almost in contact with the work. The stroke of the table is then stopped by pushing in knob *Q*, (with this particular machine) and pawl *P* is placed into engagement with the

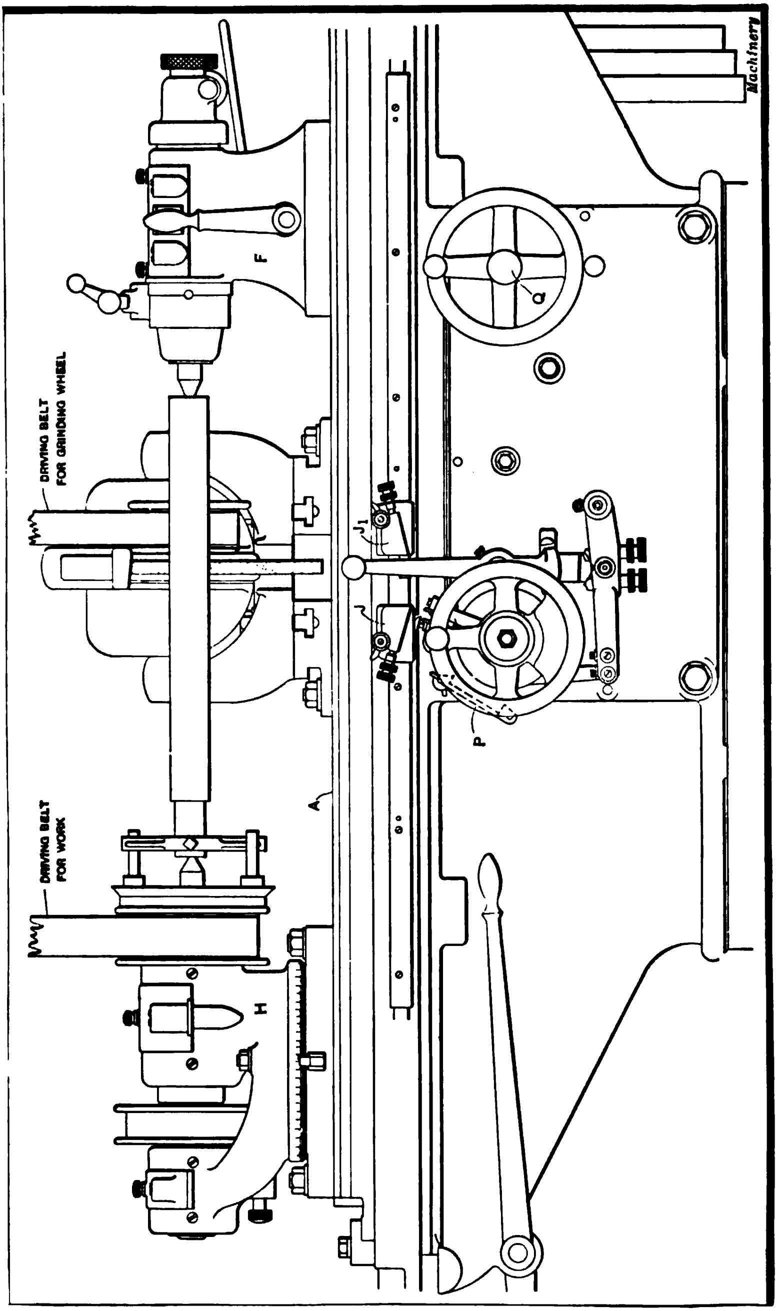

Fig. 7. Type of Machine illustrated in Fig. 2, arranged for Grinding a Cylindrical Shaft

ratchet wheel. The latch *O* (see Fig. 3) is then raised and the head *N* moved around the periphery of the ratchet wheel until the point of shield *M* has just passed the tooth occupied by the pawl, so that the latter rests upon the shield. After the table stroke is again started, thumb-latch *T* is pressed until the grinding wheel begins to cut. When the surface is ground true, the table is stopped when the grinding wheel is at the footstock end, and the diameter of the part ground is measured with a micrometer. The thumb latch *T* of the automatic feed is then pressed once for each quarter of a thousandth to be removed. To illustrate, suppose the diameter, after the surface has been trued, is 2.057 inch. Then there would be 0.007 inch stock to remove (2.057 — 2.050 = 0.007; hence, the latch would be pressed twenty-eight times, thus moving shield *M* far enough away from the feed pawl to allow the latter to continue feeding until 0.007 inch has been ground away.

When the feed has been set, the table traverse is again started and the grinding continued until the feed is disengaged. The wheel should then be stopped at the footstock end, as before, when the density of the sparks thrown off by the wheel have diminished somewhat and are about the same as for the final cut taken prior to the first measurement. If a suitable wheel has been used and the work rotated at the proper speed, the diameter should be very close to 2.050 inch, because, in this case, a comparatively small amount has been ground away, and, consequently, the wheel wear would be almost negligible. On the other hand, where it is necessary to remove considerable stock, the diameter of the work might be somewhat above the size for which the automatic feed was set, owing to the wear of the grinding wheel. After the amount of wheel wear for removing a given amount of stock is determined, the automatic feed can be set to compensate for this wear, when grinding a duplicate part. For example, if the diameter of the work were 0.001 inch over size, the latch *P* would be pressed four times or once for each quarter thousandth reduction required, and the grinding continued until the feed was again automatically disengaged. After this disengagement takes place, the traversing movement of the work should be continued until the wheel has practically ceased cutting, as shown by the decrease in the shower of sparks.

By noting the sparks and then stopping the machine when the volume or density is practically the same for the final cut, duplicate parts can be ground to a given diameter within close limit; in fact the shower of sparks thrown off by the grinding wheel is a very convenient and sensitive indication of the depth of the cut, and, with a little practice, it is possible to gage the cut to within very close limits by this method. An interesting experiment was made to determine what the depth of a cut would be when the sparks were just visible. A hardened steel gage was ground very carefully and, when taking the final cut, the work was traversed past the wheel until no sparks were visible. The exact diameter of the gage was then found by using a measuring machine, after which the gage was again placed in the grinder and the wheel was fed forward very slowly until sparks were just visible. The gage was then traversed past the wheel, as before, until all the sparks had disappeared. Then by again measuring the diameter, it was found that a reduction of 0.00001 inch had been made.

One not experienced in grinding machine operation should become familiar with the relation between the shower of sparks thrown off by the wheel and the depth of the cut, so that a given amount of stock can be ground away without wasting too much time in measuring. It is well for the inexperienced operator to note the density of the sparks when cuts of a known depth are being taken. With a little practice, one can judge the depth of a cut by this method with considerable accuracy.

When one shaft is ground and another is to be inserted in the machine, pawl *P* is disengaged and handwheel *L* is turned to the right about one revolution (without changing the position of shield *M*) in order to move the wheel away from the work. The latter is then removed and replaced by a rough shaft. When the new blank is in position, wheel *L* is turned to the left until the grinding wheel begins to cut. Then pawl *P* is again placed in mesh with the ratchet wheel, which causes the automatic feed to operate as previously described.

While the automatic feed will enable parts to be ground to a given diameter within close limits, this diameter should, of course, always be measured either with a micrometer or by the use of a fixed gage. As previously intimated, the accuracy of the automatic feed for grinding to the diameter for which it is set, depends upon the amount the wheel wears, and the wheel wear, in turn, is governed by the "grade" of the wheel and the surface speed of the work. When a wheel of the proper grade is used and surface speeds of the wheel and work are correct, the wear is surprisingly small and, in some instances, quite a number of duplicate parts can be ground without compensating for the wheel wear.

Taking Roughing and Finishing Cuts

The exact method of procedure when grinding cylindrical parts often depends on the number of pieces to be ground and their shape. A single shaft having a diameter of, say, 2 inches and a length of 12 inches, could be ground by simply placing it between the centers with a dog attached and proceeding as described in the foregoing. On the other hand, if the shaft were long and flexible, it would have to be supported by work-rests to prevent deflection and vibration. A single shaft might also be finished by taking a number of light cuts which would be, practically, a succession of finishing cuts, whereas a number of pieces would be first "rough" ground and then finished.

The difference between roughing and finishing in the grinder is as follows: For roughing, a fast side traversing movement is used that is almost equal to the face width of the wheel, and comparatively deep cuts are taken, whereas, for finishing, the side feed and depth of cut are reduced in order to obtain a fine, smooth finish. The rotative speed of the work is also changed for finishing; in some shops the speed is increased, whereas in others it is diminished. This variation in practice is doubtless due to the use of different machines and grinding wheels. The method commonly employed for ordinary machine grinding is to use a coarse, free-cutting wheel and a work speed that is fast enough to keep the wheel "sharp" and permit rapid grinding. The same wheel is then used for finishing after it has been trued with the diamond, and the work speed is reduced to get a finer finish than would be possible with the higher speed used for roughing. The advantage of rough grinding and then finishing by a separate operation, is that the stock can be removed more rapidly by the roughing operation. It is necessary, however, to true the wheel face before taking the finishing cut and when grinding a single part, it might be better to simply take a number of light cuts in order to keep the face of the wheel true.

The following example will serve to illustrate one method of handling a grinding machine when the parts are first rough ground close to size and then finished by light cuts. Suppose there are a number of cylin-

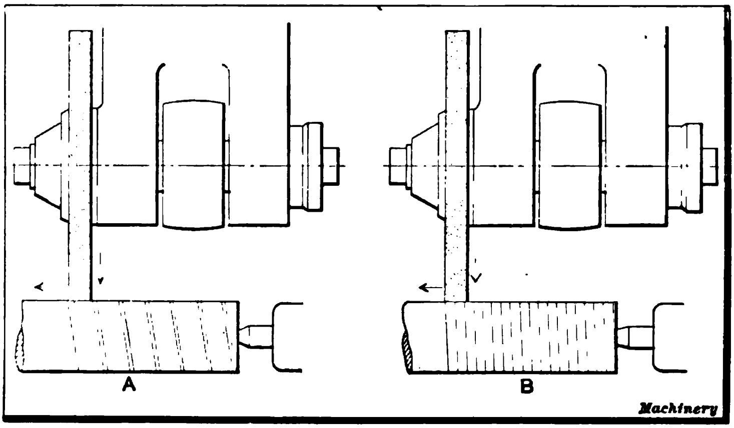

Fig. 8. (A) Wheel with Excessive Side Traverse or Feed. (B) Wheel feeding laterally a Fraction of its Width for each Revolution of the Work

drical rods which have been rough turned in the lathe to within 0.020 inch of the finish size, and are to be ground to a diameter of 2 inches and be given a good finish. Before beginning to grind, a number of steadyrests should be clamped to the table of the machine and adjusted against the work to prevent the latter from springing and vibrating. These rests are made in several different styles and the number that should be used depends on the length of the work. This matter of supporting the work is very important, and will be referred to subsequently. The grinder is next set to the right length of stroke, and the feed of the table (or side traverse of the wheel) as well as the work speed, should also be properly adjusted.

The wear of a grinding wheel, as previously mentioned, depends very much on the surface speed of the work, the wear increasing as the work speed is increased. Hence it is the modern practice to use a comparatively slow work speed in conjunction with a coarse side feed of the wheel when it is important to grind rapidly; that is, instead of feeding the wheel a distance equal to only 1/8 or 1/4 its width per revolution of the work, it is given a side feed that is only a little less than the full width of the wheel face. Comparatively wide wheels are also used in modern machines, so that the surface being ground is covered quite rapidly.

