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MACHINING TAPERED AND SPHERICAL SURFACES

BY ALBERT A. DOWD

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CHAPTER I

TAPER BORING AND TURNING ATTACHMENTS

The proposition of accurately machining male and female tapered surfaces is one of almost daily occurrence in every factory, while the tapers required are of every degree of inclination. The materials on which the work is to be done are also varied, ranging from steel or brass bar stock of small diameter to cast iron or steel castings of great size. Conditions governing the work are widely different, as the number of pieces needed obviously makes a difference in the method of handling. When only one or two are required, and the size of the work is not prohibitive, the engine lathe is most frequently used, several well-known methods of generating the taper being possible on this machine, *viz.*, setting over the tailstock to the correct angle, when the work is of such a nature that it may be held on centers; using the compound rest with hand feed; and using the taper attachment with which nearly all modern lathes are equipped and which is too well known to need description. There are also occasional instances where the lathe may be used for manufacturing work of this kind in large quantities, by means of special attachments, although this is usually applicable to conditions requiring no other machining operations except the taper. As a general thing when the number of pieces is sufficiently large to warrant it, the work is performed on the horizontal screw machine or turret lathe, the vertical turret lathe or the vertical boring mill. Many ingenious schemes for generating tapers on these machines have been devised, the construction of a number of which will be described and illustrated in the following.

Taper Turning Devices for Bar Stock

On turret lathes or screw machines equipped for bar work, there are various devices for turning a taper on the bar. These tools are in many instances patented, and may be purchased of the manufacturers. Obviously there are such a number of these that it is out of the question to attempt to describe each one. Detailed information may be easily obtained on request.

Method of Finishing a Taper Hole without Generating the Taper

Before taking up the subject of generating devices for taper work, let us first consider a method much used in turret lathe practice and one which may be depended upon to give very satisfactory results, when absolute accuracy is not essential. When the tools are properly taken care of, good commercial work may be turned out by means of the tooling shown in Fig. 1. It will be noted that all the tools used are piloted in a bushing located in the chuck. The first tool used, shown at *A*, is a plain boring bar which serves to rough-bore the hole, thereby producing an approximately true generated straight hole. The second tool *B* is a finish-boring bar which brings the hole to about the required size for the small end of the taper. The next tool *C*, is a roughing taper step reamer which removes the larger part of the stock left in the hole, and leaves the work in the form of a series of

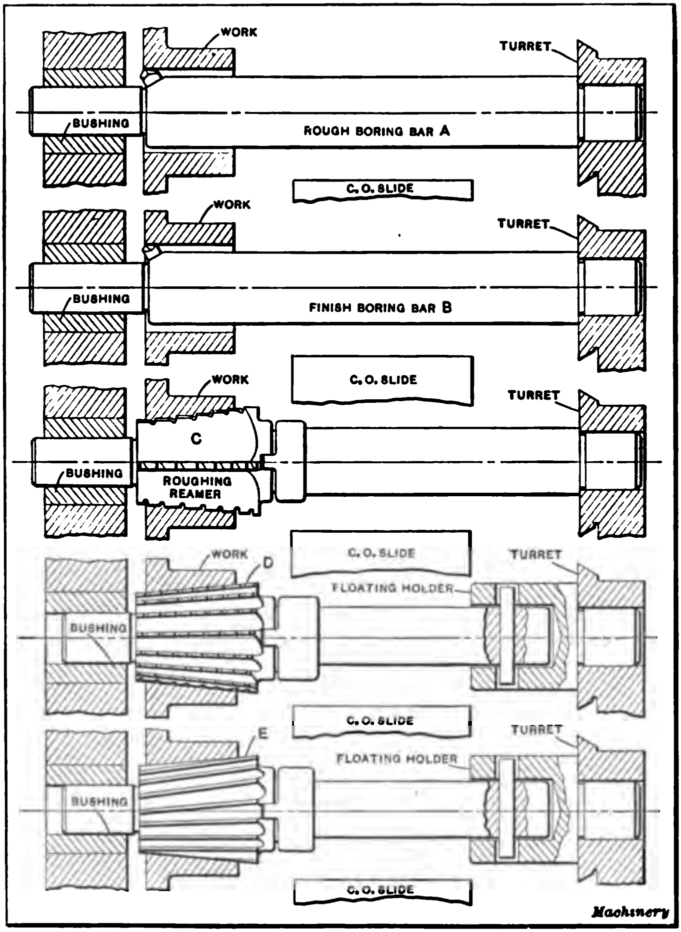

Fig. 1. Typical Boring Tools and Reamers for Taper Holes

grooves or steps with the angle of the correct inclination. A roughing taper reamer *D* is next used in a holder so made that the rear end of the reamer will float. It will be noted that this reamer is straight fluted but that a left-hand spiral groove with about 3/4 inch lead is cut the entire length of the tool. This serves to break the chip and makes possible a much easier cutting action; there is also a tendency to prevent "pulling in." The hole is sized with another reamer of the floating type *E* which may be either straight-fluted or made with a left-hand spiral of five to seven degrees, depending on the angle of the taper. The method shown here will not give as accurate results as may be obtained by generating the taper, but the sizing of the hole may be kept very nearly correct with little trouble, although slight variations in concentricity are bound to occur. One of the greatest objections to this manner of handling taper work is that the operator

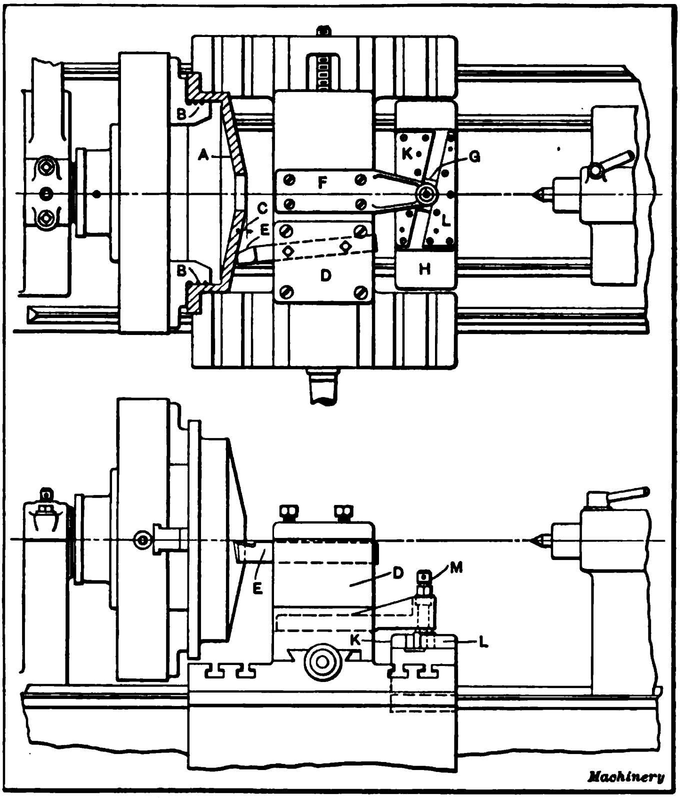

Fig. 2. Engine Lathe Attachment for turning Bevels

does not keep his tools up properly, and by being careless in regard to this matter, he leaves the reamers to do the most of the work and the results are therefore disastrous on account of the unequal wear on the reamer.

Taper Attachment for Producing a Conical Surface on the Engine Lathe

Fig. 2 shows an attachment fitted to the engine lathe for the purpose of producing the proper angle *C* on the head casting *A*. In this case the work is held in special jaws *B* which grip the interior of the casting as shown in the upper part of the illustration. The cross-slide is equipped with a special tool-block *D* in which the tool *E* is held. The casting *H* was planed on its under side to fit the inner ways of the lathe and was clamped in position by means of straps not shown. Two steel plates *K* and *L* act as guides by which the proper taper is formed. These plates are hardened and the edges of the slot were ground parallel after assembling, to insure accuracy. A bracket *F*, fastened to the cross-slide, carries a pivoted steel block *G* which travels

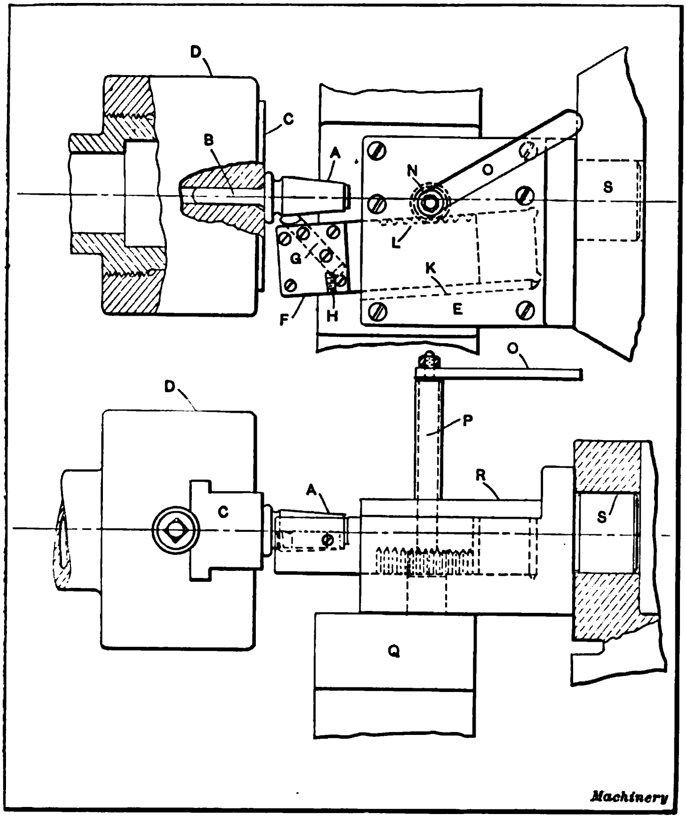

Fig. 3. Taper Attachment for Small Hand Screw Machines

in the slot, thereby controlling the movement of the carriage, and producing the desired taper. An oiler *M* acts as a gentle reminder that surfaces subject to friction are in occasional need of lubrication. The inner surface of casting *A* was machined on the same lathe in another setting, another set of forming plates being applied to the casting *H* to produce the required taper. This method of handling gave very satisfactory results.

A small brass cock, shown at *A* in Fig. 3 is a good example of an outside generated taper. The stem of the cock *B* is held in the special jaws *C* of a two-jawed chuck *D*, this being obviously screwed to the spindle of a small hand screw machine. The taper turning attachment is entirely self-contained, and indexes with the turret. The entire attachment is made of steel with a shank *S* which fits the turret hole. The body *E* is carefully fitted on its under side to obtain a bearing on the steel block *Q* which is fastened to the cross-slide. This support is of considerable help in taking up vibration and thereby preventing

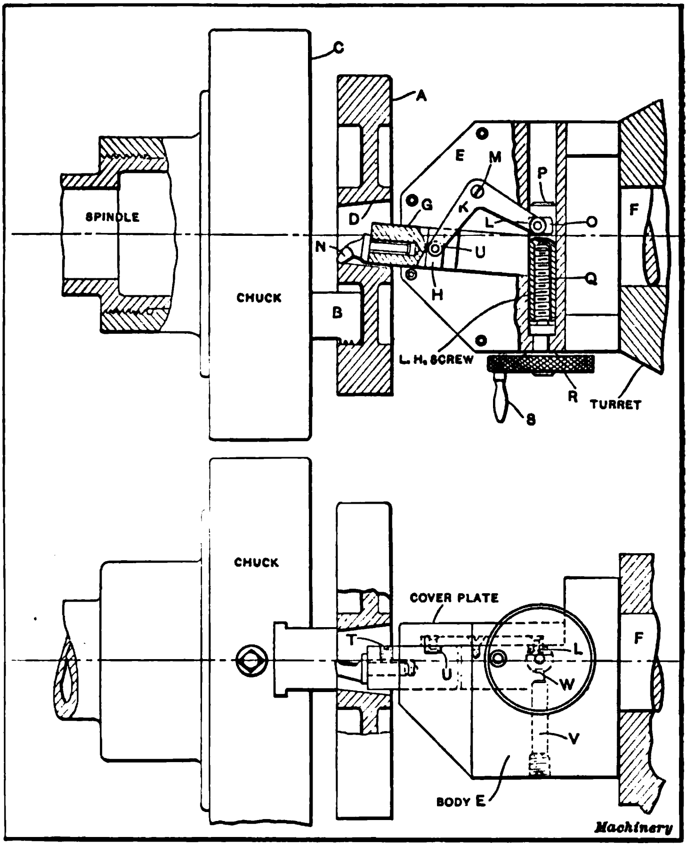

Fig. 4. Attachment for generating Small Taper Hole in a Motor-cycle Flywheel

chatter. The slide *F* fits a slot in the fixture which has been planed to the proper taper and the gib *K* acts as a take-up for wear. The cutting tool *G* is of rectangular section and accurately fits a slot in the front end of the taper slide. The headless set-screw *H* assists in setting the cut to obtain the proper diameter. A rack *L* is cut along one side of the slide and meshes with the pinion *N*, the shank *P* of which runs up through the body of the fixture and is operated by the lever *O*. A cover plate *R* is carefully fitted and keeps the parts in position. Tools of this type are much used on small brass work and the work accomplished by them is excellent where very little stock is to be removed. They are built to generate a certain specified taper and can be used for no other.

The rather complicated little attachment shown in Fig. 4 was built for a final finishing cut in the taper hole *D* of the motor-cycle flywheel

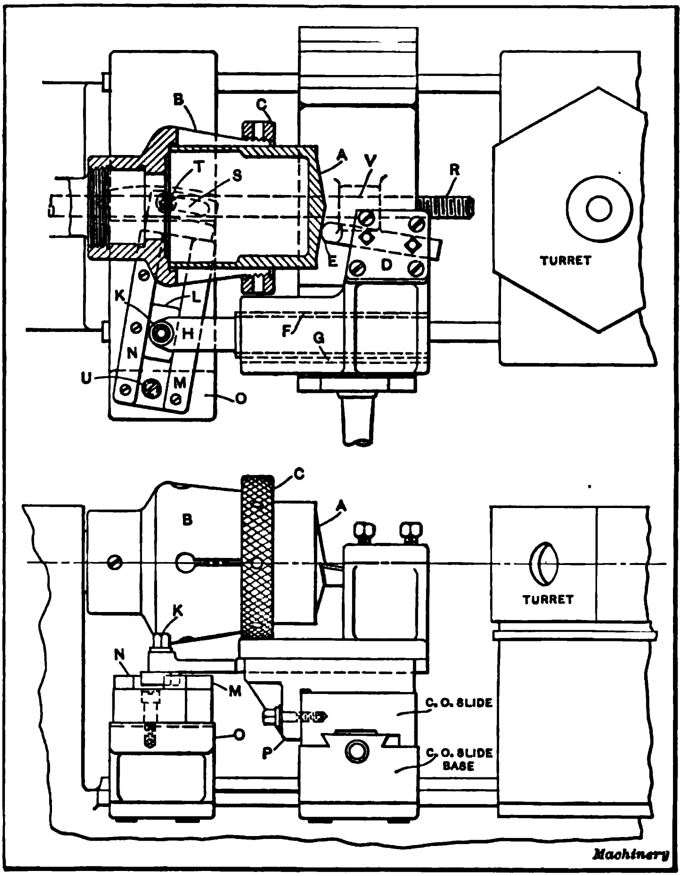

Fig. 5. Turret Lathe Taper Attachment for machining the End of an Automobile Engine Piston

A. In spite of the fact that the attachment itself is inclined toward multiplicity of moving parts, its action was so satisfactory that a duplicate order was received a few months after the original tool had been built. It will be noted that the jaws *B* of the three-jawed chuck *C* grip the work on the inside of the flange, and hold it far enough away from the chuck to permit back cutting on the hub and flange, thereby permitting the work to be finished in one setting. The body of the attachment *E* is made from a piece of round steel stock beveled on the front end and with the shank *F* turned at its rear end to the proper diameter to fit the turret hole. The taper slide *G* fits an angular slot cut in the body of the attachment and is reamed at its front end to receive the shank of the cutting tool *N*. This tool is forged to the shape shown and is carefully ground to gage. As the amount of metal which this tool removes is very slight, it requires regrinding only at long intervals. A headless set-screw *T* secures it in position. The bell-crank *K* is pivoted at *M* and the hardened steel rollers *L* and *U* are located at the two ends. The roller at the forward end operates at the slide by its action in the slot *H*, while the roller at the other end enters another slot *O* in the operating pin *P*. A teat screw *V* enters the spline *W* cut in the under side of the operating pin, thereby preventing it from turning. The small knurled handwheel *R* contains a little finger handle *S* which is used to revolve the screw *Q*. The rod *P* is tapped out to receive this screw, and obviously is moved forward or backward by its action, the motion being carried forward through the bell-crank to the operating slide.

Turret Lathe Taper Attachment for the End of an Auto Piston

The automobile piston shown at *A* in Fig. 5 has been finished on the outside but the end has not been formed to the required taper. It is held in a special spring chuck *B* which is closed in on the end by the tapered screw collar *C*. In this instance there were several conical headed pistons to be taken care of, the angle of the cone varying slightly in each case. The turret lathe selected for use in this operation was of a standard make, and the longitudinal movement of the cut-off slide was controlled by the screw *R* engaged with the nut *V* on the under side of the slide. This screw was operated by a handwheel and was not coupled up with the feed mechanism. It was used principally to move the slide back and forth along the ways to any desired location. It will be seen that in this instance any sort of floating action in a longitudinal direction was out of the question and it was therefore necessary to design a special tool block *D* having a dovetail slide *F* and an extension *H*, at the end of which the hardened and ground steel block *L* was located, pivoting on the screw pin *K*. A swivel block containing two parallel plates *N* and *M* may be swung on the shouldered screw *U*, to suit the various angles. The curbed slot *S* permits the necessary movement, while the binder *T* secures it firmly. The swivel is mounted on the bracket *O*, which is gibbed to the ways in such a way that it may be moved to any desired location. When the attachment is used the cut-off slide cross-feed is thrown into gear and the angularity of the swivel block determines the movement of the tool *E*. As a point in design, attention is called to the way in which the tool block is carried over the edge of the slide at *P*, for the purpose of obtaining rigidity and preventing any chance of side slip. The writer knows of a number of instances where attachments of this kind have been used with very gratifying results.

The bevel gear shown at *B* in Fig. 6 is held in the three-jawed chuck at *C*, by means of soft jaws, and the tools *M* and *N* are used for roughing and finishing the face of the gear, the spacing of the tools being such that the finishing tool takes up the work as soon as the roughing tool has completed its cut. This entire mechanism is special.

The carriage *S* is gibbed to the ways in the usual manner and upon this carriage is mounted the swivel slide arrangement *D*. This slide may be swung to any angle within its range and securely fastened. It

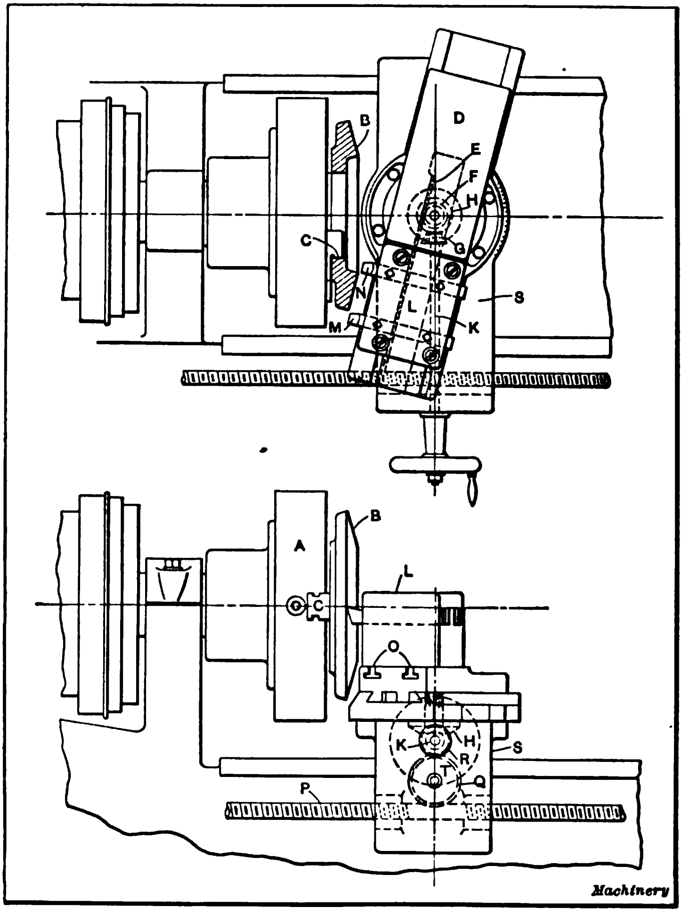

Fig. 6. Adjustable Cut-off Slide Attachment

will be noted that the feed-screw *P* meshes with the wormwheel *Q*, and the movement is transferred through the spur gears *T* and *R* to the shaft *K*. At the inner end of this shaft the pinion *G* meshes with the bevel gear *H* on the upper end of which is the spur gear *F*. This spur gear engages the rack *E* cut along the inner side of the slide, thus giving the necessary feed movement. The tool block *L* is held in place by screws which pass down through it into steel shoes in the

T-slots *O*. The operation of this mechanism is so apparent that no comment is necessary.

Taper Attachment for a Bevel Pinion

The bevel pinion *X* shown in the lower portion of the illustration Fig. 7 has been bored with a taper hole and the back side faced in a previous operation. A keyway *Y* has also been cut for driving purposes. The equipment shown was designed for a large factory manufacturing bevel gears and pinions and the taper turning device shown is so arranged that it may be used for a variety of angles. A number of taper bars such as that shown in detail in the upper part of the illustration were made to suit the different conditions.

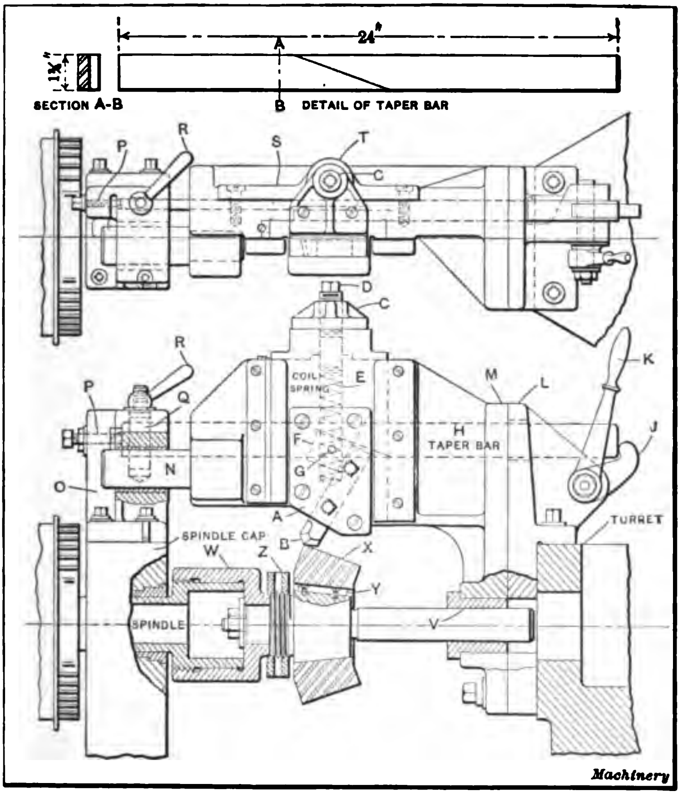

Fig. 7. Taper Attachment for machining a Bevel Pinion

The spindle nose-piece *W* contains a tool-steel arbor pilot supported at *V* in the fixture bushing. The nut *Z* is simply used to release the work after the machining operation has been performed. A cast-iron adapter *L* is screwed to the turret face, and on this is mounted the body of the fixture *M*. The cutting tool *B* is held in the sliding tool block *A*, which is scraped to a nice sliding fit, and has a taper gib provided for adjustment. A tool-steel block *F* is pivoted to the back of the slide on the pin *G*, allowing it to adapt itself to the angle cut on the taper bar. Referring to the upper view it may be seen that the plate *S* forms a cover for the open side of the fixture, and that it contains the long boss *T* which holds the spring *E*. This spring thrusts against the end of the screw *D*. The bracket *C* is fastened to

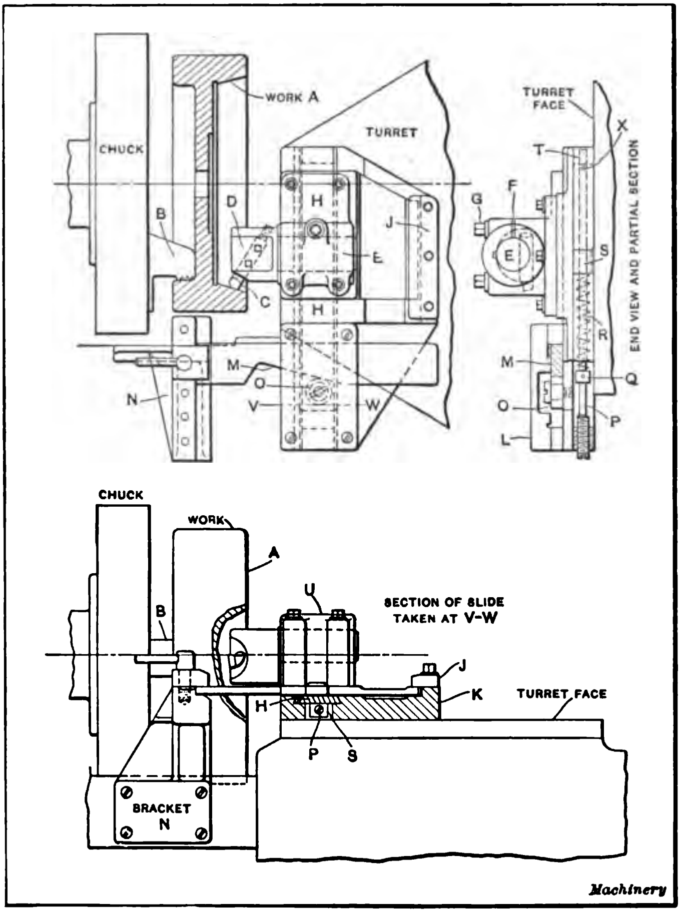

Fig. 8. Exterior and Interior Taper Turning Device

the top of the slide and is tapped out to allow adjustment of the spring by means of the screw. A bracket *O* is fastened to the spindle cap and contains a bronze bushing which acts as a guide for the pilot *N*. The stop screw *P* is used for longitudinal adjustment of the taper bar *H*. The lever *K* is used to force the taper bar forward by means of the rocker *J*. The stud *Q* is slotted to receive the forward end of the taper bar, and when this has been brought forward by the lever until it strikes the end of the screw *P* the binder lever *R* prevents any backward movement of the bar. The adaptability of this attachment for various tapers is one of the good points of its design and the results obtained by its use are rapid and thoroughly satisfactory.

The device shown in Fig. 8 is adapted for use on a turret lathe hav-

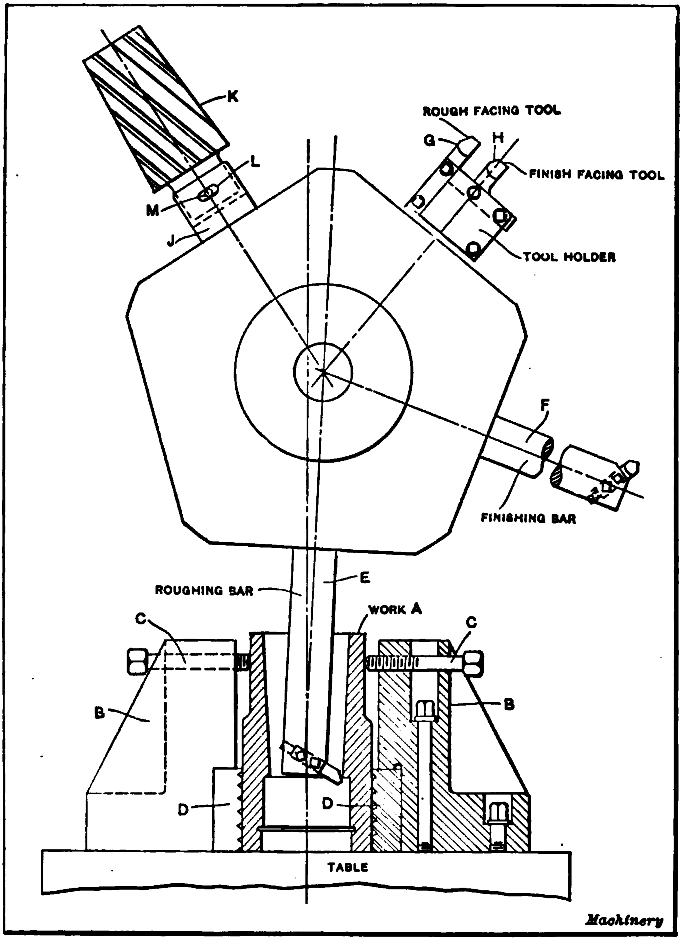

Fig. 9. Attachments for Vertical Turret Lathe and Vertical Boring Mill

ing a flat surface instead of the usual box-shaped construction. A taper bar is used in this instance also, which is cut away at *M* to the desired taper. The attachment may be arranged for either inside or outside tapers, but it is shown in this instance at work on the clutch taper of the piece *A*, this being held by the inside in the chuck jaws *B*. The bed or body of the nxture *K* is fastened to the face of the turret and is dovetailed to receive the slide *H*. A lug *S* on the under side of this slide receives the thrust of the spring *R* (shown in the end view section). A screw *P* forms an adjustment for the compression of this spring through the collar *Q* which is made removable and can be transferred to the other end of the rod at *X*, when it is desired to use the attachment for outside tapers. The roll *O* is fastened to the slide and its contact with the taper bar produces the required taper. The tool-holder *U* is split along the side at *F* and is bored at *E* to receive the shank of the tool bar *D*. The binder screw *G* is used for clamping. A cast-iron cover plate *L* is fitted so that the pads shown on its under side allow free movement to the passage of the bar. The bracket *N* is fastened to a pad on the side of the bed and is cut away at the top to the proper height so that the taper bar *M* will rest upon it. It is clamped in position by the binder shown, in order to prevent any chance for retrograde action. This attachment has been very successful and is adapted to a wide range of casting work.

Attachments for Vertical Turret Lathe and Vertical Boring Mill

Fig. 9 shows the simplest of conditions which are met with in vertical turret lathe practice, and the method of handling requires no special attachments, the swivel slide of the main head being sufficient to take care of the taper boring, the hole being finally reamed to size by a floating taper reamer. The work *A* is a cast-iron hub and it is held in the special jaws *B*. The work is centered by the steel inserted jaws *D* and the set-screws *C* are simply used to prevent vibration. The roughing bar *E* is first used to generate the taper and it is followed by the finishing bar *F*. Then the rough- and finish-facing tools *G* and *H* face the work, after which the floating taper reamer *K* is used to size the hole. It will be noted that the upper end of the reamer is flattened and enters a slot in the holder *J*, the pin *M* acting as a driver and the slot *L* allowing lateral movement.

Special Gearing used to produce Tapers

The arrangement shown in Fig. 10 is not adapted to all conditions but may be used when the required angle is not too acute to permit the use of the proper gear ratio. A piece of work such as that shown at *A* may be handled to advantage by this method.

The strap *L* is slotted at *M* to receive stud *S*, which acts as a support for the idle spur gear *N*. The lower spur gear *O* is keyed to the shaft, while the upper gear *P* is thrown into use by the clutch mechanism *Q*, by the action of the knurled screw *R*. Obviously the gear ratios between *P* and *O* must be so proportioned that the combination of the horizontal and vertical feed movements will produce the required angle. Attention is called to the fact that the power feed worm *H* is thrown into mesh with the gear *J* on the horizontal feed-screw *G* when the attachment is to be used, but it will be seen that the operation of the feed works is not disturbed by the arrangement shown, the gear *P* running idle unless the clutch is thrown in.

The work *A* in the instance shown is held by straps *C* on the special fixture body *B*. The tool *D* is held in the tool-holder *E* and follows the angle generated by the gearing. When it is required to produce an angle such that spur gearing cannot be obtained to give the exact taper, the nearest gears obtainable may be used, and the swivel slide of the main head can be set over to compensate for the variation in the gearing.

Fig. 11 shows a method of setting up a vertical turret lathe for a rush job, consisting of a few cast-iron male clutch members shown at

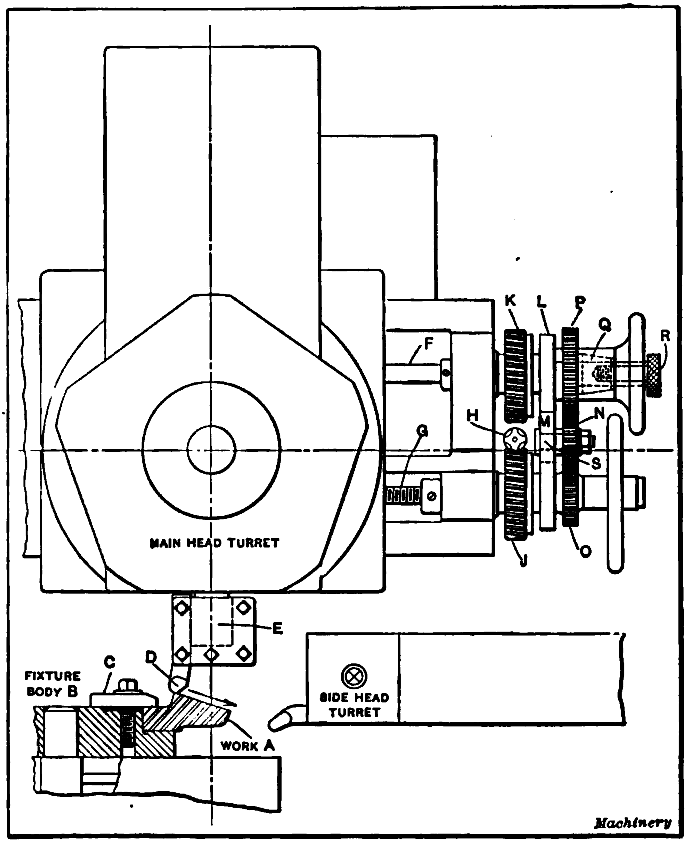

Fig. 10. Illustrating Use of Vertical and Horizontal Feed Combination to produce Tapers

A. The work is held by the jaws *B* on the inside of the rim and the tool *C* is held in the side head turret. A steel plate *F* cut to the required taper is held in the toolpost *G* in the main head turret. A roll holder *D* is fastened in the upper side of the side head turret and the roller *E* comes in contact with the tapered plate and thereby controls the movement of the tool. A flat angular sweep tool *H* is used for finishing the work. In using this arrangement it is only necessary to lock the main head turret in the proper position and bring the roll *E* against the forming plate. After this the down feed of the side head is thrown in and the roll crowded against the plate by the transverse feed crank on the apron. This method is very good for a short job and the machine may be quickly set up. Several roll holders of this kind will be found useful adjuncts to the tool equipment of the vertical turret lathe.

Another instance of a short rush job is shown in Fig. 12, the work *A* in this instance being held by the inside in the chuck jaws *B*. The

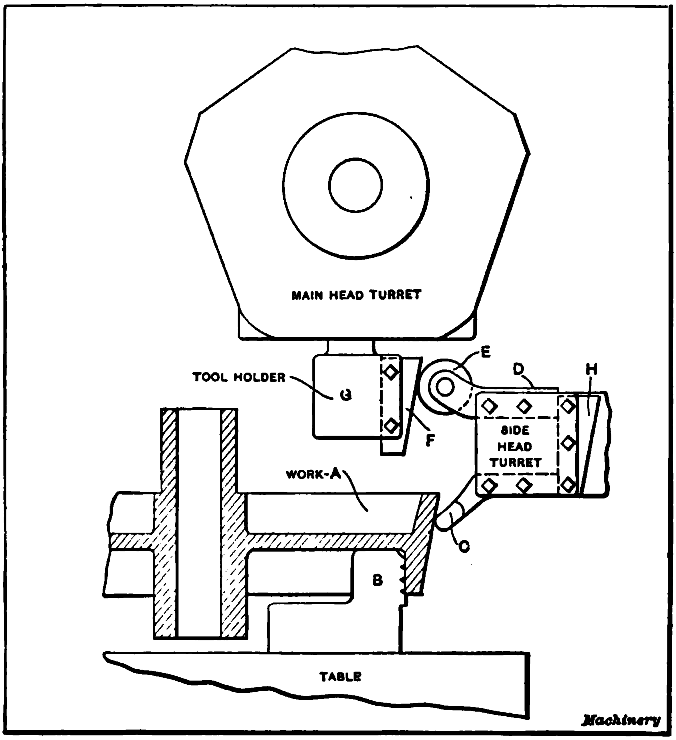

Fig. 11. Makeshift Taper Arrangement for Emergency Vertical Turret Lathe Work

tool *C* is held in the side head turret and is forced down the angle by the contact of the angular plate *D* with the roll *E*. The shank *F* which holds this roll is secured in the tool-holder *G*, in one of the side holes in the main head turret. When this arrangement is used the transverse feed of the side head is thrown in and the plate *D* crowded against the roll by means of the vertical feed crank on the side head apron. It will be readily understood that this arrangement and that shown in Fig. 11 are not to be considered in the light of attachments for taper turning, but they are given as instances of methods which may be used for short jobs, where no taper attachment is available. It is evident that these methods tie up the main head and prevent its use for cutting purposes while the taper is being formed. As this naturally increases the cutting time necessary to produce the work, the use of such an arrangement is advised only in cases where a few pieces are to be machined.

Angular Taper Attachment for Crowning Pulleys

Fig. 13 is an arrangement which is used where a double angle is required, such as the crowned portion of the pulley *A*. In this case

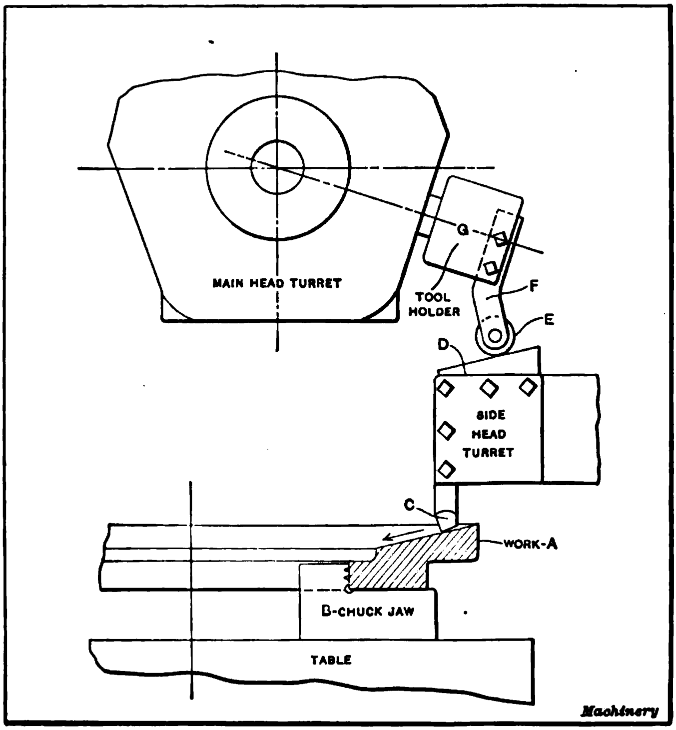

Fig. 12. Emergency Taper Attachment for Vertical Turret Lathe Work

a set of special jaws *B* grip the work on the inside bead in the V-shape part of the jaw. The movement of the tool *C* is controlled by the forming plate *E*, which is cut to produce the angular movement required. This plate is fastened at each end to the bars *F* and *L*, and these bars are, in turn, secured in the upper and lower brackets *K* and *M*. The upper boss *G* is split and the binding screw *H* pinches the bar and holds it in the desired position vertically. The arrangement of the lower bracket is on the same principle. Both the upper and lower brackets are fastened to pads on the bed of the machine. When this attachment is used the T-slot *D* is cut along the entire length of the side head slide so that the T-stud *O* which carries the roller *N*, may be adjusted for various diameters.

Swivel Side Head Forming Attachment for the Vertical Turret Lathe

Fig. 14 represents an attachment made by the Bullard Machine Tool Co., Bridgeport, Conn., for the Bullard turret lathe. The work shown in this instance at *A* is a large bevel gear which is held by the previously bored interior surface in the soft jaws *B*. The tool *C*, in its angular movement is controlled by the inclination of the slot *D* in the

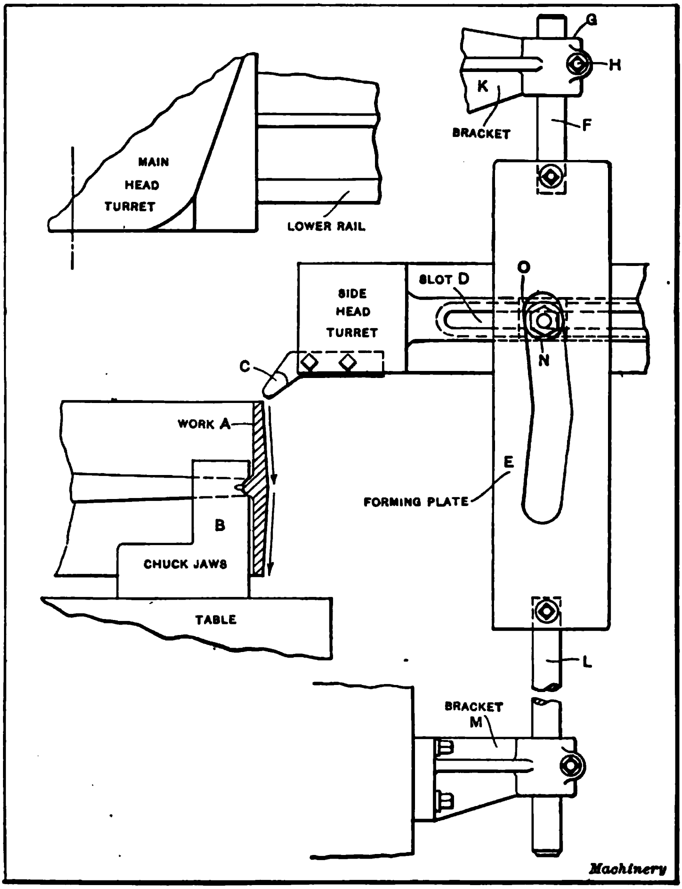

Fig. 13. Taper Attachment for crowning Tools

circular swivel plate. This plate is graduated in degrees around its upper edge so that any angle may be easily obtained. The clamps *F* and *G* secure it in position after the setting has been made. The disk containing the slot is mounted on the plate *H* which is of circular section at the center to allow free access to the roll and block *E*. As in the previous instance a T-slot *L* is cut along the entire length of the side head slide, thereby permitting various diameters to be machined. The bars *O* and *P* are secured in the brackets *K* and *Q* by the binders *N* and *M*, these brackets being secured to the bed of the machine. This attachment is adapted and may be used for many varieties of work and the results obtained are uniformly satisfactory.

The device shown in Fig. 15 is also made by the Bullard Machine Tool Co., and is adapted to both angular and formed work, and therefore is more comprehensive in its uses than that shown in Fig. 14.