Suppose the work is rotated fast enough to give a surface speed of 25 feet per minute and the fastest side feed is engaged in order to determine by trial what combination will give the best results. When the wheel is brought into contact with the work, if it leaves coarse, spiral feed lines (as shown at *A*, Fig. 8) having a greater pitch than the width of the wheel, the side feed should be reduced until the wheel does not leave any unground surface. In other words, the side feed should be somewhat less than the wheel width in order to grind a

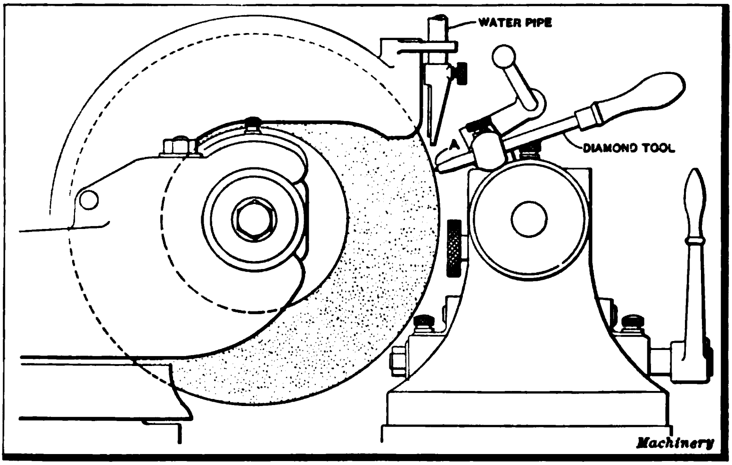

Fig. 9. Truing Face of Grinding Wheel by use of Diamond Tool

smooth surface, free from ridges. On the contrary, if the fastest side feed only moves the wheel laterally a fraction of its full width (as indicated by the narrow feed lines at *B*) the work speed should be reduced until the side feed is nearly equal to the wheel width. Owing to the rapid side feed, the wheel will pass over the surface being ground in a comparatively short time, and by using a rather slow work speed, the wear of the wheel is minimized. This method of grinding is employed when using large machines, which have sufficient driving power to enable such broad cuts to be taken and are rigid enough to prevent excessive vibration. When a small light grinder is employed, it is not always feasible to take such wide cuts, owing to the lack of rigidity and driving power. The depth of the cut or the amount that the wheel feeds inward at each reversal, is also controlled by the power and rigidity of the machine used.

After the stroke, side feed and work speed have been properly adjusted, the feed mechanism is set to give the desired depth of cut. We shall assume that in this case a cut of 0.001 inch is to be taken at each reversal, which would reduce the diameter 0.002 inch for each passage of the wheel. As soon as the rough turned surface has been ground true, the wheel should be allowed to pass across the work without feeding it inward, until the sparks diminish somewhat thus showing that the wheel has practically ceased cutting. The diameter is then measured to find out how much stock must be removed by roughing. Suppose the diameter is 2.016 inch and we want to rough grind to within about 0.002 inch of the finish size or to a diameter of 2.002 inches; there would then be 0.014 inch to be removed by rough grinding, and the automatic feed would be set for this amount. The machine is then started and the grinding continued until the feed is disengaged and the wheel has practically ceased cutting as before. The diameter is then

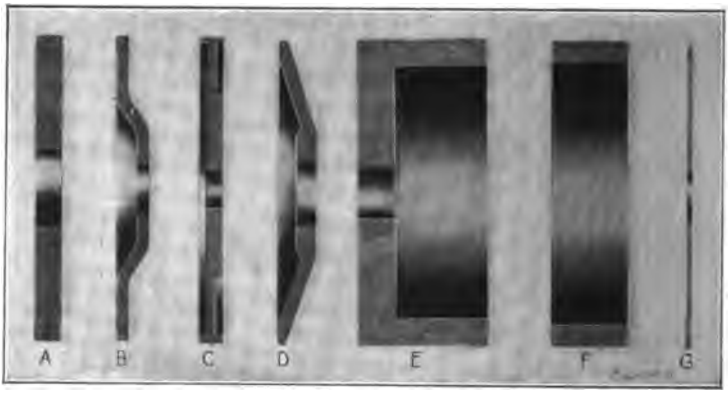

Fig. 10. Grinding Wheels of Different Shape

again measured and the difference between this measurement and 2.002 inch will show how much the wheel has worn. If the wheel wear should be excessive, it would be well to try a finer feed when grinding the next piece.

We shall assume that the rods are to be rough ground to a diameter somewhere between the limits of 2.0015 and 2.0025 inch, and that the diameter of the first piece was 0.002 or 0.003 inch over the maximum size when the automatic feed tripped. This stock should first be removed by putting on additional feed and then another blank should be placed in the machine and the roughing operation repeated, but with a reduced feed in order to diminish the wheel wear. By a little experimenting we should be able to find what combination would give the best results. All parts are then rough ground, and whenever the wheel has worn to such an extent that the diameter is greater than the maximum limit of 2.0025 inches, enough additional feed is "put on" to grind the next blank to the minimum roughing limit of 2.0015 inches. After all of the pieces have been roughed out, in this way, the wheel should be trued for finishing, as explained in the next paragraph. The finishing cuts are then taken after the side feed of the wheel and the surface speed of the work have been reduced, to obtain a smoother finish.

As little stock is removed when finishing, it should be possible to grind a number of parts without compensating for wheel wear.

Truing a Grinding Wheel

The grinding wheel should never be used unless it runs true and has an even bearing on the surface of the work. In other words, the face of the wheel should be parallel with the surface being ground, and it is especially important to have a true, even wheel face when taking a finishing cut. The only satisfactory method of truing a wheel is by the use of a diamond tool. This tool is clamped to the footstock of the machine (as shown in Fig. 9), or in a special holder attached to the table, and the stroke is adjusted so that the diamond point *A* will just clear the wheel face on each side. The wheel, which should revolve at the speed required for grinding, is then trued by bringing it into contact with the diamond as the latter travels back and forth. Very light cuts should be taken and water used to keep the diamond cool. The diamond tool should be held with the point quite close to the clamp or point of support in order to reduce vibration and give a smooth accurate wheel surface. Diamond tools usually have round shanks to permit clamping them in different positions so that the wear on the diamond will not be confined to one to two points. When truing the wheel, light cuts should be taken and the diamond traversed across the face with a uniform speed. The number of times that the wheel has to be trued depends upon the character of the work and the kind of wheel used. If it is necessary to remove considerable stock, the wheel may have to be trued before taking each finishing cut, provivded the roughing and finishing operations are performed successively. When a number of duplicate parts are ground, this is avovided by first rough grinding them all and then truing the wheel once for finishing the entire lot, or as many parts as the wheel will grind satisfactorily.

Shapes of Grinding Wheels

Grinding wheels are made in a great many different shapes and sizes for use in different types of grinding machines, and on different classes of work. A plain disk-shaped wheel *A*, Fig. 10, is used for most cylindrical grinding. The diameter and width of the wheel, for ordinary work, depends, principally, upon the size and power of the machine. The type of wheel shown at *B* is intended for grinding up to a large shoulder. It is mounted on the end of the spindle and is dished at the center, so that the retaining nut on the spindle will not project beyond the side of the wheel and strike the shoulder. Wheel *C* is especially adapted for facing the ends of bushings or small shoulders. When the wheel is used for end facing, the grinding is done by the side, which is recessed to reduce the contact area. The saucer-shaped wheel *D* is extensively used for grinding formed milling cutters, etc., especially on regular tool- and cutter-grinding machines. The cup wheel *E* is used for grinding flat surfaces by traversing the work past the end or face of the wheel. The cylindrical or ring-wheel *F* is also used for producing flat surfaces and grinds on the end or face. The cup wheel is attached directly to the spindle but the ring-wheel is held in a special chuck.

Thin wheels *G* are used for sharpening cutters, reamers, etc., or for cutting off stock. Grinding wheels are made in many other shapes, but most of them are modifications of the few styles referred to.

Rests or Supports for the Work

Practically all parts that are ground on centers should be supported by suitable work-rests or "steadies," as their use will permit taking deeper cuts with coarser feeds and also increase the "sizing power" of the wheel. When grinding long and slender parts, such supports are indispensable, and even for work which is short and rigid, rests are desirable to prevent vibration, which increases wheel wear and affects the quality of the ground surface. These rests or supports are fastened to the table of the machine and are equipped with shoes of hard

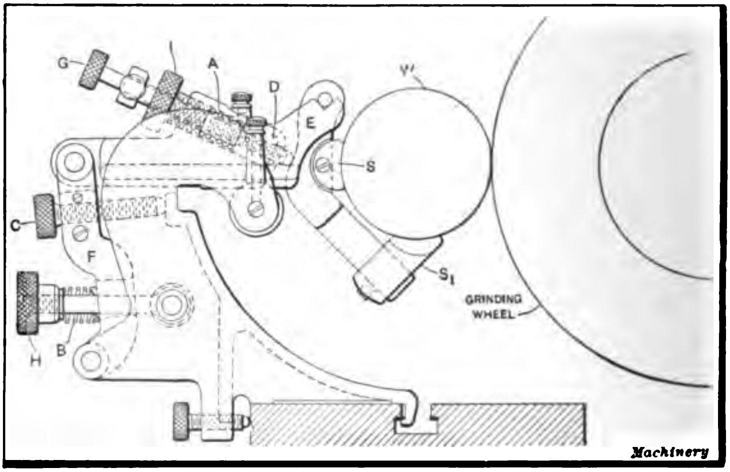

Fig. 11. Universal Back-rest for Supporting Work being Ground

wood or soft metal which bear against the piece being ground. The number of rests used, depends on the form and diameter of the work. According to a commonly accepted rule, the distance between each rest should be from six to ten times the diameter of the part being ground.

Work-rests are made in several different styles, and they may be divided into two general classes which differ in that one type is rigid and the other flexible. The rigid rest gives a positive unyielding support, whereas the flexible rest, as the name implies, can yield more or less, the supporting shoe being held against the work by springs. Most rigid rests must be readjusted by hand as the diameter of the work is reduced by grinding, whereas the shoes of the flexible type adjust themselves automatically after the rest is properly set. Then there is another form of rest which has spring tension but can be made rigid when desirable, and still another type is so designed, that the supporting shoes are adjusted automatically but the support is unyielding.

A design of work-rest that has been extensively used, is shown in Fig. 11. This is a spring or flexible type and is called a universal back-rest. The work W is supported by the shoes S and S_1 which are held yieldingly but quite firmly in position, by means of springs located at A and B. Adjustable stops C and D are provided to prevent the springs from forcing the work against the wheel after the part has been ground to the required diameter. When these stops are correctly set, no pressure is exerted by the springs upon the shoe after the work has been reduced to the finished size. Provision is also made for regulating the pressure of the springs to adapt the rest to either light or heavy work. After the stops are once set, duplicate parts can be ground to the same diameter without readjusting the rests.

Fig. 12 shows how four of these back-rests are used for supporting a long shaft which is being ground. After they are clamped to the table

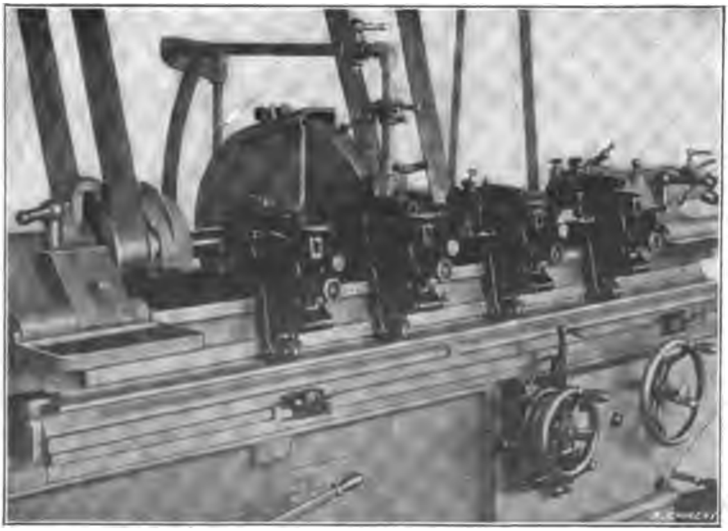

Fig. 12. Grinding Machine equipped with Four Universal Back-rests

of the machine, the shoes of each rest are adjusted, independently, to bear properly against the shaft. The way this adjustment is made will be more clearly understood by again referring to Fig. 11. The holder for the shoes has trunnions at the top which rest in V-shaped notches formed at the front end of frame E. The latter is connected at the rear with a link F which is pivoted at its lower end. Spring B tends to push frame E forward, and the extent of this forward movement is regulated by stop-screw C. In addition to this motion, the shoe holder can also be swiveled about its supporting trunnions by spring A. This spring forces screw G against the holder, and the movement of the screw is regulated by stop D. From the foregoing, it will be seen that spring B forces shoe S against the rear side of the work, whereas spring A forces shoe S_1 in an upward direction. Moreover, the pressure of the shoes can be arrested (after the work has been ground to a given diameter) by setting stops C and D in the proper position.

In adjusting a back rest, screw *G* is turned out far enough to allow the shoe to clear the work, and nut *H* is loosened to entirely relieve the tension of spring *B*. Stop screw *C* is also turned back, and nut *I* is screwed in to slightly compress spring *A*. Screw *G* is next turned forward to bring the shoes into contact with the work. The shoes are then held lightly in position and screw *C* is turned until the end just touches its stop or seat. With screw *C* in this position, both shoes should bear evenly against the work. Spring *B* is next compressed somewhat by turning nut *H*. The combined pressure of screws *A* and *B* should be only sufficient to resist the wheel pressure when taking the final cut, and also to prevent vibration.

When grinding the trial piece for adjusting the work-rests, the screws *G* on the different rests are used to keep the shoes in contact with the

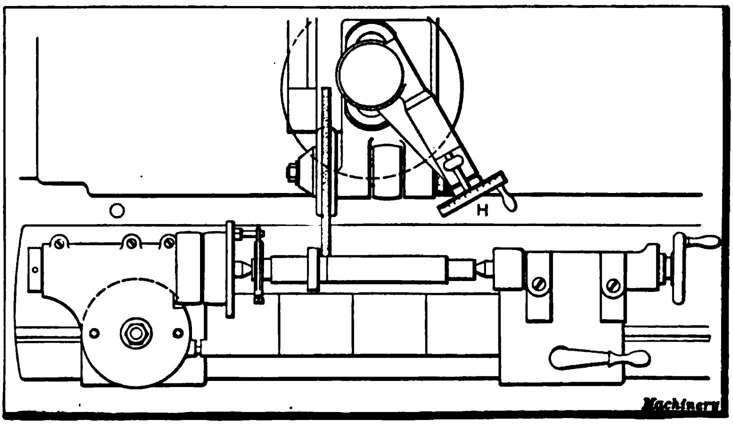

Fig. 18. Grinding Close to a Shoulder—Plan View

work, and the diameter at various points is regulated by adjusting stop-screws *C*. When the rests are correctly set, screws *G* are only adjusted to compensate for the wear of the shoes, and screws *C* are used for the delicate diameter adjustments. When short stiff pieces are being ground, the cylindrical form is obtained from the machine centers, but when the work is long and flexible, the control of the cenetrs is limited and they only steady the ends; consequently, in order to grind a slender shaft or rod cylindrical from one end to the other, it is necessary to rely on the adjustment of the work-rests.

Before adjusting the rests it is the practice in some shops to grind true "spots" for each of the supporting shoes. In order to do this, the rests are first placed in their respective positions and then the machine table is moved by hand until one of the rests is opposite the grinding wheel. The work is next "spotted" or trued by feeding the wheel in against the revolving work, while the table remains stationary. The diameter of the surface ground in this way should be within, say 0.002 inch of the finished size, although a larger allowance may be needed in certain cases. This "spotting" operation is repeated by successively placing each work-rest in front of the grinding wheel and proceeding as described. When spotting a very flexible shaft, it is well to first grind a spot for the work-rest nearest the footstock and then place this rest in position. The rest nearest the headstock is then located in the same manner and in this way a support is provided for the work, while spotting for the rests in the center of the shaft. The practice of grinding spots is not to be recommended for ordinary work, and, in many shops, parts are never "spotted" prior to grinding, even when they are ground from the rough.

There is a difference of opinion among grinding machine operators and manufacturers regarding the relative merits of the rigid work-rest and the flexible or spring type. Some advise the use of spring-rests for supporting light slender work, and the fixed or rigid form when grinding heavy stiff parts, whereas others advocate the use of rigid rests for

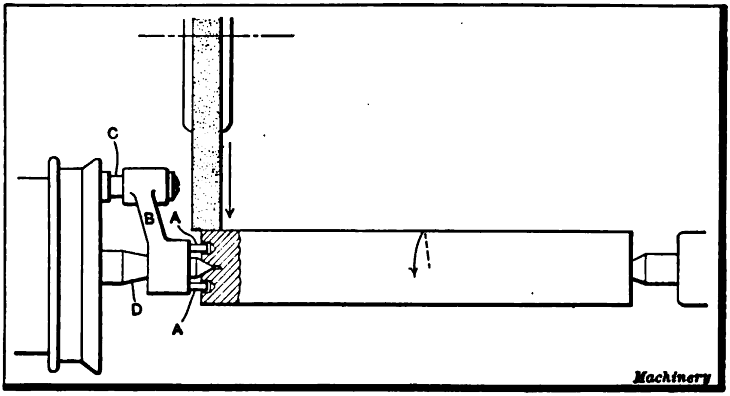

Fig. 14. Special End-driving Dog applied to Shaft for Grinding entire Length in One Operation

light as well as heavy work. It is also the practice in some shops to use spring-rests almost exclusively. Satisfactory results can doubtless be obtained with each type, under favorable conditions. When the work is light and flexible, spring-rests are often used in preference to the fixed form. On the other hand, when a heavy rigid piece is being ground, solid unyielding rests are commonly employed to provide as solid a support as possible in order to absorb vibration and prevent chattering.

When chattering is caused by vibration of the work, owing to improper supports, the surface left by the grinding wheel has minute, parallel ridges which spoil the finish; moreover the vibration which produces the chatter marks causes excessive wheel wear and greatly affects the efficiency of the grinding operation. Chatter marks are also caused by defects in the machine itself, in which case they have a spiral form. Sometimes the wheel spindle vibrates either because it is too light or the bearings are too loosely adjusted. Chattering is also produced by an unbalanced or improperly trued wheel, and the jar from a large stiff belt-joint will also set up vibrations that are copied on the work in the form of chatter marks. In some instances, chattering can be eliminated by a slight change in the work speed or by using a wheel of different grade; but, in other cases, the remedy is not so simple, especially when the trouble is caused by the design, construction or mounting of the machine.

Grinding Close to a Shoulder

Occasionally it is necessary to grind close to a shoulder, as indicated in the plan view, Fig. 13. This can be done by setting the wheel close to the shoulder with the hand adjustment and then feeding it straight in until the diameter next to the shoulder is reduced to the finished size or slightly above it; the remaining surface between the shoulder and the end of the work is then ground by using the power traverse movement in the usual way. The object in first grinding close to the shoulder is to provide a clearance space so that the wheel does not have

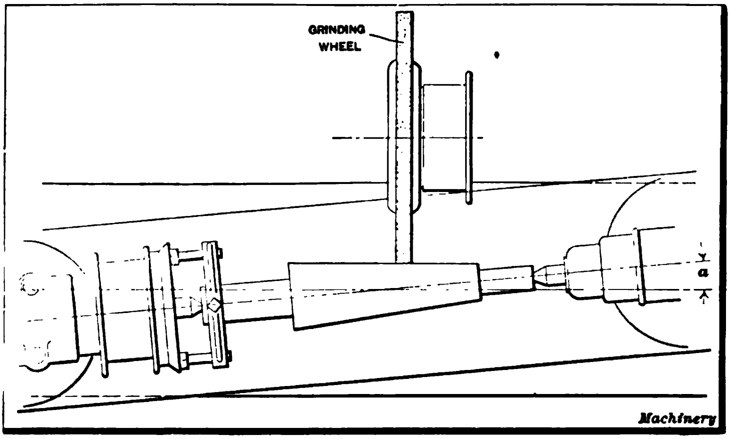

Fig. 15. Taper Grinding by Swiveling Platen to Required Angle

to travel close up to the shoulder. It is also possible to grind close to a shoulder without providing a clearance space, by carefully adjusting the stroke dogs to reverse the table when the wheel is almost against the shoulder. When this method is employed, the dog which controls the reversal at the shoulder end of the travel, must be accurately located to prevent the wheel from striking, and it may be necessary to adjust this dog for each piece ground, because the center holes usually vary more or less in depth and any such variation would change the position of the shoulder with relation to the wheel. The result is that considerable time is wasted in adjusting the stroke, and for that reason the first method referred to is preferable. With the second method, the surface next to a shoulder is also likely to be left a little large unless the wheel is allowed to dwell for a short time at the extreme end of the stroke. With the machine illustrated in Fig. 2 this dwell can be obtained by pushing in the knob located in the center of the handwheel *I*. The table traverse is again started by pulling out this knob. The machine shown in Fig. 13 is similar to the one shown in Fig. 4, but differs in that it is a universal type.