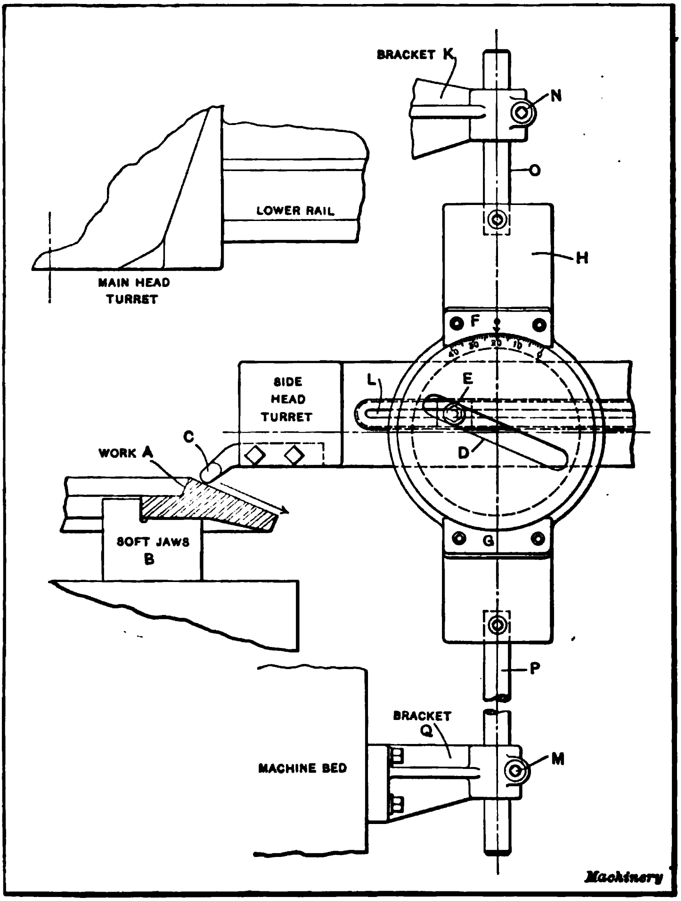

Fig. 14. Vertical Side Head Forming Attachment for the Bullard Vertical Turret Lathe

The piece *A*, held in the soft jaws *B*, is the same as that previously shown. The principles in the design of this attachment are just opposite to those of the other, for in this case the roller *P* is located in the slotted plate and may be quickly removed through either of the end holes *R*, so that the side head may be used for straight work during the same setting of the piece, without much trouble in preparation. The plate *H* is fastened to the rods *F* and S and vertical adjustment is obtained by sliding up or down. The binding screws *E* and *T* secure it in the desired vertical position. A T-slot *V* is cut along the entire length of the side head slide and a cast adapting plate *O* is secured in it by means of T-bolts. The angular plate *M* is screwed and doweled to the adapter. The brackets *K* and *L* are fastened to the side head

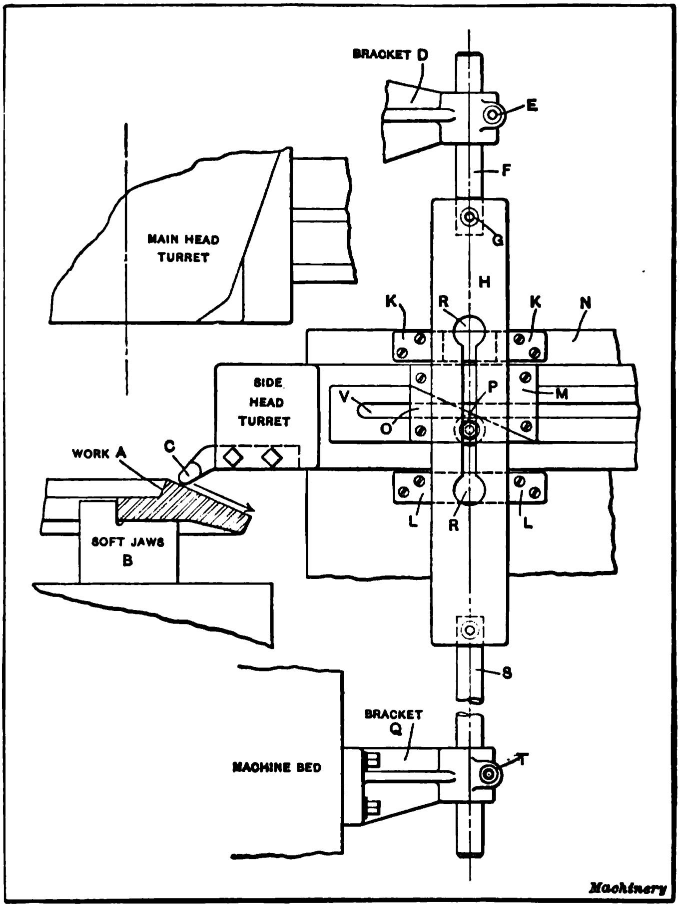

Fig. 15. Taper Turning Attachment for the Bullard Vertical Turret Lathe

down slide and are fitted to the edges of the plate *H*, in order to avoid any bending action which might be produced by the pressure against the roller *P*. The brackets *D* and *Q* are similar to those used in the former case.

Angular Forming Attachment for a Vertical Boring Mill

The work *A* shown in Fig. 16 is a male taper clutch member, and the machine upon which the work is to be done is a vertical boring mill with a turret head. The piece is held by the inside in the jaws *B* and the tool *C* forms the taper. In order to permit lateral motion a special nut was required for the horizontal feed shaft *K*. This nut is not shown in the illustration but was made somewhat on the principle of a lathe feed shaft nut so that it could be coupled and uncoupled rapidly. A special bracket *D* was fastened to the rail to the left of

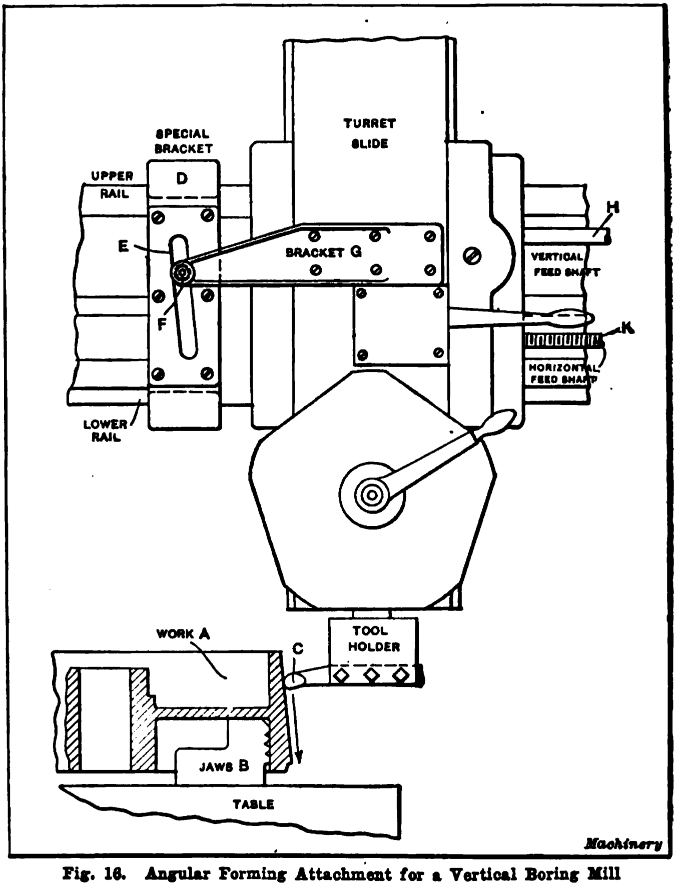

Fig. 16. Angular Forming Attachment for a Vertical Boring Mill

the turret slide and the forming plate *E* was fastened to it. A special bracket *G* was fastened to the turret slide and served as a support for the roller *F*. In use the vertical feed shaft *H* is thrown into gear and the turret allowed to float laterally as controlled by the forming plate *E*. When the other turret tools were to be used, the roller *F* was removed and the horizontal feed shaft nut recoupled. The action of this device was very satisfactory.

A very acute angle was to be produced on the work shown at *A* in Fig. 17 and a vertical boring mill was used to perform the operation shown. The work is held by the outside by the special jaws *B;* the tool *C* is used to perform the work. Two brackets *D* and *E* are bolted to the rails, one on each side of the turret slide and the cast-iron plate *G* is used to connect them and form a support for the cam plate *F.* A portion of the turret slide is machined off to permit the attachment of the roller bracket *H.* This bracket is slotted with a T-slot and

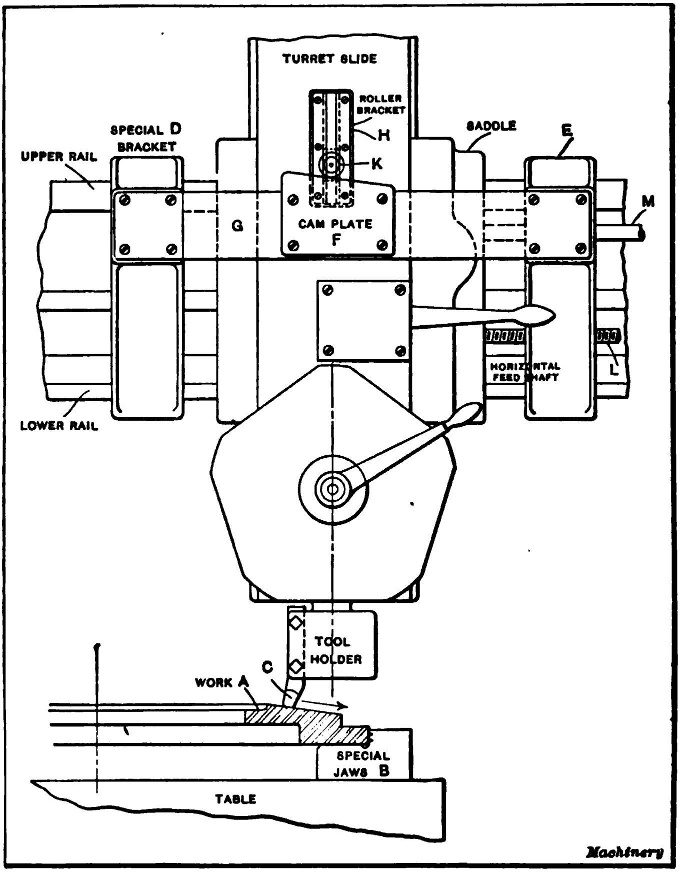

Fig. 17. Taper Attachment for a Vertical Boring Mill

the roller *K* mounted on a T-stud may be readily adjusted in it. In using this attachment it is only necessary to throw in the horizontal feed shaft gears and keep a downward pressure by hand on the cam plate *F*, by means of the handwheel on the end of the shaft *M*.

The various forms of taper attachments and devices which have been mentioned in this chapter cover nearly every variety of work and may be adapted to nearly any form of taper requirements that may be met with in the course of general manufacturing.

CHAPTER II

MACHINING CONVEX AND CONCAVE SURFACES

The machining of convex and concave surfaces is a problem which frequently confronts the mechanic, and its solution may be required under a great variety of conditions. Even the size of the work to be machined is a controlling factor, as it determines to a certain extent the type of machine to be used. For example, the small steel cup washer shown in the upper part of Fig. 1 would naturally be machined on an engine lathe or turret lathe of the horizontal type, while the huge ball pipe joint in the lower part of the illustration would preferably be handled on some type of vertical boring machine. A manufacturing proposition may be necessary where one thousand or more pieces are to be handled, or it may be that only one piece is required. The work may be concave, or convex, in a plane perpendicular to the center of rotation, or it may be parallel with it and either internal or external. As the conditions governing the handling of work of this nature are so varied, and as the pieces themselves are of such widely different forms, it is very evident that we must consider several types of machines to which the forming devices may be attached. The construction of these devices must be adapted to the class of machine on which they are to be used, and this naturally influences the design of the attachments. The reader's attention is called to a few important points along these lines.

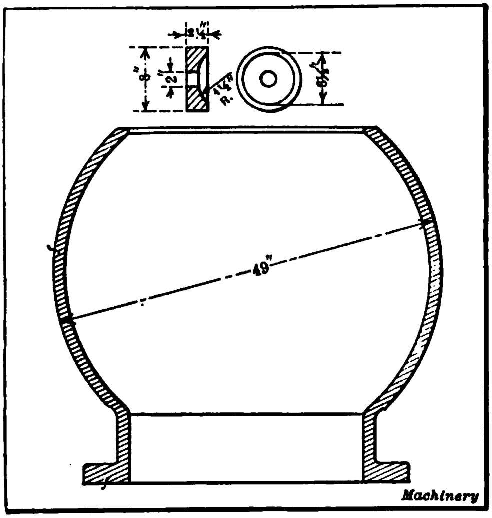

Fig. 1. Cup Washer and Ball Pipe Joint—Examples of Concave and Convex Turning

Important Points in Design

1. Whenever possible the attachment should be so designed that the form will be generated radially, so that the same portion of the tool will do the cutting at all times.

2. Try to use stock sizes of steel for the cutting tools so that replacements can be made easily.

3. See that the tool does not overhang too much, and that it is well supported and rigidly held. Care should also be taken that moving portions of the tool-holder or slide are of generous proportions and possess means of adjustment for wear.

4. Generate the curve by means of the machine alone, whenever possible, so that errors in the contour may not be occasioned by the failure of the operator to keep a certain roll or stud in contact with the forming plate.

5. When the attachment is of the type requiring the use of a roll and forming plate, it is essential to so arrange the plate that it will act as a guard against the tool being forced away from the work. That is, the action of the roll against the plate should be in the direction tending to carry the tool into the work, so that the thrust of the cut will always assist in keeping a positive contact between the roll and the plate. Counterweights or springs should also be used to obviate any tendency to draw in.

6. Economy in operating expense and the first cost of the attachment should also be considered, while the difference in workmen's rating is also a factor which should not be overlooked.

Radius Turning on the Engine Lathe

When concave or convex turning or boring is required on only one or two pieces, or, in cases where it is not practicable to combine the radial work with other operations, the engine lathe may be adapted to a great variety of conditions. In manufacturing, it may occasionally be used to advantage, especially in cases when the length of time required to do work is sufficient to permit one man to run two machines.

Fig. 2 shows the simplest kind of a forming attachment for convex work, which is adapted to the engine lathe. The work *A* is held by the inside in the chuck jaws *M*. The bracket *H* is screwed to the top of the cross-slide and carries, at its outer end, the tool-steel hardened and ground roller *K*, held in place by the screw *L*. The tailstock spindle *D* receives the holder *E* in which the plate *G* is inserted and secured by the two screws *F*. This plate is formed to the proper radius and is of tool steel unhardened. The cutting tool *B* is held in place in the regular toolpost *C*. The form of the cutting end of this is important as it must be formed to a perfect radius, in order that the cutting action may be uniform. In operating this attachment, the cross feed-screw is thrown into engagement, and the operator is required to force the roll *K* against the forming plate by means of the handwheel controlling the longitudinal feed of the carriage. An attachment of this sort requires the entire attention of the operator and, therefore, variations are liable to occur in the contour of the work, due to imperfect contact between the roll and plate; hence it is a very poor attachment to use if there are many pieces to be machined.

Piston Crowning Attachment for the Lathe

The arrangement shown in Fig. 3 was used for manufacturing in large quantities, and four lathes were equipped in this manner and required the services of two men to operate them. The piston *A* was located on a special draw-back chuck, on the steel locating ring *D*, and was drawn back firmly by the rod *C* acting on the pin *B* through the wrist-pin holes. A cast-iron bracket *E* is bolted onto the carriage of

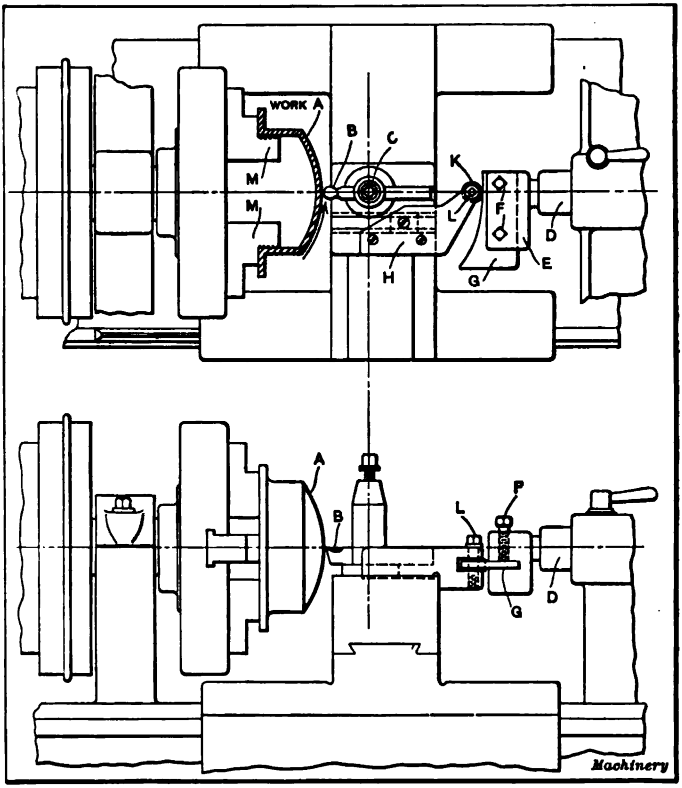

Fig. 2. Simple Attachment for Convex Turning in Engine Lathe

the lathe and is slotted at *G*. A cast-steel bracket *H* terminates at its upper end in the tool-block *K* which is dovetailed at *M* as shown in the plan view. The stud *F* is tee-shaped at its lower end to fit the slot in the bracket *E*. A steel block is screwed to the top of the cross-slide *P*, and is shouldered at *N* to fit the upper block in which the dovetailed tool-block *K* slides. The screw *O* simply holds the units together. A steel plate *Q* contains the two screws *R* and *S* which securely hold the tool *L*. In operating this device, the cross feed-screw is simply thrown into engagement and its forward action causes the tool to swing radially at the desired distance from the center *F*, thus developing a spherical surface. This device was comparatively inexpensive and the results obtained by its use were very satisfactory.

Concave Turning with a Compound Rest

A very simple device which may be used when one or two pieces only are required is shown in Fig. 4, but the radius which can be generated by this method is limited by the size of the compound rest.

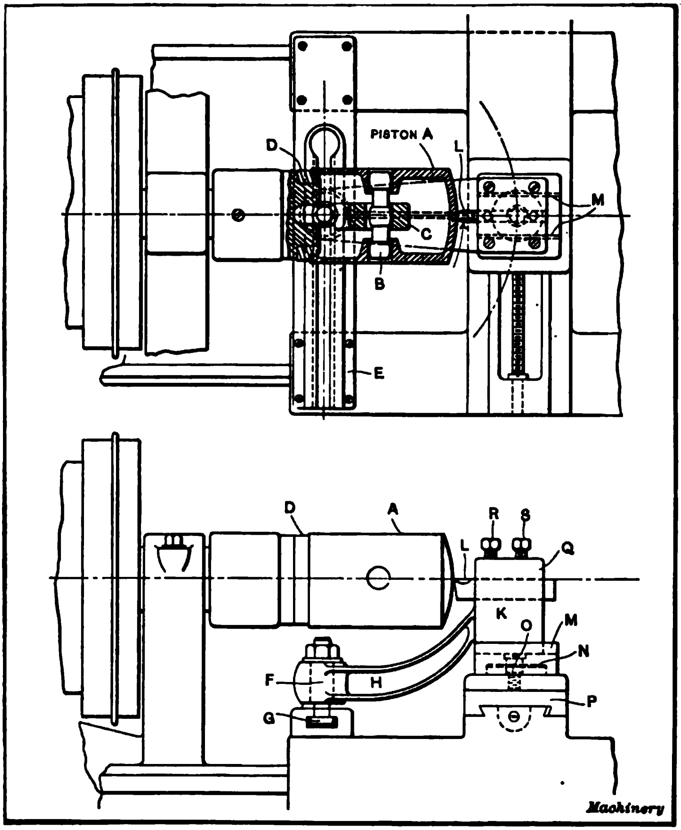

Fig. 3. Piston Crowning Attachment for the Lathe

The work *A* is held by the outside in chuck jaws, and the tool *C* generates a radius equal to the distance from the end of the tool to the center of the swivel. The socket *G* is placed in the tailstock spindle and the overhanging end contains the round head pin *H*. The bar *D* is cup-shaped at *E* and *F* and bears against the end of the compound rest screw at *E*, while the other end engages the button at *F*. In using this arrangement, the holding-down gibs or straps of the compound rest swivel are set up to produce considerable friction, and the tailstock spindle is fed forward by hand, thus causing the compound rest to swing on its own center, thereby generating the desired radius. It is obvious that the carriage gibs must be tightened to prevent any longitudinal movement.

Radius Bar for Concave Turning

A very simple arrangement for the engine lathe is shown in Fig. 5. The work *A* is held by the outside in chuck jaws and the round nose

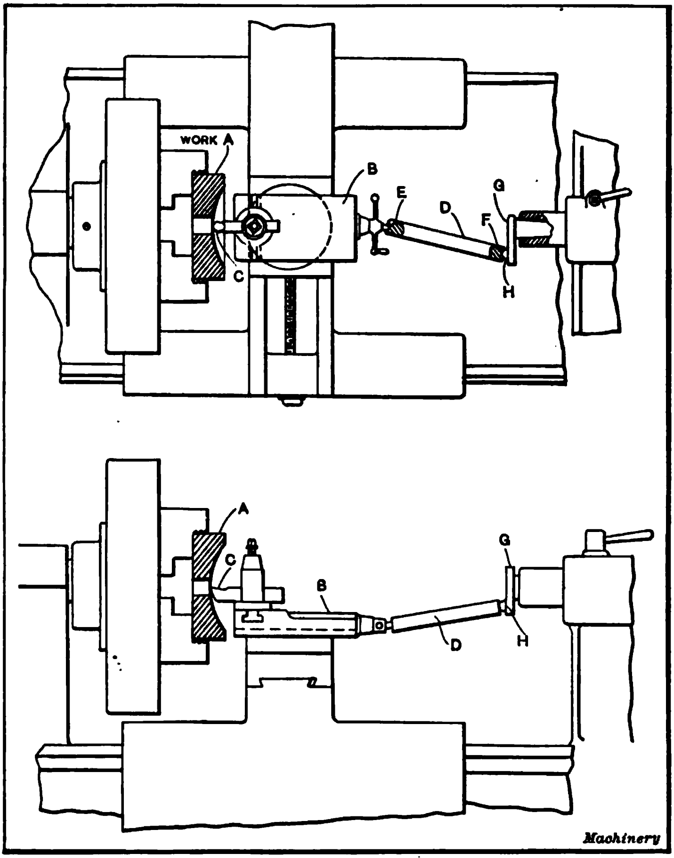

Fig. 4. Concave Turning with Compound Rest

tool *B* is used to generate the concave surface. The tool is held in the ordinary manner in the toolpost *C* on the cross-slide of the lathe. A slotted holder *K* is tapered on its rear end to fit the tailstock spindle *B* and is slotted to receive the flat steel radius-bar *G* which is held in position by means of the shoulder screw *H*. The stud *F* enters the tool slot of the cross-slide and serves as a pivot for the forward end of the radius-bar. This bar is made of the correct length to generate the desired radius. As in a previous instance, the cutting end of the tool *B* must be ground to a perfect radius. The arrangement shown here is a very simple one and may be used for various pieces of work by the substitution of a bar of the proper radius.

Pulley Crowning Attachment for the Engine Lathe

Fig. 6 illustrates an arrangement that was applied to an old-style Pratt & Whitney lathe which had, at one time, been equipped with a

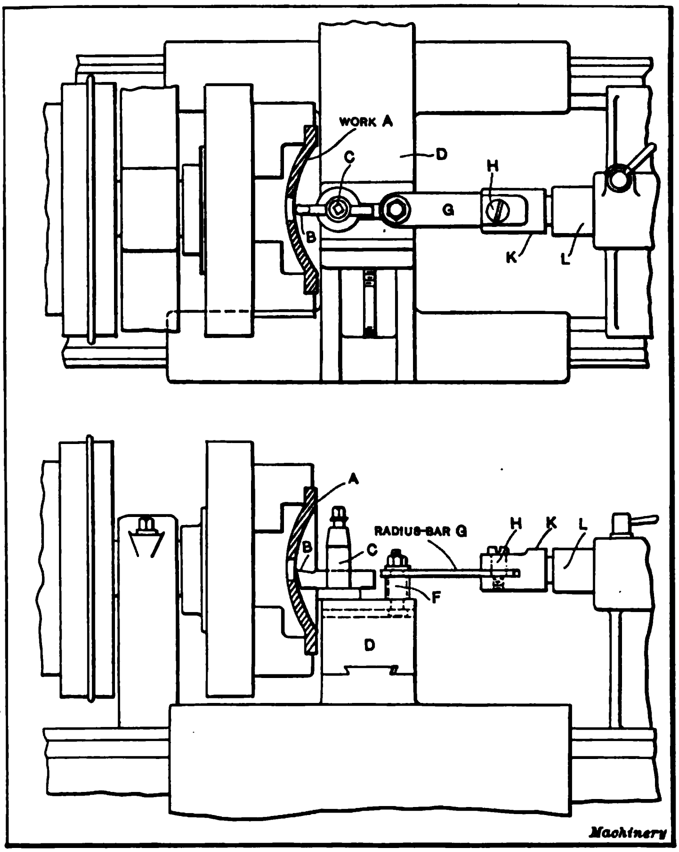

Fig. 5. Radius-bar Type of Concave Turning Attachment

taper attachment. The arrangement shown was specially designed for crowning pulleys which previously had been "chucked," faced and rough-turned straight on the periphery. A keyway had also been cut through the hub. A special arbor *D* was held on centers in a lathe, the dog *E* acting as a driver in the special faceplate *F*. The pulleys were put on the arbor until the face of the hub came up against the shoulder *H*, the spacer *J* being interposed between the two hubs. The cast-iron driving plate *K* was then put on, followed by the washer *M*. The nut *L* was then used to tighten the pieces in position. The driving bar *G* was used in order to prevent vibration which would otherwise be troublesome due to the thin flange of the pulleys. The two round-nosed tools *B* were mounted on the tool-slide *C* and held in the ordinary manner. A steel plate *Y* was bolted to the end of the slide and overhung sufficiently to permit the bar *X* to pass through it. This bar passed completely through the carriage and was a sliding fit in

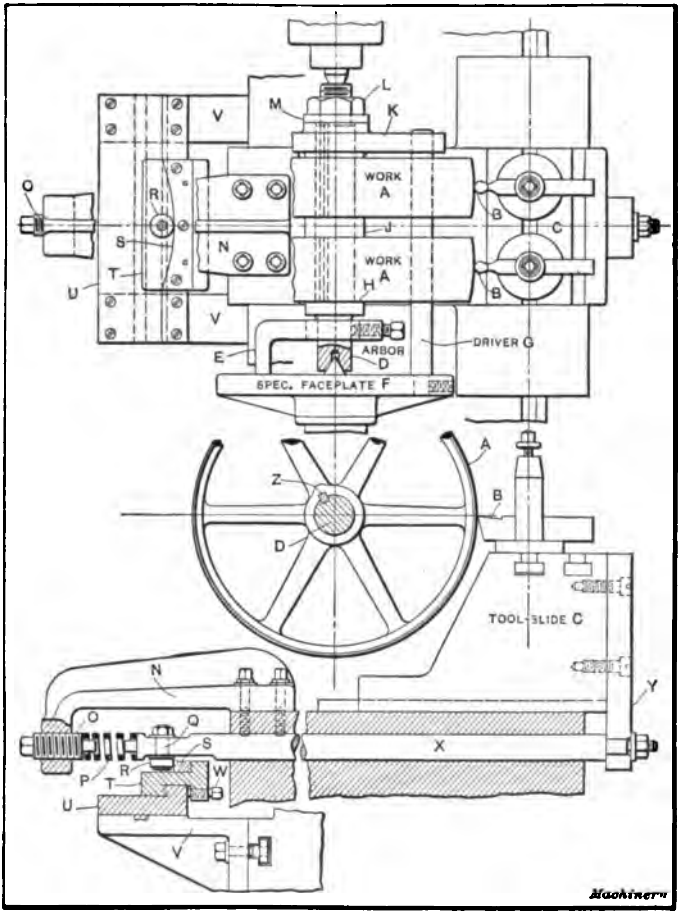

Fig. 6. Pulley Crowning Attachment for Engine Lathe

it. The stud *Q* passed through the bar and formed a bearing for the roller *R*. The cast-iron bracket *N* was fastened to the rear of the carriage and was tapped at its outer end to receive the screw *O*, which was used for adjusting the compression of the spring *P*. This spring was of square section ¼ inch in size and served to keep the roll in contact with the cam-plate *S*. Two brackets *V* and the plate *U* were a part of the taper attachment with which the lathe was originally equipped. The dovetail plate *T* served as an adjustable support for the cam-plate *S* and it was held in its proper location by the screws *W*. The upper view in the illustration is partially broken away to show the roll *R* in position against the cam-plate. The operation of this attachment is obvious and it is only necessary to state that its action was very satisfactory.

Fig. 7 shows a rather peculiar attachment for turning the convex surface on the cast-iron head-piece shown at *A*. The device is applied

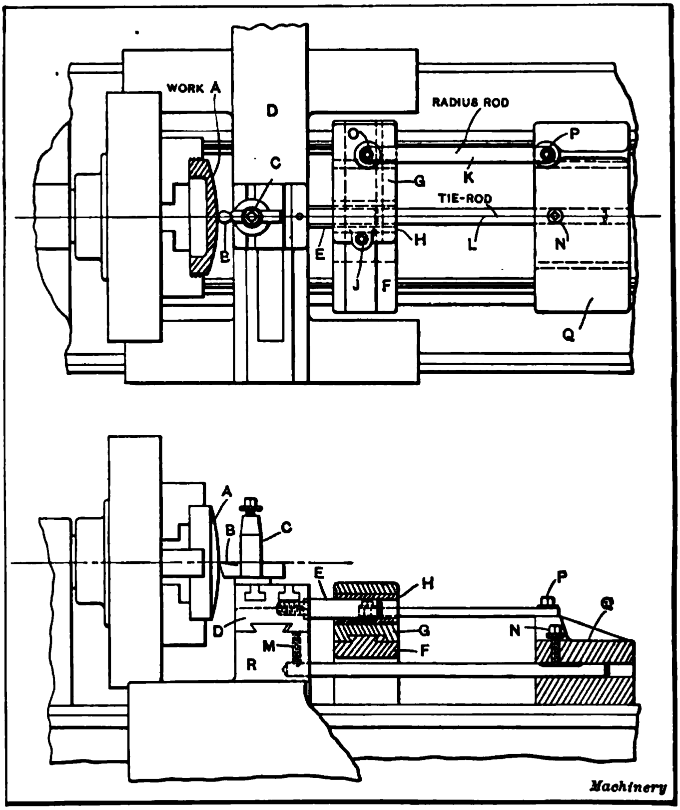

Fig. 7. Convex Turning Attachment of Radius-bar Type

to the engine lathe, and its construction is such that, by the substitution of various lengths of radius-rods, it may be used for an infinite number of radii. The cutting tool *B* is held in the toolpost *C* in the ordinary manner and the longitudinal feed-screw is left free so that the carriage *R* may be perfectly independent. The bracket *F* is secured to the inner ways of the lathe so that it is absolutely prevented from moving. This bracket is dovetailed along its upper face and the slide *G* is mounted upon it. A tool-steel stud *E* is screwed into the side of the cross-slide and enters the bushing *H* which is contained in the bracket slide *G*. This bushing is eccentric and is split along one side thus permitting a slight adjustment to compensate for wear. The binding screw *J* holds it rigidly after setting. The tie-rod *L* connects the carriage *R* with a special bracket *Q* at the rear end of the lathe, this bracket taking the place of the regular tailstock, and being gibbed to the ways in such a manner that it is

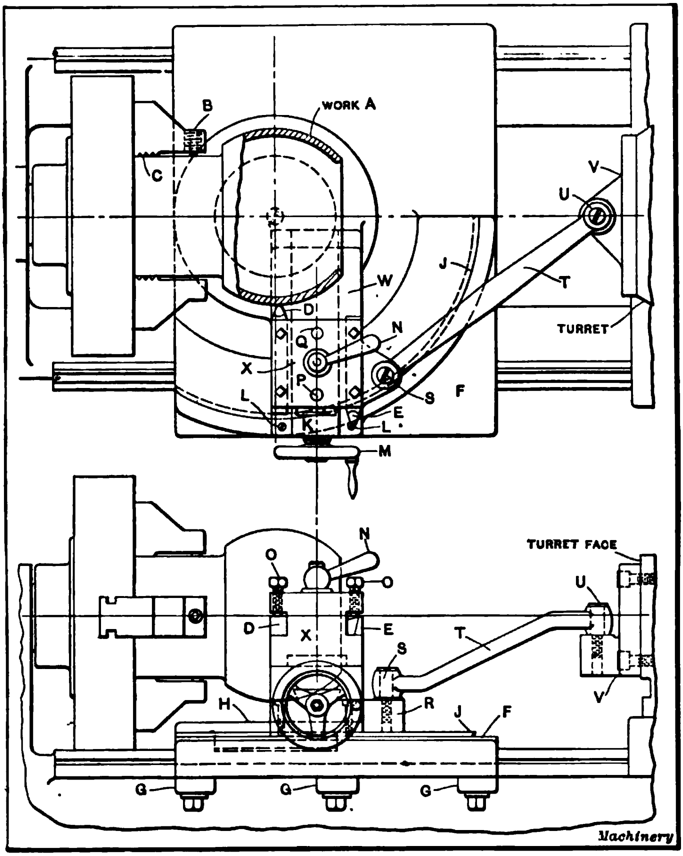

Fig. 8. Spherical Turning Device for Horizontal Turret Lathe

free to slide longitudinally. The tie-rod is held in place by the screws *N* and *M*. The radius-rod *K* is made from a piece of flat steel and swings on the two screws *O* and *P*, located in the bracket slide and the tailstock substitute respectively. In the operation of this mechanism, the cross feed-screw is thrown into mesh and the slide *D* moves forward carrying with it the bracket slide *G* to which the radius-rod is attached. As the bracket *F* cannot move longitudinally, it is evident that the tailstock substitute *Q* will be forced backward by the radius-rod and will carry with it the entire carriage and cross-slide, thereby generating the desired radius.

Ball-turning Device for the Horizontal Turret Lathe

We now come to a somewhat more pretentious device designed for the horizontal turret lathe for the purpose of generating the spherical portion of the steel pipe joint shown at *A* in Fig. 8. This work is held in chuck jaws at *C*, the supplementary screws *B* being used in the outer ends of the jaws to assist in supporting the work. The regular turret lathe cross-slide and carriage are removed and the special slide *F* is substituted. It is gibbed firmly to the ways in the desired position by the gibs *G*. Directly under the center line of the spindle, a large circular recess is bored to receive the swivel *H*, and circular rim *J* is dovetailed so that the outer end of the swivel may be gibbed at *K* to insure rigidity. The two screws *L* hold the gib. The slide *W* is dovetailed and has an adjustment for diameters, controlled by the handwheel *M*. The roughing and finishing tools *D* and *E* are held in the indexing toolpost *X*, the tools being secured by the screws *O*. The index location is insured by means of the pin *P* entering a hole directly underneath it in the slide, and the other index position is determined by the hole *Q*. The binder *N* locks it rigidly. At the right of the swivel the lug *R* is built out to receive the pivot screw *S*, on which the forward end of the radius-arm *T* is fastened. A bracket *V* is bolted to the face of the turret and carries the screw *U* which supports the other end of the radius-arm.

In the operation of this device, the turret longitudinal feed is used while the roughing tool *D* removes the scale from the casting. The toolpost is then indexed and the finishing tool *E* completes the work. This attachment gave very good results and was satisfactory in every respect. There are several points in the construction of this device to which attention should be directed. One of the points is the turret toolpost by means of which the tools always remain set, so that the diameters are easily held to size. Another point is the dovetail gibbing of the outer portion of the swivel. This method does away with all possibility of chatter, providing the gib is kept tight. Another advantage is the adjustment for various diameters by means of the slide *W* which is mounted on the swivel.

Turret Lathe Attachment for Crowning a Piston Head

The attachment in Fig. 9 is part of an equipment of tools for finishing the piston *A*, the work being held by the inside on a special chuck *B*, which is screwed onto the end of the spindle. There are turning tools fastened to the turret which are in action simultaneously with the attachment shown. These are not shown in the illustration, as they have nothing to do with the radius attachment. A special steel cross-slide *C* is mounted on the carriage in place of the regular slide, and the overhanging portion *G* carries a tool-block *M* in which the grooving tools for the piston are mounted. A special bracket *D* is firmly gibbed to the ways and secured by the screws *L*. The tool-steel forming plates *E* and *F* are screwed to this bracket and doweled in position. The plate *F* also acts as a strap for the overhanging portion of the cross-slide at *H*. A hardened and ground tool-steel roller *J* is pivoted on the stud *K*, and controls the form of the crown by its contact with the plate *F*. The other plate *E* only acts as a

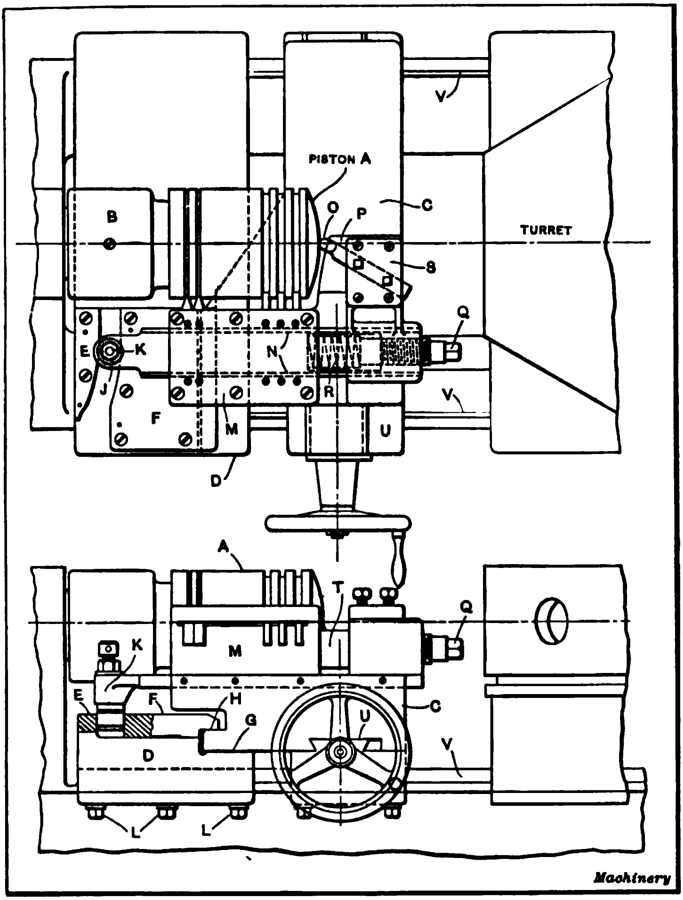

Fig. 9. Turret Lathe Piston Crowning Attachment

guard. The radius forming slide is dovetailed at *N* and passes through under the tool-block. It carries a tool *O* mounted in the tool-holder *S*. A supporting pad *P* is provided on the cross-slide directly under the tool-holder and serves to prevent vibration. A heavy coil spring *R* is used to insure proper contact of the roll with the cam-plate. The necessary adjustment is obtained by means of the screw *Q*. A brass tube *T* protects the spring from chips and dirt which might otherwise impair its action.

This attachment was built for a large manufacturing plant in the East, and proved very satisfactory. It is designed so that all the tools can work at the same time. In building the attachment, it was found necessary to fit the dovetail slides and other moving portions, after the tool-blocks were put in place, and the tools clamped in position. This was unavoidable because of the clamping strains, as these

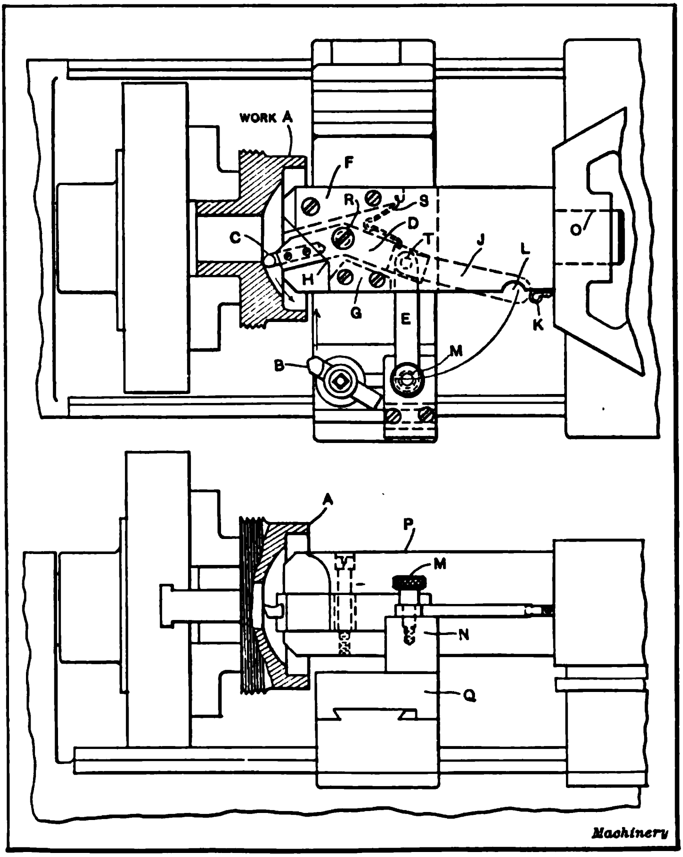

Fig. 10. Turret Lathe Attachment for turning Concave Seat

caused a certain amount of distortion, making it necessary to do the fitting after the tool-blocks were in position.

Radius Boring Attachment for a Horizontal Turret Lathe

The device for generating the internal radial seat in the brass casting *A*, shown in Fig. 10, is somewhat out of the ordinary, and in addition to this, it is comparatively inexpensive. Furthermore, it is practically a self-contained unit, and requires no special fitting or attachments to the machine.

The steel bar *P* is held in the turret by the shank *O* and is secured in place by the turret binder. The bar is slotted completely through to receive the swivel arm *D* which is a machinery steel forging ground on two sides to fit the slot. The forward end of this swivel arm carries the tool *C* which is set at the proper distance from the screw *R* to produce the desired radius. At the end of the bar, a mill cut is made at *H* in order to permit access to the screws which hold the tool in position. The steel filler blocks *F* and *G* are put in to give additional

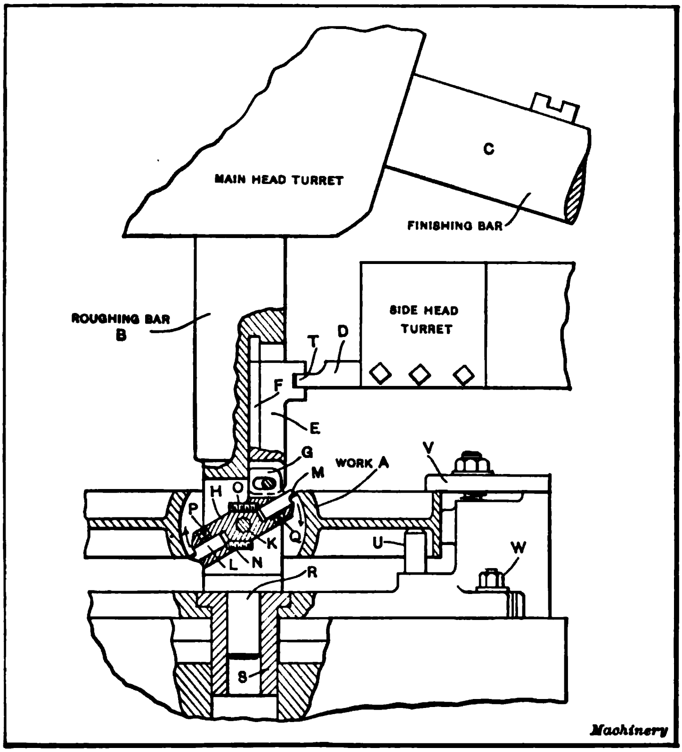

Fig. 11. Radius Boring-bar for Vertical Turret Lathe

rigidity to the end of the bar. The flat spring *S* is simply used to prevent back-lash in the swivel arm. The operating link *E* enters a slot in the end of the swivel arm and is held by the pin *T*. A special steel block *N* is fastened to the cross-slide and the knurled screw-pin *M* couples the end of the link to the slide. The tool *B* is used in connection with the attachment for facing the end of the work.

In operation, the cross-slide feed-screw is engaged and the radius nicely generated by the radial action of the arm. As soon as this operation has been completed, the knurled screw *M* is rapidly removed and the link *E*, swung over into the slot *J* where it is held by the flat spring *K*. The cut *L* allows the fingers to grasp the link when the radial attachment is again put into use. This attachment has many good points, the only serious draw-back being that there is a slight tendency to chatter when the cut is excessive.

Radius Boring Bar for the Vertical Turret Lathe

The device shown in Fig. 11 was designed for use on the vertical turret lathe, and was used in connection with other tools in the main and side heads for the purpose of boring the radial portions of the automobile crank-case cover bracket shown at *A* in the illustration.

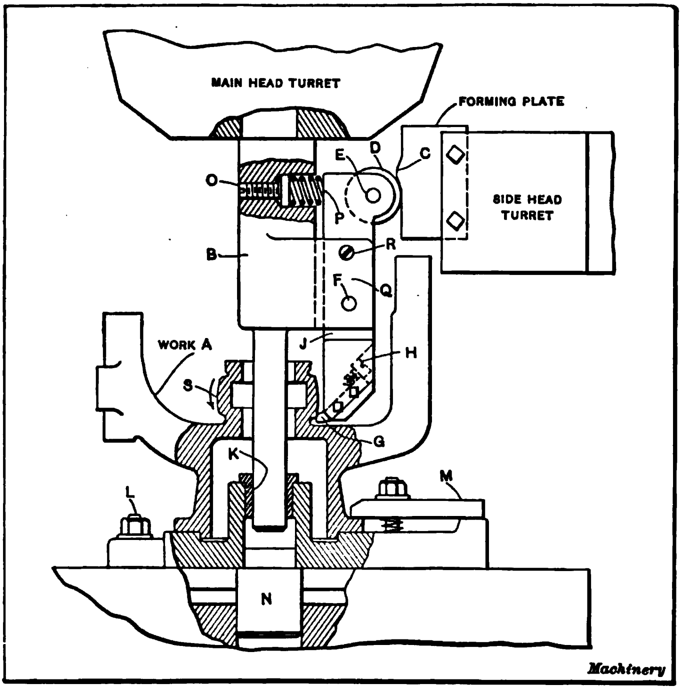

Fig. 12. Attachment for Convex Turning in Vertical Turret Lathe

The work is held on a locating fixture upon three pins *U* and is clamped by means of the straps *V*. Only a part of the work is shown, as the piece is somewhat large, and the other portions have nothing to do with the radial boring. The fixture is held to the table by three tee-bolts *W* and it is centered by the steel bushing *S*, which also acts as a guide for the stem of the boring-bar *R*. This bar is slotted out at its lower end to receive the swivel block *H*, which carries the tools *L* and *M* for rough-boring the radius. The block swings on the pin *K*, when forced to do so by the downward action of the operating arm *E*. The two cutting tools are backed up and adjusted by means of the screws *N* and *O*, and they are held firmly in position by the set-screws *P* and *Q*. The bar *B* is slotted out to receive the tongue *F* on the operating arm, and the lower end of this arm contains a pin which works in a slot at *G* in the upper portion of the swivel tool-block. The steel piece *D* is held in the side head turret and engages a groove in the upper part of the operating arm.