Special End-driving Dog

Sometimes it is desirable to grind a straight cylindrical shaft from one end to the other at one setting. Of course this cannot be done when a regular driving dog is used, because the latter will interfere with the movement of the grinding wheel. Fig. 14 illustrates a special end-driving dog which is sometimes used in cases of this kind. This dog has pins *A* which engage holes drilled in the end of the work. The arm *B* swings freely on pin *C* and has a hole which is larger than the machine

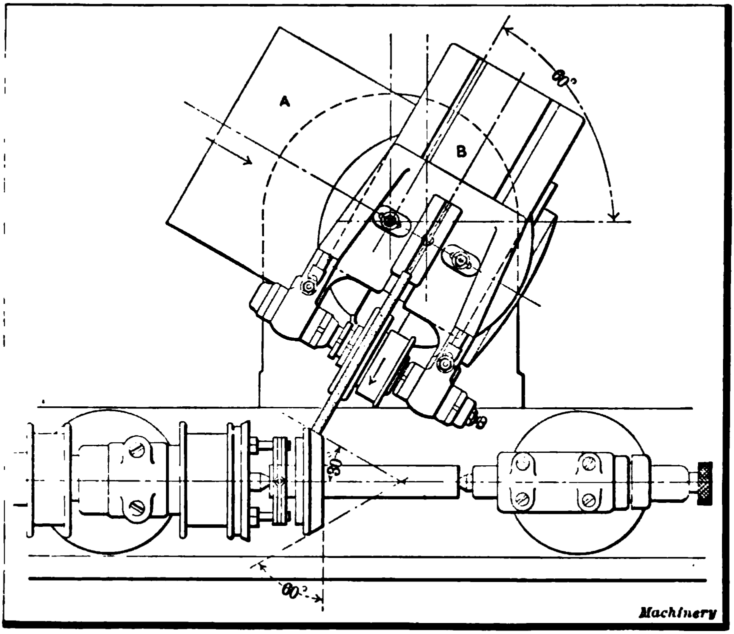

Fig. 16. Grinding Abrupt Taper by Setting Wheel-slide to Required Angle

center *D*, thus allowing it to turn on pin *C* until the driving pins *A* engage the holes on both sides. With this arrangement, the grinding wheel can move across the entire shaft, thus permitting the latter to be ground in one operation, instead of reversing it on the centers for grinding the driving or "dogged" end.

Taper Grinding

Taper parts are ground practically the same as those that are straight or cylindrical, provided the taper is not too steep or abrupt. The work is placed between the centers, as illustrated in Fig. 15, and the table is set to the required angle *a*, as shown by the graduations at one end. This adjustment locates the axis of the work at an angle with the table's line of motion; hence a taper is produced, the angle of which depends upon the amount that the swivel table is turned from its central or parallel position. There are usually two sets of graduations for the swivel table, one reading to degrees and the other giving the taper in inches per foot. The taper should be tested before the part is ground to the finished size, by using a gage or in any other available way.

The plan view, Fig. 16, shows how a taper surface is ground when the angle is beyond the range of the swivel table. The wheel slide *A* (which is normally at right angles to the table) is set to bring its line of motion parallel with the taper to be ground. The upper wheel stand *B* is also set at right angles to slide *A*, to locate the wheel face parallel with the taper surface. The table of the machine should be set in the zero position, so that the angular graduations on the wheel slide base will give correct readings with relation to the axis of the work. After adjusting

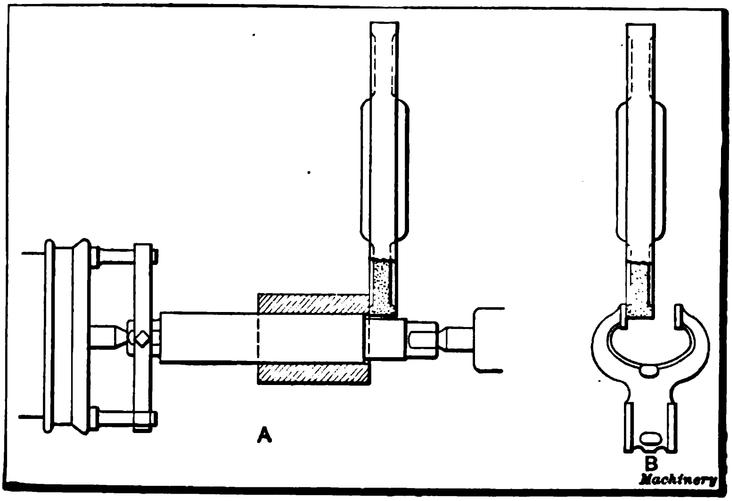

Fig. 17. Grinding with Side of a Recessed Wheel

the table to the proper longitudinal position, the grinding is done by moving the wheel across the taper surface by using the hand cross-feed, and the depth of each cut is regulated by slight longitudinal adjustments of the table. When the taper is tested, if any adjustment is necessary, this can be made by the table adjusting screw. Evidently an operation of this kind must be done on a universal machine, because the wheel slide of a plain type does not have the angular adjustment.

Parts having a double or compound taper can be ground at one setting, provided one taper is within the range of the swivel table. The latter is set for the smaller angle and the wheel slide for the greater angle, as indicated by the sketch *A*, Fig. 18. The wheel is set at right angles to the longest surface and one corner is beveled to suit the other surface. One part is then ground by traversing the table, and the other by moving the wheel slide. The wheel base, in this instance, should be set to an angle corresponding to the sum of the angles of both tapers, as measured from the axis. The sum of both angles, in the example illustrated, is 50 degrees.

Grinding with Side of Wheel

When it is necessary to grind bushings or sleeves, they are sometimes mounted on a mandrel as shown at *A*, Fig. 17. This view illustrates how the end of a bushing is finished by grinding with the side of the wheel. A wheel for end facing should be soft and porous and it should also be recessed on the sides (as shown by the sectional view) to reduce the working area. The grinding should be done by moving the work

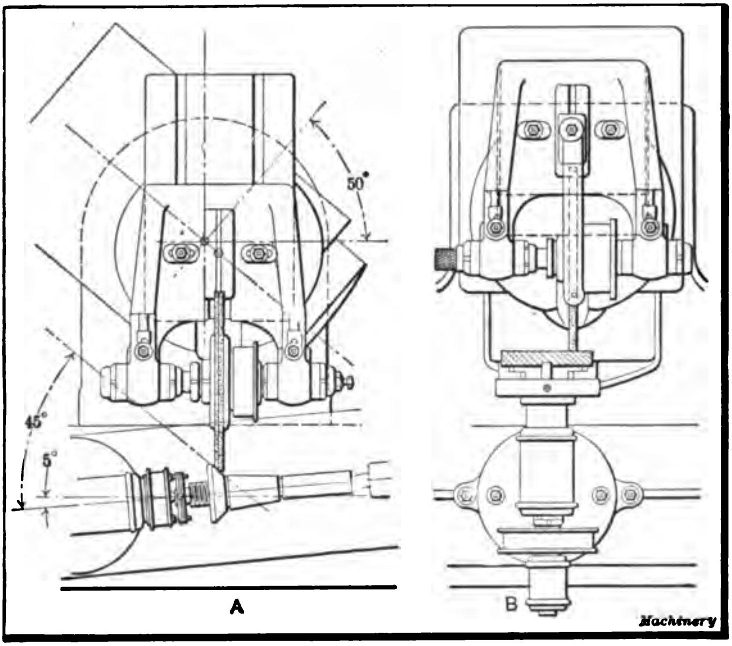

Fig. 18. (A) Grinding a Double Taper by Traversing both Platen and Wheel Slide. (B) Grinding the Side of a Disk

endwise against the side of the wheel, instead of traversing the wheel laterally. This method of facing the ends of cylindrical parts is only employed when the surfaces are quite narrow. Sketch *B* indicates how the jaws of a caliper gage are ground by the side of the wheel. The gage is held in a fixture attached to the table of the machine and the wheel is traversed across the face of the jaw being ground. It is necessary to traverse the wheel in this instance because the work is not revolving.

Use of the Universal Head

The headstock of the universal grinder is used for holding and revolving many parts, such as saws, milling cutters, and other pieces that cannot be revolved between the centers. Sometimes the work is held in an ordinary chuck screwed to the headstock spindle, and special collet chucks or fixtures are also employed, as well as magnetic chucks, where electric power is available. Sketch *B*, Fig. 18, illustrates how the side of a plain, flat disk is ground. The headstock spindle is set at right angles to the table, and the work, in this case, is held in a four-jawed chuck. When grinding, the wheel operates on only one side of the disk, and the automatic table traverse is used. If the surface must be flat it can be tested with a straightedge or by allowing the wheel to pass clear across the face and noting the density of the sparks on both sides. When the sparks show the same at all points the surface is flat within close limits. The fine adjusting screw for the table should be used for making adjustments. Obviously, concave or convex surfaces can be ground by setting the headstock to the required angle.

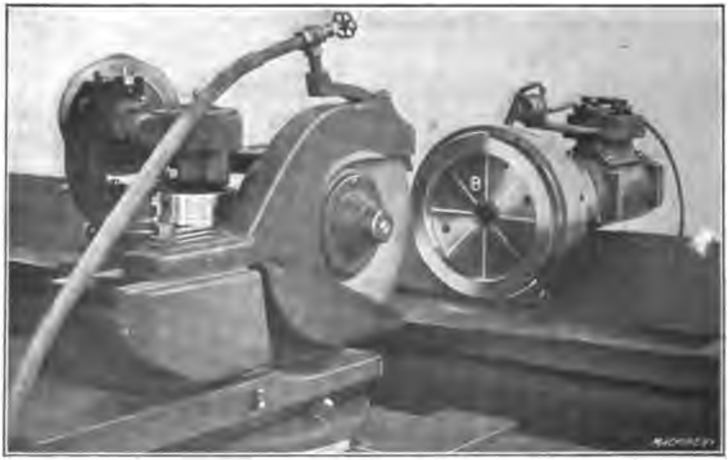

Fig. 19. Grinding Side of Steel Ring which is held by a Magnetic Chuck

Fig. 19 illustrates the use of a magnetic chuck attachment for face grinding. The operation is that of grinding the sides of a steel ring *A*. As these sides must be flat, the headstock spindle is set at right angles to the wheel spindle. The work is rotated by a belt (not in place) which passes over a pulley located just back of the magnetic chuck *B*. The current for magnetizing the chuck is conveyed through the wires and brushes shown. The wheels used for grinding flat surfaces should be of a softer grade than for cylindrical work, owing to the greater contact area.

Truing Grinding Machine Centers

Fig. 20 illustrates how a universal grinding machine is used to true its own centers. The headstock is set to an angle of 30 degrees, giving an included standard angle of 60 degrees, and the grinding is done by traversing the wheel across the conical surface. The tailstock center is ground first by inserting it in the headstock spindle, these centers being interchangeable. The table stroke should be adjusted so that the wheel overlaps the taper surface slightly on each side, and a copious supply of water should be used, when grinding, to prevent drawing the temper of the hardened centers. The centers of a plain grinder are inserted in a special fixture while being trued. This fixture is clamped to the table and holds the center at an angle of 30 degrees. It is very important to keep the centers in good condition, as otherwise parts ground upon them will not be accurate.

Preparation of Work for Grinding

The amount of stock that can economically be removed by grinding depends largely on the size and power of the grinding machine. The modern practice, when using heavy machines, is to reduce the work in a lathe to within somewhere between 0.015 and 0.030 inch of the required diameter and then finish by grinding. The lathe is simply used for roughing, and the stock is removed by taking one or more coarse

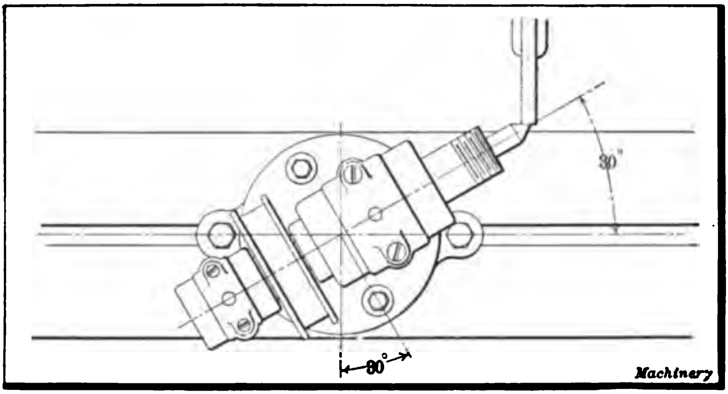

Fig. 20. Truing Conical Center of a Universal Grinder

cuts, leaving a rough surface on the work. When the diameter has been reduced to within say 0.025 inch of the finished size by turning, it is more economical to remove this stock by grinding than by taking a light finishing cut in the lathe. It is also practicable, in some cases, to grind bar stock from the rough without any preliminary turning operation, although most work is first turned. When using a light grinder the allowance for grinding must be comparatively small and is governed more or less, in any case, by the size and character of the work, as well as by the power and stock-removing capacity of the grinding machine.

Parts which have been hardened are occasionally so distorted by the hardening process that they cannot be finished to the required size. Straightening can then be resorted to, but this should not be done while the work is cold, as there is always a tendency for the piece to resume its original shape owing to internal strains, and even if properly heated, there is more or less danger of such distortion. When a hardened part must be straightened it should first be heated (though not enough to anneal it) and then straightened in a press. By proper annealing prior to the hardening process, this tendency to spring out of shape is often overcome. The annealing, which releases the internal strains incident to the rolling or forging operations, should take place after the outer surface has been removed in the lathe; then if the work runs practically true when tested, it can be machined to the grinding size, but if the piece is badly warped, it should be heated to a cherry red, straightened, and then annealed as before. Whenever possible, grinding should be done last, so that the work will not be marred or sprung out of true by other machining operations that may be performed later. Keyways in shafts, etc., should invariably be finished prior to grinding, as the removal of metal for the keyway from one side of the shaft will often distort the latter.

The machine itself should be carefully examined frequently, as its efficiency often depends upon a little intelligent care. The bearings, particularly of the wheel spindle, should be carefully adjusted to eliminate all lost motion, and the cross-slide for the grinding wheel should be thoroughly oiled so that it moves freely. The centers in the work should correspond to the angle of the machine centers and be carefully cleaned and oiled before the work is placed in position. When a grinding wheel is being mounted on the spindle, see that the central hole is a close but easy fit. If the diameter of the hole is about 0.005 inch large, the wheel will slide on without cramping, and it will not only have a good fit on the spindle, but an even bearing against the inside flange. Soft washers of blotter or rubber should be placed between the wheel and flanges on each side, as they compensate for any roughness in the wheel and distribute the clamping pressure evenly. The flanges should be tightened just enough to hold the wheel firmly, to avoid any unnecessary strain.

CHAPTER III

GRINDING WHEELS—WORK SPEEDS

If satisfactory work is to be done in the grinder it is absolutely essential that the grinding wheel be of a grade and grain which is adapted for the material to be ground. Grinding wheels are composed of a large number of grains or kernels of some suitable abrasive material, such as alundum, corundum or carborundum, which are held together by what is known as a bond. By varying the amount and composition of this bond, wheels of different grades are obtained. The term grade does not refer to the degree of hardness of the abrasive, but to the tenacity with which the bond holds the grit in place. A wheel from which the grit or cutting particles can easily be dislodged is called soft, and one which holds the particles securely is referred to as a hard wheel.

The degree of hardness or grade of a wheel is commonly denoted by the letters of the alphabet. According to one system the letter *M* represents a medium grade and the successive order of letters preceding and following *M* denote softer and harder wheels. For example, grade *E* is soft; grade *I*, medium soft; *M*, medium; *Q*, medium hard; *U*, hard; *Y*, extremely hard; whereas the intermediate letters indicate grades between those mentioned. Thus wheel *L* is one grade softer than *M*, and *N* one grade or degree harder. This method of grading wheels is not universal, as a standard system has never been adopted by the different manufacturers.

The grain or coarseness of a wheel is designated by numbers which indicate the number of meshes to the linear inch through which the kernels of grit will pass. To illustrate, a 36 grain means that the grains or cutting particles will pass through a sieve having 36 meshes to the linear inch. The combination of grade and grain is marked on the side of the wheel by using the letter for the grade and the number for the grain; thus a 36-M wheel is one having cutting material of No. 36 grain and a medium degree of hardness.

Selection of Wheel for Grinding

When selecting a grinding wheel there are several factors which must be considered. The grade and grain depend largely upon the character of the material to be ground and its degree of hardness. For example, machinery steel requires a harder wheel than hardened tool steel. The reason for this will perhaps be better understood if we think of a grinding wheel as a cutter having attached to its periphery an innumerable number of small teeth, for this is literally what the thousands of small grains of abrasive are. When the wheel is of the proper grade these small teeth or cutting particles are held in place by the bond until they become too dull to cut effectively, when they are torn out of place by the increased friction. Obviously these grains or cutters will become dulled sooner when grinding hard than when grinding soft steel; hence, as a general rule, the harder the material, the softer the wheel, and *vice versa.*

When a hard wheel is used for grinding hard material, the grit becomes dulled, but it is not dislodged as rapidly as it should be, with the result that the periphery of the wheel is worn smooth or glazed, so that grinding is impossible without excessive wheel pressure. Any undue pressure tends to distort the work, and this tendency is still further increased by the excessive heat generated. If the surface of the wheel becomes "loaded" with chips and burns the work, even when plenty of water is used, it is too hard.

Soft materials, such as brass, are ground with a soft wheel, which crumbles easily, thus preventing the wheel from becoming loaded or clogged with metal, as would be the case if a hard-bonded wheel were used. When a wheel is used which is too soft, the wear is, of course, greatly increased, as the particles of grit are dislodged too rapidly, and, consequently, the wheel is always "sharp." This means that the abrasive has not done sufficient work to become even slightly dulled, and the result is a rough surface on the work.

The area of the surface which is in contact with the wheel should also be considered when selecting the proper grade. For a given material the wheel should be softer as the area increases. To illustrate, a wheel of grade *N* might be suitable for grinding cylindrical pieces 2 inches in diameter, but not suitable for a diameter of 4 inches, because of the increased contact area, owing to the increase in diameter.

The grain or degree of coarseness of the wheel is another point to be considered when making a selection. Generally speaking, coarse wheels are better adapted to most work because the larger grains permit deeper cuts to be taken. When a very fine finish is required, particularly on a number of duplicate pieces, fine wheels are sometimes used for finishing, after the work has been ground to within, say, 0.002 inch of the required size with a coarse wheel. It is not necessary, however, to use a fine wheel in order to obtain a smooth surface, as a wheel of comparatively coarse grain will produce a finish fine enough for most purposes, if the work speed is reduced somewhat and the wheel is trued with a diamond just before taking the finishing cut; in fact, very fine surfaces can be obtained with a comparatively coarse wheel, provided there is tne proper relation between the surface speeds of the wheel and work. When roughing cuts are being taken, the cutting particles are constantly worn away or dislodged so that the face of the wheel is kept rough or "sharp," and the ground surface is also comparatively rough. After the wheel face has been trued with a diamond, however, light finishing cuts, in conjunction with a reduced work speed, will give a finish which is smooth enough for all practical purposes, even though a fairly coarse wheel is used.

Incidentally, it is not always the highly polished surface which represents the most accurate work, because this finish is sometimes obtained at the expense of accuracy, by using hard wheels that require so much pressure to make them grind that the work is distorted. In order to secure accuracy, the wheel must cut freely and without perceptible pressure. Sometimes a coarse wheel refuses to cut after a surface has been finished to a certain point, because the cutting particles wear off somewhat and the ends become too large and blunt to enter the smooth surface. If this occurs, the wheel should be trued with a diamond or be replaced with one of finer grain. When grinding brass or soft bronze the grain of the wheel must be as fine as the finish desired; in other words, it is not practicable to use a coarse wheel for finishing these metals.

Peripheral Speed of Work and Grinding Wheel

A wheel which is perfectly adapted to grinding a certain kind of material will not work satisfactorily if the relative surface speeds of the wheel and work are not approximately correct. The work speed affects the wear of the wheel, which, when excessive, also affects the finish of the surface being ground. The amount of stock that the wheel removes for a given amount of wear can be increased or diminished by varying the work speed, the wheel wear being excessive when the speed is too high. This close relation between the work speed and the wheel wear makes it possible to use a wheel which is somewhat harder than it should be for a given piece of work, by increasing the work speed, with the result that the grit is dislodged more easily, and, consequently, does not remain long enough to cause glazing, which would otherwise take place; this practice, however, is not to be recommended.

As there are a number of factors, such as kind of material, finish desired, etc., which determine the proper work speed, it is impractical to say just what this speed should be unless the conditions are known. A speed of twenty-five feet per minute might be correct for grinding a certain piece of steel, and not correct for another steel part having a different carbon content. The finish of a ground surface, as previously stated, is also affected by the work speed. It is possible to grind a very rough or smooth surface by simply varying the speed, depth of cut and side feed of wheel, the surface becoming smoother as these are diminished. For this reason the speed and feeds (when within, say, 0.002 inch of the finish size) are often reduced before taking the finishing cuts. The best method of ascertaining the proper speed for a given piece of work, and, incidentally, of determining the best wheel to use, is by experimenting until the desired results are obtained. This does not necessarily mean that whenever a new piece of work is to be ground considerable time must be wasted, as the speed adjustments are easily made, and besides, experience will soon teach what combinations of speed will give the best results.

The peripheral or surface speed of a grinding wheel is usually somewhere between 5500 and 6000 feet per minute, although speeds between 5000 and 6500 feet per minute are employed. As the wheel diminishes in size, it appears to get softer, even though the peripheral or surface speed is maintained. This increase in wear is due to the fact that the grit of a small wheel is in contact with the work oftener owing to the increased number of revolutions necessary for the same surface speed.

It should always be remembered that the thing to be sought after is maximum production. When choosing a grinding wheel, for example, if one too hard for the work is selected with the idea of reducing the wheel wear, the corresponding reduction in the output will much more than off-set the increased expense incurred by using a softer and more rapidly wearing wheel. The wheel wear, however, should be considered, and, as it is dependent upon the work speed, the vibration of the work, and depth of cut, these should receive careful attention. When certain combinations of speed, feed, etc., have been found correct for a certain kind and size of material, it is advisable to record this information for future reference, for while such data may not always be applicable, owing to a difference in the grade of the material, it will, in many instances, enable one to save considerable time.

Composition of Grinding Wheels

There are several kinds of abrasive materials used in the manufacture of grinding wheels, and the composition of the bond for holding the abrasive grains together in the form of a wheel is also varied to produce wheels adapted to different purposes. At one time practically all grinding wheels were made of emery, but other materials possessing superior cutting qualities are now largely employed for machine grinding. Three of the abrasives commonly used in modern grinding wheels are corundum carborundum and alundum. Both emery and corundum are natural abrasives, whereas the other materials mentioned are produced artificially. Corundum is much purer than emery and contains a much larger percentage of crystalline alumina, which is the element in both abrasives that does the cutting.

Carborundum, which is a trade name for carbide of silicon, is a product of the electric furnace. The principal materials used in the manufacture of carborundum are coke and sand. The coke is used to supply the carbon, and the sand the silicon. These elements are placed in an electric furnace, where they are subjected to a temperature ranging between 7000 and 7500 degrees F., for a period of thirty-six hours. In this terrific heat all impurities in the coke and sand are destroyed and the carbon and silicon unite to form masses of carborundum crystals. These crystals are only inferior to the diamond in hardness. After the furnace is cooled the masses of crystalline carborundum are crushed to grains which are subjected to various forms of treatment and are finely graded. Alundum is also made in the electric furnace by the fusion of a mineral called Bauxite, which was considered infusible until the invention of the electric process. The chemical composition of alundum is similar to the ruby and sapphire which are the hardest natural minerals, except the diamond.