The finishing bar *C* is of the same general construction as the roughing bar except that only one tool is used for finishing, instead of the two shown in the roughing bar. It is well to note that the use of two tools in roughing practically reduces the roughing time one-half, it being only necessary to cut half way with each tool, as one comes

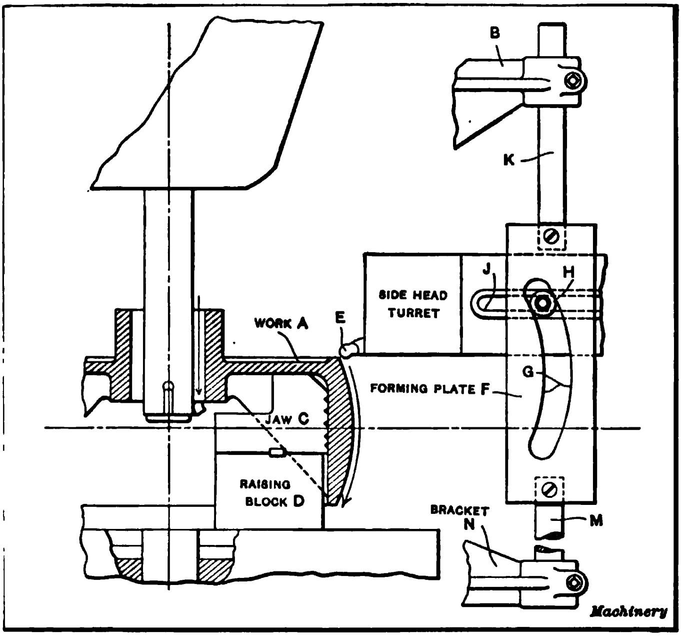

Fig. 13. Device for crowning Pulleys in Vertical Turret Lathe

up from the bottom while the other is coming down, so that the two cuts meet at the center. In operation, the down feed of the side-head turret is started, thus providing the necessary power for operating the device. This scheme gave very satisfactory results as far as accuracy is concerned, but as the mechanism was confined in a small space, the size of the tools could not be made large enough to properly conduct away the heat generated in boring.

Convex Turning Device for a Difficult Piece of Work

Fig. 12 shows a device for convex turning. The jack-shaft tube bracket *A* has been previously machined at its lower end and is located for this setting by the finished surfaces. A special fixture is bolted to the table of the vertical turret lathe, by the three tee-bolts *L*, and it is firmly secured by the straps *M*. The stud *N* serves to center the fixture on the table, while the bushing *K* acts as a guide for the end of the bar. The radial surface *S* is to be machined at this setting, and it will be noted that it is somewhat confined. The generating bar *B* is a 0.40 carbon steel forging, and the piloted end is carbonized, hardened and ground to a running fit in the bushing *K*. The projecting portion *Q* of the bar is of rectangular section and is slotted to receive the swinging arm *J*, which is pivoted on the pin *F*. This pin is equi-distant from the end of the cutting tool *G* and the center of the pin *E*. A hardened and ground tool-steel roller *D* revolves upon the

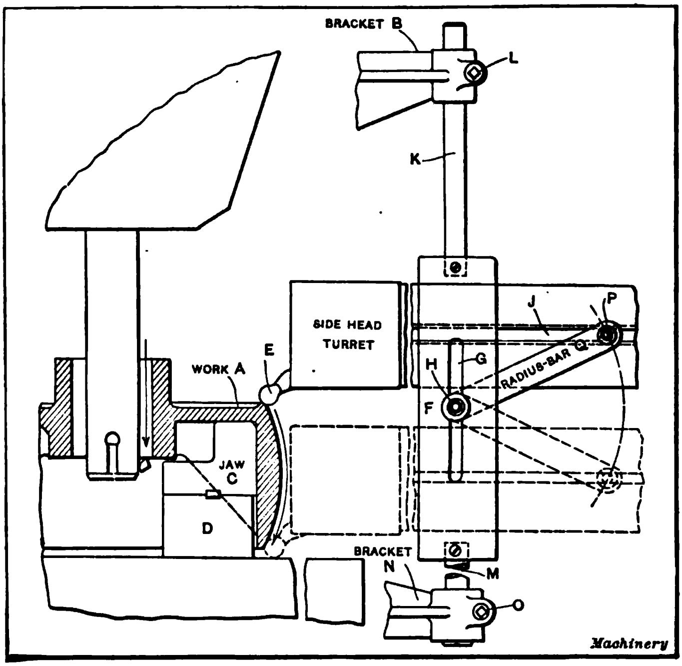

Fig. 14. Another Pulley Crowning Attachment

latter, and is kept in contact with the forming plate *C* by means of the spring *P*, which is very stiff. Adjustment is provided through the screw *O*.

In operating this device, the turret down feed is used and the side-head turret is locked in the proper relation to the cutting tool, to produce the radius at the correct height on the casting. For the finishing cut, the roughing tool *G* is removed and a finishing tool substituted. A special screw *H*, having a large head against which the ends of the tools bear, makes this comparatively easy. The work can be turned closer to size if two roughing tools and a finisher are used, leaving only about 0.010 inch for the final cut. A defect in this fixture is that the thrust of the cut has a tendency to force the roll away from the cam-plate, and the action of the spring is sometimes insufficient to entirely overcome this. Had it been possible to design this attachment in such a way that the thrust of the cut would simply hold the roll more firmly against the forming plate, its action would have been more positive. The results obtained were sufficiently close, however, to conform to the required limits of accuracy, and it may therefore be stated that its work was satisfactory.

Convex Forming Attachment for the Vertical Turret Lathe

A simple arrangement for the vertical turret lathe which permits the simultaneous use of both the main head and side heads, is shown

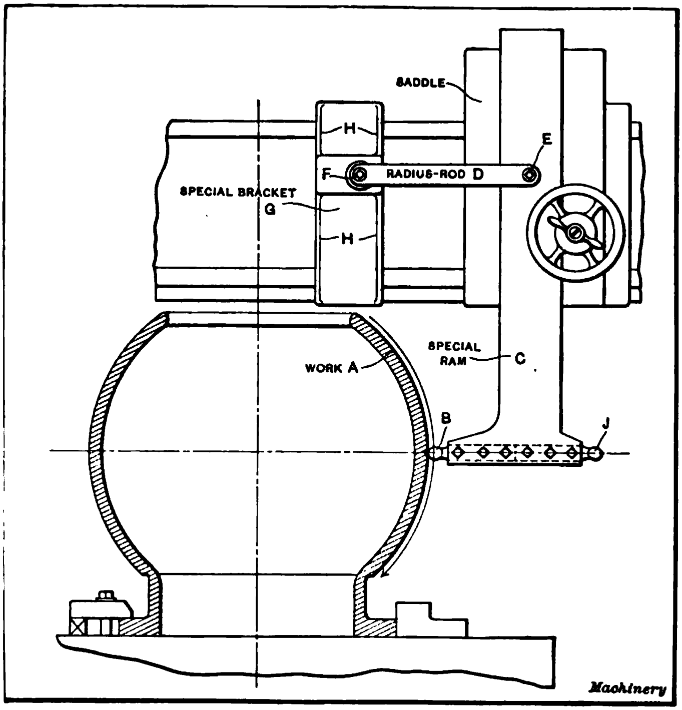

Fig. 15. Spherical Turning Attachment for Vertical Boring Mill

in Fig. 13. The work *A* is a tractor pulley of large size. This is held by the inside, in the jaws *C* which are mounted on the raising blocks *D*. The boring-bar shown may be used if desired, while the radius turning is taking place, as the radius attachment does not interfere in any way with the movements of the main head. The construction of this device is extremely simple and the results obtained by its use are very satisfactory. The upper and lower brackets *B* and *N* are attached to the bed of the machine and carry the rods *K* and *M*, which support the forming plate *F*. This plate is cut at *G* to the desired radius, and the tool-steel roller *H* travels along the slot and forces the tool *E*, which is held in the side-head turret, to take a similar path.

thereby producing the convex surface on the rim of the pulley. A tee-slot *J* is cut along the entire length of the side-head slide, and the roll *H* is fastened to a special bolt which can be adjusted to any position in the slot. The forming plate is also adjustable vertically, by sliding the rods up or down in the brackets.

Side-head Attachment using a Radius Bar

Another method for crowning the outside of a tractor pulley is shown in Fig. 14, a radius-bar being used in this case to generate the desired

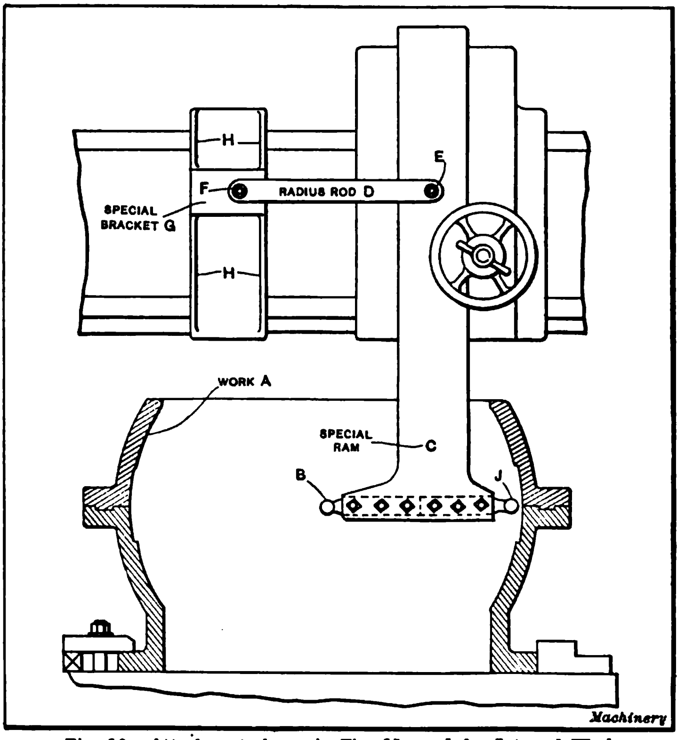

Fig. 16. Attachment shown in Fig. 15, used for Internal Work

curve. The work *A* is held, as in the previous instance, by the jaws *C* on the raising blocks *D*. The same brackets are also employed, but the plate *F* is not used for forming. It is slotted at *G* for adjustment only and a special screw or stud *H* is used in the slot as a pivot for the radius-bar *Q*. A tee-slot *J* is cut along the entire length of the side-head slide and receives a special stud *P*, to which the other end of the radius-bar is fastened. The down feed of the side-head is thrown into engagement when operating the device, and the tool *E* naturally follows the radial path controlled by the length of the radius-bar. This device is simple and good and only requires extra radius-bars in order to handle a great variety of work.

Vertical Boring Mill Attachment for Spherical Turning

The male member of a very large ball-and-socket pipe joint is shown at *A* in Fig. 15. The spherical portion, which is to be machined, has an outside diameter of forty-nine inches. This member fits the female portion shown in Fig. 16, and the attachments used for boring and turning are the same, although the locations and the tools are different. A special bracket *G* is mounted on the rail and is gibbed at the rear

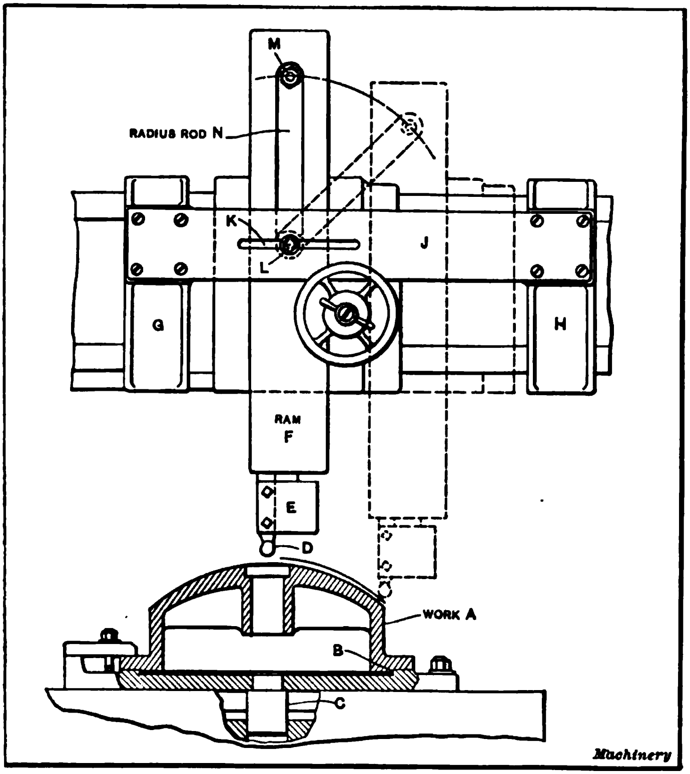

Fig. 17. Convex Turning in a Horizontal Plane

so that it can be adjusted easily. It is well gibbed at *H* to insure rigidity. The special ram *C* was made in the form shown, its lower end acting as a tool-holder for the tools *B* and *J*; the former is used for the outside turning and the latter for the inside boring. The ram itself is a steel casting of extra-heavy section on account of the excessive overhang required. The radius-rod *D* was fastened at the two ends by the screws *F* and *E*, and was made of the proper length to give the correct radius. A special arrangement, not shown in the illustration, permitted a side floating action to the saddle along the rail, when the down feed was engaged.

For handling the socket portion of the joint shown (Fig. 16), the entire mechanism was moved over on the rail far enough to bring the tools in the desired position for boring, the tool *J* being used for this purpose.

Attachment for Convex Turning in a Horizontal Plane

The work *A* shown in Fig. 17 is a steel casting which has been previously machined at *B*. It is held on a fixture (located centrally on the table by the plug *C*) and clamped down by the three clamps around the flange. Two brackets *G* and *H* are mounted on the rail and serve

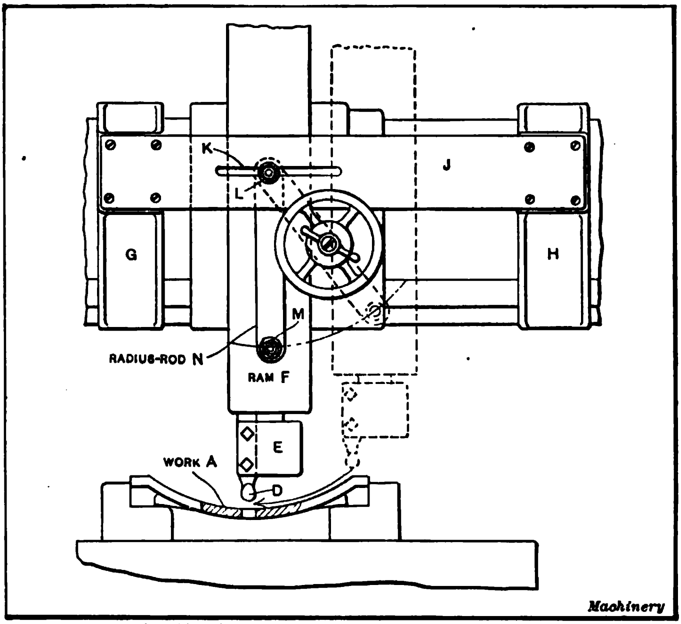

Fig. 18. Concave Turning in a Horizontal Plane

to carry the supporting plate *J*. As these brackets necessarily extend some distance in front of the rail they are strongly ribbed, as shown in the illustration. The supporting plate *J* has a slot cut in it at *K* for adjusting the pivot stud *L* in a longitudinal direction. This stud supports one end of the radius-rod *N*, and the other end is attached to the upper portion of the ram *F* by pivot stud *M*. A regular tool-holder at the lower end of the ram holds the tool *D*. No special arrangement is necessary to allow the saddle to "float" in a transverse direction, as the horizontal feed-screw is used in this case, the vertical feed being simply thrown out of mesh. This permits the ram to float vertically, as controlled by the radius-rod *N*.

Attachment for Concave Turning in a Horizontal Plane

The steel casting shown at *A* in Fig. 18 is turned concave by the same device as that illustrated in Fig. 17, the only difference being that the radius-rod *N* is pivoted to the ram below the supporting plate instead of above. The operation of the mechanism is exactly the same as that for the convex surface.

Many variations of the devices described in this chapter have been used for generating radial surfaces, but enough have been described to enable the reader to select a method most suited to the particular problem that may require a solution. Adaptations may be readily made to fit almost any condition likely to be encountered in general manufacturing.

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BROACHING

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PREFACE

The cutting of keyways and machining of holes in metal to shapes other than round by broaching is an old practice, but one that has attracted comparatively little attention until within the past ten years. While machines were built and used for broaching they were not in common use until about 1900, when the automobile business developed rapidly. Now the broaching process is used very extensively, not only by automobile manufacturers but by many other concerns. While relatively large work is being broached at the present time, the trend of practice indicates that much larger and heavier parts will be machined in this manner when the quantity of work warrants the necessary investment in machines and tools. The broaching machine is also becoming a recognized means of cutting external shapes that are readily machined with standard tools. The reason for this practice is the high rate of production and low cost.

The advantages of the broaching process are speed, interchangeability of work, adaptability to irregular forms, employment of comparatively unskilled labor, and adaptability to a great variety of work. The chief disadvantage is the high cost of broaches and the uncertainty of their life. One broach may cut 20,000 holes while another made of the same steel and tempered in the same manner may fail before 2000 are cut. While chiefly applied now to interior work, exterior work is also being successfully done, and one of the possibilities is broaching spur gears when the quantity of duplicate gears is large.

In preparing this treatise on broaching, many examples from practice have been included, and we desire to acknowledge our indebtedness especially to the J. N. Lapointe Co., and the Lapointe Machine Tool Co. for much practical information relating to modern broaching methods.

CHAPTER I

THE BROACHING PROCESS—BROACHING MACHINES

The broaching process consists in machining holes in castings or forgings by drawing or pushing through the rough cored or drilled hole one or more broaches having a series of teeth which increase slightly in size from one end of the tool to the other, and successively cut the hole to the required form. Broaching is especially adapted to the finishing of square, rectangular or irregular-shaped holes. It is also applicable to a wide variety of miscellaneous work, such as the

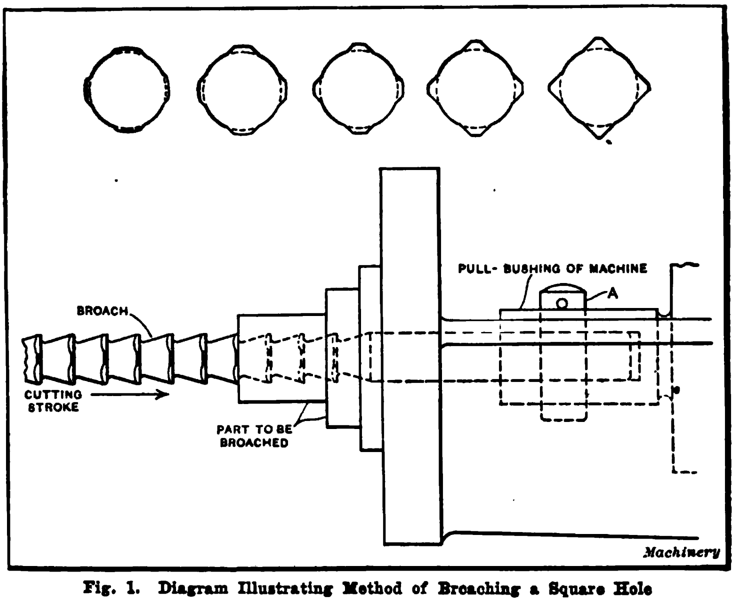

Fig. 1. Diagram Illustrating Method of Broaching a Square Hole

cutting of single or multiple keyways in hubs, forming splines, cutting teeth in small internal gears and ratchets, etc.

There are two general methods of broaching: One is by pushing comparatively short broaches through the work, usually by means of a hand press, a hydraulically operated press, or an ordinary punch press. With the other method, a special broaching machine is used, and the broach, which is usually much longer than a "push broach", is pulled through the work by means of a screw forming part of the machine. Push broaches must necessarily be quite short to prevent excessive deflection; consequently it is often necessary to force several broaches through the work. The longer broaches which are pulled through in regular broaching machines commonly finish parts in one passage, although a series of two or more broaches are often used for long holes, or when considerable stock must be removed. The number of broaches ordinarily used varies from one to four. Comparatively short broaches are sometimes used, because they are easier to make, are not warped excessively in hardening and are easier to handle. Two or more parts can frequently be finished simultaneously on a regular broaching machine, the pieces being placed one against the other, in tandem.

A simple example of broaching by drawing the broach through the work is illustrated by the diagrams, Fig. 1. A square hole is to be broached in the hub of a gear blank, this being a sliding gear (such as

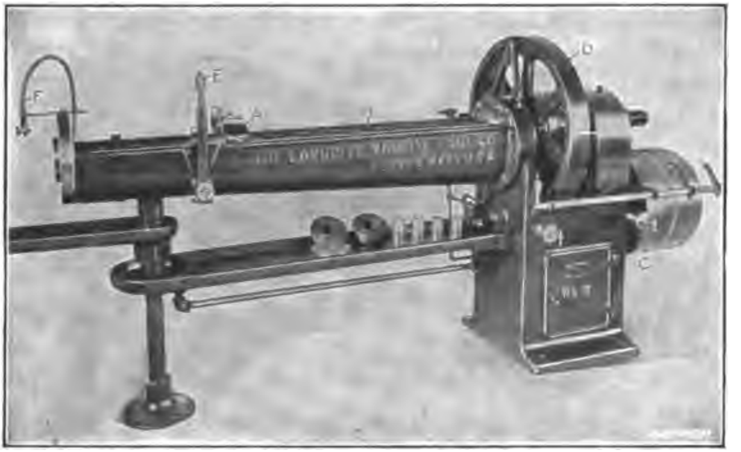

Fig. 2. Broaching Machine made by the Lapointe Machine Tool Co.

is used in automobile transmissions) that is to be mounted upon a square driving shaft. Prior to broaching, a hole is drilled slightly larger in diameter than the width of the square. The starting end of the broach, which at first is detached from the machine, is passed through the drilled hole in the blank, which rests against the end of the broaching machine. The end of the broach is then fastened to the "pull bushing" by a key *A* (which fits loosely to facilitate its removal), and the machine is started. By means of a powerful screw the broach is drawn through the hole in the gear blank and this hole is gradually cut to a square form by the successive action of the teeth which increases in size 0.002 or 0.003 inch per tooth. The process is illustrated by the enlarged diagrams at the top of the illustration.

The first few teeth take broad circular cuts which diminish in width so as to form a square-shaped hole. Of course, it will be understood that for cutting a hexagonal, round, or other form of hole, a broach of corresponding shape must be used. The blank to be broached does not need to be fastened to the machine, but is simply slipped onto the broach or a work bushing, in some cases, in a loose manner. As soon as the broaching operation begins, the work is held rigidly against the end of the machine or fixture when the latter is used.

From the preceding description of the broaching process, it will be seen that the function of the broaching machine is to draw the broach through the work at the proper speed.

General Description of a Broaching Machine

A typical broaching machine is illustrated in Fig. 2. The broach is secured to a draw-head *A* which in turn is attached to the end of

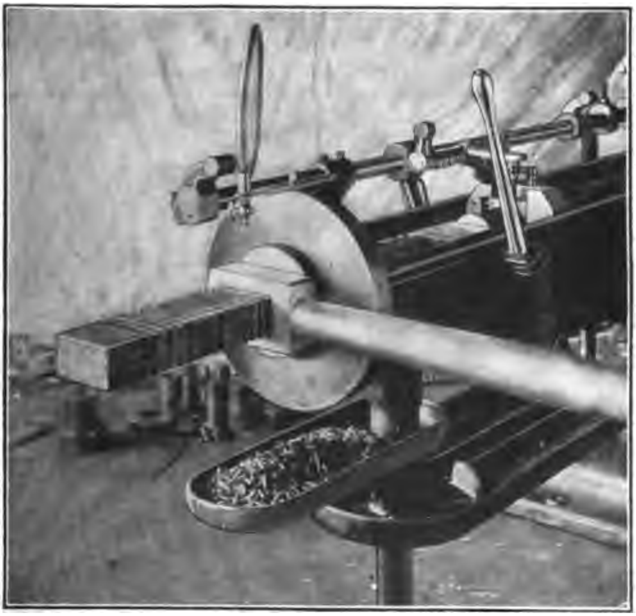

Fig. 3. Broaching Engine Connecting-rod End

a large screw *B*. This screw passes through a phosphor-bronze nut which is held against endwise movement and is rotated through gearing connected with the belt driving pulley *C*. As the nut rotates, screw *B* is moved one way or the other, depending upon the direction of rotation. On the broaching or cutting stroke, the drive is from a pinion on the belt pulley shaft, to a large gear (enclosed by guard *D*), which is connected to the screw operating nut by a clutch. On the return stroke, the clutch is shifted out of mesh with the large gear and is engaged with a smaller and more rapidly moving gear which rotates in the opposite direction.

The stroke of the machine is automatically controlled by two adjustable tappets mounted on a rod extending along the rear side. When either of these tappets is engaged by an arm which extends backward from the draw-head *A*, the rod upon which they are mounted is shifted. This movement of the rod operates the clutch, previously referred to, which reverses the motion of the nut on the screw. The stroke of the machine is regulated by simply changing the position of the tappets. The vertical lever *E* operates this same tappet rod and is used to start, stop or reverse the movement of the machine by hand. Cutting lubricant for the broach is supplied through the flexible tube *F*. These are the principal features of a broaching machine of the type illustrated.

Broaching a Connecting-rod End

A simple example of broaching is illustrated in Fig. 3 which shows how the rectangular opening in the end of an engine connecting-rod is finished. The hole is 2¼ inches wide by 4½ inches long, and the

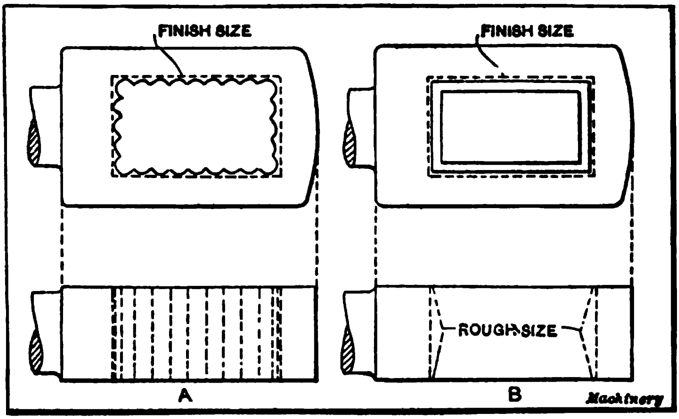

Fig. 4. (A) Rod End Blocked Out by Drilling. (B) Rod with Forged Hole

end of the rod is 1⅞ inch thick. This rectangular opening is finished by broaching in from four to five minutes, the time depending somewhat upon the facilities for handling the work. The end of the rod, prior to the broaching operation, is either blocked out by jig drilling as indicated at *A*, Fig. 4, or a rough hole is formed by forging as indicated at *B*. The full lines in these sketches show the rough surfaces in each case, and the dotted lines, the finished hole.

For broaching an opening of this size, two operations are required; one for roughing and one for finishing. The roughing broach removes the greater part of the metal and enlarges the hole to within 1/16 inch of the required size, there being 1/32 inch left on each of the four faces for finishing. The starting end of the finishing broach fits into the hole made by the roughing broach. These broaches are made of a solid piece of steel and are approximately 48 inches long.

As each of these rods weighs from three hundred to four hundred pounds, they are usually handled by means of a hoist. The end of the rod to be broached is supported by the broach itself, and the opposite end rests on a suitable stand. In this way, the work is held parallel or in position to bring the finished hole in alignment with the rod. The broach operates in a fixed position and finishes the hole according to the way the rod is set. After the support is properly located, any number of pieces can be broached without further adjustment, the holes produced being uniform in size and in alignment with the rod.

Fig. 5. Broaching Square Holes in a Vertical Hydraulic Press

Broaching in a Vertical Press

Fig. 5 shows an example of "push broaching," comparatively short broaches being forced down through the work by means of a hydraulic press. The operation is that of broaching the holes for the squared ends of the live spindles of the rear axle in the axle dogs in an automobile plant. The dogs are held in position by the hollow jig *A*, which is bolted to the base of the press, the jig being slotted to conform to the teeth of the dog, as shown at *D*. As the ram of the press forces the broach through the hole, the dial shown registers the pressure in tons; the maximum allowable pressure is 30 tons. At *R* is shown one of the dogs after it has been broached.

Duplex Broaching Machine

A duplex or double type of broaching machine is illustrated in Fig. 6. The distinctive feature of this machine is that there are two operating screws so that two broaches can be used at the same time. The design of the machine is such that one head is being returned while the other is on the cutting stroke. As it is possible to disengage one of the operating screws, the machine can be changed into the equivalent of a single broaching machine if desired. Both operating screws are provided with individual trips for regulating

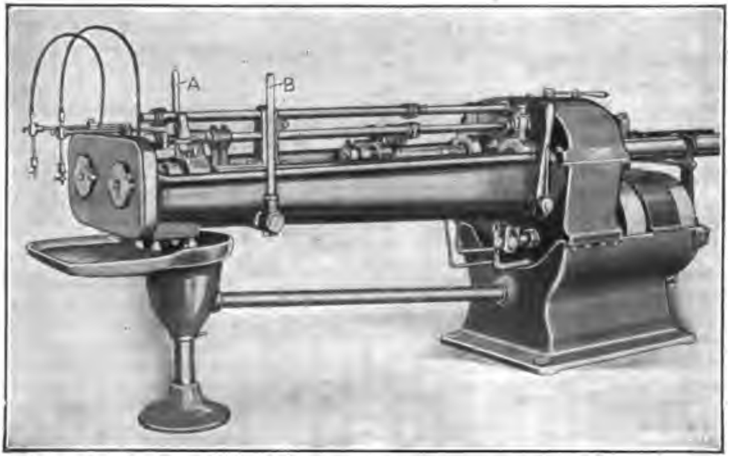

Fig. 6. Duplex Broaching Machine made by the J. N. Lapointe Co.

the length of the stroke. These trips are mounted upon rods which are located above the operating screws. Two broaching speeds are available, and two operating levers *A* and *B* are used to control the machine from either side. There is a pump and oil reservoir in the base of the machine to supply lubricant to the broaching tools. Two flexible tubes at the front end of the machine direct the cutting compound upon the broaches at the point where the cutting action takes place.

Means are provided for adjusting the stroke of the machine so that each screw operates on the same length of stroke. When making the adjustment, one of the sliding heads is brought into position ready for the cutting operation. The lever seen at the top of the gear-case is then moved sideways to disconnect this head. The operating lever on the machine is next shifted to the working position, and the other sliding head is moved to a position corresponding with the extreme length of stroke required. The stops are then set in this position and the stops for the other head are set in alignment with them. The lever on top of the gear-case is then shifted to bring the first head into operation. The travel of the sliding head on the low speed is 3 feet per minute, and on the high speed, 6 feet per minute. The maximum stroke of the machine is 54 inches, and it has a capacity for broaching holes up to 3 inches square.

CHAPTER II

BROACHES AND BROACH MAKING

A number of typical broaches and the operations for which they are intended are shown by the diagrams, Fig. 7. Broach *A* produces a round-cornered, square hole. Prior to broaching square holes, it is usually the practice to drill a round hole having a diameter *d* somewhat larger than the width of the square. Hence, the sides are not completely finished, but this unfinished part is not objectionable in most cases. In fact, this clearance space is an advantage during the broaching operation in that it serves as a channel for the broaching lubricant; moreover, the broach has less metal to remove. Broach *B* is for finishing round holes. Broaching is superior to reaming for some classes of work, because the broach will hold its size for a much longer period, thus insuring greater accuracy, and more economical results are obtained on certain classes of work.

Broaches *C* and *D* are for cutting single and double keyways, respectively. The former is of rectanglar section and, when in use, slides through a guiding bushing which is inserted in the hole. Broach *E* is for forming four integral splines in a hub. The broach at *F* is for producing hexagonal holes. Rectangular holes are finished by broach *G*. The teeth on the sides of this broach are inclined in opposite directions, which has the following advantages: The broach is stronger than it would be if the teeth were opposite and parallel to each other; thin work cannot drop between the inclined teeth, as it tends to do when the teeth are at right angles, because at least two teeth are always cutting; the inclination in opposite directions neutralizes the lateral thrust. The teeth on the edges are staggered, the teeth on one side being midway between the teeth on the other edge, as shown by the dotted line.

A double cut broach is shown at *H*. This type is for finishing, simultaneously, both sides *f* of a slot, and for similar work. Broach *I* is the style used for forming the teeth in internal gears. It is practically a series of gear-shaped cutters, the outside diameters of which gradually increase toward the finishing end of the broach. Broach *J* is for round holes but differs from style *B* in that it has a continuous helical cutting edge. Some prefer this form because it gives a shearing cut. Broach *K* is for cutting a series of helical grooves in a hub or bushing. The work rests against a special rotating support, and revolves to form the helical grooves, as the broach is pulled through.

In addition to the typical broaches shown in Fig. 7, many special designs are now in use for performing more complex operations. (Some of these will be referred to later.) Two surfaces on opposite sides of a casting or forging are sometimes machined simultaneously by twin broaches and, in other cases, three or four broaches are drawn

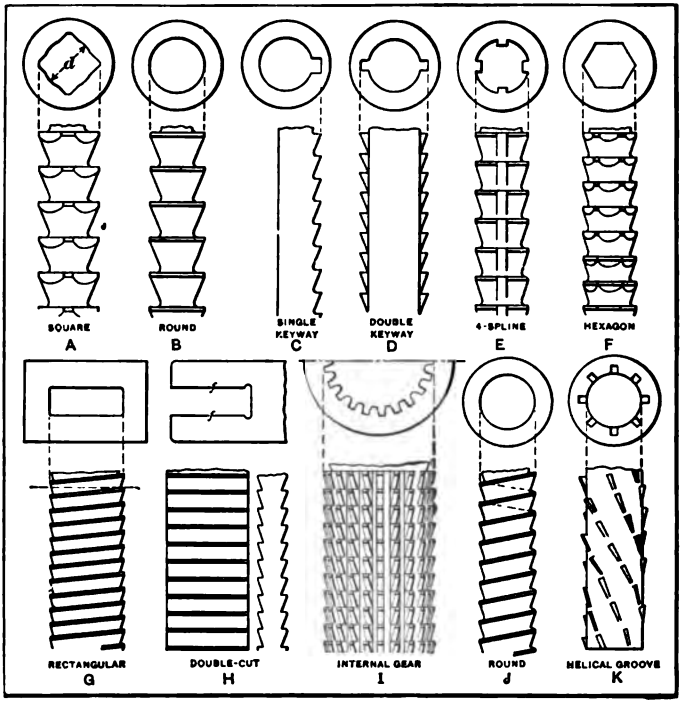

Fig. 7. Types of Broaches and Examples of Broached Work

through a part at the same time, for finishing as many duplicate holes or surfaces. Special work-holding and broach-guiding fixtures are commonly used for multiple broaching. In Chapter III a variety of special broaching operations are described and illustrated and indicate in a general way the possibilities of the broaching process.

As broaches have a series of teeth that successively cut the work to the required form, naturally the proportioning of these teeth is one of the most important features of broach design. While the design of a broach, aside from its general shape or form, depends largely upon its intended use, there are certain features which apply to broach making in general. One of the first things to determine is the pitch of the teeth, or the distance from one tooth to the next.

Pitch of Broach Teeth

As a general rule, the pitch P (see Fig. 8) should increase as the length of the hole increases to provide sufficient space between the teeth for the chips. The pitch of the teeth for broaching under *average* conditions can be determined by the following formula, in which P = pitch of teeth and L = length of hole to be broached:

$$P = \sqrt{L} \times 0.35$$

This formula expressed as a rule would be: *The pitch of the teeth equals the square root of the length of the hole multiplied by the constant 0.35.* For example, if a broach is required for a square hole 3 inches long, the pitch of the teeth would equal $\sqrt{3} \times 0.35 = 0.6$ inch, approximately.

Of course a given pitch will cover quite a range of lengths, the maximum being the length in which the chip space will be completely filled. The constant given in the preceding formula may be as low as 0.3 for some broaches and as high as 0.4 for others, although the

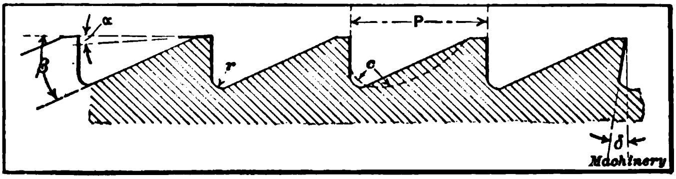

Fig. 8. Diagram illustrating Pitch, Clearance, Rake, and Filleting

pitch obtained with the value 0.35 corresponds to average practice. When a broach is quite large in diameter, thus permitting deep chip spaces in front of the teeth, the pitch might be decreased in order to reduce the total length of the broach. On the other hand, if the work is very hard and tough, a coarser pitch might be advisable in order to reduce the power required to force the broach through the hole.

If the pitch is too fine in proportion to the size of the broach, there may be difficulty in hardening, owing to the fact that the fine teeth will cool much more rapidly than the broach body, thus producing severe strains which tend to crack the teeth, especially at the corners. If the teeth are too closely spaced, so much power may be required for drawing the broach through the work that there is danger of pulling the broach apart. In general, the pitch should be as coarse as possible without weakening the broach too much, but at least *two teeth should be in contact* when broaching work of minimum length.

Depth of Cut per Tooth

The amount of metal that the successive teeth of a broach should remove, or the increase in size per tooth, depends largely upon the hardness or toughness of the material to be broached. The size of the hole in proportion to its length also affects the depth of cut, so that it is impossible to give more than a general idea of the increase in size per tooth. Medium-sized broaches for round or square holes usually have an increase of from 0.001 to 0.003 inch per tooth for broaching steel, and approximately double these amounts for soft cast iron or brass. Large broaches up to 2 or 3 inches may have an increase of from 0.005 to 0.010 inch per tooth. Obviously, the depth of cut is governed almost entirely by the nature of the work. For example, a small broach for use on brass or other soft material might have a larger increase per tooth than a much larger broach for cutting steel. If the amount of metal to be removed is comparatively small and the broach is used principally for finishing, the increase per tooth may not be over 0.001 inch even for large broaches.

The diagrams *A* and *B*, Fig. 9, show a common method of broaching square holes in the hubs of automobile transmission gears, etc. Prior to broaching, a hole is drilled slightly larger in diameter than the

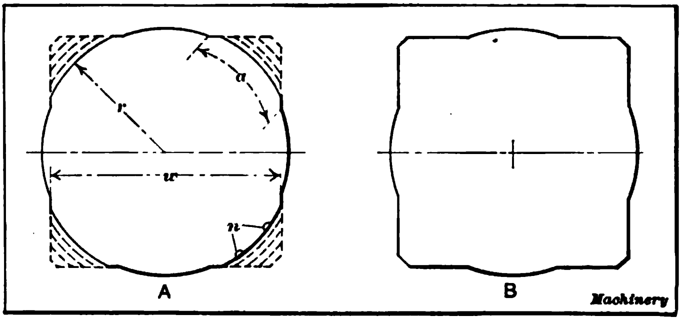

Fig. 9. Diagram illustrating Distribution of Tooth Cuts in broaching a Square Hole

square width. The first tooth on the broach is rounded and cuts a long circular chip, as indicated at *a*, and the following teeth form the square corners by removing successive chips (as shown by the dotted lines) until the square is finished as at *B*. As will be seen, the first tooth has the widest cut, the chip width *a* greatly decreasing toward the finishing end of the broach. Hence, if this hole were finished with a single broach, it would be advisable to vary the sizes of the teeth so that the depth of cut gradually increases as width *a* decreases.

It is good practice to nick some of the wide teeth as indicated at *n*, in order to break up the chips, as a broad curved chip does not bend or curl easily. In case two or more broaches are required, the first broach of the set may have a uniform variation in the radii *r* of different teeth, but the depth of cut should be less than for the following broaches which remove comparatively narrow chips from the corners of the square. Several end teeth, especially on the last broach of a set, are made to the finish size. This feature, which is common to broaches in general, aids the broach in retaining its size and tends to produce a more accurately finished hole.

Testing Uniformity of Teeth

When testing a broach to determine if all the teeth cut equally, first use a test piece not longer than 2 × pitch of teeth. Pull the broach through and note the amount of chips removed by each tooth; then "stone down" the high teeth and test by drawing through a longer piece, and, finally, through the full length required. If a broach is warped much, or is otherwise inaccurate, some teeth may take such deep cuts that the broach would break if an attempt were made to pull it through a long hole on the first trial.

Clearance Angles for Broach Teeth

The clearance angle a (Fig. 8) for the teeth of broaches is usually very small, and some broaches are made with practically no clearance. Ordinarily there should be a clearance angle varying from 1 to 3 degrees, 2 degrees being a fair average. A common method of providing the necessary clearance is as follows: All the lands of the hardened broach are first ground parallel and then they are "backed off" slightly by means of an oilstone. Just back of the narrow land (which may not be over 1/32 inch wide) there is a clearance of 2 or 3 degrees, machined prior to hardening.

The clearance space required for the chips depends upon the length of the hole and the depth of the cut. When the cut is light, and especially if the material to be broached is tough, thus making it necessary to use as strong a broach as possible, the clearance space should be proportionately small. The fillet at the base of each tooth should have as large a radius r (Fig. 8) as practicable and the grooves between the teeth should be smooth so that the chips will curl easily. A curved clearance space, similar to that indicated by the dotted line c, is superior to the straight slope, although not so easily machined. The front faces of the teeth are sometimes given a rake δ of from 5 to 8 degrees so that the broach will cut more easily and require less pressure to force it through the holes.

Steel for Broaches

Three kinds of steel are used for making broaches: namely, alloy steel, carbon steel and, to some extent, casehardened machine steel for short "push" broaches. Carbon-vanadium tool steel is especially adapted for broaches. This steel differs from the high-speed steels in which vanadium is also used in that it does not contain tungsten or chromium, but is simply a high-grade carbon steel containing a certain percentage of vanadium. The addition of vanadium to carbon steel imparts certain qualities, the most important of which are, first, the higher temperature to which the steel can be heated without coarsening the grain(thus permitting a greater range in temperature for hardening without spoiling the tool), and second, the tough core which makes the broach stronger and more durable than one made of regular high-carbon steel. The makers recommend hardening carbon-vanadium steel at a temperature varying from 1350 to 1425 degrees

F., the temperature depending somewhat upon the size of the tool. The steel is then drawn to suit conditions, the drawing temperature generally being about 460 degrees F. This particular brand of steel will not harden in oil.

Regular carbon steel that is used for broaches should have from 1.00 to 1.10 per cent carbon. To prevent the steel from warping excessively, the broach should be annealed after the teeth have been roughed out. A successful method of hardening to prevent excessive warping is as follows: After machining the broach and before hardening, heat to a dark red and allow the broach to cool while lying on a flat plate, then heat to the hardening temperature and harden in the usual manner. This method, which is applicable to all tool steels, reduces warping to a minimum and is of especial value when hardening slender broaches.

Straightening Hardened Broaches

Broaches that have been warped by hardening can be straightened at the time the temper is drawn. Place the broach on two wooden blocks on the table of a drill press equipped with a lever feed, and insert a wooden block in the end of the drill press spindle. Heat the broach with a Bunsen burner until the hand can barely touch it; then apply pressure to the "high" side. Continue heating (as uniformly as possible) and bending until the broach is straight, but complete the straightening operation before the broach has reached a temperature of about 350 degrees F., so that the drawing temperature will not be exceeded. With this method the heat required for straightening is also used for drawing the temper, the broach being removed and quenched as soon as the tempering temperature is reached. The temperature is judged by brightening some of the teeth throughout the length of the broach and watching the color-changes as the temperature increases.

Proportions of Broaches for Different Operations

The following examples of broaching taken from actual practice indicate, in a general way, the proportions of broaches for various operations:

Operation 1.—Broaching 15/16-inch square holes in alloy steel gears having hubs 3 inches long. Broaches used: The first or No. 1 broach in the set of three has teeth which increase in diameter from the starting end 0.002 inch; the teeth on No. 2 broach increase 0.003 inch, and those on No. 3, 0.004 inch. The leading ends or shanks of the three broaches are 0.005 inch less in diameter than the 1-inch hole drilled prior to the broaching operation. The pitch of the teeth is ½ inch; the width of the lands, ⅛ inch; the last two teeth on broaches Nos. 1 and 2 are made the finished size; six teeth of the finished size are left on broach No. 3. When more than one broach is used, it is common practice to make the last tooth on one broach and the first tooth on the following broach of the same size.

Operation 2.—Broaching a ⅝-inch square hole, 1½ inch long, in carbon steel. Broaches used: Set of three push broaches (for use under a press), 10¼ inches long; pitch of teeth, 5/16 inch; increase in size per tooth, 0.003 inch (0.0015 on each side). A 21/32-inch hole is drilled prior to broaching.

Operation 3.—Broaching a 9/16-inch hexagon hole, ⅞ inch long, in high-grade carbon steel. Broaches used: Set of four push broaches, 6 inches long; pitch of teeth, ¼ inch; increase in size per tooth, 0.010 inch (0.005 on each side) for first six teeth (because of small corner cuts taken by leading teeth), and 0.003 inch for remaining eight teeth. The last six teeth on broach No. 4 are made the same size.

Operation 4.—Finishing babbitted or bronze bearings, 1½ inch diameter, 3 inches long. Broaches used: Pitch of teeth, 7/16 inch; length of toothed section, 4 inches; increase in size per tooth, 0.001 inch; number of uniformly sized finishing teeth, 3; width of lands, 1/32 inch; size of pilot, 1.495 inch; length, 1¾ inch; size of plain cylindrical section following finishing teeth for producing hard and compact surface, 1.505 inch.

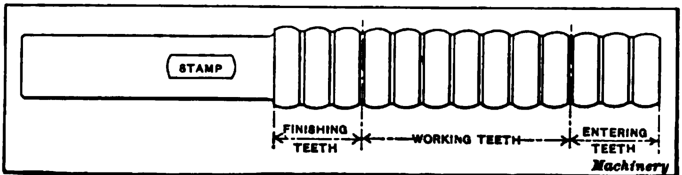

Fig. 10. Smooth, Toothed Broach used for machining Bearings

Operation 5.—Broaching the teeth in machine steel internal gears of 3.3 inch pitch diameter; 20 diametral pitch, with teeth ½ inch long. Broaches used: Pitch of teeth (distance between centers of successive rows), ⅜ inch; increase in outside diameter for each annular row of teeth, 0.006 inch; number of rows of uniform diameter, last three. This type of broach is illustrated at *I*, in Fig. 7, and is made as follows: After roughing out the blank, anneal the steel; then mill the teeth the same as if making a long gear; harden and grind the front faces of the teeth to produce sharp edges. The cutting ends of the teeth require little or no clearance.

Smooth-tooth Broaches

Fig. 10 shows a broach of novel design which has the teeth rounded at the top instead of being finished to a cutting edge as in the ordinary type of broach. These teeth are highly polished, and experience has shown that the higher the polish, the better will be the results obtained with the tool. It will be seen that the first few teeth are small enough to enter the hole which is to be broached, the intermediate teeth are of slightly larger diameter, and the last three teeth are of the size to which it is desired to finish the work.

This tool is used for broaching bearings and for operations on other classes of work where the metal is relatively soft, the tool compressing the metal, and thus giving it a surface hardness. This is of particular value in the case of bearings, on which class of work this broach has found wide application. The amount of metal displaced by the broaching operation is about the same as that removed by reaming, depending largely on the kind of metal and the construction of the broach. Although the tool is primarily intended for operations on babbitt and white bearing metal and brass, it has been used satisfactorily for producing glazed surfaces on cast-iron bearings.

The distance from center-to-center of the teeth depends somewhat on the length of the work which is to be broached. It is desirable to have at least six or eight teeth working at all times. This broach is usually made as shown in the illustration and is pushed through the work instead of being pulled in the ordinary way. An arbor or screw press may be used for this purpose and it is generally advisable to apply lubricant to the broach while in operation.

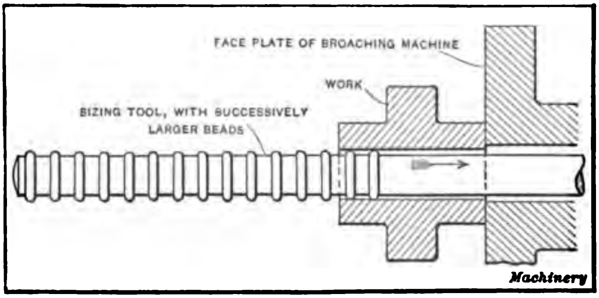

Fig. 11. Method of Sizing Phosphor-bronze in the Broaching Machine by Compression

The noteworthy feature of the operation of a broach of this type, as compared with an ordinary smooth plug, lies in the reduction of friction. It will be evident that the teeth of this broach are fully as efficient as a plug for handling the class of work for which the tool is intended. At the same time, the area of the tool in contact with the work is greatly reduced, with a corresponding reduction of friction and the amount of power required to drive the tool. The provision of teeth also makes it possible to apply lubricant to the work more readily than could be done if an ordinary plug were used.

Sizing Round Holes with Smooth-tooth Broach

Fig. 11 shows how a broaching machine and smooth-tooth broach were used for sizing holes in hard phosphor-bronze bushings. This material, as any mechanic who has had any experience with it knows, is difficult to finish ream. It is tough, elastic and slippery, and the less there is to ream the more difficult becomes the operation. Instead of reaming, the holes are enlarged slightly by pulling a smooth-tooth broach through in a regular broaching machine. It will at once be seen that the operation is that of compressing the metal in the sides of the hole, until it has been enlarged to the finished size. Each of the rounded rings or beads on the broach is a little larger than its predecessor, thus gradually compressing the metal the desired amount. The finished hole springs back to a diameter a few thousandths inch less than the diameter of the largest ring on the tool, so that the size of the latter has to be determined by experiment. This allowance varies slightly also, as may be imagined, with the thickness of the wall of metal being pressed. In such a part as that shown, for instance, after drawing through the sizing tool in the broaching machine, it will be found that the hole will be somewhat larger in the large diameter of the work than in the hubs. It has been found that this difference in size can be practically avoided by passing the sizing tool through the work three or four times. The operation is a rapid one as compared with reaming.

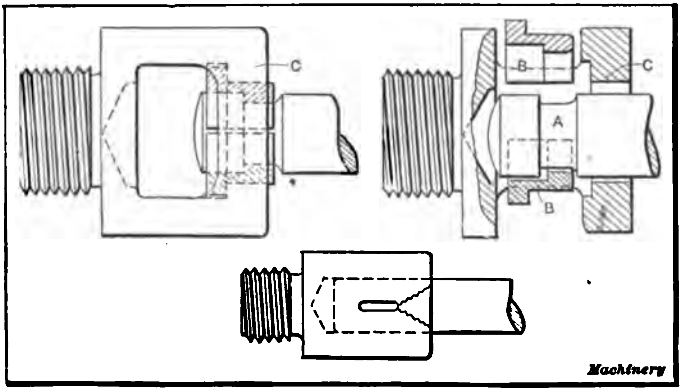

Fig. 12. Design of Pull-bushing for Broaching Machines

Pull-bushing for Broaches

The broaches used on regular horizontal broaching machines are usually secured to the pull-bushing by means of a key passing through the bushing and broach. This connection frequently fails, the pull-bushing giving way as shown by the lower view in Fig. 12, or the end of the broach breaks off. The trouble can be overcome by using a pull-bushing of the type illustrated by the two upper views.

The end of the broach is reduced in diameter as shown at *A*, leaving a shoulder; half-bushings are turned to suit the bore *C* of the pull-bushing and are made to fit freely the end of the broach. The pull-bushing has a slotted hole, wide enough for the insertion of these split bushings.

In use, the broach end is inserted through the hole in the pull-bushing, the half-bushings are placed on the neck and are then drawn back into the hole, as shown by the view to the left. By making the bore large enough when designating a pull-bushing of this form, it is quite a simple matter to arrange for one bushing to cover a large range of broaches, and in each case retain the greatest possible strength in the broach. Split bushings are made to suit each size of broach. The width of the shoulders in the split bushings should be such that they will break before the strain is great enough to break either the main pull-bushing or the end of the broach.

CHAPTER III

EXAMPLES OF BROACHING PRACTICE

A general idea of the adaptability of modern broaching machines, when equipped with well-made broaches, may be obtained from the following examples, all of which represent actual practice.

Broaching Rack-teeth in a Drop-forging

Fig. 13 illustrates a method of broaching the vacuum cleaner part shown in Fig. 14, the rough forging being illustrated at *X* and the

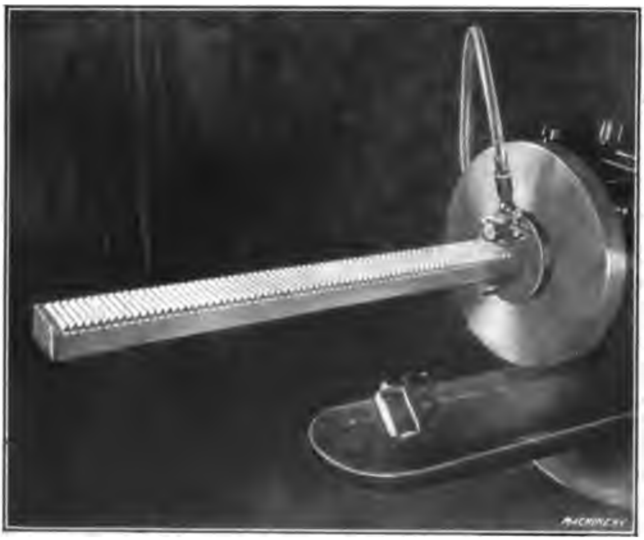

Fig. 13. Broach for Finishing Drop-forging shown in Fig. 14

finished part at *Z*. These pieces are light drop-forgings, and the thinness of the metal at *B* provides very little support to withstand the strain of heavy broaching. In this operation, rack teeth are not only cut (as indicated at *Z*), but also the clearance at *C*, the angular teeth *D* and the end surface *E*, all of these surfaces being finished at one passage of the broach. In finishing these pieces, it is necessary to have the center line *F-F* equi-distant from the end surfaces *E* and this feature was easily provided for by finishing the pieces on the broaching machine. If the surfaces *E* had been machined by separate operations on any other machine than a broaching machine, there would be a possibility for the introduction of an error at this point.

It will be seen that the pieces are approximately ½ inch thick and that they have a draft *H* on the inside of the forging. The amount of material removed at the dimension *J* was 0.198 inch on each side. The broaching operation would have been easier to handle if this draft had not been necessary. Attention is also called to the fact that the rack teeth were machined with a degree of accuracy which held the dimension *K* within a limit of 0.002 inch, which is exceptionally close

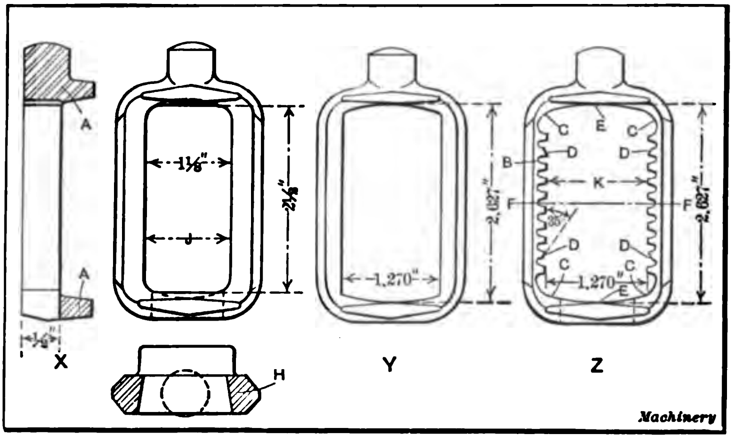

Fig. 14. Method of Broaching a Drop-forging

when the lightness of the work is considered. After the first two thousand pieces had been broached, the first and last pieces of the series were checked in order to determine if any wear had developed in broaching. There was not any error between the dimensions of these two pieces which could be measured. It is stated that in broaching this first series of 2000 pieces, a saving of 80 per cent was made over the time that would have been required to manufacture them by any other method; this saving is net, the cost of the broaches being included in the cost of production.

The broach is made so that the rough forging shown at *X* is first machined to the outline shown at *Y*. After this section was obtained, the clearance at each end, the teeth and the angular cut on the teeth *D* were machined. The gear tooth section was given very little clearance, so that the broach could be sharpened at the front of the teeth; this feature greatly increased the life of the broach. This broach will machine at least 6000 pieces at a rate of production of about 30 pieces per hour.

Broaching Heavy Bench-vise Bodies

The rectangular hole in the back jaw of an ordinary machinists' bench vise is an interesting example of broaching. A common practice has been to cast the back jaws with the rectangular opening cored as closely as possible to the required size and to fit the sliding jaw bar to it by filing. The result, of course, is considerable hand labor and more or less unsatisfactory work in many cases. The application of the broaching machine enables the vise manufacturer to cast the back jaws with smaller openings and to remove metal all around the inside of the hole with the broach. This insures perfect bearing and working surfaces free from hard scale.

Fig. 15 shows an equipment used by a vise manufacturer for broaching the holes in heavy vises. The chief feature of interest,

Fig. 15. Broaching Machine Finishing Rectangular Hole in Vise Body

aside from the general operation, is the means provided for supporting the heavy broach. The broach weighs 275 pounds and is, therefore, entirely too heavy to be lifted by hand. The necessity of handling the broach at each operation is neatly avoided. The broach is provided with a round shank at the rear, which telescopes into a supporting bracket. The bracket holds it up in line with the pulling shaft and thus eliminates the necessity of the operator's handling it. The round shank enables the broach to be turned readily to clean off the chips.

The vise jaw weighs about 150 pounds. It is mounted for broaching with the broach as indicated in Fig. 16, and the broach is then slipped up over the pulling shaft which projects out of the machine and is connected with a key. As soon as the machine begins to pull the broach through the vise jaw, the teeth come in contact with the metal all around and by the time the supporting shank of the broach leaves the bracket at the rear, the pressure developed is sufficient to hold the broach and vise jaw in position. The bracket for supporting the broach is pivoted on the round column beneath the end of the machine bed, and can be swung around beside the bed out of the way when the machine is being used on lighter broaching work. The time required for broaching a jaw varies from four to five minutes.

Broaching Taper Holes

The broaching machine is adapted to the broaching of taper holes when provided with a special fixture as shown by the diagram Fig. 17. The shape of the hole broached in this particular instance is shown in Fig. 18. It is evidently impossible to complete the forming of a square taper in one operation with a solid broach, as this would require a broach made in sections and guided in such a way as to travel in

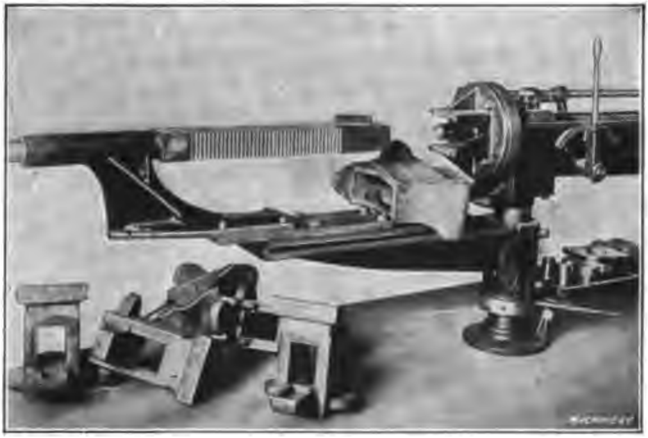

Fig. 16. Showing Heavy Broach supported on Bracket ready for placing Work in Position

paths at the proper angle with each other to give the required taper. In the case of small work like that here shown, the plan is followed of cutting one corner of the taper at a time, and then indexing the work to four successive positions until each corner has been cut, which thus finishes the entire hole.

As indicated by the dotted lines in Fig. 18, the hole to be broached is first finished with a taper reamer slightly larger at the large and small diameters than the width across the flat sides of the finished taper hole at the large and small ends. This gives a little clearance space for the broach on each of the operations. This round tapered hole also serves as a seat for the taper bushing on which the work is supported during the cutting operation, and as the broaching does not entirely clean out this hole, the bearing remains to the completion of the final operation. The work bushing is turned on its outside to the taper of the hole in the blank, and is mounted at the head of the machine on a base which is inclined to the angle of the corner of the internal taper to be cut. In a groove formed on the under side of this tapered work bushing, slides the broach or cutter bar (see Fig. 17), having teeth formed in it after the usual fashion of such tools, smaller at the inner end and gradually increasing in height to the outer end until they conform to the full depth of the cut to be made. The work has clamped to it a dog with a slotted tail, adapted to engage any one of four pins disposed equidistantly about the edge of a disk which forms the base of the taper

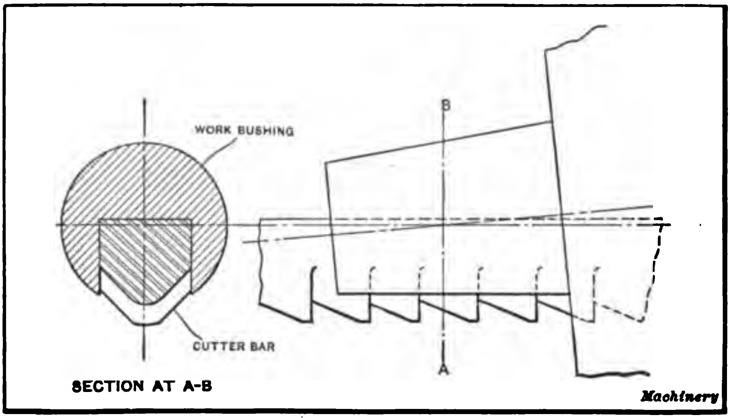

Fig. 17. Device used for Broaching Taper Holes

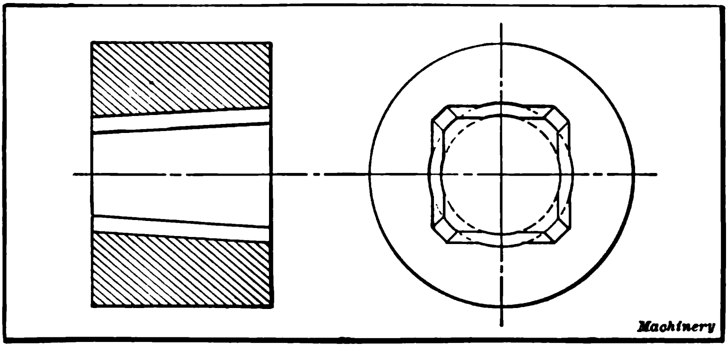

Fig. 18. Taper Hole Broached by Means of the Device shown in Fig. 17

work bushing. By means of these pins the casting is indexed for broaching the four corners.

In operation, the broach having been run out to the extreme of its travel, the work is inserted over the broach and pushed on to the taper work-holding bushing, and is located as to angular position by engaging the dog with one of the four pins. The machine is then started up and the broach is drawn back through the work, cutting out one of the corners. Then the blade is again run out, the work is drawn off by the taper bushing far enough to permit rotating it until the dog engages a second pin, when the operation is repeated, cutting out a second corner. The other two corners are successively finished in the same way, thus completing the machining of the hole to the form shown in Fig. 18.

It may be noted that while the hole shown has flattened corners, these are not required, as the broach can be made with a sharp corner if necessary. In all cases, however, it is necessary to leave a portion of the taper hole in the flat of the square so as to center the work with the bushing. Less of the circle, however, can be left than is shown in the engraving. For instance, at the large end the round taper hole need be only about 0.010 inch deeper than the square to be cut.

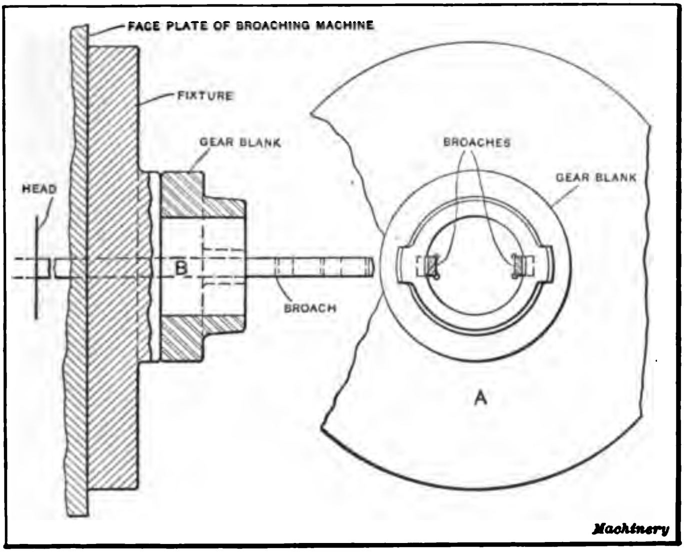

Fig. 19. Fixture used for holding Gear Blanks while broaching Two Keyways in One Stroke of Machine

Broaching Keyways in Gear Blanks

An interesting fixture for holding a gear blank while broaching two keyways in it is shown in Fig. 19. This gear blank is made from a vanadium steel drop-forging, and the broaching length is 1⅜ inch, two keyways which are 5/16 by 5/32 inch being cut in one pass of the broaches. In cutting these keyways it is not necessary to remove the broaches, which are held in the head, as the operator simply allows the head of the machine to advance toward the fixture, then grips the two broaches, closing them together, and slips the work over.

The broaches *B* have no teeth for a distance of about 2½ inches from the face of the fixture, so that when these are held together it is a simple matter to slip the work over them and locate it on the fixture *A*. It is evident that when the head of the machine travels away from the fixture, the broaches are drawn in, and as they are made thicker toward the outer ends, they cut the keyways to the correct depth. The illustration shows how these broaches are guided when in operation on the work. Holding the broaches in the manner shown, enables a large production to be obtained, the time generally taken in removing and replacing the broach being saved. On an average, 800 gear blanks are broached in ten hours, which means that 1600 keyways are cut in this time. The possibilities of broaching when suitable fixtures are provided are almost unlimited, and the job described in the preceding illustrates the adaptability of the broaching method to the cutting of keyways in gears.

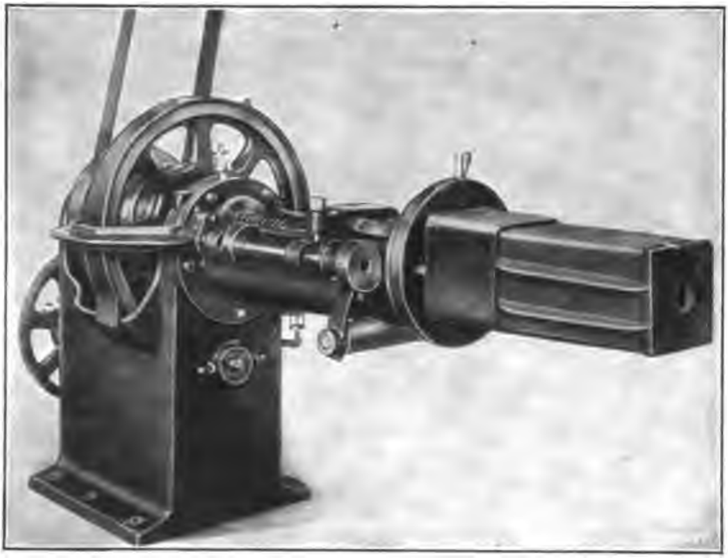

Fig. 20. The Broaching Machine with the Work in Place

Broaching a Large Steel Casting

Figs. 20 and 21 show a broaching machine provided with special cutting tools, and engaged on an exceptionally heavy broaching operation. The size of the hole to be broached is approximately 8 inches square, though the hole is not really square, being of the special shape shown in Fig. 22. Not only is the work remarkable on account of its size, but also because the surfaces had to be broached on a taper, the outer end of the hole being ½ inch further across than at the bottom, while the work is rendered still more difficult from the fact that the opening is closed at the small end. The method of broaching this casting is to begin at the bottom and work outward. A recess 3 inches long and about ¼ inch deep is furnished at the bottom to provide a clearance space for starting the broach. The stock to be removed on each of the finished surfaces of the work is about 1/16 inch thick; the total area to be broached is 14 inches long, with a developed width of 24 inches. In the center of each face of the hole, it will be noticed that there is a half-round recess; no broaching is done in this part.

The machine used is an unusually large size which operates on the same principle as the machines previously referred to. The mechanism consists primarily of a threaded draw bar or ram, operated by a revolving nut, driven by suitable gearing and reversing mechanism, this mechanism being operated by dogs and adjustable stops to give the required length of operating and return strokes. Practically the only special feature of the equipment is the special broaching head

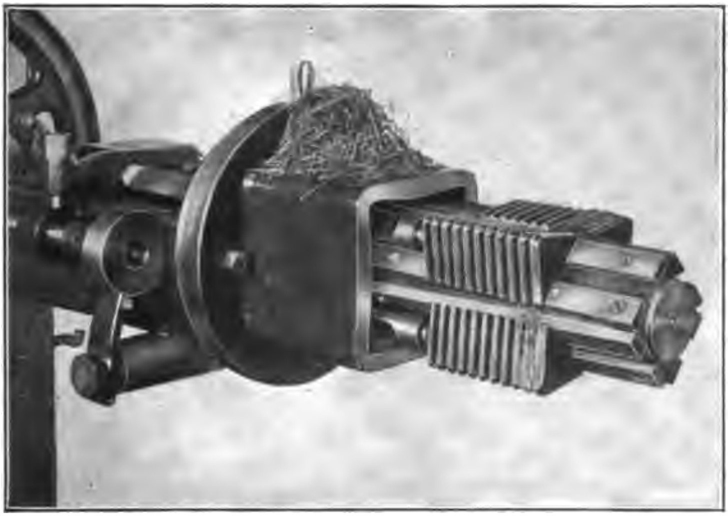

Fig. 21. The Taper Broach used for Broaching the Steel Casting shown in Fig. 22

and broaches used. These are of such unusual size and ingenious construction as to be of decided interest.

The construction of the broaching head is plainly shown in Fig. 21. It consists essentially of a central square mandrel, tapered to the taper of the hole to be finished in the work, and provided with ways in which slide four separate broaches—one for each corner of the work. These broaches are connected with the head of the ram of the machine by bars, which are milled down thin enough to have sufficient flexibility to permit the broaches to spread apart as they approach the inner end of the stroke, and come together again as they return to the starting position on the outer end of the mandrel. Each of the broaches is made of a solid piece of tool steel, with a series of 13 teeth of suitable shape milled in it.

In operation, the ram is first extended to the outer limit of its stroke, with the broaches at the outer and smaller end of the square central mandrel. The work is then placed over the mandrel as shown in Fig. 20, in which position the broaches nearly touch the closed bottom of the hole. The outer teeth in this position are in the recess. The machine is then started up, and the revolving nut, and threaded ram pull the broaches up on the tapered guides of the square mandrel, by means of the flexible pulling rods.. As the broaches are thus drawn inward on a gradually expanding form, they cut the required shape in the interior of the steel casting. The broaches first are tapered, so that the outer end is 1/32 inch larger than the end to which the pulling rods are connected, this being the amount which is to be removed from the work in each operation.

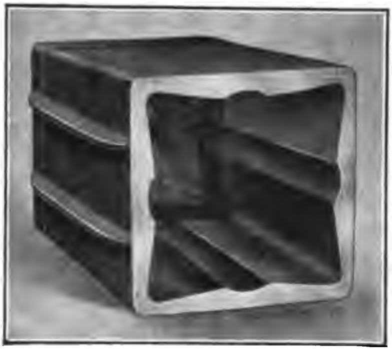
Fig. 22. Large Steel Casting Broached as Illustrated in Figs. 20 and 21

As is shown in the engraving, a special abutment or base is provided for taking the thrust of the work as it resists the action of the cutters. Piled up on this special base, in Fig. 21, will be seen the chips produced at one stroke of the machine. It will be noted from their character that a cutting action is effected by the broaching blades. The approximate pulling strain on the four rods operating the broaches is estimated to be from 75 to 100 tons.

Broaching Round Holes

The broaching of round holes has been adopted within the last few years by many manufacturers on certain classes of work in preference to reaming. This change is due to two reasons: The cost of the operation is less and the finish on the particular work referred to later is superior to that of reaming.

It is an acknowledged fact that the boring and reaming of seamless steel tubing, especially when the walls are light, is not a very satisfactory operation; in fact, the pieces are usually distorted, due to the method of holding them. One of the principal objections to reaming, and one reason why it is so hard to obtain a well reamed hole in steel tubing, is that the reamer tears or "bites in" at some point on the surface. This is due to the fact that the fibers of the steel are drawn lengthwise or at right angles to the cutting edges of the reamer, which is one of the reasons why it is so hard to obtain a good clean finish in steel tubing by reaming.

On the other hand, when broaching the hole in a tube, a very nice finish can be obtained because the fibers lie or are drawn in the same direction as the broach is operated. The ordinary seamless steel tubing is about 0.008 to 0.030 inch under standard size, which is about the right amount to broach out. For broaching this material, with diameters up to 2 inches, the high speed of the broaching machine can be used, the cutting tool traveling at about six feet per minute. There is no clamping of the work for this operation and the shell is not distorted as much as it would be by boring or reaming. Six or seven pieces can be broached while one is being reamed.

Broaching Round Holes in Steel Gears

The method of machining the holes in sliding and differential gears, adopted by one of the largest automobile gear manufacturers in the country, is as follows: The work is placed on a drill press, in a suitable fixture, and the holes, which vary from 1 1/16 to 1 1/2 inch in diameter, are drilled in one operation with a drill 1/32 inch smaller than the finished size of the hole. On the spindle of the drill press a facing head is arranged so that after the hole is drilled, the spindle is fed down and the gear faced off by this facing head; this forms a flat surface which is square with the hole and is used for locating the work while the holes are being finished by broaching. The old method was to drill these gears, then follow with a light boring chip, and then a reamer. The reduction in cost obtained with the new method is 1½ cent per hole, which is quite an item when we consider that the original cost of machining the holes was very low. The results obtained by broaching are that a well finished hole is obtained in addition to greater production; moreover, the life of a broach is eight to twelve times that of a reamer.

Broaching Round Holes in Bronze Bearings

Another operation of broaching round holes is that of finishing holes in bronze machine bearings, up to about 2½ inches in diameter. Take, for instance, the broaching of a 2-inch round hole in bronze castings 4½ inches long. It is the practice in one shop to allow ⅛ inch of stock to be removed or 1/16 inch on each side, the hole being cored 1/8 inch smaller than the finished diameter. When these bearings were being bored and reamed to size, ¼ inch was allowed and the average time was 10 minutes per piece. They are now broached at the rate of one in 1¼ minute and the pieces are not clamped and do not lose their shape. The finish of the broached holes is better than was obtained by reaming. The trouble when reaming hard bronze is to overcome the chattering and waving of the reamer in the hole; this has been done by broaching.

Broaches for Round Holes

The results when broaching round holes depend on the tool itself. The broaches are ground all over after hardening and are backed off at the proper angle to give them a nice cutting edge. The teeth are nicked to break the chips on the heavy cutting part of the broach, but the last six or eight teeth that do the sizing are not nicked. Following the last six or eight sizing teeth is a short pilot which supports and guides the broach. One very important thing in broaching round holes is the proper spacing of the broach teeth. At no time must there be less than three teeth in the work, in order to properly support the broach; if the teeth were so coarse that only one tooth was cutting while another was entering, it would give the broach a slight movement, causing waves in the work. The broach must always be made up with differential or uneven spacing of the teeth. If the teeth are all evenly spaced, as a rule unsatisfactory results will be obtained.

When making broaches a number of things must be taken into consideration, *viz.*, material to be cut, length of work, amount of stock to be removed on the outside, and the shape of the work, so that the proper support can be provided. The length of the broach depends entirely on the metal to be removed. Of course in cases where the

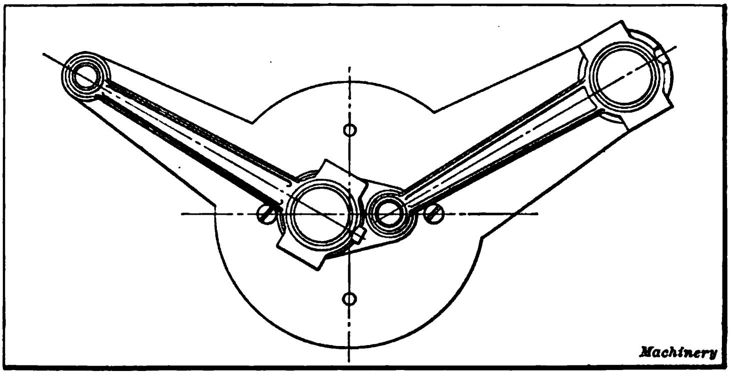

Fig. 23. Engine Connecting-rods, and Fixture Used when Broaching

broaching operation is for sizing, a short broach is used, usually having about 10 inches of cutting edge. If the broach is to remove 1/8 inch of stock, the length may vary from 28 to 40 inches, depending on the length of the work.

Broaching Round Holes in Chrome-nickel Steel

It has been demonstrated that the broaching of hard chrome-nickel steel, such as is used in automobile work, is a much cheaper process than reaming. A typical job is shown in Fig. 23, which illustrates two connecting-rods and their broaching fixture. The small end of one rod and the large end of the other are broached simultaneously and one complete rod is finished for every stroke of the machine. The fixture is not absolutely necessary but adds considerably to the production. These connecting-rods are first drilled to the size of the broach shank or to a diameter of from 0.015 to 0.018 inch under the required size. They are then finished by broaching, thus eliminating both machine and hand reaming. After the rods have been broached, the large end is split and the lining bushing for the large end is inserted. The bushing for the small end is pressed into the rod. These bearings or bushings are then broached.

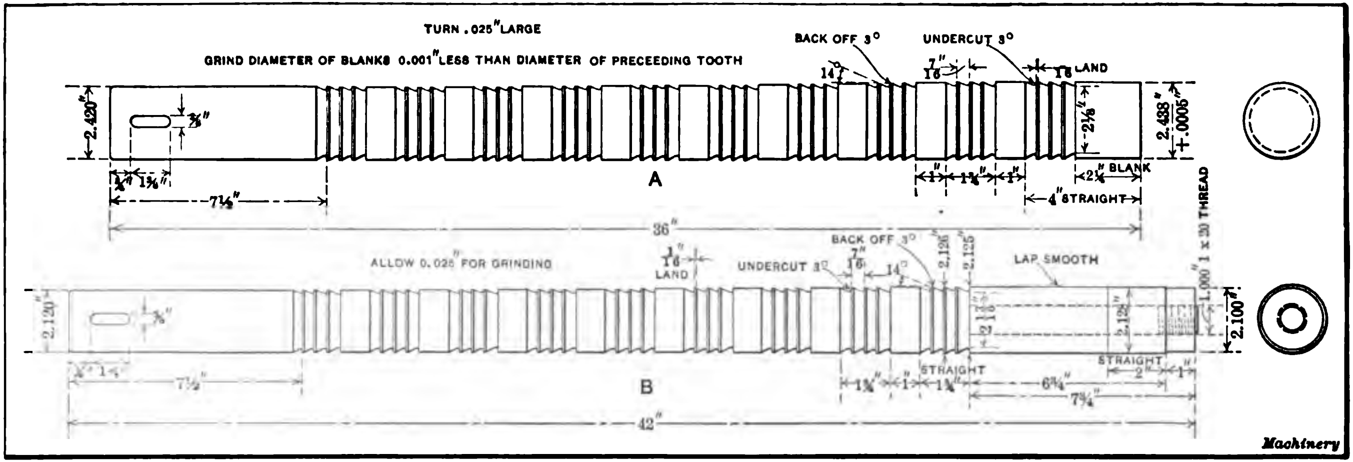

Fig. 24. Broaches used for Connecting-rods shown in Fig. 23

The broach illustrated at *A* in Fig. 24 is used for broaching the hole in the large end of the rod, whereas the smaller broach *B* is for finishing the bushing. The plain round sections seen on these broaches are for the purpose of keeping the broach from "running" or "crawling," as it is essential that the center-to-center distance of these rods be kept fairly accurate. By introducing plain blanks or sections between the teeth, as shown, the broach is kept properly aligned with the hole because there is always some portion of the blank section in the work while some of the teeth are cutting. In other words, the blank sections serve as guides and prevent lateral movement.

When using a broach, it is passed through the work and is fastened to the draw-head of the machine by a cotter-key which passes through the slotted end in the usual way. Only such clamping as is necessary to support the work is required as the blank sections on the broach will hold the part in alignment. When using these broaches in cast iron, a soap cutting compound is used, as this gives the broached surface a highly polished finish. For chrome-nickel steel, a good grade of cutting oil will give satisfactory results. On some work, no drilling whatever is done prior to broaching, and very often only one broach is used, but if the work is longer than say two inches, a roughing broach usually precedes the finishing broach. Of course, broaching from the rough can only be done when the broaching operation comes first, as otherwise the broach would follow the rough hole and, consequently, the finished hole would be out of true with any other surfaces which might be machined afterward.

Broaching Round Holes in Vanadium Steel

The following example represents the practice of a large automobile manufacturer in the broaching of round holes in vanadium steel forgings: The forging, which is 5½ inches long, is first rough-drilled in a high powered vertical drilling machine, from 0.005 to 0.010 inch

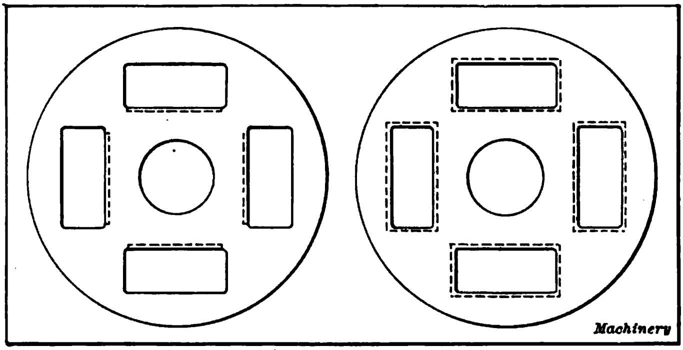

Fig. 25. Plan View showing Four Rectangular Holes which are Finished by Broaching in Two Operations

being left on the diameter of the hole to be removed by the broach. The forgings are taken from the drilling machine to the broaching machine and the hole, which is 1 3/16 inch in diameter, is completed in one pass of the broach, a production of 750 being obtained in ten hours.

The fixture used is of very simple construction, consisting simply of a cast-iron ring fastened to the faceplate of the machine, against which the forging is held by the broach as it is drawn through. A small straight portion about 1¼ inch in length is provided on the end of the broach, which passes through the hole and gives it a burnished appearance. The hole is superior as a bearing surface, to that produced by a reamer. This is because when the reamer is working in alloy steel, especially that containing a percentage of nickel, it usually tears rings around the hole, producing a rough surface. The broach, on the other hand, if it scratches or tears at all, makes these in a line parallel with the axis of the work, which is less detrimental to a bearing surface than annular grooves. Another advantage of broaching round holes instead of reaming them is that the broach retains its size much longer than a reamer.

A Special Broaching Operation

The progress which has been made in the broaching machine and its use is illustrated by a broaching operation which is being performed at the factory where universal joints for automobiles are manufactured. Fig. 25 shows two plan views of the piece which is to be broached, showing the work done at each of the two operations. Fig. 26 illustrates the special broaching fixture and broaches used for doing the work, and part *E* is the rough steel forging upon which the broaching is done. This is one of the parts of a universal joint. It is one inch thick, having four roughly formed rectangular holes, which must be broached on all four sides, finishing each hole to an accurate size; moreover the broaching must be so done that the finished holes will all be equi-distantly spaced from the central hole.

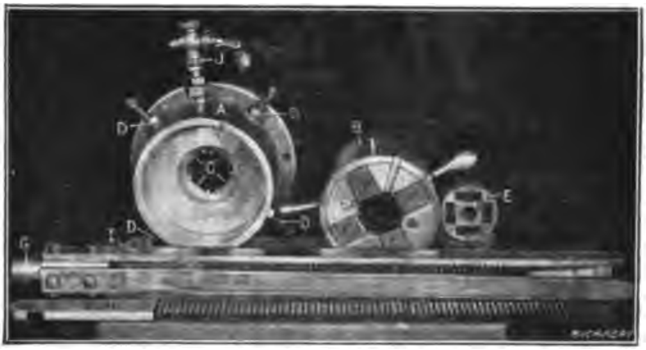

Fig. 26. The Broaches and Broaching Fixture used for the Operation Illustrated in Fig. 25

This central hole is finished by drilling and reaming and the outside edge of the piece is turned, so that the piece may be held by the edge.

Referring to Fig. 26, it will be seen that the broaching fixture consists of a very heavy faceplate casting *A* that fits on the head of the broaching machine, and this casting is bored out to receive the other half of the fixture *B*, which acts as a guide-sleeve.

The faceplate *A* is fitted with four hardened steel guides *C* which are adjustable radially by means of set-screws *D*. It will be noticed that these guide-blocks are slotted to receive and guide the broaches while they are cutting. The piece to be broached indicated at *E*, is a snug fit for the smaller bored hole in casting *A*, allowing it to seat close to the guide-blocks *C*. After being placed in this recess, guide-sleeve *B* which is a sliding fit for the large bored section in faceplate *A*, is inserted. This part of the fixture is also provided with four hardened steel guide blocks *F* which may be adjusted radially after the manner of chuck jaws. Guide-sleeve *B*, while free to slide in faceplate *A*, is prevented from turning and throwing the two sets of guide-blocks out of line, by means of suitable tongues.

There are two operations required to complete the broaching on this piece. At *G* is shown the broach holder with the four broaches *I*, used for the first operation. One of the features of this job is that four cuts are made at each draw of the machine. The first operation is performed after adjusting the position of jaws *C* and *F*, so that when the four broaches *I*, held on broaching head *G*, start to cut, they will clean out a place on the inside edge of each of the four holes, leaving the forging with four cuts as indicated by the dotted lines in the left-hand view in Fig. 25. It will be seen that by adjusting the guide-blocks *C* and *F*, against which the blank sides of the first operation broaches bear, the broaching may be controlled as regards its distance from the central hole in the forging.

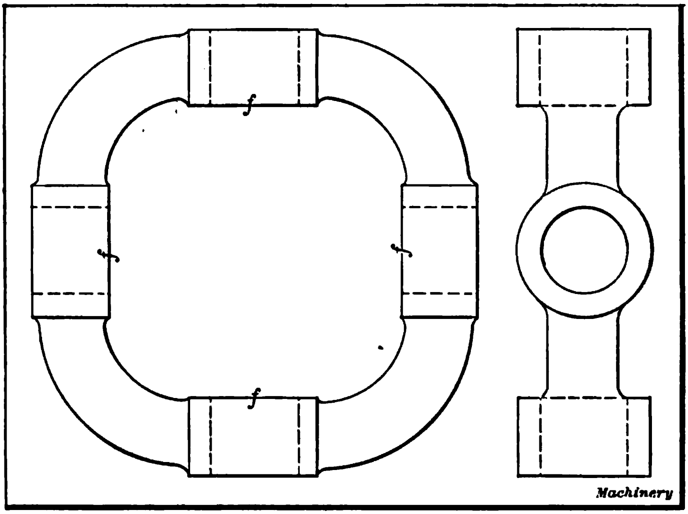

Fig. 27. Ring-coupling to be broached

This completes the work done at the first operation. The second operation is performed with the aid of four broaches, one of which may be seen at *H*, which are held upon the same broaching head *G*. These broaches are provided with one flat side which bears against the surface already broached. Teeth are provided on the opposite side and the two edges, so that the other three sides of each of the four holes are broached out true with the four surfaces already broached, thus cleaning the holes out on all four sides and insuring that the finished holes will be true with the central hole. Lubrication is provided through pipe *J* which enters the faceplate casting opposite the cutting point.

In broaching these parts, the entire lot is run through the first operation and then the broaches are changed and the second operation performed. The broaches are not removed from the machine after each pass, as is necessary in most broaching, for as they do not cut to the full width of the hole, and as they are spring-tempered and beveled at the ends, they may be pressed together and the forging slipped over them to the starting point. The broaches are made of slightly different lengths so that they do not all begin cutting at once.

Fig. 28. Broaching the Ring-coupling

These pieces are broached at the rate of thirty-six operations, or eighteen completed pieces per hour.

Broaching Flat Surfaces

The operation of broaching is too often viewed in the light of a process used principally for cutting keyways or square holes, but with

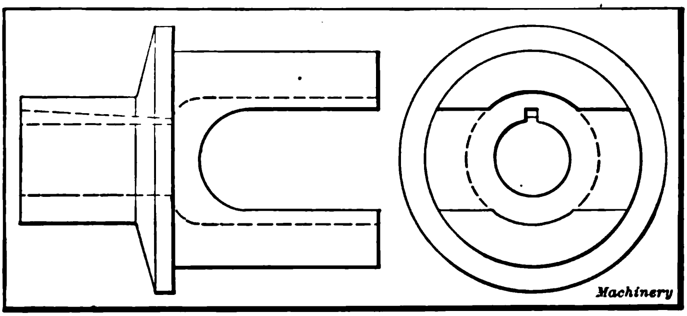

Fig. 29. Universal Joint Yoke in which Tapered Keyway is to be Broached

proper equipment the broaching machine is really a machine tool capable of handling a great many otherwise impracticable jobs. Incident to the manufacture of automobile parts there are many interesting broaching operations.

One of these jobs consists of broaching the inside of a ring-coupling which is a part of a universal joint. The ring-coupling, which is shown in Fig. 27, has been previously drilled and broached through the four round holes and it is essential that the inside faces (marked *f*) be finished true with the holes. In order to accomplish this successfully, the work is held upon a special fixture which is mounted upon the faceplate of a broaching machine. Fig. 28 illustrates the method of holding and broaching the work. The work, shown at *A*, is supported on the fixture *B* by means of four pins *C* which engage the holes in the coupling. These pins are merely a sliding fit through the bosses of the fixture, and the cross handles are added to assist in

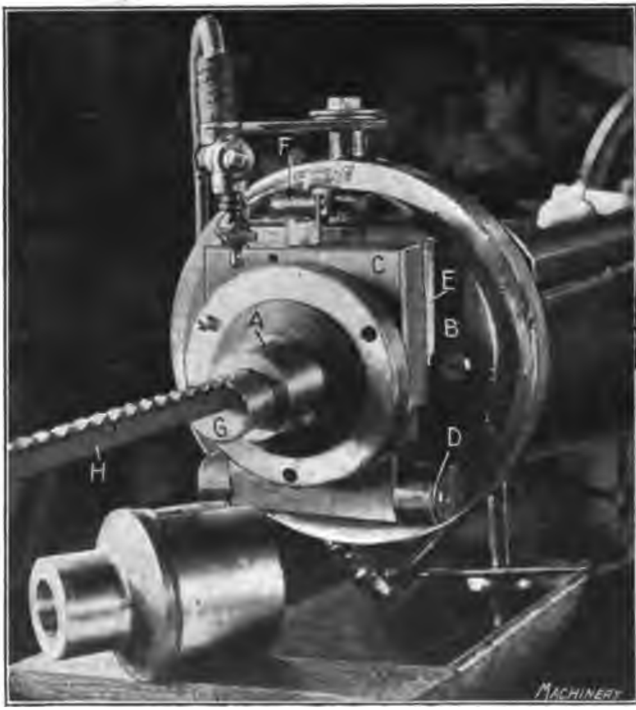

Fig. 30. Broaching the Tapered Keyway

withdrawing them. The broach itself is shown at *D* and is pulled through the work in the usual manner. In order to facilitate centering the broach in the work as well as to distribute the cutting over the length of the broach, the cutting surfaces of the teeth are made very narrow at the beginning of the tool, gradually increasing in width until at the end of the work they are full width, finishing the entire surface. These pieces are broached at the rate of twenty-five per hour and the surfaces are finished true with the holes.