In the manufacture of grinding wheels the abrasive grains are bound together by mixing them with an adhesive substance or "bond." which is usually composed either of clays and fluxes, silicate of soda, or shellac.

The Vitrified Process

When clays are used they are thoroughly mixed with the abrasive in large power-driven mixing kettles. This mixture is then drawn off into molds and dried. The wheels are then shaved off to the proper shape in a special machine, after which they are baked or burned continuously for a period of 100 hours or more, the time depending upon the size of the wheels. During this baking process the temperature is gradually raised until the clay is partially melted and vitrified. The wheels are then allowed to cool slowly for a week, and great care must be taken to maintain uniform temperatures and prevent sudden changes. As the cooling takes place the clay crystallizes and binds the abrasive grains firmly together. This is known as the vitrified process and is the method employed for making most grinding wheels.

The Silicate and Elastic Processes

There are two other common methods of making grinding wheels, one of which is known as the silicate, and the other as the elastic process. With the silicate process, silicate of soda is the principal ingredient of the bond. The abrasive grains are first mixed with the bond in special machines, and the mixture is then tamped into molds. After the wheels are molded they are dried and baked in special ovens. The temperature of these ovens is much lower than is requird in connection with the vitrified process.

Wheels made by the elastic process have shellac as the principal ingredient of the bond. They are also molded and then baked at a comparatively low temperature to set the shellac. Wheels made by this process have great tensile strength and also a certain amount of elasticity so that very thin wheels can be safely used; in fact elastic wheels only 1/32 inch thick are manufactured. Elastic wheels are also made by what is known as the Vulcanite process, in which case the bond is composed of vulcanized rubber. Tough, thin wheels can be produced by this method, but they are very expensive.

The vitrified wheel is generally considered superior for most grinding operations, as it is very porous and free cutting. It is adapted to cylindrical and surface grinding, and for a variety of other operations. Vitrified wheels are difficult to make in large sizes as they are liable to crank in the kiln, and the process requires about four weeks, which is sometimes a decided disadvantage. Silicate wheels are recommended for wet tool grinding, wet surface grinding (especially when cup wheels are used), and whenever accuracy of grading is required. Silicate wheels can be made in large sizes and the process only requires a few days, which is an advantage, particularly when special shapes are needed.

CHAPTER IV

INTERNAL GRINDING

The grinding of holes is known as internal grinding. This class of work is done on universal machines and also on special types designed exclusively for internal grinding. When a universal cylindrical grinder is employed for internal work it is equipped with an internal grinding attachment. Fig. 21 shows how an internal attachment is applied to a Landis machine. The regular wheel head is turned half way around on its slide, and the internal fixture *A* is bolted to the front of the slide after the wheel-guard has been removed. The spindle of the internal

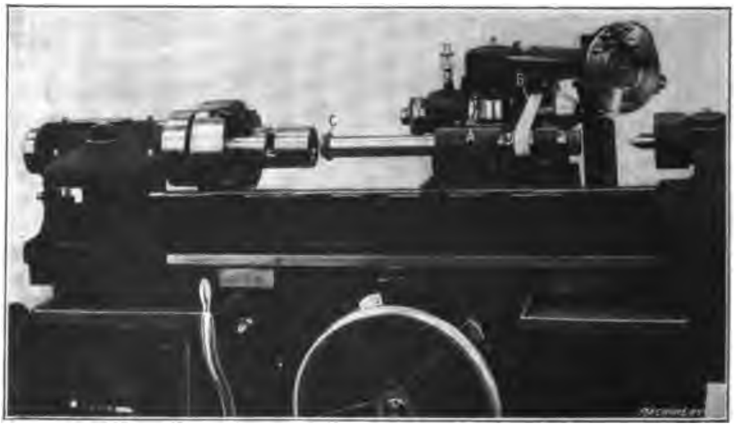

Fig. 21. Landis Universal Grinder equipped with Internal Grinding Attachment

fixture is driven by a short belt *B* connecting with a pulley which replaces the regular grinding wheel. The work is held in a chuck mounted on the headstock spindle, and the grinding is done by a wheel *C*. The wheel to use in any case must, of course, be somewhat smaller than the hole to be ground, and the grinding is done by traversing the wheel through the hole. The work is rotated rather slowly when grinding, and the wheel cuts along one side as it passes through.

The wheels used for internal grinding should generally be softer than those employed for other grinding operations, because the contact area between the wheel and work is comparatively large. The wheel spindle is also rather weak so that a soft wheel that will cut with little pressure, should be used to prevent springing the spindle. The grade of the wheel depends on the character of the work and the stiffness of the machine, and where a large variety of work is being ground, it may not be practicable to have an assortment of wheels adapted to all conditions. By adjusting the speed, however, a wheel not exactly suited to the work in hand can often be used. If the wheel wears too rapidly, it should be run faster, and if it tends to glaze, the speed should be diminished.

When adjusting the machine for grinding a hole, the length of the stroke should be regulated so that the wheel will only travel beyond the ends of the hole, one-fourth or one-half its width, because if it is allowed to pass clear through the hole, the spring of the spindle will cause the hole to be ground "bell-mouthed" or large at the ends.

When a hole is to be ground straight or cylindrical, the head can be accurately set by the following method: Before attaching the internal fixture a cylindrical piece is gripped in the chuck and ground

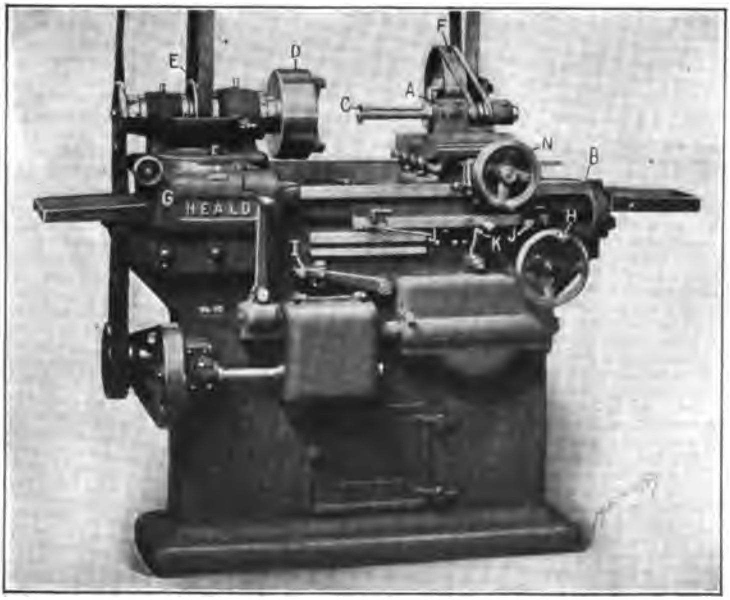

Fig. 22. Heald Internal Grinding Machine

externally with the regular wheel. When the head is adjusted so that this test piece is ground straight, then it is properly set for grinding a straight or cylindrical hole. The straightness of a hole can also be tested when grinding it, by the following method: First grind the hole true with the wheel operating in its normal position on the rear side; then bring the wheel into contact with the opposite side of the hole and, as it passes through, note the density of the sparks in order to determine whether the hole is straight or tapering. If the wheel cuts heavier as it approaches the back end of the hole the latter is smaller at that end, but if the density of the sparks becomes less, the hole is smaller in front. When the sparking is even on both sides the hole is straight or cylindrical.

The work shown in Fig. 21 is held in an ordinary three-jawed chuck, but draw-in collets and special fixtures are often used for internal grinding. When gripping frail parts in a chuck, care should be taken to prevent springing them out of shape. As the pressure of grinding is comparatively light, it is not necessary to clamp the work very tightly, although if a part is held insecurely, it may be shifted when testing the diameter of the hole with a plug gage, especially if the gage sticks in the hole. Therefore, a greater clamping pressure than is necessary for grinding is often required. In the case of thin bushings and similar work, this matter of distortion is very important; for work of this class, the Heald Machine Co. recommends the use of a special chuck which clamps endwise, thus avoiding all radial pressure and distortion.

Internal grinding is often done dry, although cooling water should be used whenever practicable, as it not only keeps the work cool but washes away the chips and abrasive. When a part that has been ground dry, is being measured with a plug gage, the latter may stick or "freeze" in the hole, unless the work is cooled somewhat before inserting the gage. This sticking is due to the fact that the hole being ground is expanded by the frictional heat of grinding and when the cold plug gage is inserted, the hole contracts and grips the gage. Internal grinding wheels should be kept true in order to secure smooth accurately finished holes. A diamond tool is preferable for truing the wheel face, although a piece of some hard abrasive such as carborundum can be substituted. The diamond tool or carborundum "rub," as the case may be, should be held in a fixed position when in use.

Heald Internal Grinder

A machine that is designed especially for internal grinding is shown in Fig. 22. The grinding wheel head *A* is mounted on a cross-slide which is carried by the table *B*. The latter has a reciprocating movement on the bed for traversing the grinding wheel *C* through the hole. The work is held in some form of chuck *D*, or in a special fixture, and it is rotated by a belt operating on pulley *E*. This belt connects with a pulley overhead, the speed of which can be varied by a change gear box forming part of the countershaft. This feature enables the work speed to be varied for grinding holes of different diameter. The pulley *F* for driving the wheel spindle, is driven by belt from an overhead drum which allows the table to move longitudinally. The headstock is mounted on a base *G* which forms a bridge over the table so that the latter can pass beneath it. The headstock can be set to an angle of 45 degrees either side of the center-line, for grinding taper holes. The table can be operated by handwheel *H* or by power. Lever *I* engages the power feed clutch, and the stroke of the table and grinding wheel is controlled by the position of dogs *J* which engage reverse lever *K*. The travel of the table per revolution of the work is controlled by lever *L*. By means of this lever three rates of feed are obtained for each work speed, a coarse feed being used for rough grinding and finer feeds for finishing. The cross feed for the wheel slide can be operated either by hand or automatically. The automatic feed mechanism is located just back of wheel *N* which is used for the hand movement.

CHAPTER V

SURFACE GRINDING

The grinding of plane or flat surfaces is called surface grinding. There are several different types of surface grinders, some of which are adapted principally to tool-room work, and others to general manufacturing. A common method of grinding a flat surface is indicated by the diagram *A*, Fig. 23. The work *w* is traversed to and fro beneath the grinding wheel *G* (as indicated by the dotted lines), and either the wheel or work is fed laterally (see end view) at each end of the stroke, so that the periphery of the wheel gradually grinds the entire surface. Another method of producing flat surfaces is illustrated at *B*. The wheel *g*, in this instance, is a cup type, and the vertical surface *a* is ground by being traversed past the face of the wheel; hence this is often called face grinding.