Broaching a Tapered Keyway

Cutting the tapered keyway through the yoke shown in Fig. 29 is a broaching operation that has some interesting features. The keyway must be cut through the bore of the work at an angle of 10 degrees. The cut is 5/16 inch deep at the beginning and only 5/32 inch deep at the end of the cut. The method of doing the work is illustrated in Fig. 30, in which the yoke is shown in the foreground and also on the machine at *A*. It is supported on the special fixture *B* which consists of a faceplate provided with a leaf *C* that is hinged at *D*. This leaf is held in an upright position by a clamp *F* and the work *A* fits closely in the bushing in the leaf *C*. As the broaching must be done at an angle to the machined hole, the leaf of the fixture is not held at right angles to the broach, but is backed up by a tapered wedge *E* so that the work is thrown off at an angle to the broach.

When broaching, the work is placed in the leaf of the fixture and the tapered plug *G* is entered into the hole around the broach *H*. This

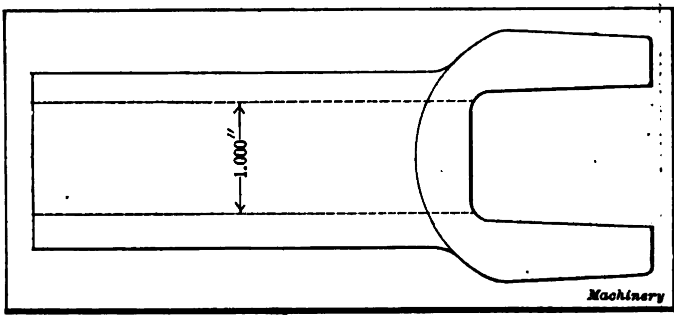

Fig. 31. Slip-hub in which the Round Hole is finished by broaching

plug is cut out to receive the broach, and serves as a guide, preventing the broach from springing away from the work. The broaching is then carried on in the usual manner. When broaching must be done at a different angle it only requires the substitution of a wedge of the required angle at *E*. Thus the fixture can be used on more than one job. This broaching operation is performed at the rapid rate of thirty-three pieces per hour.

Broaching a Round Hole in Alignment with Other Surfaces

The universal slip-hub shown in Fig. 31 is first rough-drilled throughout its length. It is necessary, however, that this hole be finished true to size and exactly in line with the projections at the end. This is accomplished by broaching, as shown in Fig. 32; in this illustration the piece may be seen lying beneath the fixture. The fixture which is shown at *A* has a leaf *B* provided with an adjustable bushing *C*. The leaf is dropped and the work placed within the fixture so that the projecting lugs are centered. Then the leaf is replaced and secured with pin *G*, and the bushing is screwed up against the work so that the countersunk inner end will engage the piece from the outside edge and hold it in a central position ready for broaching.

The broach is then inserted and one pass finishes the piece, leaving it exactly to size and finished as smooth as if done with a reamer. Twenty-five broached pieces per hour is the rate of production.

Broaching a Dovetail Keyseat in a Taper Hole

It was desired to broach a dovetail keyseat in the crank-shaft hole of a large quantity of bicycle cranks. The cranks were of nickel steel

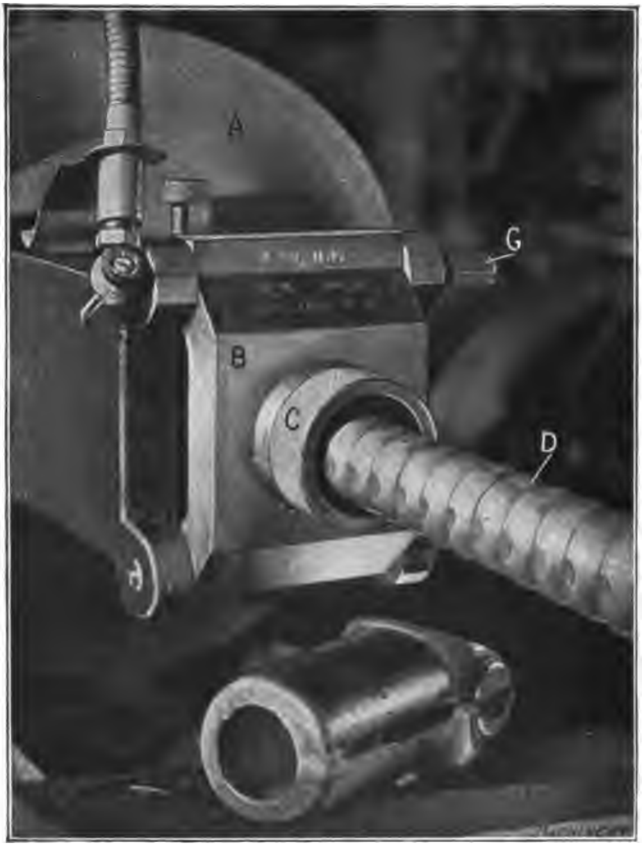

Fig. 32. The Broaching Fixture for the Slip-hub

and had a 10-degree taper hole in the hub, with a minimum diameter of 17/32 inch. It was necessary to broach the hub to receive a flat key, 3/8 inch wide by 1/16 inch thick, dovetailed to a 10-degree included angle. When the keys were driven into place in the cranks, the latter were required to be interchangeable on the crank-shafts, which were slabbed off on one side of the taper end to correspond with the key in the crank, and fitted with an ordinary check-nut to retain the crank.

To fit a key in this manner and insure interchangeability and a simultaneous fit on both key and crank, requires a nice degree of accuracy;

considering this, and the toughness of the steel, as well as the necessarily limited diameter of the broach, it was expected that the operation would prove expensive. Subsequent experience with the use of the device here illustrated, however, proved otherwise, as thousands of the parts were broached most successfully at a remarkably small cost.

Fig. 33 shows the piece to be broached. Fig. 35 shows a machine steel plate, planed on the bottom and sides to fit the die-bed of an

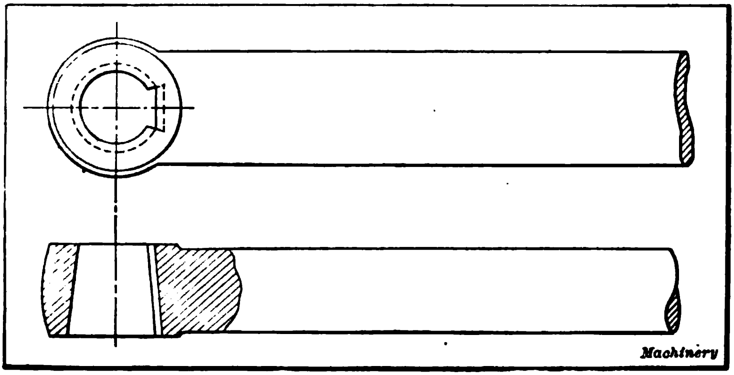

Fig. 33. Bicycle Crank, in Hub of which Dovetail Keyseat is Broached

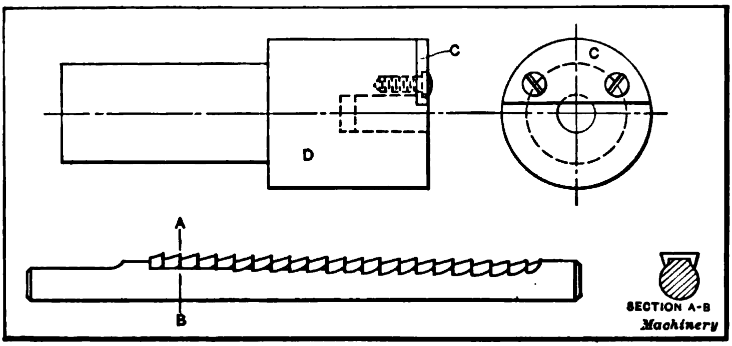

Fig. 34. The Broach and Holder used for Broaching Bicycle Crank

ordinary 8-inch stroke drawing press, and planed on the top to an angle of 5 degrees. After the planing operation a hole was bored at right angles with the top surface, to receive a tempered guide bushing *A*, which was pressed into place. The guide hole for the broach was then put through at right angles with the bottom of the plate. Thus it will be seen that when the crank is placed in position over the guide bushing and brought into contact with the stop pin *B*, the surface to be broached will be parallel with the line of travel of the broach.

Fig. 34 shows one of a series of three broaches which are required to complete the cut. These are made to slide freely through the guide bushing *A* (Fig 35), and are held in the proper position in the holder

D by means of a locating piece *C*. As the press reaches the limit of the downward stroke, the broach, which has ceased cutting, simply drops through the bushing into the hand of the operator, who then inserts broach No. 2 into the holder as the press reaches the upward limit, thus making it unnecessary to stop the machine to insert the tools. Great care should be experienced to keep the teeth of broaches of this kind free from chips, which can easily be accomplished by the operator pass-

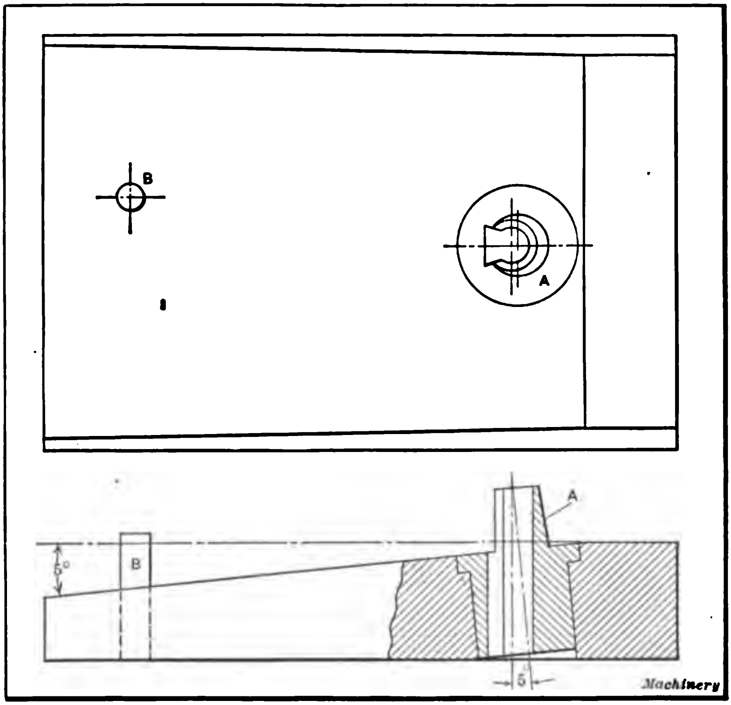

Fig. 35. Fixture for Holding Bicycle Crank while Broaching Keyway

ing his fingers downward over the face after each removal from the guide bushing, and before depositing in the pan of oil.

In tempering broaches of the shape used in this operation, the best results can be obtained by slowly heating the piece, face downward, in a charcoal fire. When heated face upward, the piece will invariably bend, making the face concave, and as they require to be reasonably hard, it is a difficult matter to straighten them.

Time Required for Broaching Operations

Some typical broaching operations are illustrated in Fig. 36. The dimensions of these parts and the number broached per hour are given in the following:

Sample A: ¾-inch square hole; sharp corners; 1⅜ inch long; 40 per hour.

Sample B: 15/16-inch square hole; sharp corners; 1 1/2 inch long; 40 per hour.

Sample C: 1⅜-inch square hole; sharp corners; 4 inches long; 15 per hour.

Sample D: 1 3/32-inch square hole; round corners; 2 inches long; 40 per hour.

Sample E: 1⅜-inch square hole; round corners; distance across corners, 1¾ inch; 1½ inch long; 40 per hour.

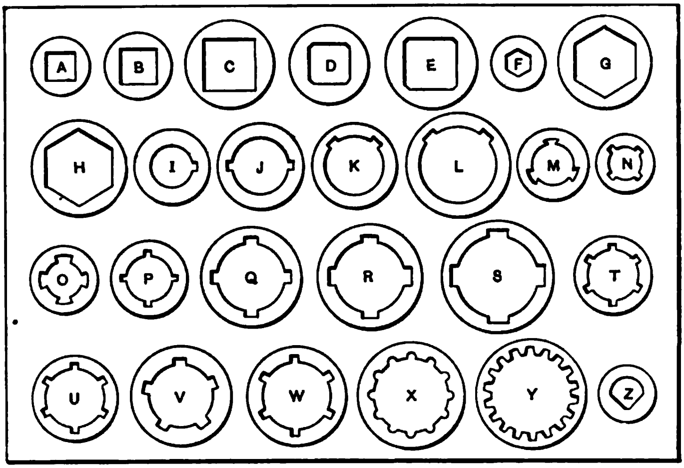

Fig. 36. Typical Examples of Broaching Operations

Sample F: ⅝-inch hexagon hole; 1⅜ inch long; 40 per hour.

Sample G: 1⅝-inch hexagon hole; 2 inches long; 35 per hour.

Sample H: 1¾-inch hexagon hole; 1½ inch long; 35 per hour.

Sample I: 1-inch hole; ¼ by ⅛ inch keyway; ½ inch long; 210 per hour.

Sample J: Two-spline hole; 1½-inch diameter; 5/16 by 5/32 inch splines; 1½ inch long; 80 per hour.

Sample K: Two ½ by ¼ inch keyways in 1½-inch holes; 3 inches long; 40 per hour.

Sample L: 2-inch hole; 3/4 by 5/16 inch keyways; 3 inches long; 30 per hour.

Sample M: Three-spline dovetail hole; 1⅛-inch diameter; outside diameter, 1⅜ inch; ½ inch long; 100 per hour.

Sample N: Four-spline 15/16-inch hole; splines ¼ by ⅛ inch wide; 1 inch long; 100 per hour.

Sample O: Four-spline dovetail hole; 29/32 inch; 2 inches long; 40 per hour.

Sample P: Four-spline hole; 1¼-inch diameter; 1⅝-inch outside diameter; width of spline, 5/16 inch; 3 inches long; 40 per hour.

Sample Q: Four-spline hole; 1¾-inch diameter; outside diameter, 2⅜ inches; splines 9/16 inch wide; 4 inches long; 20 per hour.

Sample R: Four-spline hole, 1 7/8 inch; keyways 3/4 by 3/16 inch; 3 inches long; 20 per hour.

Sample S: Four-spline hole; 2⅛-inch diameter; outside diameter, 2½ inches; splines ⅞ inch wide; 2 inches long; 20 per hour.

Sample T: Six-spline, 1 7/16-inch hole; outside diameter, 1 11/16 inch; width of spline, ⅜ inch; 4 inches long; 20 per hour.

Sample U: Six-spline hole; 1 1/2-inch diameter; splines 3/8 by 3/16 inch; 1½ inch long; 40 per hour.

Sample V: Five-spline hole, 1 47/64 inch; outside diameter, 2 3/16 inch; width of spline, 7/16 inch; 3 3/4 inches long; 20 per hour.

Sample W: Six-spline hole; 1 13/16-inch diameter; splines 3/8 inch wide; outside diameter, 2 1/16 inches; 4 inches long; 20 per hour.

Sample X: Twelve-spline; 2-inch diameter; grooves ⅛ inch radius; 1½ inch long; 60 per hour.

Sample Y: Internal gear; 18 teeth; 2⅛-inch hole; ½ inch face; 120 per hour.

Sample Z: ¾-inch semi-square; 1-inch corner diameter; 1 inch long; 80 per hour.

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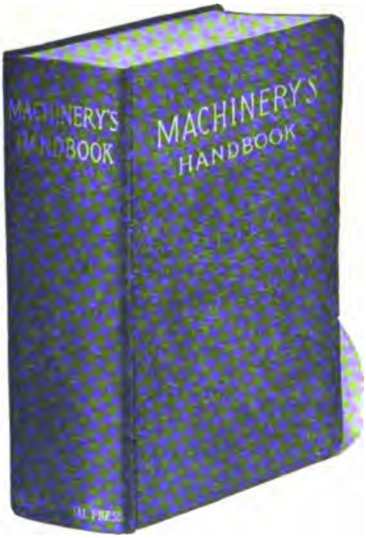

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METAL COLORING AND FINISHING

METHODS OF PRODUCING COLORS ON IRON, STEEL, COPPER, BRONZE, BRASS AND ALUMINUM—BURNISHING METALS

MACHINERY'S REFERENCE BOOK NO. 123

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METAL COLORING AND FINISHING

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CHAPTER I

PRINCIPLES OF METAL COLORING

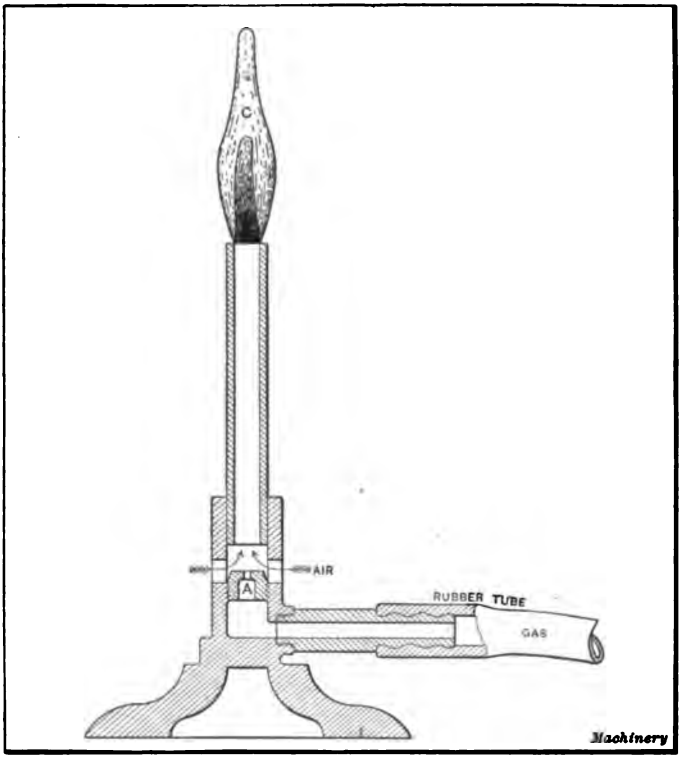
The subject of metal finishing and coloring has received but scant attention in mechanical publications; this is rather surprising when we note the inclination of the manufacturers of today to combine this artistic treatment with utility, and add contrast of color to the severe straight-line plainness of our commercial products, to produce more beautiful effects. There is nothing new in metal coloring. Ages ago it was old in Japan, and to the Orient we must really turn for original authority on successful coloring of metals.

The purpose of this book is to give to those who are interested the results of the experience of a number of authorities in coloring metals, solely from the manufacturing side, rather than from the chemist's standpoint. So many conditions enter into the work that no law can be laid down by which everyone can obtain the same satisfactory results, for with everyone the coloring of metals must at first be more or less of an experimental nature. A cheap monochrome color can be produced by the novice who is unacquainted with the metallurgical properties of metals and chemical actions of solutions used, but the very fact that the slightest change in the alloy, as well as in the strength of the coloring solutions, produces a different shade of coloring under the same treatment, makes it essential that the operator should have considerable knowledge of metallurgy and chemistry for any except the simplest work.

First, let us consider the different methods and conditions under which color can be obtained, *viz.*, by heat-treatment alone; by varnishes and lacquers; and by corroding agents or chemical compounds. We will treat each under its separate heading, but first will refer briefly to the Bunsen burner, by the use of which, together with a pot of heavy fish or lard oil and a pair of tweezers, one can color small pieces by the heat process.

The Bunsen Burner

We will take for granted that some readers, at least, are not acquainted with the Bunsen burner, or at least the principle of its operation. The illustration herewith will explain its construction. The object of this burner is to procure a flame capable of producing great heat, but which will not smoke any vessel or article heated in it or over it; by carefully noting the construction, it will be readily seen how this is accomplished. The force of gas, escaping through the small aperture at *A*, draws the air through the holes in the sleeve surrounding the jet. The air and gas mix together, consuming the carbon produced by the decomposing gases before it becomes incandescent, and producing the flame desired. The air is controlled by a sleeve, which turns around the inner tube, thereby increasing or decreasing the size of the opening through which the air is drawn. A few minutes' use of the burner will enable anyone to get the flame right, but a few points with respect to this may be useful. The flame should be about 2½ inches high only; it should not blow; it should burn with blue light, showing a defined inner cone of blue-green light immediately *above* which, at point *C*, the greatest heat is obtained.



Sectional View, showing Principle of Action of Bunsen Burner

Producing Color by Heat-treatment

The work treated over a Bunsen burner is necessarily small, such as small screws, bolt heads, washers, pins, etc. The work should be thoroughly cleansed from all grease, either by dipping in a strong hot lye solution or in alcohol, and then dried in clean sawdust; it is absolutely essential that the entire surface presents the same physical condition, to obtain uniformity of color. The work should be subjected to the flame immediately above the inner cone of light. Carefully watch the varying change of color and withdraw from the heat before it quite reaches the blue desired; then hold the work in the air until the desired shade appears, and "check" the color change by dipping the piece in the oil and allowing it to cool in it. Very good bluing can be done in this way by the beginner on pieces of uniform shape, but much more skill will be required on pieces where the shape is irregular, having large surfaces in one place and small in another, when the heat must be confined to the larger part for a longer period of time than is necessary for the small parts. In such cases the amount of heat contained in the larger part is usually sufficient to produce the desired effect in the smaller details after taking the piece from the flame.

Another very common method, especially for flat work, is to heat a flat piece of iron or steel of sufficient size to retain the heat for a long time and place the piece to be colored on the hot surface, sometimes in direct contact with the hot metal, and at other times on a piece of sheet iron placed on the hot piece. When the desired color appears, plunge the work into an oil bath. Yet another way is the hot-sand method. A pan of sand is heated to a high degree, the parts are buried in it and rolled around, and when the required color appears it is "checked" as before. In all these methods the colors that appear to the eye come in the following order: Pale straw, dark straw, brown, purple, blue and green. The processes are identical with those of tempering steel by the color method. The wearing life of work done by these methods is naturally very short, as the colors rub off very quickly by handling.

Corroding Agents

We now come to the corroding agents—chemical compounds—by which the most successful results are obtained, by the dipping process, or "wet coloring," as it is called. There are many methods known as "dry coloring" which have been repeatedly tried; in this compounds are mixed together, forming pastes that are applied with a brush and allowed to remain any number of hours and then rubbed off, but most of these methods are more or less failures. The wet method presents many advantages, both as regards economy of time and uniform results.

To color copper articles, such as ash trays, pin dishes, receivers, etc., a solution of ammonium sulphide will give the best results to the beginner. The greatest variety of colors, from light brown to black, can be obtained by this simple method. Use a dilute solution, cold. A good working solution is produced by diluting a saturated solution of ammonium sulphide with 10 to 40 parts of water. A light brown color is produced by dipping the work for a very short time in the solution, withdrawing it, and allowing it to dry in the air. A darker shade of brown is obtained by a longer immersion, according to the color desired, after which the work is allowed to dry in sawdust. To obtain a black coloring, allow the article to remain quite a while in the bath, and, after removing, dip it in alcohol, after which the alcohol is burnt off, leaving a black coating. These colors can be permanently fixed by a transparent lacquer. The objection to ammonium sulphide is the great care necessary in handling, as it leaves an indelible stain upon the fingers, and also has a very obnoxious odor. The ammonium sulphide also decomposes in time, depositing sulphur. It should be kept in a dark-colored bottle provided with a glass stopper. It is not good for brass, being adapted only for copper.

Another solution for coloring copper which yields very good results is:

Copper nitrate	1 part
Water	3 parts

This forms a deposit of copper salt, and, if heated, the salt is decomposed into a black copper oxide. The greenish tints are obtained by the following solution:

Ammonium carbonate	2 ounces
Ammonium chloride	2/3 ounce
Water	16 ounces

This solution gives good results on both copper and brass, different colorings being obtained by repeated dippings in the solution, allowing ample time between each for the articles to properly dry.

Many varieties of color can be obtained by different chemical solutions on both copper and brass, but the desirable colors for commercial use are dead black and steely gray.

The following mixture has also given very good results for brass: hydrochloric, or more commonly termed muriatic acid, white arsenic, and silver.

Take any given quantity of arsenic, say ½ ounce, dissolve it in strong muriatic acid, and then snip off a small piece of a silver dime, if no other silver is at hand. Heat the article to a dull red and dip it in the solution; then allow it to remain until cool. This produces the dull black result so often seen on mathematical instruments. The steely gray is obtained in the same manner, except that the article is not heated to such a high temperature as in the preceding case. By the arsenic solution many good results are obtained by cold dipping also.

In every case where chemical solutions are used, it is well to remember that the slower the rate of deposition the better the results from the wearing standpoint; hence, the longer a dilute solution takes to deposit its coating, the better the color will last, and that is, of course, a very desirable quality. In Chapter III is given a more complete review of the whole subject of coloring non-ferrous metals.

Cleaning Old Brass and Copper

In conclusion, it will be well to touch upon the method of cleaning old brass or copper from impurities. The brass articles are strung on a wire, which should be of the same material as the articles, and dipped in the following solution: 1 part nitric acid, 6 parts muriatic acid (hydrochloric acid), and 2 parts water.

The articles are first dipped in a strong hot solution of soda in water, and then into the bath, where they are swirled around for a time, removed and rinsed in cold water and dried in sawdust. If the metal looks dark and is not quite bright, the nitric acid in the solution should be reduced. Where many pounds of small brass fittings are to be treated, they are put in an earthenware pot containing numerous perforations.

Zinc is often cleaned by dipping into a solution of 16 parts water and 1 part oil of sulphuric acid, for a few moments, and then washing it thoroughly to remove all trace of the bath.

Coloring Iron and Steel

The coloring of copper and brass, especially copper, is for its artistic value alone; but from the purely commercial standpoint the coloring of iron and steel is of greater value, because it is used for so many machine parts and parts of guns, small arms, etc., which are treated to produce a blue or black color for the purpose of preserving the metal against corrosion, as well as to give it a handsome appearance.

The following solution will give very satisfactory results with iron or steel if carefully treated: Take equal parts of potassium nitrate and sodium nitrate and fuse by heating mixture until completely melted. The melting point of the mixed nitrate salts is about 600 degrees F. Dip the articles first in boiling lye or strong hot soda water to thoroughly cleanse them from grease; then dip them in the hot mixed nitrate flux, and from there remove them into boiling water to rinse off the nitrate. Different temperatures of the solution will produce different shades of coloring, and sometimes it will be found advisable to use the flux at a temperature as high as 700 degrees F.

In many cases where hardened articles are to be treated it would not be possible to bring the steel to the desired color by this process, because the temperature of the fused nitrates would be so high as to draw the temper of the articles. In such cases the old nitric acid rusting process is generally resorted to. The nitric acid is placed in an earthenware jar and inclosed in a box that can be made practically tight by closing the lid. The article is suspended in the box and the lid closed, and the fumes arising from the acid oxidize the surface of the article; if the article is moistened before placing it in the box, a very much more rapid oxidation is assured, saving considerable time.

Many experiments have been tried with different mixtures for coloring iron and steel, where there is danger of drawing the temper of the metal; of these the following has proved very successful: A wooden box is used, of a size according to the kind of work to be colored. A small steam pipe connects with the box, so that a quantity of steam may flow into it continuously and moisten the air in the box. A bath made of the following ingredients is then placed in the box:

Iron chloride (muriate tincture of steel)	1 ounce
Alcohol (spirits of wine)	1 ounce
Corrosive sublimate (mercury bichloride)	¼ ounce
Strong nitric acid	¼ ounce
Blue stone (copper sulphate)	⅛ ounce
Water	1 quart

The vapor arising from this bath forms a deposit on the articles, which are allowed to remain in the receptacle a number of hours and rubbed off with a cloth; the operation is repeated if a darker color is desired. Very rich coloring can be obtained by this process, after a little experimenting, and the temper is not affected. Many other methods are included in the detailed descriptions dealing with the coloring of iron and steel given in the next chapter.

Removing Rust from Steel

A quick method of removing rust from steel parts, which is not generally known, is outlined in the following: Rub the surface of the piece of work from which rust is to be removed with muriatic acid. A convenient way to do this is to dip a match or other small stick into the acid and rub it over the surface of the work. This procedure is continued for several minutes, dipping the stick in as often as necessary to obtain a sufficient quantity of acid. After this treatment has been completed, the work should be washed with a solution of common washing soda and water and then dried in sawdust. This will leave the work free from rust and scratches, but with a dull gray surface. The surface of the metal can be restored to its original color by a little rubbing. In one factory this method has been used for several years with successful results.

Varnishing and Lacquering

Varnishing and lacquering, as being somewhat apart from the subject matter, will be treated very briefly. The method cannot be used to produce an artistic color effect, but is nearly always used for protecting the surfaces of instruments and machines from discoloration by atmospheric influence. In nearly every instance lacquering is used only on metal alloys. It might be well in this connection to note the discoloring tendencies of metals in alloys, as given by a noted German authority. The discoloring action upon metals takes place to the greatest extent upon tin and the least upon gold. In the following list of metals the action becomes less from the first to the last: 1. Tin; 2, nickel; 3, aluminum; 4, manganese; 5, iron; 6, copper; 7, zinc; 8, lead; 9, platinum; 10, silver; 11, gold.

CHAPTER II

COLORING IRON AND STEEL PRODUCTS

There are three ways in which to produce colors on metals, namely: First, by heat-treatment; second, by dipping in a bath; third, by electro-plating. Often two of these methods are used in combination. A fourth might be added, that of brushing or rubbing a powder, or liquid, onto the piece to be colored. This is so similar to the dipping process, however, that it can be classed under that head. None of these metal-coloring processes can be learned from a few receipts that may be printed. Metal coloring is in reality a trade in itself and must be learned.

Some of the solutions get weaker with use, and the last article treated will be of a different color from the first. Nearly all of the coloring materials have different effects on cast iron, wrought iron and malleable iron and will produce different shades, if not different colors. The chemical composition of the steels is so varied that no set of rules will apply to all steels. Likewise the preparation of the metal before coloring and the treatment given it after coloring must be changed to suit the kind of metal being colored. Hence it is necessary to know the metal that is being worked upon. It is always best to first experiment with a few pieces and see if uniform results are being obtained. It is a good rule not to treat miscellaneous steel pieces by the one coloring process, although some of the plating processes that deposit heavy coatings might be relied upon.

Preparing Work for Coloring

Preparing the work for the coloring operation is of the most vital importance. It is absolutely necessary to remove all grease, and the removal of all other foreign substances for the surfaces to be colored is of just as much importance. In fact, only the clean metal surface should present itself to the coloring materials, no matter what their nature may be. When all the layers of oxide, grease, dirt, etc., have been removed the entire exposed surface can be given a uniform color and a quantity of pieces will be the same shade if the other conditions are properly looked after.

Rust-proof Black Finish

When a rough surface, such as is presented by castings, forgings, etc., is to be given the rust-proof black finish, sand blasting is the quickest and cheapest method of cleaning the work. In this black finish the metal is oxidized and coated with black magnetic oxide of iron. One method of producing this is to heat the work to a red heat in a muffle furnace in the presence of steam and hydrogen gas. A small amount of gasoline, injected with the steam, improves the color. The work should be subjected to red heat in the muffle for about an hour. If the work is given a thin coating of linseed oil after it has cooled off the color will be deepened and present a smoother appearance.

This coating is quite hard and not easily worn away, and is a dead black. It is free from the red oxide that has spoiled so much work of this kind. The hydrogen gas is generated by passing steam over red hot iron chips or turnings. Cast iron, malleable iron and steel may all be given this black finish. The principle on which it is based is that of giving the surface all the oxide it will take up so that the oxygen in the air cannot reach it and cause corrosion. Tests have shown it to resist this action for many years and the color to be preserved.

Black Oil Finish

Black oil finish is produced by heating the work to a bright red; then quenching it in lard oil, afterward putting it back in the furnace to burn the oil off, and then quenching it in water. The oil must be kept cool and the water clean. A thin coat of linseed oil applied to the black gives the same results as described above. This coating is not durable but it will prevent rusting until the goods are sold, and is useful for such tools as can be heat-treated in the same operation.

Gun-metal Finish

Gun-metal finish is based on the same fundamental principle as the black finishes described above but is a great improvement over them and applicable to a finer class of work. For this work, as well as for the browns, blues or other fine colors that are produced on polished surfaces, the pieces must be cleaned by methods that will not injure these surfaces, as does the sand blast.

Grease and dirt are readily removed by boiling the work in a solution of one pound of potash to one gallon of water. This turns the grease to soap, which is absorbed by the water, and the dirt falls off from the work. The potash will last a long time and the water can be replenished as it boils away. When exhausted, the bath can be renewed by adding fresh potash. On small work, or a few pieces, stirring about in benzine or paraffine will remove the grease and dirt. If used continuously three vessels should be provided. In the first the bulk of the grease would be cut from the work; in the second the balance of it would be cleaned off; and the third should be kept clean to remove any particles that might still remain. The first two could contain paraffine and the third benzine.

After this cleaning the pieces should be washed with clean water and thoroughly dried. If boiling water is used they will dry in the air; if cold water is used clean sawdust is effective for drying them. The work should never be touched with the bare hands as the fingers are likely to leave grease marks.

Pickling preparatory to Coloring

Scale, oxide, etc., are not removed by the above washing methods and hence a pickling in acid solutions is required. One part of sulphuric acid to twenty parts of water is often used for iron. This mixture leaves the work dark colored and sometimes it has a different appearance at the edges. To make the work bright, the following pickling solution should be used: Dissolve two ounces of zinc in one pound of sulphuric acid and mix this with one gallon of water; then add one-half pound of nitric acid. The volume of the bath should be twenty times that of the work, to prevent it from becoming weakened too soon. The glassy patches on cast iron, which are usually iron silicate, can be removed by hydrofluoric acid.

After pickling, the solution should be thoroughly washed off and the work brushed with steel scratch brushes revolving at from 600 to 1000 R. P. M. Cleaned work can be protected from rusting by keeping it immersed in water containing some caustic alkali until it is needed. Caustic soda and sodium carbonate are both effective for this purpose.

Polished steel surfaces can be pickled by immersing them, in contact with a piece of clean zinc, in a moderately strong solution of the acid potassium sulphate and water. Hydrogen gas is liberated when the zinc decomposes the solution and this removes the oxide of iron or rust from the steel. Another good pickling solution for steel is made of twenty parts hydrochloric acid and eighty parts water. Iron and steel can also be pickled white, in concentrated nitric acid to which has been added some lampblack. After pickling, the work should always be thoroughly washed and scratch brushed.

Other Gun-metal Receipts and Methods

Several different chemical solutions have been used successfully in giving steel the gun-metal finish or black color. Among these are the following: Bismuth chloride one part, copper chloride one part, mercury chloride two parts, hydrochloric acid six parts and water fifty parts. Ferric chloride one part, alcohol eight parts and water eight parts. Copper sulphate two parts, hydrochloric acid three parts, nitric acid seven parts and perchloride of iron eighty-eight parts. Other solutions have been prepared from nitric ether, nitric acid, copper sulphate, iron chloride, alcohol and water, and from nitric acid, copper sulphate, iron chloride and water.

Applying these and finishing the work is practically the same in all cases. The surface of the work is given a very thin coating with a soft brush or sponge that has been well squeezed, and is then allowed to dry. If put on too thick the surface will be unevenly corroded and white spots will appear. The work is then put into a closed retort to which steam is admitted and maintained at a temperature of about 100 degrees F. until covered with a slight rust. It is then boiled in clean water for about fifteen minutes and allowed to dry. A coating of black oxide will cover the surface, and this is scratch brushed. After brushing, the surface will show a grayish black. By repeating the sponging, steaming and brushing operation several times a shiny black surface will be obtained that is lasting. For the best finishes these operations are repeated as many as eight times.

Another process employs a solution of mercury chloride and ammonium chloride which is applied to the work three times and dried each time; a solution of copper sulphate, ferric chloride, nitric acid, alcohol and water is then applied three times and dried as before; a third solution of ferrous chloride, nitric acid and water, is applied three times and the work boiled in clean water and dried each time; the third and last solution of potassium chloride is then applied and the work boiled and dried three times. The work is then scratch brushed and given a thin coating of oil. Ordnance for the French Government was treated in this way.

The above methods are useful for hardened and tempered steels, as they are only heated to about 100 degrees F. and this temperature does not draw the hardness. For steels that will stand 600 degrees temperature without losing the desired hardness, better and much cheaper methods have been devised.

The color does not form a coating on the outside, as with the other processes, but a thin layer of the metal itself is turned to the proper color, which should make the color wear well. By varying the temperature of the furnace, the time the work is in it, and the chemical, different colors can be produced from the light straws to the browns, blues, purples and black, or gun-metal finish. Rough or sand-blasted surfaces will have a frosted appearance, while smooth, polished surfaces will have a shiny brilliant appearance.

A variety of colors can be produced on iron and steel by immersing the pieces, for different lengths of time, in a boiling hot solution of the following composition: Lead acetate fifty grains, sodium thiosulphate fifty grains, water five fluid ounces. A half-hour immersion will make the work black and a shorter time will make it steel-gray, blue, mixed purple and blue, purple, dark brown and light brown. By controlling the time, the desired color can be obtained. These colors are very beautiful but fade quickly. A coat of lacquer on top of the color, however, will preserve them for years. On top of a nickel plating these colors are exceptionally brilliant.

Coloring Steel by Heat

Producing colors on steel by heat-treatment is almost too well known to comment on here, and has already been referred to in the previous chapter. Suffice it to say that 430 degrees F. produces a faint yellow, 460 degrees dark yellow, 490 degrees light brown, 500 degrees dark brown, 520 degrees light purple, 540 degrees dark purple, 560 degrees light blue, 580 degrees dark blue, 600 degrees blue green and 620 degrees black. By mixing potassium nitrate and sodium nitrate in an iron pot and melting them, the bath can be maintained at any of these temperatures. By immersing the work in this bath until it absorbs its temperature and then cooling it, any of these colors can be obtained. The work can be cooled by plunging it into boiling water and the coating of salt removed at the same time. A thin coating of these salts sticks to the steel and prevents the oxygen in the air from attacking the metal and altering the color while it is being transferred from the nitrate bath to the boiling water. The contained heat will dry the work when removed from the water.

Browning Iron and Steel

A good brown color can be obtained as follows: Coat the steel with ammonia; dry it in a warm place; then coat with muriatic or nitric acid; dry in a warm place; then place in a solution of tannin or gallic acid; and again dry. The color can be deepened by placing the work near the fire, but it should be withdrawn the minute the desired shade is reached or it will turn black.

The U. S. Government adopted the following formula for browning gun barrels: Alcohol three ounces, tincture of iron three ounces, corrosive sublimate three ounces, sweet spirits of niter three ounces, blue vitriol two ounces, nitric acid one and a half ounce and warm water two quarts. The solution is applied with a sponge, allowed to dry for twenty-four hours, and after this the loose rust is removed by scratch brushing. A second coat is given in the same manner. After that the piece is boiled in water and dried quickly. A thin coat of boiled linseed oil or lacquer is then put on to preserve the color.

Another process for browning iron and steel consists of dissolving four ounces of copper sulphate in two quarts of water and then adding one ounce of nitric acid, one ounce of spirits of niter, two ounces of alcohol and one ounce of ferric chloride. Scratch brushing and rubbing with a piece of smooth hard wood will polish and burnish the work and a coat of shellac or lacquer will preserve the color. Rubbing with the polishing wood will give the lacquer or shellac a polished surface.

A solution that may be used in place of the above is spirits of niter one ounce, copper sulphate one ounce and water twenty ounces. This must be allowed to remain on the work for twenty-four hours and then brushed off with a stiff brush. The operations can be repeated enough times to get the depth of color desired.

To Produce Bronze-like Color

A warm bronze-like color can be produced by exposing iron or steel to the vapors of heated aqua regia, dipping them in melted vaseline, then heating until the vaseline begins to decompose and wiping it off with a soft cloth.

Another method of producing this bronze-brown color is to slightly heat the work, cover the surfaces evenly with a paste of antimony chloride, known as "bronzing salt," and let it stand until the desired color is reached. It can be made more active by adding a little nitric acid.

Still another bronzing process consists of soaking the work for some time in an acid solution of ferric chloride, then vigorously moving it about in hot water and allowing it to dry, and finally brushing with a waxed brush. The oxygen, liberated by the decomposition of the water, combines with the iron and forms a dark layer of oxide.

To Produce Gray Color

A gray color can be obtained by immersing the work in a heated solution of ten grains of antimony chloride, ten grains of gallic acid, 400 grains of ferric chloride and five fluid ounces of water. This is doubtless due to the antimony. The first color to appear is pale blue and this passes through the darker blues to the purple and finally to the gray. Thus if immersed long enough the metal will assume the gray color, but if not any of the intermediate colors may be produced. Used cold it is also one of the bronzing solutions.

The Niter Process for Bluing Iron and Steel

This process was first brought to the notice of the public in a paper read before the American Society of Mechanical Engineers, by Mr. William H. Weightman in 1886. This method produces a beautiful color and may, therefore, be of general interest. The process is very simple, the niter (nitrate of potash, often called saltpeter) is melted in an iron pot and heated to about 600 degrees F. The articles to be blued are cleaned and polished and then immersed in the molten niter, in which they are allowed to remain until the desired color has been obtained in a uniform manner. Only a few seconds are required, or, in general, only the length of time necessary for the articles to arrive at the heat of the niter. The articles are then removed and allowed to cool, after which they are immersed in water and the adhering niter washed off. Articles which will not warp or twist may be immersed in water immediately after having been removed from the niter. After the cleaning process the articles are dried in sawdust and then oiled with suitable oil, such as linseed, to prevent them from rusting. If a uniform color is to be attained continuously, a pyrometer should be used to control the temperature of the heated niter, because a higher heat than 600 degrees F. will produce a dark color, while a lower heat will make the objects light.

The niter process can scarcely be called suitable for small articles on account of its cost. Niter itself is not expensive, but the pieces must be dipped carefully in order to obtain the desired color and the handling in washing them off afterwards and drying them makes the cost per piece high. It is, therefore, used mostly for medium-sized and large work.

Mottling

The mottled colors can be produced by heating the steel pieces to a good cherry red for several minutes in cyanide of potassium, then pouring the cyanide off and placing the pot of work back in the fire for five minutes and then quickly dumping the contents into clean water. To heighten the colors the work should afterward be well boiled in water and oiled while hot. This also carbonizes the work and larger lots could be handled in the regular carbonizing furnaces.

CHAPTER III

COLORING NON-FERROUS METALS AND ALLOYS

In thickly inhabited sections a great deal of coal gas is burned. More or less of the products of combustion, together with the gases arising from the manufacture of other materials, stay in the atmosphere and give to brass and bronze objects a dark, dirty color by attacking their surfaces. The oxygen and moisture in the atmosphere also give these metals or alloys a disagreeable color. Hence coloring or coating is also resorted to for the purpose of enhancing and preserving the original beauty of the metal. Sometimes rich and beautiful browns and greens are produced on copper alloys that have been subjected to atmospheric conditions for years. Therefore these conditions have been studied and chemical means have been found for producing the colors quickly and on a commercial scale.

Copper is more susceptible to coloring processes than any of the other metals, and hence the alloys containing large percentages of copper are readily given various shades of the yellow, brown, red, blue and purple colors and also black. Alloys with smaller percentages of copper, or none at all, can be given various colors, but not as easily as if copper were the principal ingredient, and the higher the copper content, the more readily can the alloy be colored. The shades, and even the colors, can be altered by varying the density of the solution, its temperature and the length of time the object is immersed. They can also be altered by finishing the work in different ways. If a cotton buff is used one shade will be produced; a scratch brush will produce another, etc. Thus to color work the same shade as that of a former lot all the data in connection with these operations must be preserved so they can be repeated with exactness.

Many different kinds of salts are made into solutions for the coloring processes. When capable of producing the desired results it is always best to use the simple salts. It is often necessary to combine two or more salts in the solution to get the required color, but these deteriorate in strength much more rapidly than the simple salt solutions and hence the last piece immersed will have a lighter color than the first one. When adding salts to bring back the original strength of the bath, they should first be dissolved in a small amount of water to prevent their settling to the bottom where they might become covered with an insoluble mud that would prevent them from being dissolved. In making the solutions it should be remembered that a strong solution will produce the color quickly and a weak solution more slowly. When a uniform coating can be produced the strong solution is always the best owing to the time factor. The most effective and lasting results, however, are obtained with the weaker solutions, and hence they are used for high-grade work. While these solutions are often used cold, there are many cases where better results can be obtained when they are heated. Raising the bath to the boiling point will insure a complete solubility of the salt.

Cleaning Work to be Colored

Cleaning the work is of the utmost importance before attempting to give it any kind of color. A greenish or brownish film forms on copper, brass, bronze, etc., when they stand, as they are attacked by the moisture in the air and the simultaneous presence of carbonic acid which gradually changes into carbonates. This film is a mixture of carbonate of copper and oxide. Often sulphur compounds are formed when the atmosphere is impregnated with the products of combustion arising from the coal gas burned in cities and towns. This is nearly always stronger in rooms than in the open. If these films are not removed before coloring they show up as stains and the work will be streaked or spotted. Touching the work with the bare hands after it is cleaned will also leave a slight film that will make the work spotted, and hence it should be strung on wires or handled in other ways that will prevent it from being touched with the hands.