Diagram *C* illustrates the operation of a vertical surface grinder. The grinding is done by either a cup or ring wheel *g*, which revolves about a vertical axis. The work *w* is attached to a reciprocating table and is traversed beneath the grinding wheel. This type of machine is used quite extensively, at the present time, and it has proved very efficient for work within its range. Diagram *D* illustrates the operation of another vertical-spindle machine. In this case the work table has a rotary instead of a reciprocating movement. This type is especially adapted to grinding the sides of flat disk-shaped parts, such as saws, etc., and for a variety of other work. For example, to finish the side of a circular plate *w*, wheel *g* is placed in the position shown by the plan view, and the surface is ground as the table and work revolve in the directions indicated by the arrows. The grinding is done by the lower edge or face of the wheel, and the latter is slowly fed downward until the part has been ground to the required thickness.

The surface grinder is indispensable in the tool-room for truing parts that have been distorted by hardening and for producing fine accurate surfaces. Many of the machines built at the present time are also efficient for producing flat surfaces in connection with manufacturing operations. Ordinarily the surface grinder is used for finishing parts which have been milled or planed approximately to size, although many pieces are ground from the rough on the large machines used for manufacturing purposes.

Fig. 24 shows a plain surface grinder of medium size which operates on the principle illustrated by diagram *A*, Fig. 23. The part to be ground is attached to table *A*, and the grinding is done by wheel *G* which can be adjusted to the proper height by handwheel *B*. The stroke of the table is controlled by the position of dogs *D* and D_1 which operate the reverse lever *C*. As the table reciprocates, the wheel with the column which supports it, feeds laterally at each end of the stroke.

The movement of the table and the lateral feeding movement of the wheel are automatic when grinding, but they can be effected by hand for making adjustments. Crank *E* is for traversing the table, and wheel *F* operates the hand cross feed.

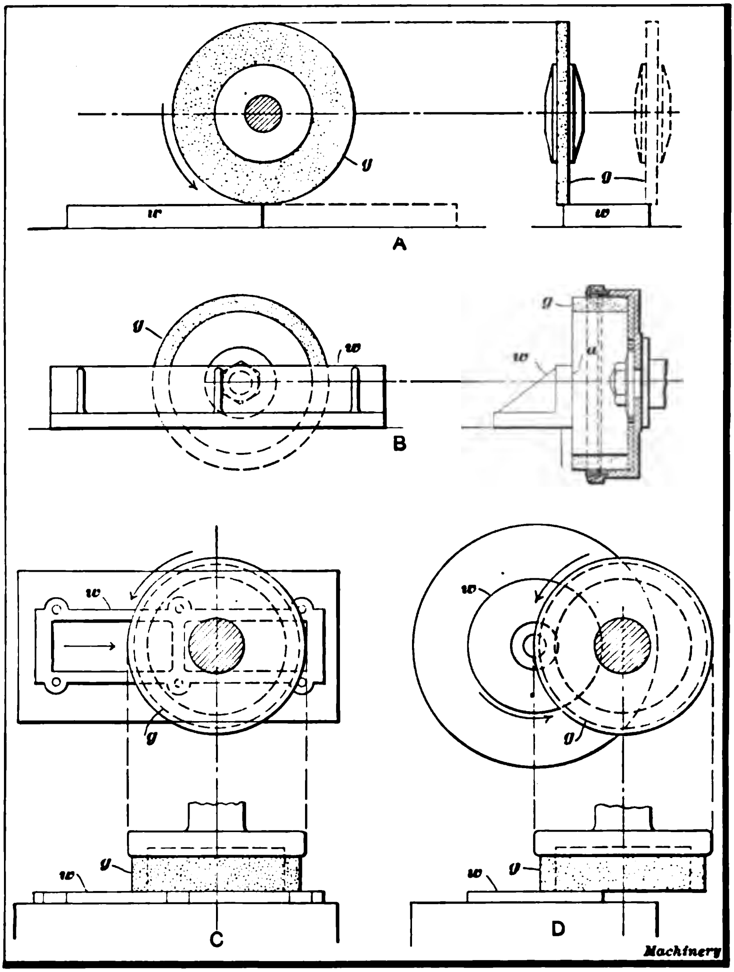

Fig. 23. Diagrams illustrating Four Methods of Surface Grinding

The belt which drives the grinding wheel connects with pulley *H* and the latter is driven by belt *I* from an overhead shaft. The reciprocating movement of the work table is derived from the belts *J* and *K*. One of these belts is open and the other crossed, so that the pulleys which they engage rotate in opposite directions. Interposed between these pulleys there is a clutch which is splined to a shaft that operates the table driving mechanism. This clutch is engaged with first one pulley and then the other, whenever the dogs *D* strike lever *C*, thus reversing the direction of the table's movement. The motion of lever *C* is transmitted to the clutch at the rear, by means of suitable links and levers. This movement of lever *C* (which is caused by engagement with dogs *D*), not only operates the table, but also operates the mechanism for feeding the grinding wheel laterally.

The traversing motion of the work table can be stopped automatically when the wheel has fed across the part being ground, by means of a

Fig. 24. Walker Surface Grinder of Reciprocating Type

trip mechanism. In connection with this mechanism there are two adjustable collars mounted on a horizontal rod located on the left side of the machine. There is also a trip-finger attached to the wheel housing, and whenever this finger engages one of the collars, the horizontal rod is shifted slightly, which makes it impossible for the reverse clutch at the rear to engage the driving pulleys; consequently, the reciprocating motion of the table is stopped. The point at which the trip mechanism operates, depends upon the position of the stop-collars which are adjusted so that the table will stop after the wheel has passed across the surface to be ground.

Some surface grinders which grind with the periphery of the wheel like the machine illustrated in Fig. 24, are designed along the lines of an ordinary planer; in fact the construction is almost identical except that a grinding wheel is mounted on the crossrail, instead of a tool-head. When this type of machine is in operation, the work table reciprocates and the wheel feeds laterally across the surface to be ground.

Horizontal Face Grinding Machine

A face grinding machine is illustrated in Fig. 25. This type operates by traversing the work past the face of ring-wheel *G*, as previously explained in connection with diagram *B*, Fig. 23. The part being ground is clamped to table *A* which has an automatic reciprocating movement.

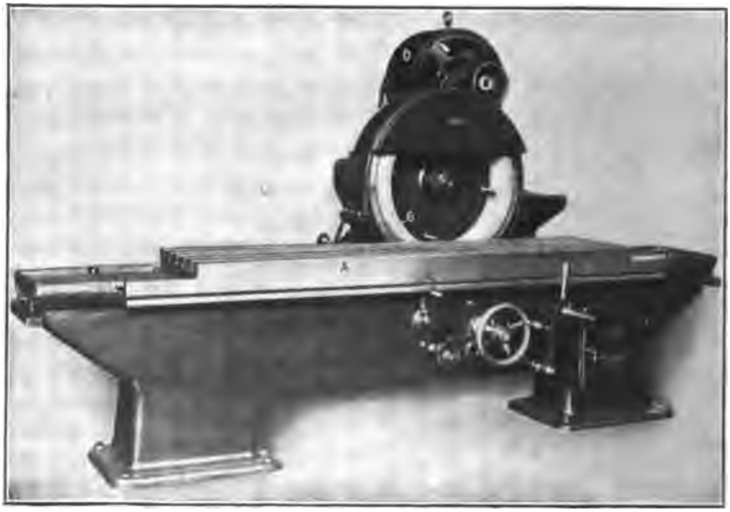

Fig. 25. Diamond Motor-driven Face Grinder

The length of the stroke is regulated by dogs (not in place) which engage reverse lever *C*. The wheel has an adjustable automatic power feed, and both the wheel and work table can be moved by hand. This particular machine is driven by a motor *D* which is connected to the wheel spindle by a belt.

The face grinder has some advantages over the type of machine using a wheel that grinds on the periphery. In fact, the advantages are similar to those which a face milling cutter has over an axial milling cutter. In the first place, the power consumption is less and plane surfaces are produced with fewer passes of the grinding wheel. The radius of a cup wheel also remains the same until it is worn out, instead of changing constantly, as with a disk wheel. The type of face grinder shown in Fig. 25, is generally used for grinding quite heavy parts and it is especially adapted to that class of work which can be held to better advantage when the surface to be finished is in a vertical plane. For example, the ends of rather long castings, such as machine legs, etc., can easily be ground on this style of grinder, because the work can be clamped to the table of the machine, in a horizontal position. Evidently it would be impracticable to grind work of this class on a machine having a vertical spindle, because the castings would have to be held in an upright position. The horizontal face grinder is often used in locomotive shops for truing or finishing the

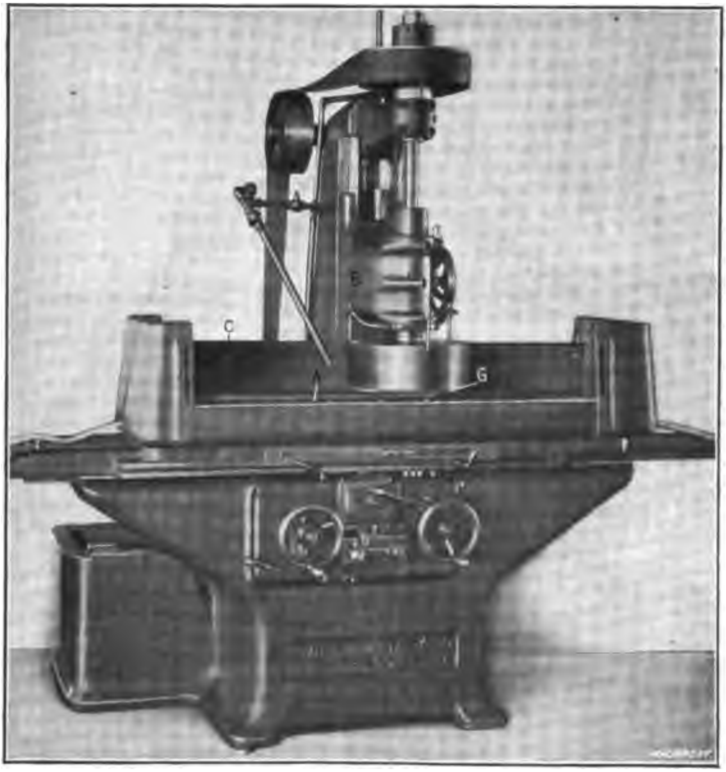

Fig. 26. Pratt & Whitney Vertical Surface Grinder

bearing surfaces of guide-bars, and it can be employed to advantage for many other grinding operations.

Vertical Surface Grinder

Fig. 26 shows a surface grinder of the vertical type. The grinding is done by ring or cup wheel *G* which covers the full width of the work. With this machine, the work can be given either a reciprocating or rotary motion, depending upon the shape of the part being ground. For grinding rectangular surfaces, or parts that should move in a straight line beneath the wheel, the table *A* is given a reciprocating movement, the length of which is controlled by dogs in the usual manner. On the other hand, the sides of saws, rings or flat disk-shaped parts are rotated while being ground, by placing them on a rotary chuck which is mounted on the grinder table. When the rotary chuck is in use, the table remains stationary.

It will be seen from the foregoing that this machine operates either as illustrated by diagram *C*, Fig. 23, or as shown by diagram *D*. The grinding wheel and its spindle is carried by a head *B* which can be fed vertically on the face of the column. The vertical feed can be operated automatically or by hand, and be disengaged automatically at any predetermined point. The reciprocating table has two rates of feed or travel and it can be moved by hand, if desired. This grinder is equipped with a pump for supplying cooling water to the wheel. The water is pumped into the hollow spindle, at the top, and passes down to the inside of the grinding wheel, after which it is driven outward by centrifugal force between the wheel and the work. An outside stream of cooling water is also provided and the table is surrounded by a water guard *C* which prevents the water from flying about.

The vertical type of grinder can be used advantageously for grinding long rectangular surfaces, disk-shaped parts (by using the circular attachment) and it is very efficient for grinding a number of small castings simultaneously. When several parts are to be ground at the same time, they are grouped on the table of the machine or on a magnetic chuck, so that the wheel will grind each casting as the table feeds along. It is comparatively easy to hold several small castings on a grinder of this type, because they are placed horizontally on the machine, and, as the wheel operates on the top surfaces, the pressure of grinding is mostly downward against the table and bed, which provide a solid unyielding support. This type of machine is used extensively for grinding from the rough; that is, castings or forgings are finished by grinding without any preliminary machining operation, such as planing or milling. This practice is followed when it is not necessary to remove very much metal.

Rotary Surface Grinder

Still another type of surface grinder is shown in Fig. 27. This machine is designed for rotary grinding exclusively, the principle of its operation being indicated by diagram *D*, Fig. 23. A cup wheel *G* is carried by an upper slide *B* and the work is held on a rotary magnetic chuck *C* mounted on lower slide *D*. The wheel spindle is driven from a horizontal shaft at the rear by a quarter-turn belt, as shown, whereas the work table is driven from drum pulley *E*. When the machine is in operation, the wheel is fed down against the work until the latter is finished to the required thickness, by operating hand-lever *F*. The wheel slide is fed against a positive stop, and the thickness of the work is varied by adjusting the lower slide which is equipped with a vertical feed screw. This screw is operated by handwheel *H* which is graduated to thousandths of an inch. When the lower slide has been set, its position is not changed for successive operations except to compensate for wheel wear.

The link-and-lever mechanism seen at the side of the column, connects the wheel slide with a jaw clutch inside the work-table driving drum, and disconnects this drum from the shaft on which it is mounted, when the wheel slide is in the upper position. By this means, the work spindle is automatically stopped whenever the wheel is raised from the work. As the wheel is moved vertically by lever *F*, it will be seen that the latter controls the starting and stopping of the work-table. This lever also controls the magnetizing current for the chuck, and the demagnetizing current for neutralizing the residual magnetism

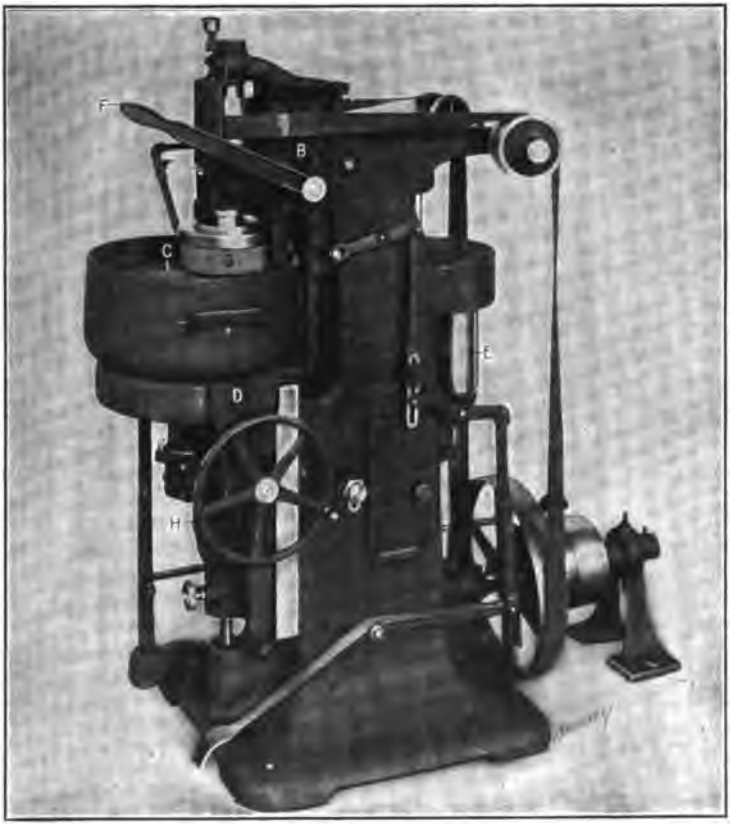

Fig. 27. Walker Rotary Surface Grinder

always found in a magnetic chuck after the electric current has been switched off. If desired, the drum-clutch operating mechanism can be disengaged, and the motion of the work-table be controlled independently by means of the foot lever seen at the base of the machine.

This machine can be used for concave grinding, in which case the knee supporting the work-table is tilted to the required angle. Work having a concave surface is not held directly against the magnetic chuck, but on an auxiliary plate. The magnetic power of the main chuck is transmitted through this auxiliary plate, the upper surface of which is shaped to suit the surface of the work. The use of an auxiliary plate in connection with the grinding of a milling saw is illustrated in Fig. 28. After the saw is ground concave on one side, it is held for grinding the opposite side on a plate *A* having a convex face. If the saw were held for grinding the last side against the flat face of the regular chuck, it would be sprung down in the middle, so that both sides would not be finished alike, or to the same concavity. Fig. 29 shows how a number of parts can be ground simultaneously on a rotary surface grinder. In this instance, three castings are arranged in a group on the magnetic chuck, in such a way that they support each other to some extent, while the top surfaces are being ground flat.

Fig. 28. Grinding Side of Saw Concave

Fig. 29. Grinding Three Castings Simultaneously

These views indicate, in a general way, the kind of work that is ground on a machine of this type.

Use of Magnetic Chucks

The method of holding work to the table of a surface grinder depends, of course, more or less on the shape of the part to be ground. Ordinary clamps and bolts are sometimes used, but where electric power is available, magnetic chucks are preferable for most work. The magnetic chuck is a special form of electro magnet which is connected by wires and a control switch, with the electric power circuit. The top surface against which the parts are held, has a series of positive and negative holes which are separated by an insulating material. When in use, the chuck is clamped onto the table of the surface grinder, and the work is held by magnetic force when the current is turned on.

A rectangular magnetic chuck is illustrated in Fig. 30. This is the form used on surface grinders of the reciprocating type, whereas for rotary grinders, round chucks are employed. The control switch is located at *D*, and the work is held against surface *A* which has a number of positive and negative poles, as the engraving shows. There is a thin steel aligning strip *B* attached to the rear side of the chuck and also a vertically adjustable back-rest *C* which is used to support parts

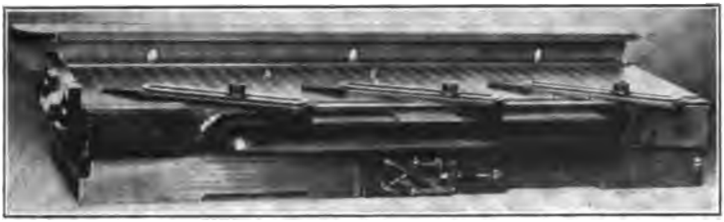

Fig. 30. Walker Magnetic Chuck

that are high in proportion to their width. In addition, there is an end-stop *E* having vertical adjustment. The work to be ground is simply laid on the chuck face, against end-stop *E* and the back-rest *C*. The slotted fingers *E* which are provided on this particular chuck, are also used, in some cases, to stay the work edgewise and prevent it from shifting. Magnetic chucks are sometimes used on planers, as well as surface grinders, in which case fingers *E* are of especial value.

This chuck is equipped with a duplex switch which enables the chuck

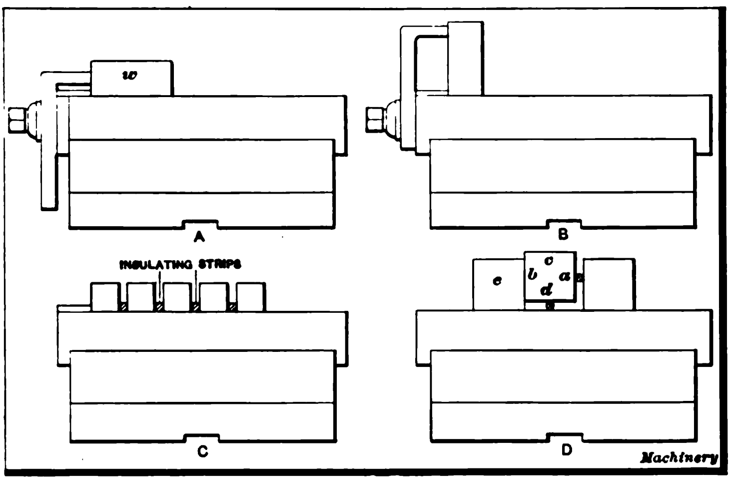

Fig. 31. End Views illustrating Different Methods of holding Work on Magnetic Chuck

face to be demagnetized so that work can easily be removed after the grinding operation. This demagnetizing is accomplished by simply reversing the current through the chuck coils, momentarily, until the residual magnetism is removed. In order to do this, the switch is opened and moved until the switch bars are nearly in contact with the posts at the opposite end of the switch. The handle is then gripped tightly with the tips of the fingers, and the bars are quickly moved in and out of contact with the posts. This movement, when timed correctly, will remove the magnetism lift by the previous charge. When demagnetizing, if the contact should be for too long a period, the chuck will simply become oppositely charged, and in such a case it can be discharged again by making quick contact with the posts on the opposite side. It should be mentioned that this switch does not demagnetize the work itself. This is necessary, however, for certain classes of work, because some materials become more or less permanently magnetized and this causes them to attract small particles, which is sometimes quite objectionable. When the work must be demagnetized, a special apparatus called a demagnetizer is used.

The way the back-rest *C* of the magnetic chuck shown in Fig. 30, is used is illustrated by the diagrams *A* and *B*, Fig. 31, which represent end views of the chuck. The operation is that of grinding a true rectangular block *w*. While the sides are being ground, the block is held as indicated at *A*. The edges are then ground square with the sides by holding the block against the aligning strip and back-rest, as shown at *B*. Sketch *C* shows how a number of strips are held on the chuck and ground simultaneously. When parts are arranged in this way, it is sometimes advisable to place magnetic insulating strips of brass or paste-board between them, so that the magnetism will get an independent grip on each piece and hold it firmly against the face of the chuck.

Sketch *D*, shows how a piece is sometimes held for grinding the sides square to each other. Two of the sides, as at *a* and *b*, are first ground by holding the work directly against the face of the magnetic chuck. One of these finished sides, as at *b*, is then held against the vertical surface of an accurately finished square block *e*, while the upper side is ground. The lower side, instead of resting directly on the chuck face, is placed upon a piece of drill rod to reduce the contact area. In this way, the work is held more securely against block *e*, than against the chuck face, because the holding power depends upon the area of the surface in contact with the magnetized part. If the side *d* were in direct contact with the chuck face, side *b* might not be held evenly against block *e*, in which case the work would not be ground square. In this instance, the work is further secured by a block on the right side which is separated by drill rod to reduce the contact area.

Magnetic chucks are made in many different styles and shapes. Some are so arranged that the clamping face can be set at any angle for taper grinding and others have faces that are vertical. There is also the rotary type which has previously been referred to, and other special designs. The rotary form is used when a continuous rotary movement is required, instead of a reciprocating motion.

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