Several acid dips can be made that will remove these films and leave the bright clean metal with its original smooth surface. Work that will stand heating can be heated to a dull red and then plunged into dilute sulphuric acid, after which it should be soaked in old aquafortis and then thoroughly rinsed. It should be soaked long enough to have a uniform metallic appearance, and the bath should be large enough in volume to prevent its heating up from the hot work. The best results are obtained with straw-colored aquafortis, as the white is too weak and the red too strong. In diluting the sulphuric acid it should always be poured into the water slowly, as heat is generated, and too rapid mixing generates so much heat that the containing vessel is liable to crack and the escaping liquid to cause burns. To pour water into sulphuric acid will cause an explosion that is almost sure to result in serious, if not fatal, burns from the flying liquid.

A good method of removing these films, without heat, is to soak the work in a pickle composed of spent aquafortis until a black scale is formed and then dip it for a few minutes into a solution composed of 64 parts water, 64 parts commercial sulphuric acid, 32 parts aquafortis and 1 part hydrochloric acid. After that the work should be thoroughly rinsed several times with distilled water. If the strong aquafortis is used for the pickle in which the work is soaked it will cause a too rapid corrosion of the copper during the time of the solution of the protoxide. Hence the spent aquafortis is better on account of its slower action and it also saves the cost of new. A dip that is useful for removing the sand, etc., that sticks to castings is composed of 1 part spent aquafortis, 2 parts water and 6 parts hydrochloric acid. A few minutes will suffice for small pieces, but large castings can remain in the bath for thirty minutes. They become coated with a black mud and when this is thoroughly washed off they should be bright.

If a further whitening of the work is desired a solution may be made by mixing 3 pounds nitric acid, 4 pounds sulphuric acid and 40 grains sodium chloride (table salt), combining this with 40 times its bulk of water and allowing it to cool before using. If a dead surface is desired the following mixture can be added to the bath: 2 pounds nitric acid, 1 pound sulphuric acid, 10 grains sodium chloride and 40 grains zinc sulphate. The degree of deadness is determined by the length of time the work is left in the bath. As with all other solutions, the work should be well rinsed after leaving the bath and then thoroughly dried. Another dead dipping bath can be made from one part of a concentrated solution of potassium bichromate and two parts of concentrated hydrochloric acid. Many other combinations of chemicals may also be made for cleaning or whitening the work or giving a dead finish after it has been colored, but those given above will suffice for the present.

Bright Castings

The bright clean color sometimes seen on bronze castings has been thought by many to be the result of an acid dip. This has been produced, however, by plunging the castings into water while they are still red-hot. It is seldom that brass castings can be given this color as they usually contain too much lead. Likewise the bronze castings must be free from lead as well as iron, antimony or other impurities, and the water into which they are plunged must be clean, or a dirty, unpleasant color will be the result. The castings must also be as hot as possible when quenched. If too hot the metal will be brittle and hence the highness of the temperature is governed by the toughness that is desired in the casting, but if quenched after they have cooled too much the color will be dull. Copper ingots can be given a beautiful rose-red color by this method.

To Produce Yellow to Orange Colors

Polished brass pieces can be given a color from a golden yellow to an orange, by immersing them for the correct length of time in a solution composed of 5 parts caustic soda to 50 parts water, by weight, and 10 parts copper carbonate. When the desired shade is reached the work must be well washed with water and dried in sawdust. Golden yellow may be produced with the following: Dissolve 100 grains lead acetate in 1 pint water and add a solution of sodium hydrate until the precipitate which first forms is redissolved, and then add 300 grains red potassium ferri-cyanide. With the solution at ordinary temperatures the work will assume a golden yellow, but heating the solution darkens the color until at 125 degrees F. it has changed to a brown. A pale copper color can be given brass by heating it over a charcoal fire, with no smoke, until it turns a blackish brown, then immersing in a solution of zinc chloride that is gently boiling, and finally washing thoroughly in water. Dark yellow can be obtained by immersing for five minutes in a saturated solution of common salt containing some free hydrochloric acid and which has as much ammonium sulphide added as the solution will dissolve.

To Produce a Rich Gold Color

A rich gold color can be given brass by boiling it in a solution composed of 2 parts saltpeter, 1 part common salt, 1 part alum, 24 parts water, by weight, and 1 part hydrochloric acid. Another method is to apply to the work a mixture of 3 parts alum, 6 parts saltpeter, 3 parts sulphate of zinc and 3 parts common salt. The work is then heated over a hot plate until it becomes black and then washed with water, rubbed with vinegar and again washed and dried. Still another solution is made by dissolving 150 grains sodium thiosulphate in 300 grains water and adding 100 grains of an antimony chloride solution. After boiling for some time the red-colored precipitate must be filtered off, well washed with water and added to 4 pints of hot water. Then add a saturated solution of sodium hydrate and heat until the precipitate is dissolved. Immerse the brass articles in the latter solution until they have attained the correct shade. If left in too long they will be given a gray color.

To Produce White Colors or Coatings

The white color or coating that is given to such brass articles as pins, hooks and eyes, buttons, etc., can be produced by dipping them in a solution that is made up as follows: Dissolve 2 ounces fine grain silver in nitric acid, then add 1 gallon distilled water and put into a strong solution of sodium chloride. The silver will precipitate in the form of chloride and this must be washed until all traces of acid are removed. Testing the last rinse water with litmus paper will show when the acid has disappeared. Then mix this chloride of silver with an equal amount of potassium bitartrate (cream of tartar) and add enough water to give it the consistency of cream. The work is then immersed in this and stirred around until properly coated, after which it is rinsed in hot water and dried in sawdust.

Silvering

Another method of silvering that is applicable to such work as gage or clock dials, etc., consists of grinding together in a mortar 1 ounce very dry chloride of silver, 2 ounces cream of tartar and 3 ounces common salt. Then add enough water to make it of the desired consistency and rub it on the work with a soft cloth. This will give brass or bronze surfaces a dead white thin silver coating, but it will tarnish and wear if not given a coat of lacquer. The ordinary silver lacquers that can be applied cold are the best. The mixture as it leaves the mortar, before adding the water, can be kept a long time if put in very dark colored bottles, but if left where it will be attacked by light it will decompose.

Assorted Colors

Some very interesting results in coloring brass can be obtained by dissolving 200 grains sodium thiosulphate and 200 grains lead acetate in 1 pint water and heating it to from 190 to 195 degrees F. Immersing the work in this for five seconds will make it pale gold; fifteen seconds, brown gold; twenty-five seconds, crimson; thirty seconds, purple; forty-five seconds, an iridescent bluish crimson green; sixty seconds, pale blue; sixty-five seconds, mottled purple; eighty seconds, nickel color; eighty-five seconds, mottled blue and pink; one hundred and ten seconds; mottled purple and yellow; two and one-half minutes, pale purple; four minutes, mottled pink and yellow; five minutes, mottled gray; ten minutes, mottled pink and light blue. Other combinations of colors can also be obtained, but some of these fade and change color unless protected by a coat of lacquer. By using one-quarter ounce of sulphuric acid in place of the lead acetate a variety of colors can also be produced, but they will not be as good a quality as those made with the above solution. Nitrate of iron can also be used.

To Produce Gray Colors

A solution of 1 ounce of arsenic chloride in 1 pint of water will produce a gray color on brass, but if the work is left in too long it will become black. The brass objects are left in the bath until they have assumed the correct shade and then are washed in clean warm water, dried in sawdust and finally in warm air. A dark gray color that can be made lighter by scratch brushing can be obtained by immersing the work in the following solution: 2 ounces white arsenic oxide, 4 ounces commercially pure (c. p.) hydrochloric acid, 1 ounce sulphuric acid and 24 ounces water. A steel gray can be produced with the following: 20 ounces arsenious oxide, 10 ounces powdered copper sulphate, 2 ounces ammonium chloride and 1 gallon hydrochloric acid. After mixing, this should stand for one day. A 5 per cent solution of platinum chloride in 95 per cent water will also produce a dark gray color if it is painted on and the brass is warmed. Weaker solutions will make the color lighter. Copper can also be colored, but the platinum does not adhere as firmly to the surface as it does on brass. A coating of lacquer is required to make it permanent. By smearing the work with a mixture of 1 part copper sulphate and 1 part zinc chloride in 2 parts water and drying this mixture on the brass, with heat, a dark brownish color is obtained. If desirous of immersing the work a weaker solution could be used. The color is changed very little by exposure to light.

To Produce Lilac Blue and Violet Colors

The lilac shades can be produced on yellow brass by immersing the work in the following solution when heated to between 160 and 180 degrees F. Thoroughly mix 1 ounce chloride, or butter, of antimony in 2 quarts muriatic acid, and then add 1 gallon water.

To give brass a blue color dissolve 1 ounce antimony chloride in 20 ounces water, and add 3 ounces hydrochloric acid. Then warm the work and immerse it in this solution until the desired blue is obtained. After that, wash it in clean water and dry in sawdust. A permanent and beautiful blue-black can be obtained by using just enough water to dissolve 2 ounces copper sulphate and then adding enough ammonia to neutralize and make it slightly alkaline. The work must be heated before immersion. Copper nitrate, water and ammonia will also yield this rich blue-black, but if the brass is very highly heated after immersion it changes to a dull steely black. On copper or work that is copper-plated this latter produces a crimson color.

A beautiful violet color can be produced on polished brass with a mixture of two solutions. First, 4 ounces sodium hyposulphite is dissolved in 1 quart water, then 1 ounce sugar of lead is dissolved in another quart of water and the two are well stirred together. By heating this to 175 degrees F. and immersing the work the correct length of time, it takes on the violet color. The work first turns a golden yellow and this gradually turns to violet. If left a longer time the violet will turn to blue and then to green. Thus this same preparation can be used for all of these colors by correctly limiting the time that the work is immersed.

To Produce Green Colors

When left to the natural action of the atmosphere, or ageing, most of the brasses and bronzes first turn green, and very decidedly so if near the ocean where the moisture from the salt water attacks the metal. This green color gradually darkens and then turns brown and finally black. Some of the shades it assumes are very beautiful and hence they have been produced by chemical means, as nature is too slow in its action. So many different chemical combinations are used for this purpose that it would require a book to enumerate them all and hence only a few can be mentioned. Some of the green colors can be produced by the solutions given above, but the antique, or rust, greens require different mixtures.

One solution that will produce the verde antique, or rust green, is composed of 3 ounces crystallized chloride of iron, 1 pound ammonium chloride, 8 ounces verdigris, 10 ounces common salt, 4 ounces potassium bitartrate and 1 gallon water. If the objects to be colored are large, this can be put on with a brush and several applications may be required to give the desired depth of color. Small work should be immersed and the length of time it is immersed will govern the lightness or darkness of the color. After immersion, stippling the surface with a soft round brush, dampened with the solution, will give it the variegated appearance of the naturally aged brass or bronze. Another solution that will give practically the same results is composed of 2 ounces ammonium chloride, 2 ounces common salt, 4 ounces aqua-ammonia and 1 gallon water. The work may have to be immersed or painted several times to give it the desired coating, and after washing and drying it should be lacquered or waxed. The Flemish finish can be given brass with a solution composed of ¼ ounce sulphuret of potassium, 1 to 2 ounces white arsenic, 1 quart muriatic acid and 10 gallons of water. The arsenic should be dissolved in a part of the acid by heating and then mixed with the balance of the acid and water. Two ounces sulphuret of potassium in a gallon of water may also be used if it is heated to 160 degrees F. One ounce sulphuric or muriatic acid in a gallon of water darkens the color produced by this last mixture.

To Produce Brown Colors

Many different shades of brown can be produced and many different chemicals are used to form solutions or pastes for this purpose. In these liver of sulphur, either potassium sulphide or sodium sulphide, is one of the most commonly used chemicals. One-fourth ounce liver of sulphur in 1 gallon water will give bronze a brown color when used cold but if heated it is more effective. The depth of the color is governed by the length of time that the work is immersed. If left in too long, however, it becomes black and if too much liver of sulphur is used the color will be black. Copper is turned black even with the weak solutions. To set the color it should afterwards be immersed in water containing a small amount of sulphuric or nitric acid. Brass is not attacked by this solution but if caustic potash is added it causes the liver of sulphur to color the brass. Then 2 ounces liver of sulphur should be added to 1 gallon water and from 2 to 8 ounces caustic potash, according to the shade of brown that is desired; the more potash the darker will be the color. A solution composed of ½ ounce potassium sulphide in 1 gallon of water will produce a gray or greenish color on brass when cold but when heated to 100 degrees F. it produces a light brown; at 120 degrees, a reddish brown; at 140 degrees, a dark brown; and at 180 degrees, a black color.

The barbedienne bronze, or brown, color can be produced on cast brass or bronze by immersing in a solution made by dissolving 2 ounces golden sulphuret of antimony and 8 ounces caustic soda in 1 gallon water. The work must be properly cleaned beforehand and afterwards scratch-brushed wet, with a little pumice stone applied when brushing. It must then be well washed and dried in sawdust. A second immersion in a solution of one-half the above strength will have a toning effect, and the work must again be washed and dried. The high light can be made to show relief by rubbing the object with pumice stone paste on a soft rag. A dead effect can be produced by immersing in a hot sulphuret of antimony solution for ten or fifteen seconds, then rewashing and immersing in hot water for a few seconds and drying in sawdust. The work should be lacquered to preserve the tones and waxed when the lacquer has become dry and hard. This brown color can be darkened by a five-seconds immersion in a cold solution of 8 ounces sulphate of copper in 1 gallon water. Some other processes use two solutions, the first of which is heated and the second used cold, after which the work is rinsed in boiling water.

To Produce Black

There are as many different processes and solutions for blackening brass as there are for browning, and consequently only a few can be given. Trioxide of arsenic, white arsenic or arsenious acid are different names for the chemical that is most commonly used. Its use can be traced back to the fifth century and it is the cheapest chemical for producing black on brass, copper, nickel, German silver, etc. It has a tendency to fade and a much greater tendency if not properly applied, but a coat of lacquer will preserve it a long time. A good black can be produced by immersing work in a solution composed of 2 ounces white arsenic and 5 ounces cyanide of potassium in 1 gallon water. This should be boiled on a gas stove, in an enamel or agate vessel and used hot. Another cheap solution is composed of 8 ounces sugar of lead, 8 ounces hyposulphite of soda and 1 gallon water. This must also be used hot and the work afterwards lacquered to prevent fading. When immersed the brass first turns yellow, then blue and then black, the latter being a deposit of sulphide of lead.

The ammonia-copper carbonate solution much used for medals, ornaments, etc., is made by taking the desired quantity of the strongest ammonia water and mixing it with an equal amount of distilled water, and dissolving carbonate of copper in it until it is thoroughly saturated and a little remains undissolved. This is placed in a stone crock and surrounded with water and then heated to from 150 to 170 degrees F. before the work is immersed. After immersing for a few seconds the brass will turn black; it is then removed, rinsed in cold water, dried, and given a coat of dead, black lacquer.

"Heat-Black" Finish on Brass, Bronze and Copper

The so-called "heat-black" finish on brass, copper, or bronze is one of the new methods of coloring metals that has recently appeared and is one of the most durable. It is adapted for a large variety of work and is even replacing nickel-plated work for some kinds of articles. Desk telephone sets are now being finished in the "heat-black," and in many parts of the United States have supplanted the nickel-plated article previously used.

The adaptability of the "heat-black" finish is wide, and the reader will undoubtedly find many new uses for it. The color is an absolute dead black, and as it is not difficult to apply, the future will undoubtedly find it extensively employed. It can be applied to brass, bronze or copper. It does not work evenly on steel or iron.

The article to be treated should be free from grease, although a slight tarnish does no harm. It is usually customary to sand blast the surface, although very good results may be produced without it. A sand-blasted surface takes an excellent finish, but those who do not possess the apparatus for producing it need not have any hesitation in using the finish without it, as about the only difference between the results is that the sand-blasted surface is a little more dead.

Two stock solutions are first made up. One is a solution of nitrate of copper in water, and the other is a solution of nitrate of silver in water. The proportions need not be exact, although it is preferable to keep them fairly close. According to the *Brass World*, they are made up as follows:

Nitrate of Copper Solution

Water	1 oz.
Nitrate of copper	1 oz.

This gives a practically saturated solution of nitrate of copper in water and is used for a "stock" solution. If desired, the nitrate of copper may easily be made by taking 1 ounce of strong nitric acid and dissolving in it all the copper wire it will take up. A thick, blue solution is left which is used for the "stock" solution. As few platers have nitrate of copper in stock, it can easily be made from the copper wire.

Nitrate of Silver Solution

Water	1 oz.
Nitrate of silver	1 oz.

This solution can also be made by dissolving pure silver in nitric acid until no more will dissolve, but dilute acid (1 part acid and 1 part of water) should be used as silver does not dissolve readily in strong nitric acid. It is preferable, however, to purchase the nitrate of silver as it is easily obtained. The nitrate of silver solution is practically a saturated solution and is used as the "stock" solution.

Mixed Solution for Applying

The mixed solution for applying to the metal is made as follows:

Water	3 parts
Nitrate of copper solution	2 parts
Nitrate of silver solution	1 part

The solution is kept in a glass or stone-ware vessel for use.

Applying to Brass or Other Metals

The brass, bronze or copper article to be treated is heated on a hot iron plate or in an oven to a temperature of about 250 degrees F. and the solution applied with a brush or cotton swab so as to cover the surface uniformly. The brush should be a rather soft one in order to allow the coating to be made in the best manner. The so-called "rubber-set" brushes are the best for the purpose, as there is no metal on them to be attacked by the solution.

One or two coatings of the solution on the surface of the article is usually enough; it dries almost immediately leaving a green froth. The temperature is not sufficiently high to draw the temper of hard brass, but it will usually melt soft solder.

When the entire surface has changed to a uniform black color, allow the article to cool and then brush off the fluffy material on the surface of the metal with a stiff-bristled brush. The color will now change to a brownish-black that is quite pleasing for many purposes and which is very tenacious. When the fluffy material is completely brushed off, it is surprising how even and uniform the coating is and how tenaciously it adheres. If the brown-black finish is desired, the surface may now be waxed or lacquered, but it is usually customary to give the article an additional treatment in a liver of sulphur solution in order to change the brown-black coating to one that is absolutely dead black.

Final Treatment

When the smut has been brushed off from the surface of the article, it is immersed in a cold liver of sulphur solution for 5 minutes. This solution is made by dissolving 2 ounces of liver of sulphur in 1 gallon of water. The article is immersed in it, allowed to remain about 5 minutes and then, without rinsing, is again heated until the surface is uniformly black.

The surface is now brushed again with the bristle brush when it will be found that the color is a dead black and quite uniform. It should be borne in mind that the article is not rinsed at all after it is removed from the liver of sulphur solution, but is simply drained off and then heated.

The article may now be lacquered with a flat lacquer or waxed as may be desired. The final appearance of the surface will be found quite satisfactory and contrary to what one would naturally expect. The coating of the solution that is first applied need not be very even as long as a sufficient quantity is put on.

The process as arranged by steps may be summed up as follows:

1. Applying the solution to the metal.

2. Heating on a hot plate or oven until the solution has dried and the residue left by evaporation has turned black.

3. Brushing off the smut.

4. Immersion for about 5 minutes in a liver of sulphur solution.

5. Drying without rinsing and heating on the plate or in the oven again.

6. Lacquering or waxing.

If the surface is not satisfactory, or an old article is to be refinished, the wax or lacquer may be burned off and the process repeated.

It is believed that this is one of the most satisfactory black finishes known, as it is dead black, is readily applied and is very durable. It is calculated to resist considerable handling, such as a desk telephone would receive. There are many articles that can well be treated by it.

Oxidizing

Solutions that produce the green, brown or black colors are usually used when it is desired to oxidize copper, brass or bronze. A dark slate green can be produced with a solution composed of 8 ounces double nickel salts, 8 ounces sodium hyposulphite and 1 gallon water. The color is almost instantly produced when the temperature of the solution is above 150 degrees F., but below the boiling point, and the articles immersed. After removing and rinsing in water the relief is easily produced with pumice stone or other abrasives. This green color harmonizes well with the metal color.

The browns and blacks are coated on the metal in the same manner as described under these headings; those solutions that are used hot give the best results, as the coating is more tenacious and better withstands the buffing that is necessary when oxidizing the work. Many beautiful effects are produced by these combinations of colors, and while it is not difficult to relieve the rough surfaces of cast, stamped or pressed articles it requires considerable skill to properly relieve turned or polished surfaces.

Mottling

After properly buffing and cleaning the work, a handsome mottled effect can be produced by first immersing it in a boiling solution composed of 8 ounces sulphate of copper, 2 ounces sal-ammoniac and 1 gallon water. This produces a light taffy color that soon changes to an olive green. The work should be removed when the taffy color appears and dipped in a second solution composed of 4 ounces sal-soda in 1 gallon water and that has the surface covered with a small amount of lard oil or gasoline. After that the work is again immersed in the first solution until the olive-green color is produced. The oil spreads over the surface and prevents the uniform action of the first solution, and hence the taffy and olive-green colors are mottled together with a pleasing effect. The same process might be used with different chemical solutions to mottle work with other combinations of colors.

Coloring Aluminum

Aluminum is the most difficult of metals to color. Heretofore aluminum parts have only been colored by coating them with lacquers of different colors, but a process has recently been patented by Salamon Axelrod in Germany that produces different metallic colors. Either a neutral or alkaline cobaltous nitrate is made into a water solution into which the articles are dipped, or it may be painted on pieces too large to dip. After that the work is heated and the degree of heat determines the color. A low temperature produces a steel gray color that changes to brown with a higher heat and to a durable and permanent dead black when the temperature is still higher. Zinc, tin and other white metals may also be colored with similar cobalt salt solutions.

The gun-metal finish can be given aluminum by immersing it for from six to ten seconds in a cold solution of 12 parts hydrochloric acid, 1 part chloride of antimony and 87 parts distilled water. After that, thoroughly wash it in running water for several minutes, dry with heat and lightly buff with a high-speed wheel. The color penetrates the metal and its depth is governed by the length of time it is immersed. If immersed longer than ten seconds the solution should be weakened, as hydrochloric acid eats the metal.

Nearly any color can be plated on any of the metals or alloys by electro deposition, but this is an art or trade that requires experienced platers. Electrochroma is the name given a new plating process that promises to revolutionize the older methods of plating on colors. It produces any desired shade of green, blue, red, violet or yellow and black and white by immersion in the electrolyte for from one-half minute to two minutes. The work is made the cathode. One of its special features is the coloring of leaded glass. The lead can be given any desired color, while the glass is not affected but is left clean and with a clear luster. Heretofore the lead has been painted by hand, which is a long, tedious job, often consuming a day or more for one piece. It is also easy to match colors with this plating process and they are permanent enough not to require lacquering or waxing. The plating processes, however, are separate and distinct from those given above, as these do not require an electric current nor the high degree of knowledge and skill that goes with the plater's profession.

CHAPTER IV

LATHE BURNISHING OF METALS

The burnishing of metals while not requiring the skill of the spinner, or the multiple operations or tools used in that craft, still is a trade that is separate and distinct from spinning. Metal burnishing can be divided into three classes:

1. Hand burnishing of irregular shapes, such as tableware, jewelry, belt buckles, metal clocks, ornaments and all metal parts that cannot be revolved on the lathe, using steel hand tools of various shapes.

2. The burnishing of small round work in the lathe, such as buttons, ornaments, etc.—mostly plated ware that has already been surfaced and is operated on to brighten only—not requiring the heavy pressure of the tool, and being mostly done with blood-stone burnishers, a natural stone of small size mounted in a steel holder. These stones, some of which are very expensive, last for years.

3. The burnishing of unfinished or rough work in the lathe, which requires smoothing and polishing at the same time; this requires considerable pressure. The blood-stone burnisher would be ruined on this class of work. The tools used are of steel and the handles are short; they are held in the hand only. A strong wrist and muscular arm are required for burnishing, as well as a steady feed of the tool, which is partly accomplished by the movement of the body, in conjunction with the arm and wrist motion; the hand is steadied by being held against the body.

Burnishing may be described as an economical way to finish, polish or brighten the surface of metal, without wasting any of the material. It is also a means of strengthening the metal by tempering or hardening it; this is accomplished by pushing the tool over the work, beginning at the front end and pushing always against the chuck. The toolpost is used as a fulcrum and the tool, which is pressed against the work, as a lever. The tool is given a slight rotary motion, and only the thin edge or end is used.

While the pressure against the work does not seem great, still the area in contact with metal is so small, and the speed of the lathe so high, being from 3200 to 5000 revolutions per minute, that the tool leaves a bright mark. The skill of the operator lies in passing the tool over the metal so as to leave a continuous bright surface without

Fig. 1. View showing Method of Moistening Work with Finger Pads and also Position and Angle of Burnishing Tool

any trace of the tool marks; to do this the tool must be fed with regularity and without overlapping or leaving any dull places.

After sheet metal is spun, or drawn in presses, the smooth, even surface which it has when it comes from the mills is changed to a rough, uneven surface having high and low spots which are hardly noticeable to the naked eye, but very easily distinguished under the magnifying glass. The working operations distend or elongate the molecules, and the annealing operation restores them to their original shape. Some shells are annealed several times before the burnishing operation is reached, besides being pickled after each annealing to remove the scale; this leaves the surface of the metal in a pebbly or matted condition, as well as soft and without temper.

A spun shell can be gone over with a planisher, and hardened, but the scale and dirt is crowded into the grain of the metal, and the only way to get a smooth surface is to buff or cut it down until this pitted face is removed thus wasting about 10 per cent of the metal.

The spinner can do this in another way, that is by skimming or shaving the uneven surface, but even more metal is wasted than by buffing, and the shell is also weakened by gouging the high places. This same shell could be left without polish, and the chuck transferred to the burnishing lathe, which runs at much greater speed than one used for spinning. After the shell is dipped bright to remove all spinning dirt and scale, it can then be polished to an even surface, the uneven face of the metal being amalgamated or smoothed down to a bright surface of the proper temper; it is then colored with a cloth buff to obtain a perfect finish. The gage or thickness remains the same as there is no dirt or scale to buff out.

Burnishing is economical, especially on pressed or drawn work made in large quantities, some work being finished at the rate of five

Fig. 2. Burnishing Lathe Equipped with Split Chuck

hundred or more an hour. It is necessary to have a metal chuck in burnishing, and where the shell has been spun on such a chuck, the latter can be used for both operations. Some work can be lacquered without coloring on the buff wheel, the only operation after burnishing being to wash in hot water and dry at once in hot sawdust.

A burnishing lathe is smaller than a spinning lathe, and it has only one speed. The countershaft is fastened to the floor under the lathe; this is necessary on account of the great speed, besides a down-pull of the driving belt causes less vibration than the up-pull of a belt from an overhead countershaft. The speed of burnishing lathes is varied for different classes of work. In a group of four lathes in use in one factory one is belted to run at 5000 revolutions, two at 4000 revolutions and one at 3200 revolutions a minute. Lathes for very large work of 12 inches and over in diameter have straight babbitted bearings, with a back screw and button to take up the end shake. The babbitt has to be renewed about once a year for continuous service, only the best grade being used. All threads on the spindles are of one standard size, the chucks being interchangeable for the burnishing and spinning lathes.

In some shops it is customary to have a small stream of water running on the work above the chuck, the connections being hinged, so that the stream can be guided above the tool. A back center is used to hold the work against the chuck. The operator wears a rubber apron to protect himself from the flying water, and stands in a shallow trough that has a drain. The great speed of the lathe throws off all surplus water, leaving only a thin film next to the metal—all that is necessary.

This chapter describes a method of burnishing that is used in many shops. The shells are first dipped in a tank of water, which is on the bench back of the lathe head; they are then held on the chuck by the left hand, the thumb and first three fingers being covered with canvas pads. These pads are dipped in the water and are held opposite the burnishing tool and slightly in advance of it to keep the metal moist,

Fig. 3. Burnishing Lathe Steady-rests and Finger Pads

thus leaving no surplus of water to be thrown off. The hand also holds the work against the chuck instead of the back center. Sometimes on large work it is necessary to dip the pads in the water a second time; also where a very fine polish is wanted it is necessary to pass the tool over the work twice, roughing it down on the first pass and finishing it on the second, using the same tool without taking it off the chuck.

Fig. 1 shows the method of using the pads on the fingers and also the proper position and angle of the tool, as well as the height of tool-post or rest. The chuck shown is 8½ inches in diameter and weighs 36 pounds; it runs at 4000 revolutions per minute. The shell has been gone over twice.

Fig. 2 shows a burnishing lathe equipped with a split chuck, one part being in the tail-spindle and having a roller end bearing. All chucks for burnishing are like the spinning chucks, except that greater care must be taken in machining them to have them perfectly balanced.

Fig. 3 is a view of the steady-rests that are used on burnishing lathes. These are different from the spinning rests, for while the spinner uses only one pin as a fulcrum, changing it from one hole to another as the work advances, the burnisher uses several pins of much smaller size, inserting as many pins as he needs positions for the sweep of his tool. These pins are about $\frac{1}{4}$ inch to 9/32 inch in diameter and are tapered $2\frac{1}{2}$ degrees on the end which is inserted in the cross-bar of the steady-rest, the holes also being tapered and the pins driven in tight. The canvas finger cots that are used on the left hand to moisten the work are shown at *A*.

Fig. 4 shows a group of burnishing tools, some of which are of high speed steel, and others of regular tool steel. These tools are made extremely hard and no temper is drawn. They project out of the handles from $2\frac{1}{2}$ to 5 inches and are $\frac{3}{8}$, 7/16, $\frac{1}{2}$, and $\frac{5}{8}$ inch in

Fig. 4. Group of Tools used for Burnishing

diameter. The round tools *A* are used on heavy work; also to get in sharp corners and to burnish shells which are part plain and part embossed, requiring the tool to be lifted from one part of the work to another to avoid the embossed area. *B* is a flat tool with a slight curve on the end; it is used mostly on straight work and convex surfaces. *C* is a flat tool with a greater curve on the end, and it is used mostly on concave surfaces, while *D* is a flat tool with a still greater curve on the end, for use on small curved work, such as that shown in Fig. 5. These tools have to be polished when they become coated with metal, the interval between polishings depending on the texture of the metal worked and its temper, a shell that has been annealed several times coating the tool more than one that has not. It is a quick operation to polish the end of a burnisher. A board of soft wood or a strip of leather fastened to a board and to the bench, in a position convenient to the operator, is used. Grooves are worn into the leather or board, and flour of emery and oil, or flint flour and water is used to clean the tools, a few passes of a tool being all that is necessary to polish it.

Fig. 5 shows samples of burnished work; some of these are spun but most of them are drawn in presses. The bright dip which is used to clean work before burnishing is composed of: Oil vitriol (sulphuric acid), 2 parts; aqua fortis (nitric acid), 1 part. This solution should be kept in a crock set in a tank of running water, and mixed 7 or 8 hours before using, as the acids when combined heat up. It is best to mix the acids the day before using. In dipping brass, copper and German silver, the parts are strung on a wire whenever possible. If there are no holes in the metal that can be used for stringing, they can be put in a metal or crock basket, but they cannot be handled to good advantage as it is very difficult to thoroughly wash and dip them. After stringing the work on a stiff brass or copper wire, it should be washed in boiling potash, and then dipped in cold water to clean the potash off and cool the metal.

Fig. 5. Samples of Burnished Work

After cooling in the water, they are dipped for a few seconds in the acids, keeping the work constantly in motion, so that the surfaces will be all exposed equally; they are then shaken thoroughly above the acid and immediately washed in two separate cold-water baths, then in hot soap water, and then in hot water, after which they are dryed at once in hot sawdust. This operation will leave a bright, clean surface free from acid.

Common yellow soap, dissolved to thick paste, is used as a lubricant when burnishing brass. The shells and the finger pads are dipped in clear water, and the tool is dipped in the soap paste before burnishing each shell.

A lubricant for copper is made by dissolving about one ounce of ivory or castile soap in a gallon of water. The shells and pads are dipped in this solution, no lubricant being used on the tool. Yellow soap should not be used on copper, as the action of the rosin on copper is different from that on brass, the metal being so glazed or greased that the tool works badly.

For copper plate on steel, such as copperized steel oilers, etc., about one-half ounce oil vitriol to four gallons of water should be used. The burnishing tool should be dipped in a mixture of mutton tallow that has been melted with 5 per cent of beeswax, and the work and the finger pads should be dipped in the acid mixture. The tool is lubricated in the tallow mixture before burnishing each shell.

For German silver, the shell should be dipped in clear water, the finger pads in sour beer, and the tool in yellow soap paste.

For white metal or Britannia, use ivory or castile soap in the paste form for the tool, and sour beer or ox gall in water (4 ounces to the gallon) for the finger pads. Wash the work in hot alkali water (a spoonful of cream of tartar, saleratus or soda to a pail of water), and dry in hot sawdust.

For burnishing work which is to be lacquered, without coloring on the cloth buff, use thin glue for a lubricant, and also on the finger pads. When the part is burnished put it in saleratus water to keep it from tarnishing; then wash in hot water and dry in hot sawdust. Most plated work can be burnished with the sour beer mixture for the finger pads, and castile or ivory soap paste for the tool lubricant.

CHAPTER V

THE BALL-BURNISHING PROCESS

Burnishing, as used in the ordinary sense of the word, consists in finishing exterior surfaces of work by rubbing with a highly polished steel hand tool, which hardens and polishes the surface metal. The Abbott ball-burnishing process produces the same effect, but in an entirely different manner, employing quantities of hardened and polished steel balls which are caused to roll over the work while under

Fig. 1. Character of Work finished by Abbott Ball-burnishing Process

pressure. This pressure is effected by the weight of the balls which are confined within a tumbling barrel like that shown in Fig. 2. Thus, each ball acts as an individual burnishing tool, and as it rolls over the work, pressed by the mass of balls and work above, it leaves a burnished path on the work. Fig. 1 shows some representative burnishing jobs which have been efficiently handled by this process. Some idea of the action which takes place within the tumbling barrel may be gathered by noticing the balls and work which are represented in Fig. 3.

Fig. 4 shows the general form of the ordinary tumbling barrel as contrasted with the Abbott burnishing barrel. From this it will be seen that in the Abbott barrel, the balls are confined in a deep narrow space so that the same amount of balls being restricted within a narrower space exert a heavier burnishing pressure upon the work. The Abbott ball-burnishing process cannot be used when any metal is to be removed or deep scratches are to be taken out. It is purely and simply a burnishing process for putting a high finish upon the work, and on work within its limitations is highly successful. Not only can a large amount of work be done in a short space of time, and in a very efficient manner, but many jobs which cannot be burnished by hand are efficiently finished by this process. Referring to Fig. 3 again, it will be seen that it is a simple matter for the balls to burnish the inside of a tube, the center of a deep depression, or the inside of a wire loop as shown in Fig. 1. Such pieces as these would be difficult to burnish in any other way. In order to burnish corners and depressions, it is necessary to employ balls small enough to come in contact with the surfaces of such places; therefore, on other than the very plainest of work, two sizes of balls are commonly used as shown in Fig. 3. Again, on work which is lettered, ordinary polishing processes "drag" the letters, but with the ball-burnishing process this trouble is not experienced.


Fig. 2. Type of Burnishing Barrel used

The balls used for this work are made of low carbon steel, by the heading process, carbonized and hardened clear through and then highly polished. The balls are not truly spherical, nor of an exact size, but they are highly finished and very hard. The barrels may be of the single or multiple type, having one or more compartments. The barrel shown in Fig. 7 has two sections, and gives a general idea of the construction. The compartments are octagonal in shape and are lined with maple wood so that the balls and work do not come in contact with any metal during the burnishing process. Two hand-holes are provided for each compartment with covers which may be clamped in place. The two hand-holes furnish a means for quickly removing the contents and washing out the barrel. A lubricant is employed in burnishing, which ordinarily consists of soapy water.

To burnish a quantity of work, the work and balls are placed in the barrel in the proportion of one peck of work to two pecks of steel balls. Water is then added until it stands about one inch above the contents of the barrel. In this water, about four ounces of burnishing soap chips have previously been dissolved. The hand-hole covers are then clamped in place, and the mixture tumbled from one to five hours, depending upon the character of the work, metal, etc. The speed ordinarily employed for tumbling ranges from 10 to 30 R. P. M., the usual speed being 15 R. P. M. If after tumbling the work has a dull or smutty appearance, the soap solution should be drained from the work and clean water substituted, to which should be added a piece of cyanide of potassium about the size of a pea. It is highly important that the balls be kept from rusting, for rust, of course, destroys their burnishing qualities. The balls are easily kept in good condition by returning them to the barrel with the soap solution on them, but in no event should they be washed in clear water and allowed to stand.

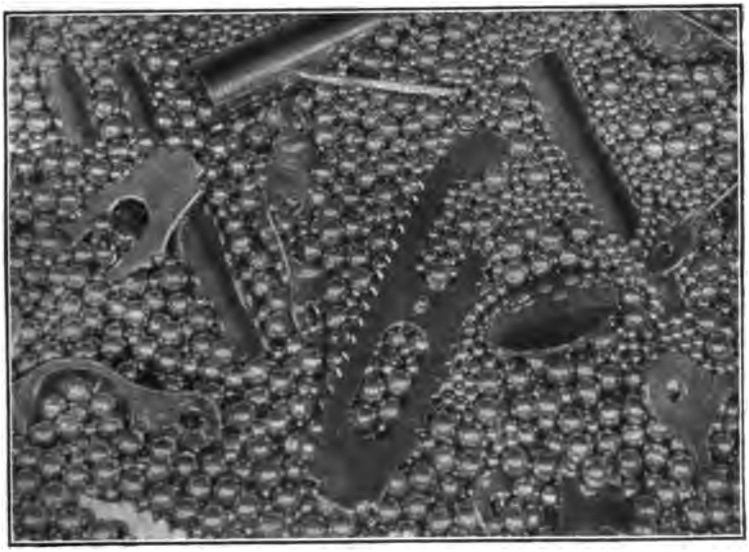


Fig. 3. View within the Barrel to show Burnishing Action of the Balls

The burnishing operation is the same on all kinds of metal. After the work has been burnished sufficiently, it is separated from the balls by dumping the mixture into a screen of sufficiently coarse mesh to allow the balls to drop through. A convenient arrangement to use for separating the balls from the work is shown in the illustration Fig. 5.

If the work is not to be plated, it is taken from the barrel and dried in sawdust, but if to be plated, it is cleansed in the usual manner and plated. The cleaning operation incident to plating is usually very troublesome on account of the rouge that is driven into corners of the work by the polishing wheels. No such trouble is experienced after ball-burnishing, as no rouge is used. It is only necessary to rinse off the soap solution, dip in potash and plate. After plating, the work is returned to the barrel and tumbled in a soap solution for a half hour to impart a high finish.

While most commonly used for small work, say under three inches in greatest dimension, larger work may be handled by a modification of the process. The difficulty in burnishing large work is due to the fact that the weight of the piece is often great enough to injure other

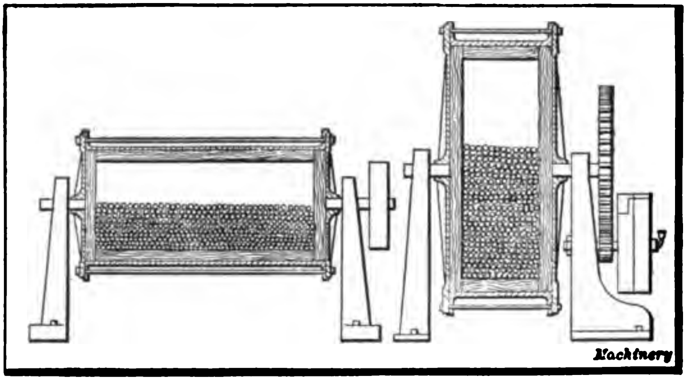


Fig. 4. Comparison of Old-style Barrel with Abbott Barrel

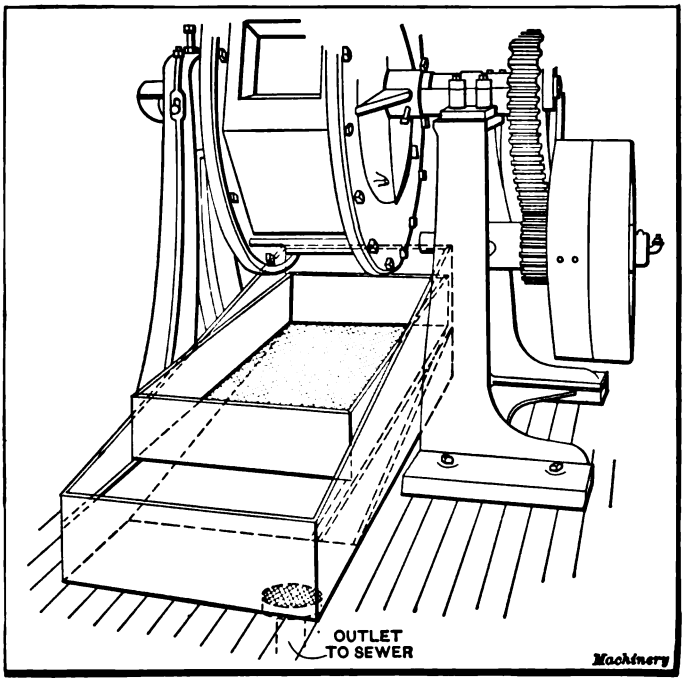


Fig. 5. Convenient Arrangement for Separating Balls and Work

pieces of work, and, of course, if the pieces are easily bent, there will be trouble from this source. Aside from the danger of bending large work in the burnishing barrel, a greater source of trouble is from scratches caused by the sharp edges of such pieces coming in contact with the finished faces of other pieces in the barrel. Referring to the illustration Fig. 8 a method of mounting pieces of this character is shown. Any convenient method of clamping is employed, depending, of course, on the shape of the pieces, but the fundamental idea is to support the pieces so that they cannot move in the barrel, and yet give

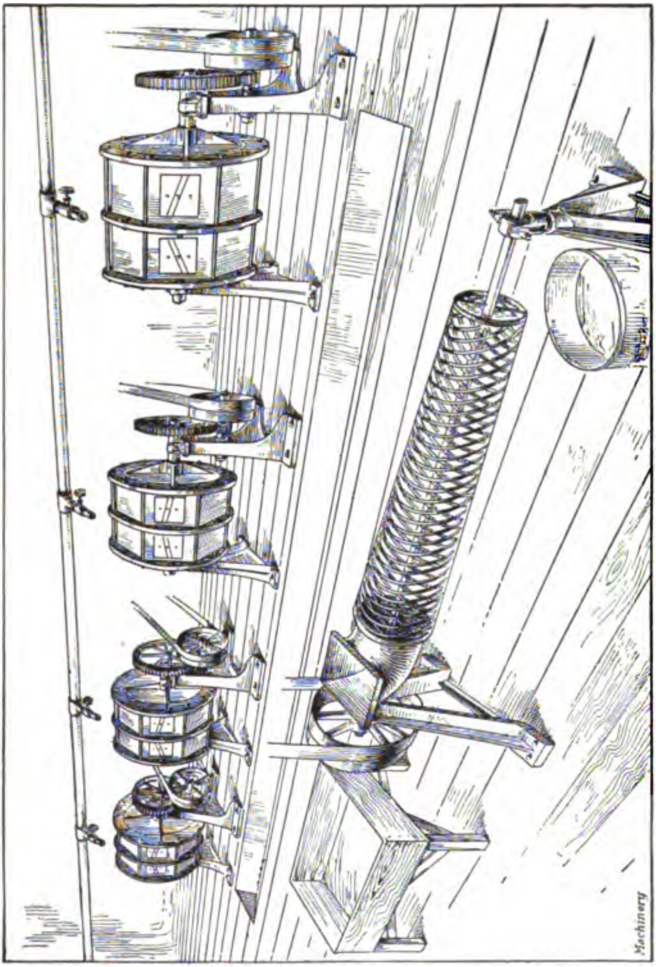


Fig. 6. Abbott Ball-burnishing Installation at Heron Mfg. Co.'s Plant

the burnishing balls a chance to act upon the work exactly the same as though it was loose in the barrel. Mounted in this manner no possible injury can be done to the work and yet the balls have access to every part of the piece except the edge, even to the inside. It is apparent that this method cannot be used for all work, but a little ingenuity will often solve the problem without having to resort to hand polishing.

A typical installation of the Abott ball burnishing process is found at the Heron Mfg. Co., Utica, N. Y. This installation is represented by the illustration Fig. 6, in which are shown four double barrels driven from a common shaft. A line of piping extends over the four barrels, being connected with a hot water tank on the floor above. By means of outlets over the barrels, water may be admitted to the barrels for

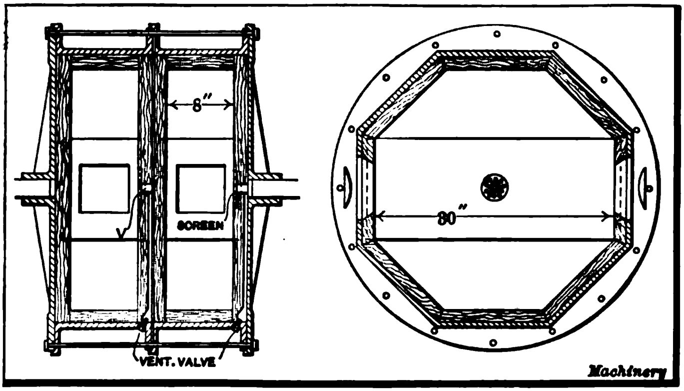


Fig. 7. Construction of Ball-burnishing Barrel

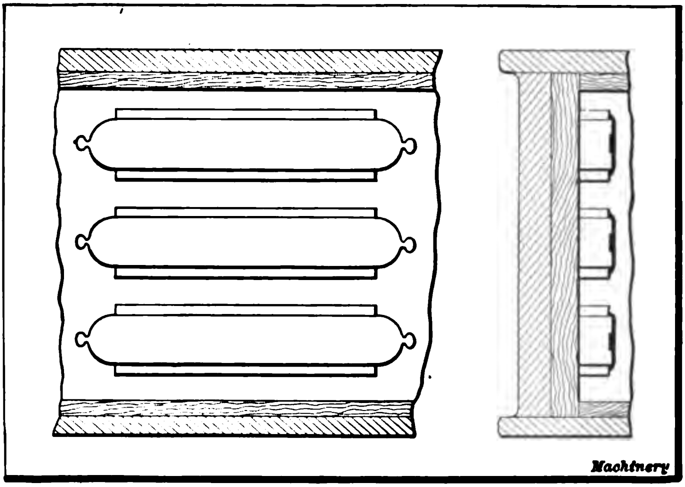


Fig. 8. Section of Barrel to show Method of Mounting Large Work

mixing the burnishing solutions, and for cleaning the barrels and their contents after the burnishing operation. A trolley system is arranged so that after the work has been dumped from a barrel into a basket, during which operation the suds and soap solution are carried away by means of the trough in front of the barrels, the work may be carried to the sawdust box for drying. This sawdust box is of the usual type and after the work has been sufficiently dried, it is shoveled into the chute shown at the right of the sawdust box, from which it enters the revolving conical screen cylinder and is separated from the sawdust, emerging from the small end of the screen, completely dried and ready for shipment.

By the use of this apparatus, the Heron Mfg. Co., who manufactures casters of all kinds, states that it is producing twice the number of parts at half the cost, and getting a better finish than when using hand polishers. Thus an expensive polishing and buffing equipment is eliminated, as well as the high priced labor formerly employed.

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CUTTING LUBRICANTS

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CHAPTER I

CUTTING LUBRICANTS FOR MACHINING OPERATIONS

Cutting lubricants are used in connection with most machining operations on wrought iron and steel, in order to cool the turning tool and reduce the abrasion or wear of the cutting edge, thus permitting higher cutting speeds. In many cases, however, lubricants are not used even when machining iron and steel. This may be due to the nature of the work or to the inconvenience of supplying a lubricant when the machine is not equipped for it. For instance, small turning operations in the lathe are usually performed dry or without a lubricant, regardless of the material being turned, especially when the cuts are light and the application of oil or a soda-water mixture to the tool would interfere with the work. When there is considerable superfluous metal to be removed and long roughing cuts must be taken, a good lubricant, while not necessary, is very desirable, as it permits higher cutting speeds and preserves the edge of the tool.

Many modern lathes, particularly the large sizes or those of the "manufacturing type," are equipped with pumps and piping to automatically supply a continuous stream of lubricant for the turning tool. Most lathes, however, are not so equipped and lubricant is generally supplied from a cam which is mounted at the rear of the carriage and travels with the tool as it feeds along the work. The objection to the use of a cam from which the lubricant flows by gravity is that the amount of lubricant is insufficient to properly cool the tool when taking heavy roughing cuts. The result is that the full benefit from the use of the lubricant is not obtained. (The different methods of supplying lubricant to turning tools and cutters on various machines is explained in Chapter II.) Cutting lubricants are more generally used on turning and milling machines of various types than on planing and slotting machines. In fact, cutting lubricants are not often used for rough planing operations, although in many cases a lubricant would be desirable. The same is true of many other operations which are ordinarily performed dry. Frequently a lubricant, such as soda-water, is used on the planer or shaper when taking light finishing cuts. The object, however, is to secure a smooth surface rather than to increase the durability of the tool or permit higher cutting speeds.

Quite a variety of cutting lubricants are used at the present time, some being compounds which are "home-made" and others commercial lubricants which have been placed on the market. Most of the following lubricants for different materials and operations are in general use and have proved satisfactory.

Lubricants for Turning Operations: A good grade of lard oil is an excellent lubricant for use when turning steel or wrought iron and is extensively used on automatic screw machines, especially those which operate on comparatively small work. For some classes of work, especially when high-cutting speeds are used, lard oil is not as satisfactory as soda-water or some of the commercial lubricants, because the oil is more sluggish and does not penetrate to the cutting point with sufficient rapidity. Many lubricants which are cheaper than oil are extensively used on "automatics" for general machining operations. These usually consist of a mixture of sal-soda (carbonate of soda) and water, to which is added some ingredient such as lard oil or soft soap, to thicken or give body to the lubricant.

A cheap lubricant for turning which has been extensively used is made in the following proportions: 1 pound of sal-soda (carbonate of soda), 1 quart of lard oil, 1 quart of soft soap, and enough water to make 10 or 12 gallons. This mixture is boiled for one-half hour, preferably by passing a steam coil through it. If the solution should have an objectionable odor, this can be eliminated by adding about 2 pounds of unslaked lime. The soap and soda in this solution improve the lubricating quality and also prevent the surfaces from rusting.

A mixture of equal parts of lard oil and paraffin oil will also be found very satisfactory for turning operations, the paraffin being added to lessen the expense. Another mixture is made by adding 10 gallons of lard or paraffin oil to a No. 10 can of "Oildag." For automatic screw machine work, a good lubricant is composed of equal parts of so-called "electric cutting oil" and paraffin oil.

Lubricants for Milling: For milling operations the following compound (which is also adapted to turning) is often used. Mix together 1 pound of sal-soda, 1 quart of lard oil, 1 quart of soft soap and enough water to make 10 or 12 gallons. Boil this mixture one-half hour. For general work in milling steel, the following formula has been successfully employed: Mix 96 pounds of "Cataract" compound and 21 gallons of pure water; take 12 gallons of this stock mixture, add 48 gallons of water and two No. 10 jars of "Aquadag"; mix thoroughly.

A mixture of equal parts of lard oil and paraffin oil is also used for milling, the paraffin being added to reduce the cost of the lubricant. For fluting operations, paraffin oil, not mixed, has proved satisfactory.

Compounds for Drilling: A cheap drilling composition can be made by adding to thirty gallons of water 5 gallons of lard oil and 20 pounds of washing soda. Put the material in a lard oil barrel, insert a steam hose into the bung and boil thoroughly. Do not use mineral oil or a barrel that has contained it. Another cheap drilling compound is made in the following proportions: Mix 96 pounds of "Cataract" compound and 21 gallons of pure water; to 12 gallons of this stock mixture add 48 gallons of water and two No. 10 jars of "Aquadag"; mix thoroughly.

When drilling hard and refractory steel, use turpentine, kerosene or soda water; for soft steel and wrought iron, lard oil or soda water; for malleable iron, soda water; for brass, a flood of paraffin oil, if any lubricant is used; for aluminum and soft alloys, kerosene or soda water. When drilling glass use a mixture of turpentine and camphor. Cast iron should be worked dry, or with a jet of compressed air as a cooling medium. When drilling very deep holes in cast iron, a few drops of kerosene deposited on the drill point will be found useful, but care must be taken to use a very small amount of the lubricant. For deep-hole drilling in steel use a mixture of equal parts of lard oil and paraffin oil. When drilling rawhide, apply ordinary laundry soap to the drill at frequent intervals. The drilling of hard material is facilitated by using turpentine as a cutting compound and by grinding off the sharp angles of the cutting edges so as to permit quite heavy feeds without chipping the edges. This form of point will also be found advantageous for drilling soft material, like brass, as it does not tend to dig into the metal. It is good practice to warm the lubricant before using it on high-speed steel tools. These work much better when warm, often giving good results when the chips are turned blue by the heat generated. Nothing will check a high-speed drill quicker than turning a stream of cold water onto it after it has become heated. It is equally bad to plunge the drill into cold water after the point has been heated in grinding.

Lubricant for Grinding: For grinding with hard or soft wheels, use a No. 10 jar of "Aquadag" mixed with ten gallons of water; add one-half pound of borax or sal-soda to prevent rusting.

Lubricant for Gear Cutting: The following mixture has been extensively used on gear-cutting machines: 3½ gallons of mineral lard oil, 2¾ pounds of sal-soda, and one barrel of soft water.

Effect of Lubricant when Turning Cast Iron: Cast iron, except when tapping, is usually machined dry. Experiments made to determine the effect of applying a heavy stream of cooling water to a tool turning cast iron showed the following results: Cutting speed without water, 47 feet per minute; cutting speed with a heavy stream of water, nearly 54 feet per minute. Increase in speed 15 per cent. The dirt caused by mixing the fine cast-iron turnings with a cutting lubricant is an objectionable feature which, in the opinion of many, more than offsets the increase in cutting speed that might be obtained.

Lubricants for Thread Cutting: A mixture of equal parts of lard oil and paraffin oil gives good results for threading. (The lard oil is adulterated with paraffin to reduce the cost of the lubricant.) For thread cutting on nickel steel or other hard stock, with machines running at high speed, the following compound has proved satisfactory: To 8 gallons of warm water add 25 to 30 ounces of borax. When fully dissolved, add two gallons of lard oil and stir thoroughly. When cold, add the contents of a No. 10 jar of "Aquadag" (condensed); mix thoroughly. An excess of borax will be indicated by the formation of more than two or three bubbles on the surface of the mixture after thorough stirring. Ordinary beeswax is a good lubricant to use when cutting threads in copper. The beeswax is rubbed onto the thread and produces a smooth finish.

Lubricants for Brass, Babbitt and Copper: Brass or bronze is usually machined dry, although lard oil is sometimes used for automatic screw machine work. Babbitt metal is also worked dry, ordinarily, although kerosene or turpentine is sometimes used when boring or reaming. If babbitt is bored dry, balls of metal tend to form on the tool and score the work. Milk is generally considered the best lubricant for machining copper. A mixture of lard oil and turpentine is also used for copper.

Lubricants for Machining Aluminum: For aluminum, the following lubricants can be used: Kerosene, a mixture of kerosene and gasoline; soap-water; or "aqualine" one part, water twenty parts. The last mixture specified has been successfully used by the Brown-Lipe Gear Co., where a great many aluminum parts are machined. This lubricant not only gives a smooth finish, but preserves a keen cutting edge and enables tools to be used much longer without grinding. Formerly a lubricant composed of one part of high-grade lard oil and one part of kerosene was used. This mixture costs approximately 30 cents per gallon, whereas the aqualine-and-water mixture now being used costs less than 4 cents per gallon, and has proved more effective than the lubricant formerly employed.

Lubricants for Broaching Operations: For broaching steel, cutting compounds similar to those used for other machining operations, such as turning and milling, are commonly used. The J. N. Lapointe Co. recommends a lubricant for broaching steel containing 2½ pounds of soda ash and 3 gallons of mineral lard oil to 50 gallons of water. The soda ash and lard oil is mixed with 10 gallons of water, and then the remaining 40 gallons of water added. When holes to be broached are of exceptional length, a good grade of oil is better than soda water or similar cutting lubricants, as the oil will cling to the cutting edges of the broach for a longer time.

Lubricants for Tapping: The breakage of taps can be reduced greatly by using the proper lubricant. A good grade of animal lard oil, sperm oil, and graphite and tallow mixtures (10 per cent graphite, 90 per cent tallow) are the best lubricants to use when tapping steel or iron. A good soap compound is better than "mineral lard oil." Machine oil is a poor tapping lubricant. Tests made to determine the power required for tapping demonstrated that the power required when using sperm oil is 16.5, as compared with 34.2 when machine oil is used. Incidentally, this increase is almost as great as that due to decreasing the diameter of the tap drill from 0.425 to 0.400 inch when using sperm oil, the increase being from 16.5 to 35.5. This shows that a poor lubricant may increase the power for tapping as much as would a considerable reduction in the diameter of the hole to be tapped.

For tapping cast iron, soap compounds give excellent results, and lard oil is also used. Oil for cast iron, however, has the disadvantage of causing the chips to stick in the tap flutes, thus preventing the lubricant from reaching the cutting edges; hence a thin lubricant is preferable. A few drops of kerosene will facilitate the tapping of long holes in cast iron. Only a small amount of kerosene should be used.

Lard Oil as a Cutting Lubricant

After being used for a considerable time, lard oil seems to lose some of its good qualities as a cooling compound. There are several reasons for this. Some manufacturers use the same oil over and over again on different materials, such as brass, steel, etc. This is objectionable, for when lard oil has been used on brass it is practically impossible to get the fine dust separated from it in a centrifugal separator. When this impure oil is used on steel, especially where high-speed steels are employed, it does not give satisfactory results, owing to the fact that when the cutting tool becomes dull, the small brass particles "freeze" to the cutting tool and thus produce rough work. The best results are obtained from lard oil by keeping it thin, and by using it on the same materials—that is, not transferring the oil from a machine in which brass is being cut, to one where it would be employed on steel. If the oil is always used on the same class of material, it will not lose any of its good qualities.

Prime lard oil is nearly colorless, having a pale yellow or greenish tinge. The solidifying point and other characteristics of the oil depend upon the temperature at which it was expressed, winter-pressed lard oil containing less solid constitutents of the lard than that expressed in warm weather. The specific gravity should not exceed 0.916; it is sometimes increased by adulterants, such as cotton-seed and maize oils.

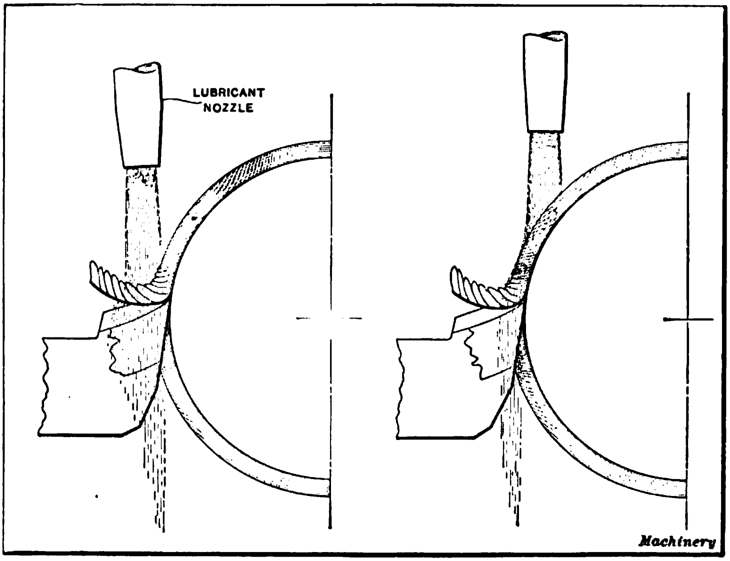
Navy Department Specifications for Lard Oil

The U. S. Navy Department gives the following specifications for lard oil: Lard oil must be of a good commercial quality, and must be purchased and inspected by weight; the number of pounds per gallon is to be determined by the specific gravity of the oil at 60 degrees F. multiplied by 8.33 pounds (the weight of a gallon of distilled water at the same temperature). Oil will not be accepted which contains a mixture of any mineral oil (10 per cent vegetable or fish oil is allowed); nor must the oil contain more acidity than the equivalent of 5 per cent of oleic acid, or show a cold test above 55 degrees F. The specific gravity must not be above 0.92 nor below 0.90.

Effect of Cooling Lubricant on Cutting Speed

Experiments made by Mr. F. W. Taylor, to determine the effect upon the cutting speed of pouring a heavy stream of cooling water upon the cutting edge of the tool, resulted in the following conclusions:

When using high-speed steel tools, a gain in the cutting speed of from 35 to 40 per cent can be made, when turning steel or wrought iron, by applying a heavy stream of cooling water at the proper point. In general practice, this percentage might be reduced somewhat, owing to the fact that the water is not always directed upon the right spot. The most satisfactory results are obtained from a stream of water falling at rather slow velocity but in large volume, because a stream of this sort covers a larger area and is much freer from splash.



Cooling Lubricant should be applied at Point where Chip is being severed, as shown by Diagram to Left, rather than as Indicated by View to Right

The stream of lubricant should fall directly upon the chip at the point where it is being removed by the tool. The left-hand view of the accompanying illustration shows how the stream should fall upon the tool and chip. Very often the water is thrown upon the work at a point above the chip to prevent splashing, as illustrated by the right-hand view. This method, however, of applying lubricant is less effective and results in a slower cutting speed.

The gain in cutting speed through the use of cooling water is practically the same for all qualities of steel from the softest to the hardest.

When cutting steel, the better the quality of the tool steel, the greater the percentage of gain through the use of cooling water. The gain for different types of tools when cutting steel was found to be as follows: Modern high-speed tools, 40 per cent; old-style self-hardening tools, 33 per cent; carbon steel tempered tools, 25 per cent.

CHAPTER II

LUBRICATING SYSTEMS FOR CUTTING TOOLS

The lubrication of cutting tools, like many other details of machine tool practice, has made great advances during recent years. Systems and methods that were at one period considered special and adapted only to a certain class of machine, are now applied commonly to various other types. New developments have also had their effect in increasing the demand for better methods of lubrication. There is considerable variation in the methods of lubricating tools, not only on different classes of machines, but on machines of the same type, the reason being two-fold: Either the work does not require the application of a lubricant, or the amount and manner of supplying the lubricant varies, ranging from a slight drip to a profuse flooding under pressure; this depends upon the nature and extent of the cut. For example, a light milling operation with a single cutter may need no more than a small supply from a drip-can, whereas, on the same machine, the operation of a gang of cutters for deep roughing cuts will require a large stream to flood the work thoroughly and wash the chips away. Some machine tools, such as brass-finishers' machines of many types, cylinder-boring machines, some lathes for machining castings only, and some of the reciprocating types of machines for brass or cast iron only, have no arrangements for lubrication of the tools. In many, a compromise is made so that the addition of a lubricating system is easily effected. In order to avoid a multiplicity of designs, some firms build certain of their machines with the channels, trays, etc., essential to the flooded system, and omit or supply the pump and piping as wanted.

The Amount of Lubricant

There are three principal reasons for the adoption of a lubricating system: One is to cool the tool or cutter, another to impart a smooth surface to the work, the third to wash away the chips. The first-named is frequently the only reason for the application of a lubricant. For instance, in many operations on brass and other alloys the surfaces would be tooled just as smoothly without the lubricant, but the tools would heat up, and the work would also become too warm if the operation were long-continued; hence the accuracy would be impaired, while the cutting edges would not endure for a sufficient length of time. On the other hand, drilling, particularly in deep holes, sometimes cannot be done at all unless the lubricant is fed with sufficient force to eject the chips as fast as they form. A quantity much in excess of the requirements for cooling alone is therefore required. When a metal or alloy cannot be tooled with a smooth finish unless lubricant is employed, it may not be necessary to use a large quantity, so long as the edges of the tool and the portion of the work adjacent thereto are covered. The necessity for an increased supply soon arises, however, as speeds and feeds are increased; otherwise the film of lubricant will be too attenuated to spread as fast as the metal is cut into, and the result will be that intervals of dry cutting will occur, and the heat will evaporate the film to such an extent that it becomes useless. A further development is reached when the heat, caused by cutting, raises the temperature of the cooling medium to such an extent that the latter ceases to act effectually. This happens when the total amount of liquid is not large enough to provide for cooling in the intervals between successive applications to the cutting tool. The remedy is a much larger amount of liquid, and preferably a return tray of ample surface area, so that the maximum amount of area shall be exposed to the air. In extreme instances, two tanks may be utilized, each holding a large body of lubricant, which are drawn from alternately, thus affording intervals for each to cool somewhat.

The essentials involved in any system of lubrication are the supply, collection and separation from cuttings, and method of return. The first two requirements include many devices and modifications, ranging from the time-honored drip-can to elaborate pump and piping arrangements, and from a simple can hung beneath a table to a complete series of rims, chutes, troughs, pipes and strainers. The distinction between the two extremes is due to the quantity of lubricant required, since a simple system that is capable of feeding and collecting a few pints of liquid used at a slow rate is totally inadequate for the flooding method; neither is it automatic in action but necessitates frequent attention.

The amount and nature of the chips also materially affects the mode of collection and one method is not suitable for all cases. Large curling chips, and fine swarf (such as from a hacksaw) are very different as regards the separation of the lubricant from them, the swarf being much more difficult to separate. The bulk of the chips is also important in considering the method of collection and separation. If they occur in small quantities, very little extra accommodation beyond that necessitated by the liquid is wanted, but if there is a large bulk of chips to be received, the sizes of pans and trays must be varied accordingly and supplementary boxes or trays on wheels are essential for frequent removal.

Drip-can Method of Supplying Lubricant

Various methods of supply and collection are illustrated in connection with this treatise by drawings of various machines, but these are only a fraction of the immense number of modifications which exist in practice. The drip-can is the oldest form of continuous supply and is still employed extensively for operations where its limited feed is suitable and sufficient. It is often included on machines which have a pump outfit as well, for use when the ample flow provided by a pump is unnecessary, the can being preferred when the class of work for which it is suited has to be done for a considerable time. The usual design is that of a cylindrical vessel, preferably with a cover, and an inside strainer of gauze (unless the liquid is strained previously). The can body is made of either sheet metal or cast iron. If the capacity of a cylindrical can is insufficient, a rectangular tank is sometimes used instead, as on some shafting lathes with multiple rests. Variations occur in the manner of holding the can, and the position and number of outlets. As a can, in most cases, is placed quite close to the point of application of the liquid, a short pipe is all that is necessary; this may be single or double-jointed, to bring the spout to the location desired. The can is either placed upon a flanged

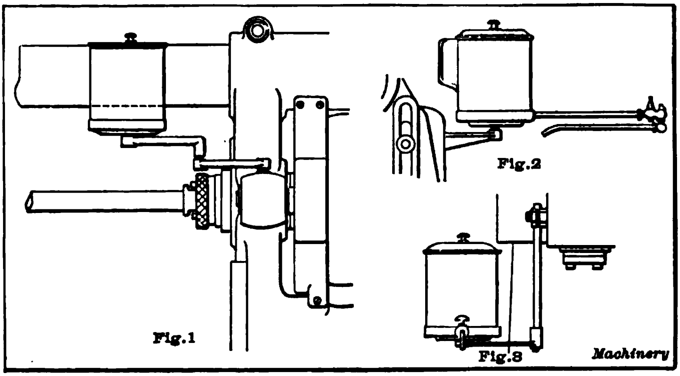


Fig. 1. Drip-can mounted on Pivoted Bracket. Fig. 2. Drip-can with Jointed Delivery Pipe. Fig. 3. Drip-can arranged for Vertical Adjustment

tray, supported upon a pillar fixed in any convenient position, or it is held either by a band, or stem and wing-nut on a slotted arm beneath, to permit of radial or vertical adjustment. The vertical adjustment is not of so much importance because the lubricant can be directed to fall on the work, but considerable adjustment in a horizontal direction is desirable, especially in machines where the cutters or tools occupy varied positions. Figs. 1, 2 and 3 illustrate common methods of adjustment. Fig. 1 shows pivoted arms, on the outer one of which the can is held; Fig. 2, a fixed bracket with jointed pipe, which gives much the same result; and Fig. 3, a suspension rod. The latter is employed on vertical milling machines, etc., to permit radial and vertical adjustments.

When the construction of a machine will not permit placing a can close to the tool, use is often made of flexible tubing of rubber or metal for connecting the can and spout.

Pumps for Cutting-tool Lubricating Systems

The drip-can ceases to meet the requirements when the quantity of lubricant that must be delivered exhausts the contents of the can in a few moments. A pump which is automatic and under the control of the attendant is then the only method of providing a sufficient supply. Four types of pumps are in use: Centrifugal, plunger, wing, and geared, the latter being in the majority. The centrifugal pump is not used to any great extent but is sometimes preferable when there is grit in the lubricant. The plunger pump is employed only to a limited extent, although in the early days it was probably the only kind used for supplying drills and boring tools for deep-hole work in lathes. Where a large supply is desired or where the parts of the machine run at such a slow speed that there is no opportunity for drawing a rotary pump at a proper speed, the plunger type is still used, the most notable example being that of certain bolt-threading machines.

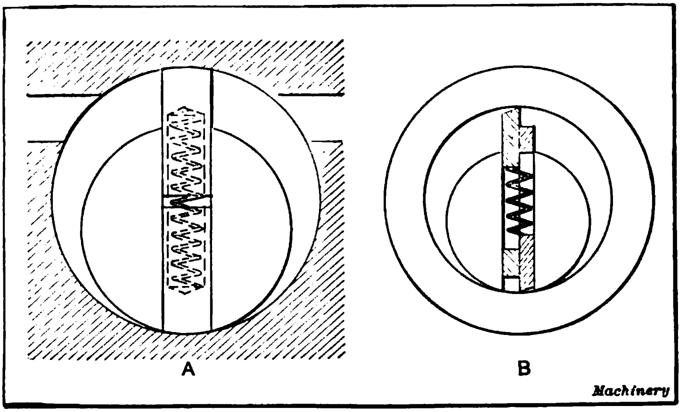


Fig. 4. Two Types of Wing Pumps for Cutting Lubricant

The construction of the wing type of pump comprises a casing with a chamber bored eccentrically (see Fig. 4) with relation to the spindle bearing. The enlarged head of the spindle is slotted to receive a pair of flat plates or wings, pressed apart by a brass spring or springs, so that as the spindle rotates, the ends of the plates maintain contact all around inside the chamber, thus drawing the liquid in and discharging it in one direction or the other according to the way in which the spindle rotates. These pumps will lift the lubricant a slight distance, but it is better to submerge them to avoid priming. A modification of the ordinary method of making the wings as illustrated at *A* is shown at *B*. The latter type is manufactured by Messrs. C. Wicksteed & Co., Ltd., of Kettering, (England) for use with their hacksawing machines. The wings, instead of meeting at the center, are thinner and pass right through the spindle head. Slots are cut in each section, as shown, so that a single spring presses the halves apart equally. The wings are tapered at the ends so that when a full discharge is not required, the pressure of the liquid will press the wings back. This renders the use of a relief or overflow valve unnecessary.

The geared pump, a type employed to a far greater extent than any other, is of simpler construction, the essential parts being a pair of spur gears revolving inside a closely fitting case and drawing the liquid around in the tooth spaces. This type has no delicate parts to get out of order, and if properly built, enables high pressures—up to 1000 pounds per square inch—to be obtained. These high pressures are, of course, not necessary for feeding to external cutting tools, but for deep-hole drilling, in which great force is necessary to remove the chips, they are utilized. The low pressure pumps work to 100 pounds per square inch or less. For the average machine, it is merely necessary to raise the liquid and overcome the friction in the pipes and distributor; any surplus pressure is only useful for washing away chips, the need for which varies with the class of operation. Some kinds of chips fall naturally out of the way whereas others tend to clog the work and the cutters. Some materials will stick to the cutters or work if lubricated to a moderate extent, and may require a larger stream and greater pressure to dislodge them. The removal of long curling chips, especially heavy ones, is not facilitated by the force of the stream, unless they are forced out of a hole.

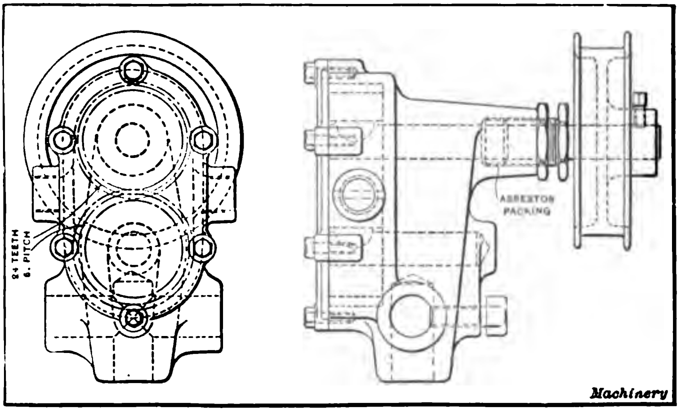


Fig. 5. Rotary Pump of Gear Type

The geared pump, an example of which is seen in Fig. 5, is rated to deliver a certain quantity at a definite number of revolutions per minute, and it may be run at higher or lower speeds if desired, with a varying output. The pump shown is made by Messrs. H. W. Ward & Co., Ltd., of Birmingham, (England). In place of the usual foot, it has holes to slip over a piece of shaft secured to the machine in any convenient location. This permits of setting the pump in three different positions, according to the belt location. The following table gives the capacities of two sizes of Brown & Sharpe geared pumps, with driving pulleys of 3½ inches and 5 inches diameter, respectively:

CAPACITIES OF PUMPS FOR LUBRICANTS

	Revs. per Min.	Capacity, Quarts per Min.	Suction	Discharge
No. 1	300	4	$\frac{3}{8}$ inch	$\frac{1}{4}$ inch or $\frac{3}{8}$ inch
	500	8		
No. 3	300	20	$\frac{3}{4}$ inch	$\frac{1}{2}$ inch or $\frac{3}{4}$ inch
	500	40		

The lift ranges up to 20 feet, but it is preferable to put the pump as near the level of the tank as is convenient, the exact location depending upon the type of machine and the facilities for attachment to the side of the framing or the edge of the tank or pan. The method of driving depends partly upon the position of the pump and partly upon the designer's ideas. The belt or cord drive is the most common. Spur gearing and chains are also used to a lesser extent, the advantage of these being that there is no bother with slipping belts nor trouble due to the splashing of oil. It is often more convenient to drive the pump by gears or chain from some constant-speed shaft

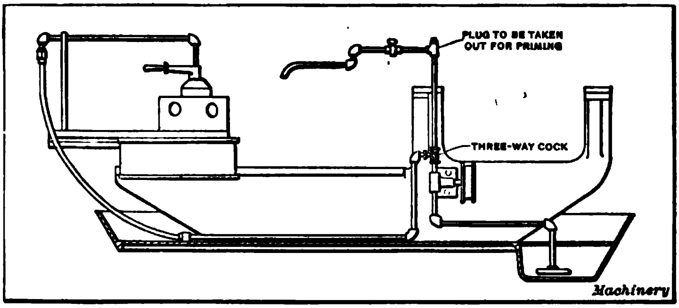


Fig. 6. Lubricating Arrangement of Bardons & Oliver Turret Lathe

on the machine than by a belt from the countershaft; when a motor drive is installed, the gear or chain method is especially applicable. The pump is thrown out when necessary, by sliding the gears out of mesh or by disengaging a clutch, if a chain is used. Generally, pumps run in one direction, provision being made to drive them from a shaft or countershaft which does not reverse, but when the machine reverses at intervals, as with certain automatic screw machines, the pump is slightly modified to enable it to run in either direction.

The fittings which are directly connected with the pump system include a strainer, which is submerged in the liquid and prevents access of grit or chips, and a relief valve, which is closed by spring pressure but opens when the flow is reduced or stopped at the delivery outlet, allowing the lubricant to run back to the tank through a by-pass. Sometimes a check valve is placed between the pump and the tank, but not invariably. Fig. 6 shows the piping for a Bardons & Oliver turret lathe, including a flexible supply pipe to the turret center for feeding hollow tools, and the diagram *A*, Fig. 7, shows the piping for a Brown & Sharpe milling machine. These two views represent, in principle, the arrangement of many machines. A pump for

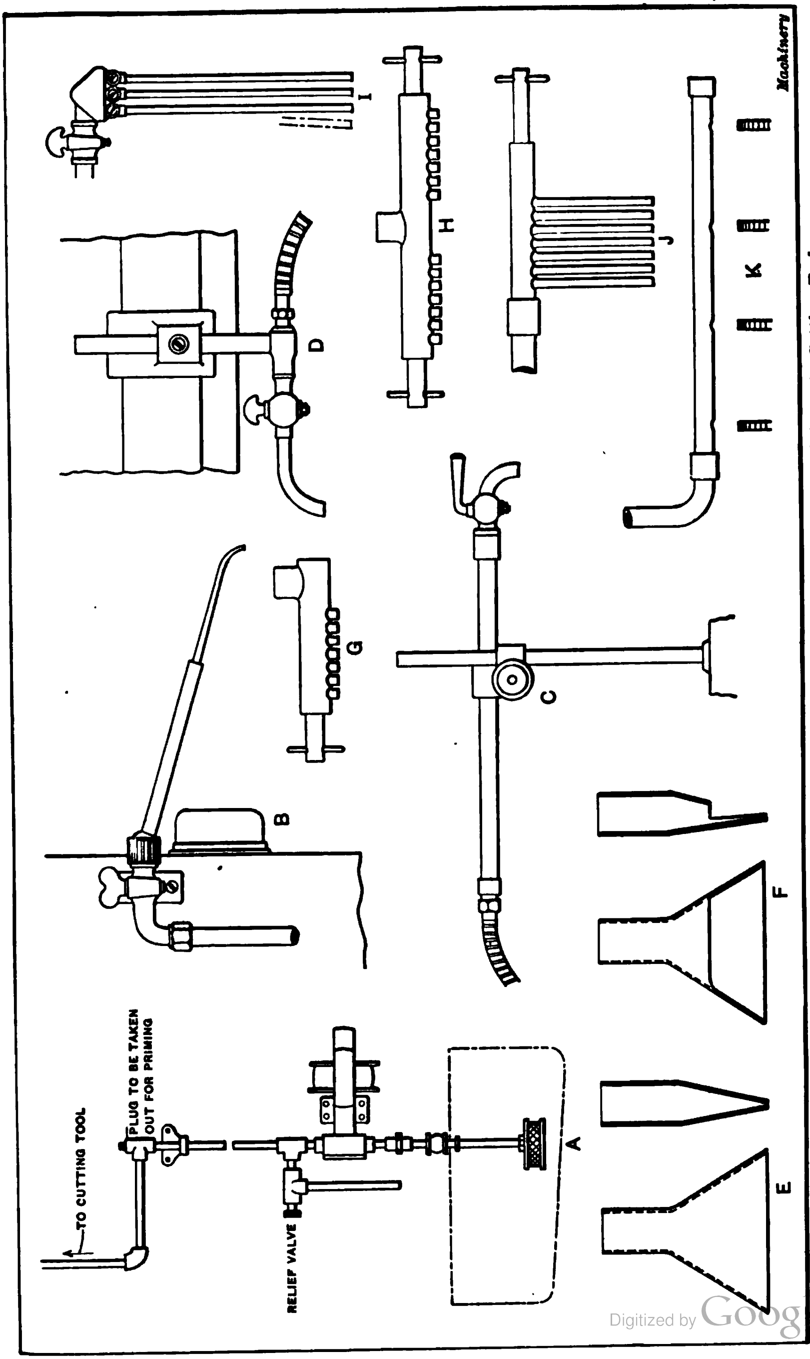


Fig. 7. Various Arrangements of Piping and Nozzles for distributing Lubricant to Cutting Tools

each unit is dispensed with in certain cases, as, for example, "batteries" of automatics or of sensitive drills, which are fed from a common supply instead of having a pump for each machine.

Methods of Distribution

The two points which we now have to consider are the means of distributing the lubricant to the tool or tools, and the means for catching the lubricant and returning it to the tank. The methods of distributing and returning the lubricant vary greatly on account of the varying conditions of cutting and different arrangements of tools, slides, machine framings, etc.

In regard to the method of distribution, the choice lies between rigid pipes, flexible pipes, and jointed pipes; between a single outlet, two or more outlets, a perforated distributor, a pipe with a number of taps or pipes leading from it, or an over head reservoir fitted with outlet pipes. Means may be provided in the case of multiple outlets to shut off any or all of these according to the amount of lubricant desired and its place of delivery. The flow may be allowed to fall from above, or it may be directed precisely to a certain spot by a pipe, or through a hollow tool or spindle, or a spout or chute may catch the lubricant and pour it onto a precise location.

Rigid pipes are chiefly applicable to machines which have no great changes of tools or adjustments of slides, so that a fixed position of the pipes is suitable, but these are the exception, and it is better to have an adjustable pipe, for convenience in moving it out of the way if necessary. The degree of movement depends on the range of possible locations of the cutting tools. Piping with three or four joints is frequently necessary, including horizontal and vertical swivel adjustments. The alternative is the flexible pipe, which, however, is likely to be in the way in many instances. A flexible pipe is more useful as a means of connecting rigid or jointed pipes to the supply or drawing-off arrangements.

A single outlet is all that is necessary for most of the single-point cutting tools, for narrow milling cutters, drills, and similar tools, but two or more outlets are required for pairs or gangs of cutters and multiple tools, unless the alternative of a single wide spout is utilized. The main support of a jointed pipe is placed according to circumstances, sometimes consisting of the supply pipe itself, sometimes of a separate rod to which it is attached, the rod being bolted or screwed in any convenient position. The main pipe or rod must be put where it is not likely to be in the way of large work, jigs or fixtures; in some cases, a portable fitting may be necessary to meet these requirements. An alternative to the gas-bracket type of jointed pipe is one having a ball-joint and telescopic second tube (see *B*, Fig. 7).

A preferable method of securing flexibility is to use a short piece of pipe equipped with a tap, and hold this in a clip against a part of the machine or on a rod, and connect to the pump with flexible tubing. This arrangement is useful when no great range of adjust-ability is essential and also when considerable horizontal or vertical range is required. In the first case, it obviates the use of a jointed pipe, and in the second it enables adjustments of several feet to be obtained without encumbering the tool with three or four jointed pipes. Typical examples are shown at *C* and *D*, Fig. 7, *C* showing a rigid pipe held by a split clamp to a rod screwed into a machine boss and connected to a flexible tube, and *D* a stem extending from the connection and clamped in a bracket horizontally adjustable along a slide. As the flexible pipe can be carried down at the rear or side of the machine, it need not interfere with the operation of the machine; moreover, if cutting is done without lubricant, the clamps may be released and the piping laid out of the way altogether. Arbor supports or overhanging arms on the machine are often used for attaching pipe clamps.

A cutter of considerable width, or a hob, must have an ample supply of lubricant along its entire length, if lubrication is to be effective and even, and cooling uniform. A good device for hobs and cutters for heavy duty is the fan nozzle. This is set vertically, or at an angle, just above the cutter, and delivers a broad copious stream. The closed type *E*, Fig. 7, is employed in the case of slab millers having the cross-slide face set at an angle, the nozzle being pointed inward or toward the back of the machine. The partly open kind *F* is suitable for horizontal delivery or delivery at a slight angle. These nozzles are attached to the delivery pipe, but in a few instances the nozzle is used separately, being clamped to a part of the machine or to the tool itself and fed by a flexible pipe brought over it, thus affording a wide stream without modifying the outlet for ordinary operations.

Adjustment for width of flow is provided for in some nozzles, the opening being blocked to any desired extent by sliding a plug along to suit the width of the cutter. When there is no adjustment to the supply pipe to accommodate the varying lateral positions of cutters on their arbors, the nozzles may be pointed to right or left, as desired, by fitting it with a swivel joint. Perforated distributing pipes which give a flow of lubricant to suit the length of work or cutter are shown at *G*, *H* and *J*, Fig. 7. They have sliding plugs to shut off some of the holes, thus reducing the supply. Pipe *G* is an ordinary form, *H* is double-ended (a type useful for gang mills on an arbor which is steadied by a central support) and *J* has extension tubes hanging down to reach in between tools which interfere during part of their stroke, with a directly vertical flow. This type of distributor is also used where the air from a belt or other rapidly moving part would disturb the vertical stream of lubricant and blow it out of its proper path. At *I* the tubes are pivoted to swivel to one side and direct the liquid to a particular place. A shut-off may or may not be provided for each tube.

The standard distributing pipes occasionally fail to meet special conditions, and it becomes necessary to cut a piece of tubing and drill it specially, as at *K*, where four slitting saws are set rather far apart and a pipe is drilled with holes to suit. If much of this class of work is likely to be done, it may be preferable to drill a larger number of holes in the pipe and plug up those not wanted. Long distributing pipes are sometimes provided with holes drilled fairly close together and having spring bands which are partly rotated to block those holes which are not required. Another special arrangement for some classes of work where a guard is fitted over the cutters is to use the hollow top of the guard for conducting the lubricant directly upon the cutters. Box-tools are also sometimes made with hollow frames, with an outlet close to the cutters, giving a broad

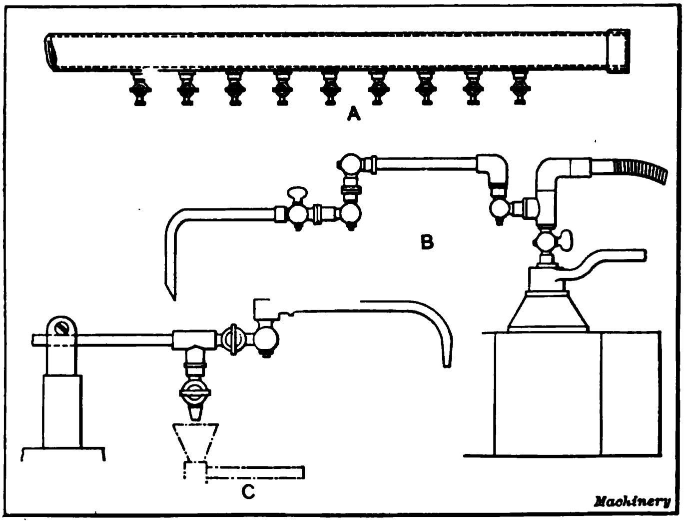


Fig. 8. A. Distributor with Row of Taps. B. Combined Supply Pipe for Interior of Turret and External Tools. C. Supply Pipe feeding into Funnel on Box-tool

stream at the best possible location. This is a mode of distribution that must be designed to suit the tools, and is not of general application.

An alternative to the practice of stopping off or plugging up unused holes in a distributing pipe is to provide regular taps for turning off the lubricant. This method is common to milling machines of the planer type, on which a pipe of ample capacity is secured to the cross-rail and has a number of taps screwed in at close intervals, as shown at *A*, Fig. 8. If the pipe runs along at the back of a machine or below a cross-rail, as in many multiple-spindle drilling machines, pipes connected to each tap will be essential in order to bring the oil to the drills, a swivel-joint permitting each pipe to be placed in the position desired.

The case of two or more pipes having outlets separated more widely than in the distributors referred to is often met with, such as when two tools or cutters are working on different parts of a piece or on two pieces of work. Either rigid or swiveling pipes are used, according to requirements, or provision for variation between the outlets is made by a length of flexible pipe. Certain multi-spindle drilling machines and multi-spindle automatic screw machines carry a pipe partly around the spindles or around the turret, and various bent pipes or distributors lead off from this common supply pipe to feed each drill or turret tool. At *B*, Fig. 8, is an example of a double supply, one pipe leading to the center of the turret for lubricating hollow tools, and the other continuing for feeding external tools held in the turret. A somewhat similar arrangement is shown at *C*; the tap nearest the turret feeds into a funnel which is connected to a slot distributor attached to one of the box-tools having a long cutter for

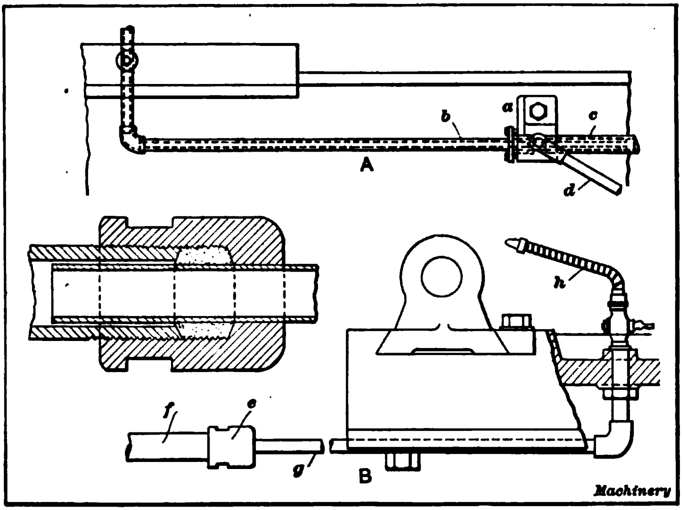


Fig. 9. A. Sliding Pipe and Stuffing-box of Turret Lathe. B. Telescopic Pipe Connection for Carriage of Gear-cutting Machine

forming steel taper pins; this arrangement insures a proper flow all along the broad-faced cutter.

Portions of machines which move intermittently or continuously along a bed, and must be fed with lubricant in any position they occupy, require the use either of jointed pipes, flexible connections, or telescopic tubes. Both of the latter are largely used. The flexible tubes are likely to get in the way and become a nuisance, while the telescopic pipes can be arranged in snug fashion and occupy a minimum of space; moreover, they are not as liable to become damaged as flexible tubes. It is chiefly in those types of machines where the tool has a horizontal feeding movement that the provision of adjustable piping is required. Gear-cutting machines and turret lathes are the most frequent examples, the cutter-slide of the one, and the turret-slide of the other requiring a supply of lubricant at all working positions. Certain other machines of less importance in point of

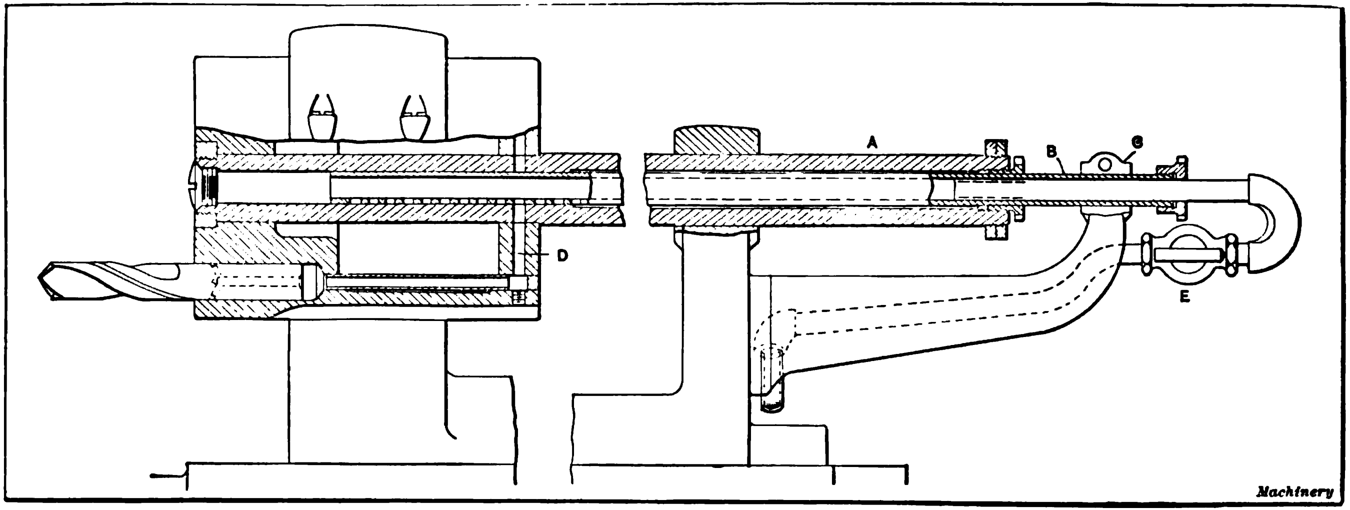


Fig. 10. Sectional View showing Method of supplying Oil to Turret of Cleveland Automatic

numbers, such as horizontal drilling machines and slot-drills with traveling cutter-heads, also require adjustable piping. The telescopic device *A*, Fig. 9, which also shows the back of a turret lathe with a portion of the turret saddle, has a fixed bracket *a*, fitted with a stuffing-box through which the sliding pipe *b* is free to move. The latter passes into the closed end of pipe *c*, which is fed by the pipe *d*, from the pump.

Connection to the sliding cutter-carriage of a gear-cutting machine is made either by the somewhat clumsy means of a flexible pipe, or by a sliding pipe which is arranged, preferably, below the base, as at *B*. (From the practice of Messrs. J. Parkinson & Son, Shipley, England.) The packed gland *e* (shown enlarged in section above) is screwed on the end of the stationary pipe *f*, and admits the sliding pipe *g*, which is united to a short vertical pipe fixed to the cutter-carriage. From this vertical pipe the short length of flexible steel tube *h* directs the stream onto the cutter.

Another system of distribution for movable parts is that requiring a supply to tools in a turret, one or perhaps two or more of which may require the lubricant to be fed through their hollow bodies during their period of operation only. This is effected by causing the rotation of the turret to turn on and cut off the oil as the tools come into their working position. The arrangement for the Cleveland automatic screw machines is shown in Fig. 10, and will serve to illustrate the

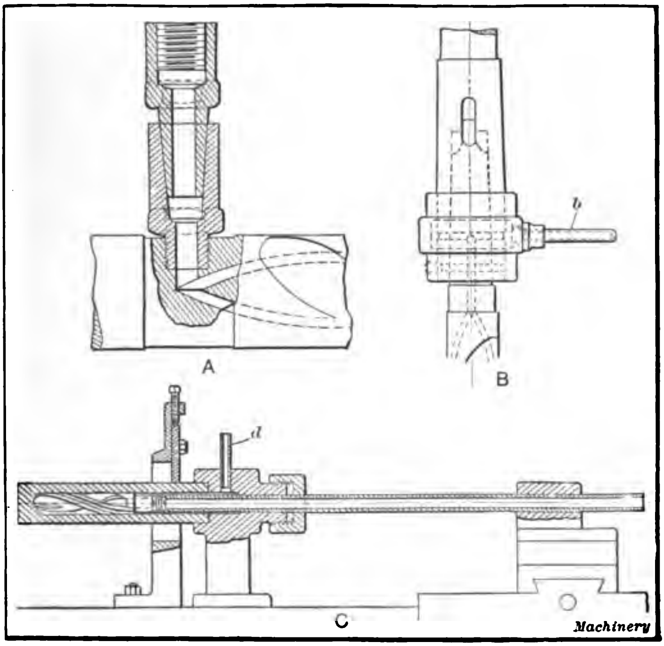


Fig. 11. A, Connection to Oil Passages of Stationary Drill; B, Connection to Oil Passages of Rotating Drill; C, Method of Lubricating Hollow Drill for Deep Hole Work

principle. The feed takes place when the drill shown is at the lowest or working position. The turret shaft *A* in its to-and-fro movements, controls the feed in the following manner: An oil tube *B* extends inside the shaft and can be clamped in the bracket *C*, whenever desired. This tube has a series of holes in its lower side, continuing for a distance equal to the turret stroke. These holes communicate with a single hole *D* connecting with a tube inserted in the turret hole which carries the tool. The position of tube *B* determines when the oil will begin to flow; it can be adjusted to start at the beginning of the stroke, or later. Valve *E* is to regulate or shut off the oil. Can action is employed in some machines to turn the oil on and off.

The cutting tools which require a supply of lubricant through their hollow bodies include drills, reamers, counterbores, boring tools, and, less frequently, taps. Threading dies are also fed by a pipe which floods their interior, or the threading machine may have a hollow spindle through which the oil is pumped. Long drills or their separate holders, not held in a turret, usually have the supply pipe screwed in at the end and the oil goes to the cutting end by way of open grooves or grooves covered with strips soldered over; sometimes holes are drilled in the solid metal to the cutting point, or pipes are laid in recesses along the body of the tool. If the oil is not taken through the end of the drill it may be supplied as shown at *A*, Fig. 11. This method is suitable for any class of drilling machine or turret lathe in which the drill does not rotate. Connection to a flexible tube enables the drill to feed along to any desired extent.

A modification in the form of a loose collar, as at *B*, is necessary to permit a drill to revolve. The collar is held from revolving by the supply pipe *b*. The oil is sometimes fed by gravity but it should preferably be pumped through; it passes to the passages which communicate with the holes or tubes of the drill. A cup-shaped collar is sometimes used, the oil being poured in from the top. In all these tools, the chips find their way out of the hole by the flutes or spaces of the tool, but in the hollow drills used for deep holes, they have a special outlet. The oil is fed by way of the body grooves, and the cuttings escape through the flutes, the hollow shank and an extension tube (see sectional view *C*, Fig. 11.) A stuffing-box surrounds the tube and the oil is pumped through pipe *d*, and goes along the outside of the tube and past the shallow flutes on the lands of the drill. The oil then forces the chips back through the main flutes and out through the shank and the tube. The hole must be first drilled to a depth equal to the body length of the drill, before the latter can be used with oil, this preliminary operation being done with a short starting drill.

Methods of Recovering Used Lubricant

The methods of catching, draining and returning the oil are simple on some of the smaller machines, but more complicated on the larger ones, particularly on types which use lubricant very freely. The provision for lubricant often affects the design of the frame and many of the smaller details. The simplest catching device is a can hung underneath a table, this being emptied into the drip-can overhead at intervals. This is quite satisfactory when the quantity of lubricant used is very small, but like the drip-can, it fails to meet requirements when a flow of any magnitude is required, and a proper tank must be employed. The three principal means of receiving waste lubricant are, by a suspended tank, a tank on the floor or bolted to the machine base, or by using the hollow base of the machine to form a tank. The pans which surround the bases of so many machines come under the second category. The suspended tank is objectionable only on account of its limited capacity; the second class can be made of any desired dimensions; the tank in the base is a means of profitably utilizing the interior space, thus making it unnecessary to provide a separate receptacle.

The simplest method of dealing with the question of waste lubricant will be to follow the lubricant in its course, from the point where it leaves the work. It is also necessary to take into consideration the provisions for dealing with chips, since these affect the matter vitally.

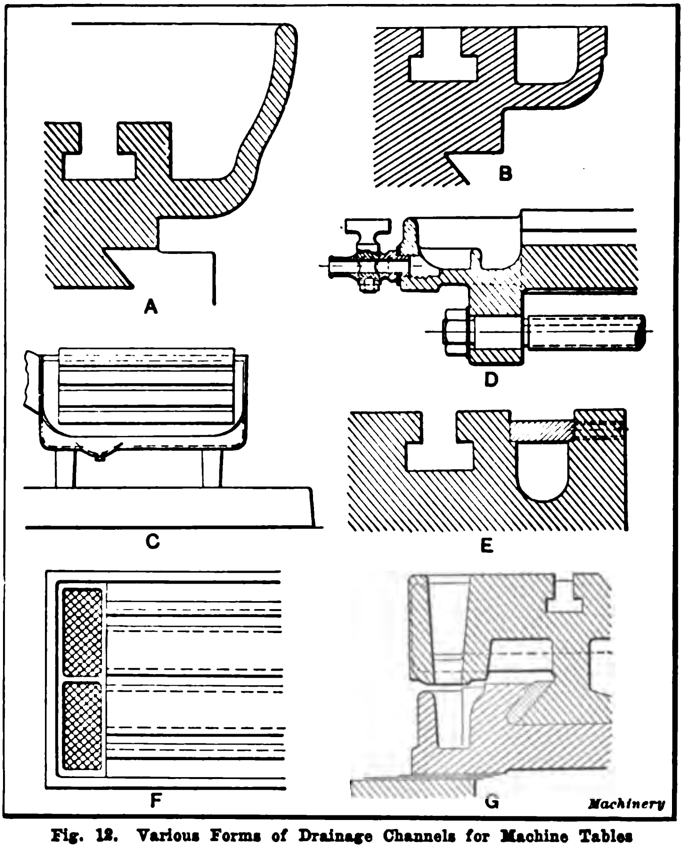


Fig. 12. Various Forms of Drainage Channels for Machine Tables

All work which is machined is held either on or over a table, or it may project beyond the bed or slide. In the first case, the table receives the waste oil, in the second, the oil either falls directly into a trough or is caught and diverted in various ways. Tables, when not intended for use with oil, simply have slots or tee-slots, and there is no rim or other provision to prevent a lubricant from falling onto the floor. The addition of a turned-up rim prevents the lubricant from escaping, excepting by the way of a spout or a hole, whence it drains into a can hung under the spout or tap, or falls through a rigid or flexible pipe, or by way of rims on subsidiary slides, to a tank below. The height of the rim is limited, in the majority of cases, by the level of the table, the rim being just below the table, but there are some exceptions. When it is known that the size of work or of jigs or fixtures will never exceed the bounds of the tee-slotted surface, then it is possible to raise the rim as shown at *A* in Fig. 12. This high rim is desirable when splashing is likely to occur. It is the practice now, with a great many milling machine manufacturers, to machine the oil rim flush with the table top as at *B*, in order that it may be utilized

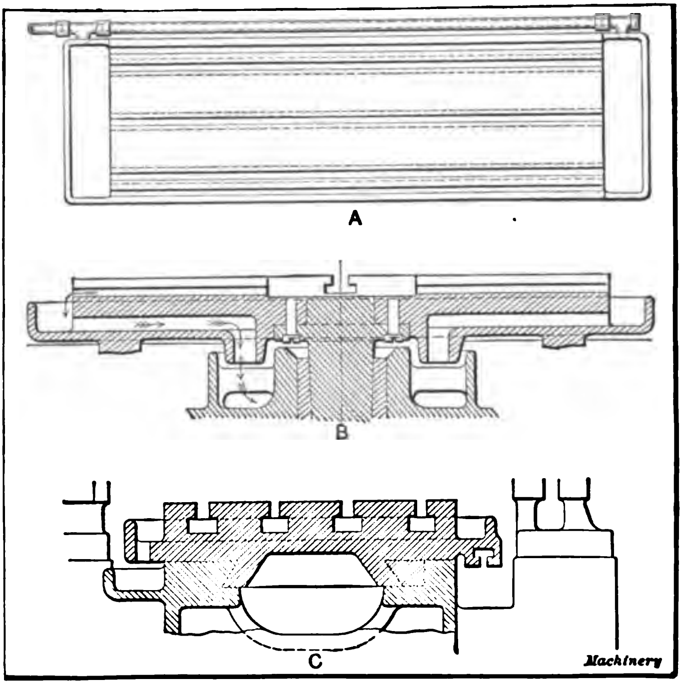


Fig. 13. A, Table Ends connected by Drain Pipe; B, Drainage leading to Annular Channel beneath; C, Drainage Channel for Reciprocating Table

as a support and form part of the table surface. Large fixtures which hang over the working surface can thus be held, and dividing heads can also be set further apart than on a table with the rim set below. If a table having a vertical face, in addition to the horizontal top face, has to be drained, the oil rim is cast as shown at *C*, which is the table of a radial drill. The channel follows around the table and has a small well at the bottom, into which the waste collects and is drawn off by a tap or pipe.

Draining the Lubricant to the Supply Tank

The end of the table is the place most commonly selected for drawing off the lubricant, because it is more convenient to apply or attach a can, or to connect a pipe. The sectional view *D*, Fig. 12, shows the end of a milling machine table, with a draw-off tap and an enclosure adjacent to the hole to prevent chips from blocking up the tap. Another device to prevent choking, which impedes the proper flow of the lubricant, is to fit guard strips to the channels, as at *E*, so that they cannot be quickly clogged with chips and thus cause table flooding. The filling up of the end pockets with chips is avoided on some tables by the use of removable strainer plates, as at *F*, which shows a plan view. These plates are set at about one-half the channel depth so that there is a clear space beneath for the liquid. In the milling machines made by Messrs. D. & J Tullis, Ltd., of Cyldebank (Scotland), the end pockets are connected by a pipe (*A*, Fig. 13), instead of having a deep channel on each side of the tee-slotted surface, com-

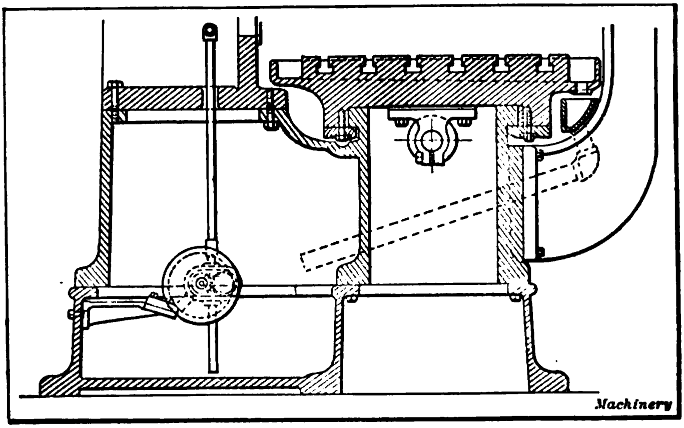


Fig. 14. Drain from Table into Tank in Base of Machine

paratively shallow grooves being milled in the top to conduct the waste to the pockets.

When a square or a circular table has to make complete revolutions, the waste is preferably drained through the center into a tank or a hollow bed, the alternative to this being to surround the table with a fixed pan into which the oil drips and is drained therefrom through a channel into a receptacle below. In the central drainage system, the precise course of the oil ducts depends on the manner in which the table is mounted. If there is no central spindle, but merely a hollow boss, the oil can flow down through this, but if a solid spindle occupies the center, the drainage takes place through passages situated some distance out, as at *B*, Fig. 13, which shows a gear-hobbing machine table. The oil falls into a rimmed enclosure and thence through apertures which lead down to a tank between the slideways.

The location of a spout or lip, when no pipe is connected, must depend upon the facilities for catching and the opportunities for maintaining the lip always over some portion of the pan or other receptacle. Frequently, it is impracticable to insure the latter condition, and then piping, or special chutes leading to the main tank have to be used. If a table or slide has a limited range of travel in relation to some part below it, the part below can, in certain instances, be utilized as an intermediate drain. The section *G*, Fig. 12, of a milling machine table and slide, is an illustration. When, as in large plano-miller tables, there is no other moving part, arrangements have to be made to receive the oil at any longitudinal position. This is done by casting or bolting a trough to the side of the bed, just below the overhanging drain hole or spout of the table, and locating the drain hole in such a position that it will never run past the lower trough. The oil drains from the latter into a tank or hollow bed. A typical arrangement is shown at *C*, Fig. 13, and also in Fig. 14 (from a Walcott

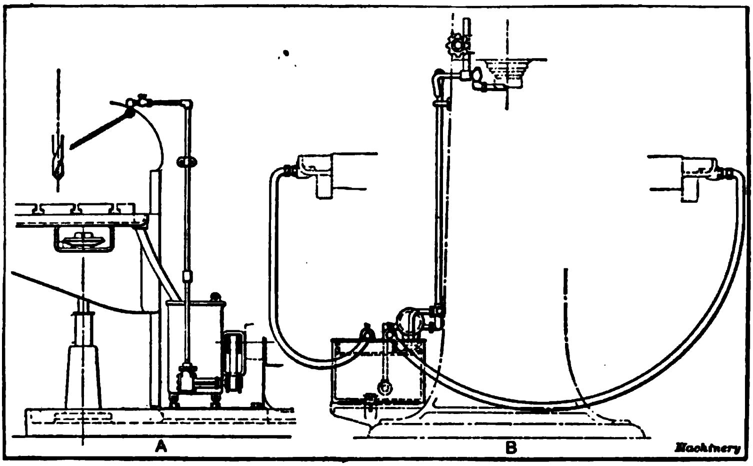


Fig. 15. A, Lubricating System for Drilling Machine; B, Supply and Return System of Vertical Milling Machine

rack cutter), which includes the drain pipe from the trough into the hollow base and the pump and suction pipe.

Flexible tubing is employed very largely for drainage purposes. The only objection to it (beyond that of possible choking if of too small a bore) is that it gets in the way of the operator, on some machines, especially when the movements are of considerable range and therefore necessitate long pieces of tubing. In a case like the one illustrated at *A*, in Fig. 15, there is no inconvenience, because the tube is short and close to the frame, but at *B*, which shows an Alfred Herbert, Ltd., vertical milling machine, the tubes are of necessity long and somewhat cumbersome. Some of this firm's horizontal machines have a telescopic arrangement of piping extending from the cross-slide on the knee to the tank alongside the frame (as shown at *A*, Fig. 16), which accommodates itself to the vertical and horizontal positions of the slide, and takes the place of a flexible connection. The lower view *B* shows how a flexible drain tube is applied under similar circumstances, this example being from French practice. A slide with vertical movements can be drained by pipes, as represented at *C*. These pipes are telescoping and the lower one conducts the oil to a pan from which an outlet leads to the tank. Section *D* illustrates the drainage into the hollow frame of a drilling machine. There is a slot *a* of sufficient length to permit the pipe to travel up to the limit of the table adjustment.

Guards and Splash-plates

Two other details which are required for many types of machines are the guards and splash-plates which prevent the oil from flying

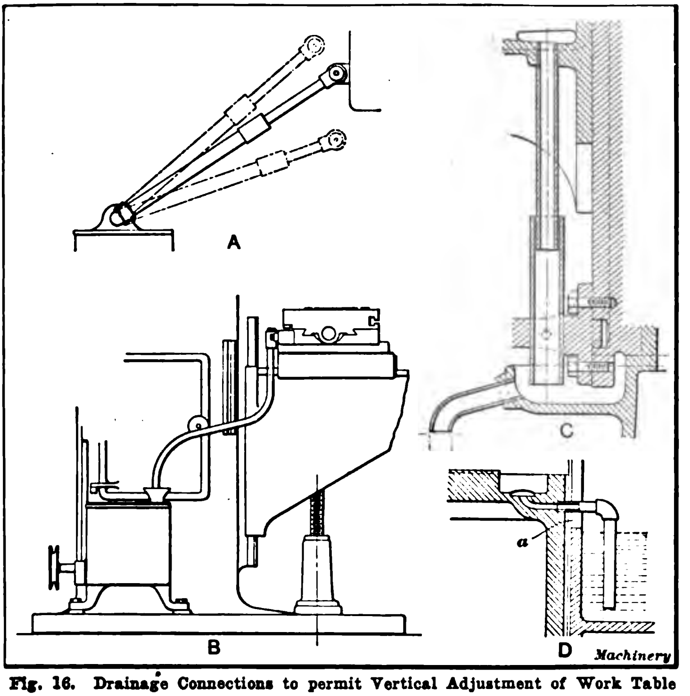


Fig. 16. Drainage Connections to permit Vertical Adjustment of Work Table

beyond the limits of the machine or drainage pan. These devices are necessary chiefly for work rotating rapidly and comprise curved plates or castings around chucks and parts of spindles as well as around rotating work, and flat or curved plates held opposite the spindles or work, at some distance, so as to deflect the waste down into the pan. Sometimes drills are also encircled by sheet guards to catch the oil thrown off by the curling chips. All these types of guards are usually removable to facilitate the work of the operator, and are either clipped to convenient places or hinged to swing back. A clip for holding a flat guard is shown at *A*, Fig. 17. This is also a convenient device for holding curved pieces to fit around the angles of a pan or base, instead of riveting the clips permanently to the splash-plate. At *B* is represented a hinged guard for protecting the whole of an automatic screw machine head, two of these being used. They can be swung down below the pan for inspecting the head. Hinged guards

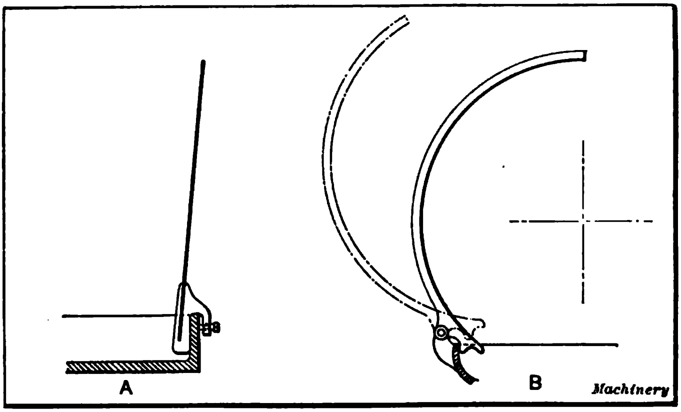


Fig. 17. Detachable and Pivoted Splash Guards or Plates

are also fitted around the tables of boring and turning mills, when lubricant must be used and the speed of rotation is rather high.

Drainage Pans for Cutting Lubricant

The nature and capacity of the drainage channels and drip-pans on any machine, depend both on the quantity of lubricant which is likely to be employed and the course which it takes after leaving the tools

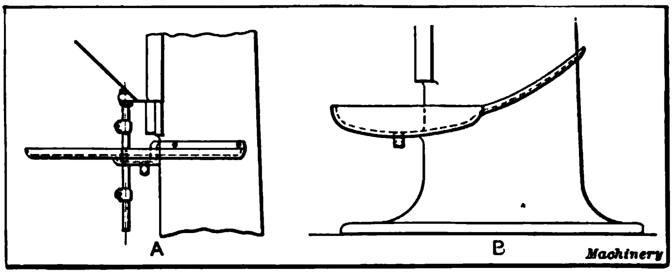


Fig. 18. A, Lubricant Tray attached to Column; B, Lubricant Tray cast integral with Column

and work. Lubricant which does not escape from the bounds of a table and is caught immediately by a pipe, or other means, does not, of course, require channels or pans for collecting it; but if there is extensive splashing, catching-lips, trays, or regular pans become essential, until, in the final development, the whole machine stands in a large pan having deep sides. With a minimum of splashing or dripping, which causes a small amount of oil or suds to trickle down the frame of a machine, a simple tray screwed on (as at *A*, Fig. 18) is

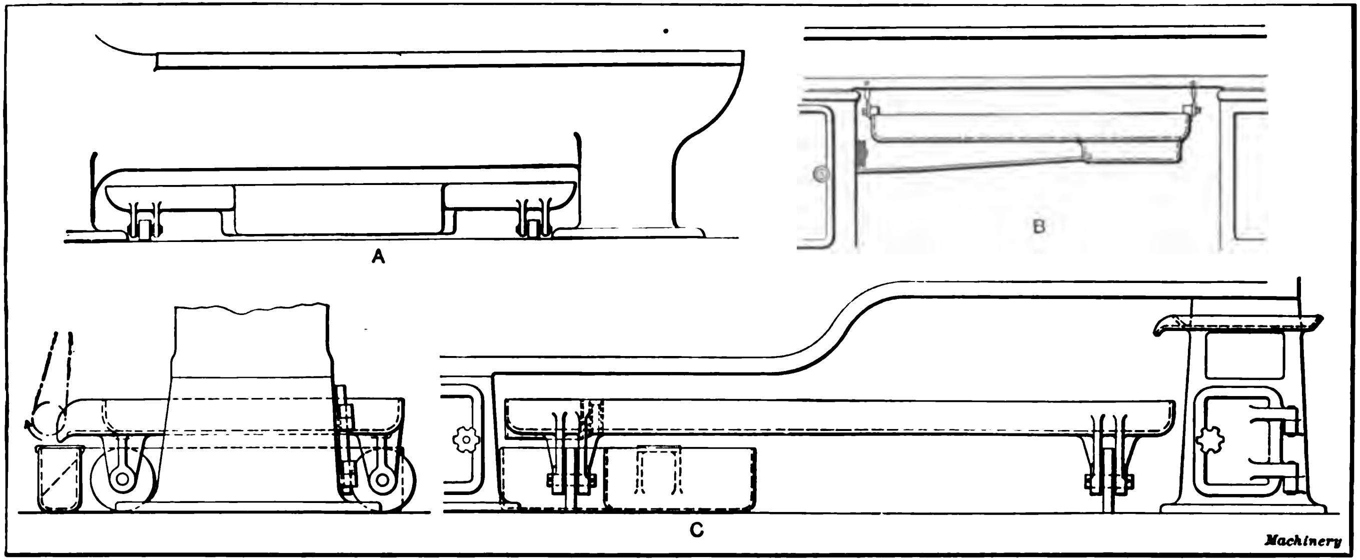


Fig. 19. Different Designs of Drainage Pans

sufficient, or the column may be completely encircled with a channel, as at *B*, the depth being increased at the front to hold a moderate quantity of oil.

A portable pan is often attached to a portion of a machine beneath the area of operation to receive the chips and lubricant, the latter draining through a pipe and away. Portable trays are also used on some boring and milling machines; these are placed under particular locations where lubricant drips down, and a flexible pipe connects the trap to the tank. A few examples of different arrangements of pans are given in succeeding illustrations. The detail *A*, Fig. 19, shows a portable pan with a well com-

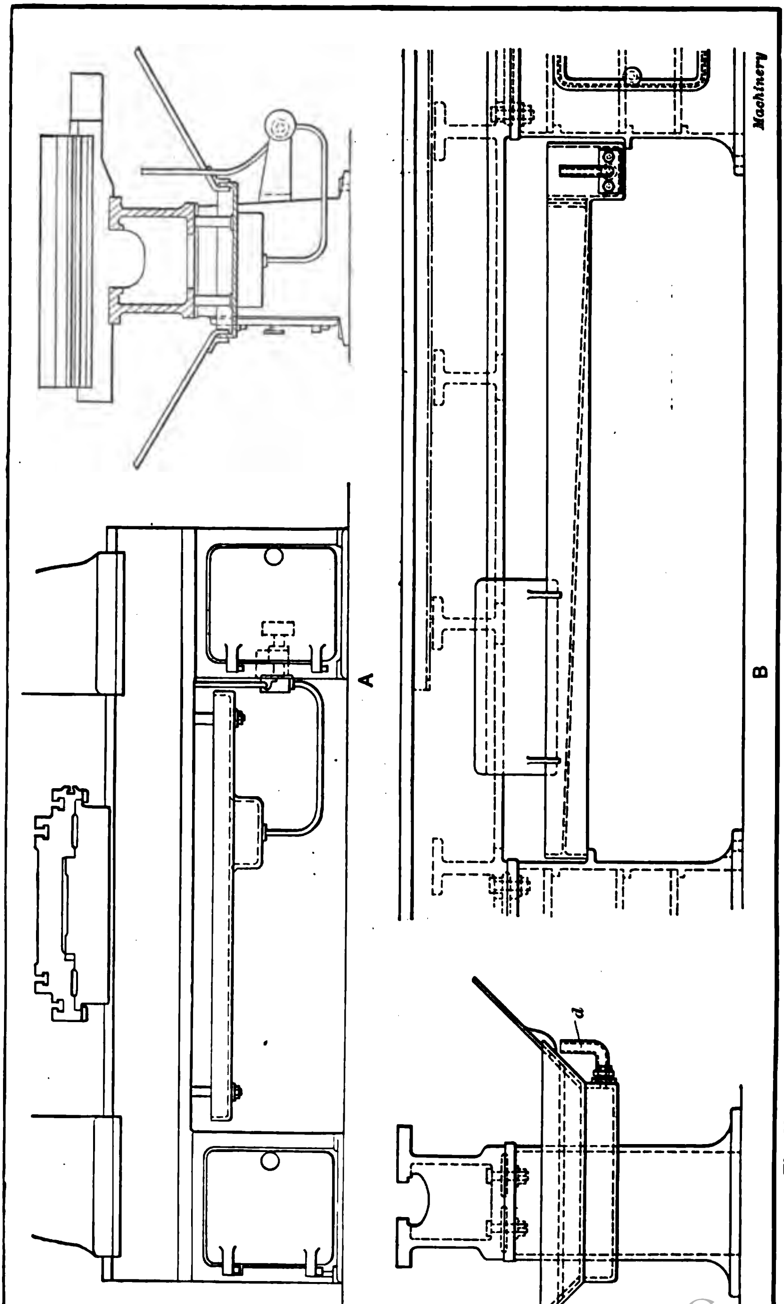


Fig 20. A. Suspended Pan with Splash Guards; B, Pan beneath Lathe Bed, having Splash Guards and Well

bined; illustration *C* shows another portable pan which has a separate tank that is fixed and carries the pump. The portable pan has a lip, as shown in the end view, to drain into the tank beneath. The right-hand cabinet leg has a channel surrounding it which drains into the portable pan. For dealing with large quantities of chips, the pan on wheels is preferable to the fixed pan from which the chips have to be removed and transferred to some other receptacle for disposal. At *B*, Fig. 19, is shown a fixed pan that is suspended beneath the machine. This practice is common in Germany because it enables pans to be added only when required, leaving the machine otherwise suitable for operation without cutting

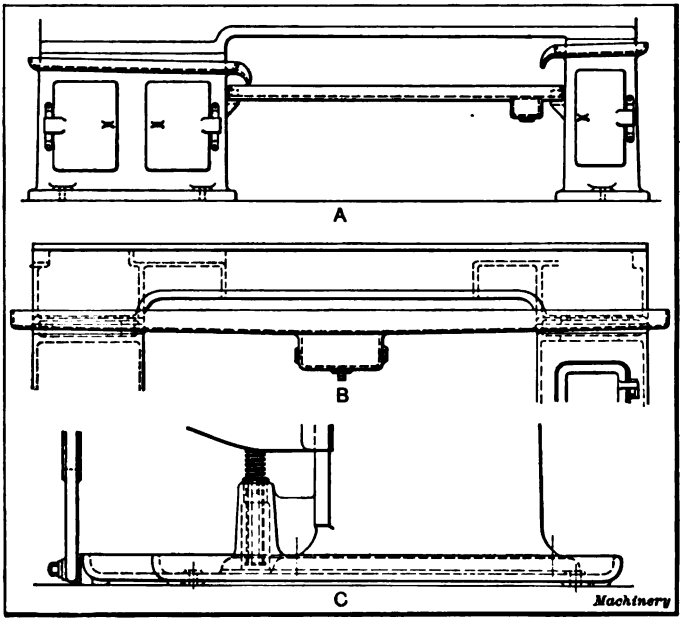


Fig. 21. Other Drainage Pan Developments

lubricant. Another suspended pan (on a Greenwood & Batley special milling machine) is shown at *A*, in Fig. 20. This pan is hung on four bolts and has plates to catch the drip from the overhanging table. A pan with splash-plate attached is shown at *B*. This pan is supported on lugs cast on the cabinet legs and has a well and drainage pipe *d*. The method of fitting a pipe of this kind is shown in Fig. 22. It has a packing ring *a* which is clamped by the shoulder of the bent pipe; the latter is held in by the gland plate *b*. In the position indicated, the pipe drains off the contents of the pan, but when turned vertically, as shown by the dotted lines, it retains the lubricant in the pan, forming a simple tap or drainage cock.

A further development is shown at *A*, Fig. 21, the drainage system including channels around each leg, so that no oil can escape, excepting into the pan; in a more complete system, the whole bed stands in a pan interposed between it and the legs, as at *B*. This is common practice with some classes of small milling and other machines which rest upon a floor stand, and with the smaller automatic screw machines. The larger ones either have a turned-up foot all around the base, or the whole machine stands in a large tray which is partly

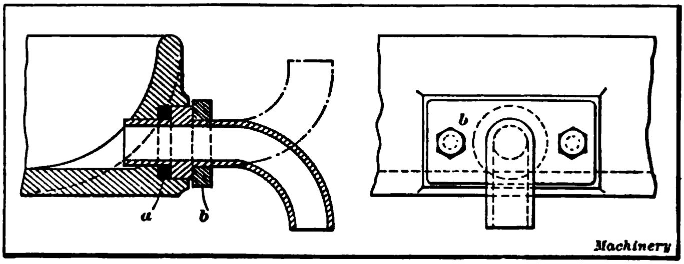


Fig. 22. Combined Drainage Pipe and Tap

filled with lubricant, the depth of the tray ranging from a few inches to a foot or more. Milling machines standing in a separate tray, as at *C*, do not require such a large oil capacity as "automatics," especially of the multi-spindle type. The latter often have a hollow cabinet leg which contains an extra oil supply. Supplementary sloping chutes overhang the edges of the trays of some automatics to receive drippings from projecting turret slides and spindle ends.

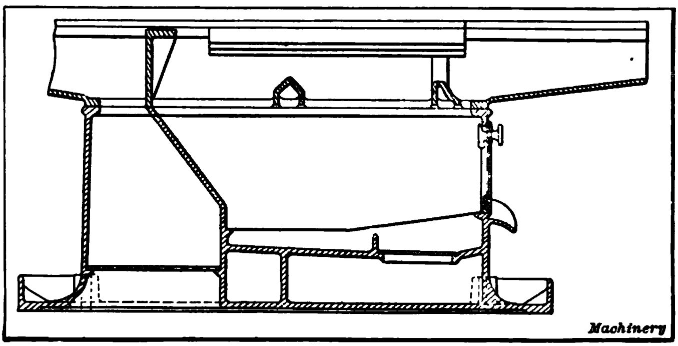


Fig. 23. Hollow Base of Turret Lathe used for Receiving Chips and Lubricant

The practice of receiving all the chips and lubricant entirely within the bed is noticeable in the Pittler (German) turret lathes (Fig. 23). The interior has a plate and grid to catch and drain the chips and there is a door at the end for their removal. The vessel to contain the chips is placed under the drainage lip by the door. The remaining portion of the machine frame, to the left, forms a tool cupboard. This utilization of the interior of the machine base to hold the oil, in order to avoid the provision of an outside tank, is a practice becoming increasingly popular. The bases of drilling machines (see

Fig. 24), milling machines, gear-cutters, etc., often form excellent tanks for the reception of cutting lubricant. The chief objection with some designs is the difficulty of cleaning the tank. If the chips cannot enter the hollow body, this objection is negligible, but if they are

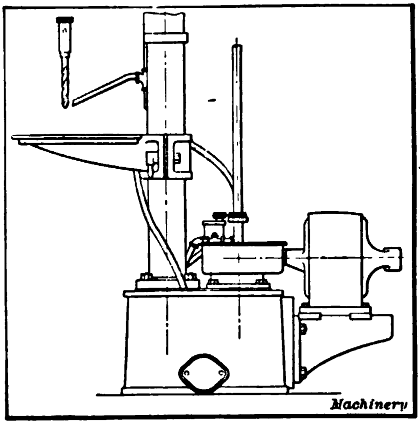


Fig. 24. Base of Drilling Machine used for Lubricant Tank

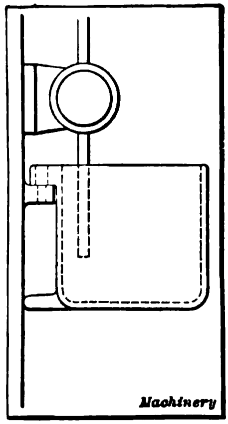


Fig. 25. Tank suspended on Lugs to permit Easy Removal

free to fall in with the oil (as in Fig. 26), the chips become a nuisance. For this reason, special facilities are afforded for cleaning the tanks from which pumps draw their supply, in cases where the chips are fine and difficult to keep back. A tank, instead of being bolted down, may be hooked over a pin standing up from a lug (Fig. 25), without

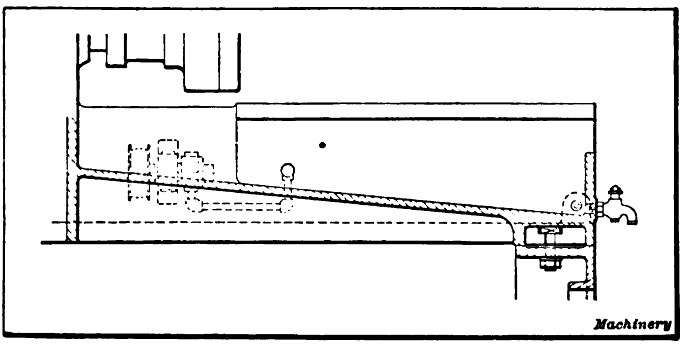


Fig. 26. Threading Machine with Tank Bed

interfering with the pipes, or it may be tilted on lugs (Fig. 27). The tanks for Lincoln millers are often suspended in this way.

Separation of Chips and Lubricant

The separation of chips presents little difficulty, when they are large and cannot possibly pass through a small opening which admits the lubricant; but when they are fine, like the small chips from threading machines, etc., and particularly those from hacksaws or cold saws, the greatest care has to be taken to prevent their entering the pump. This is done in two ways: By using strainers, and by fitting divisions or weirs so that two or three have to be passed before the liquid

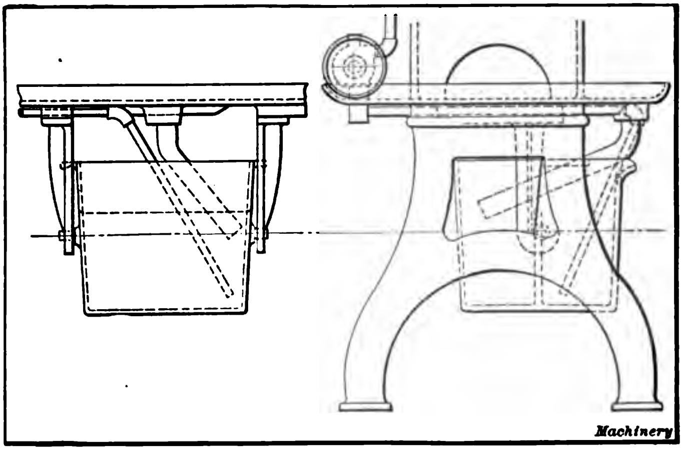


Fig. 27. Lubricant Tank suspended on Hooks for Tilting

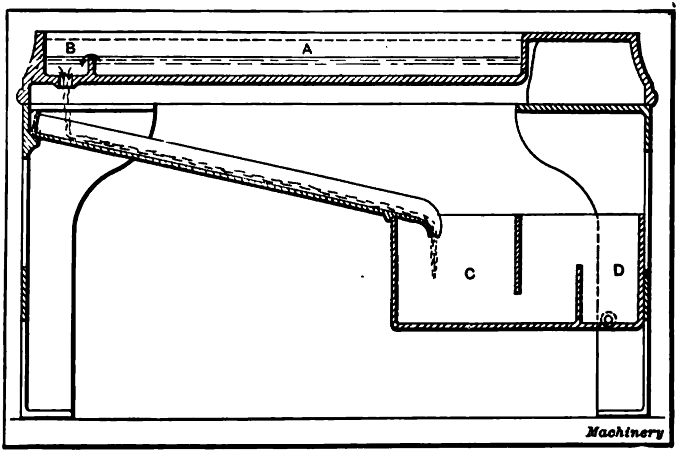


Fig. 28. Lubricant Tank with Partitions for separating Fine Chips from Lubricant

reaches the pump chamber. An example is shown in Fig. 28, which illustrates the frame of a hacksaw machine built by Messrs. C. Wicksteed & Co., Ltd., of Kettering (England). Soap-water is used as a lubricant; this is first received in the recess *A* in the bed, and is drained at the front end *B*, which is farthest away from the falling swarf or chips as they are carried back by the blade on its return stroke. A sloping trough then conveys the lubricant to the tank *C*, which has two divisions, as shown. Light swarf which floats on top cannot pass over the first division, and the clear liquid goes underneath to the pump chamber *D*.

If chips are produced in moderate quantities, it is well to have a separate perforated tray resting on the main pan, and empty this as required. One form is shown in Fig. 30. This tray should be deeper

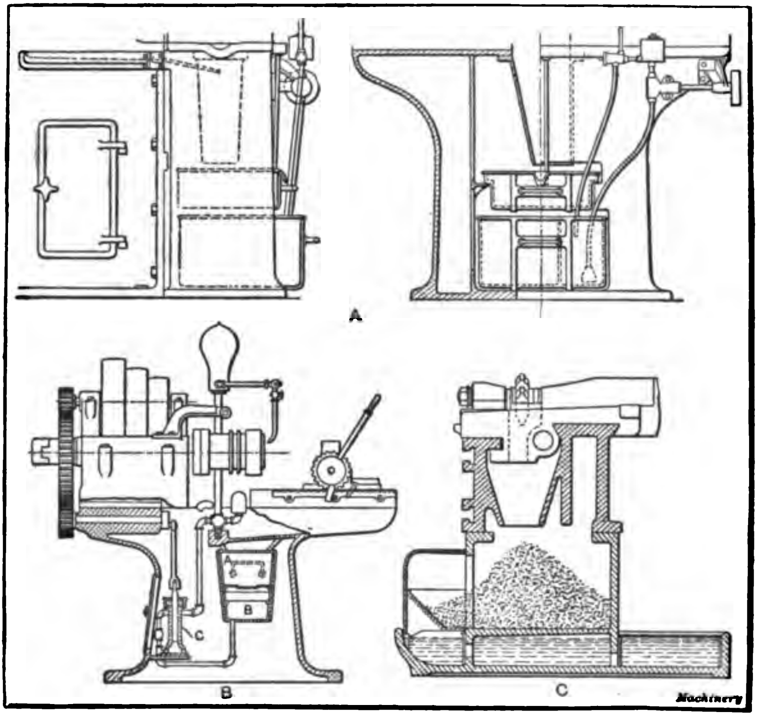


Fig. 29. A, Drainage Tank placed above Main Supply Tank; B, Common Lubricating Arrangement for Threading Machinery; C, Gear-cutting Machine with Provision for storing Oil in Base

when larger quantities of material are handled, and is placed over the main tank, as shown at *A*, Fig. 29. It is drawn out when full, for getting rid of the chips. For threading machines, the usual arrangement is represented at *B*. This view shows the chip box *A*, with strainer and the settling tank *B*, with a division which prevents any sediment that might pass through the strainer from entering pump *C*. The latter is of the plunger type, and there is an air-vessel on the delivery pipe to insure a more constant flow of lubricant. In some designs, the interior, where the pump is located, forms an oil reservoir of larger capacity than the tank *B*.

Oil is contained only in the foot or base of some machines, corresponding in this respect to automatic screw machines, and the interior of the frame or the bed is used only to receive the chips. The sectional view *C* illustrates a large Brown & Sharpe automatic gear-

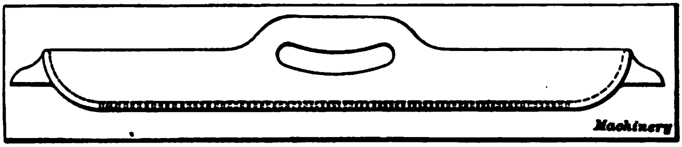


Fig. 30. Perforated Tray for separating Chips from Lubricant

cutting machine having this arrangement. The base stores the oil (from 25 to 30 gallons) and the chips fall from the cutter-slide to the position indicated, accumulating at the front eventually, and being removed through the opening for treatment in the oil separator.

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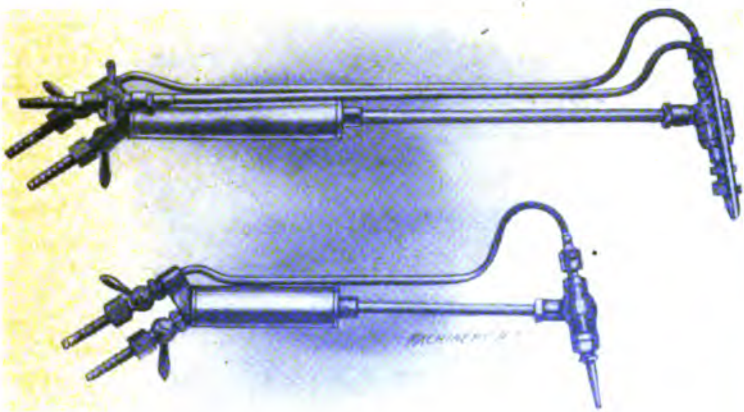

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INTRODUCTION

During the last fifteen years several interesting and valuable processes for joining metal parts have been developed. The processes of ordinary forge welding, soldering, and brazing are very old, having been used from time immemorial. Forge welding is applicable only to the joining of wrought iron, low carbon steel and a few alloys. For the sake of accuracy we must except gold which in the pure, annealed state has the curious property of welding cold under pressure; but commercially speaking, forge welding is limited to wrought iron and mild steel. Soldering can be used only on small, light work for joints which are exposed to ordinary temperatures and those slightly above the boiling point of water, inasmuch as the melting point of solder is about 400 degrees F. Brazing, that is, the joining of parts by the fusion of a spelter, is applicable to iron, steel, copper, brass, and other metals. On many kinds of work it is a process rather uncertain in results, even in the hands of experts, unless a good equipment is provided for controlling the heat and manipulating the work.

Until within a few years, cast iron could not be brazed successfully, because of the presence of the free carbon in the iron. The brazing of cast iron was made possible by the "ferrofix" process, which first decarbonizes the joint, placing the metal in much the same condition as wrought iron, so far as the action of brazing is concerned, and then brazing follows in the usual manner. Prior to this discovery the Thompson electric welding process had been developed, by which almost all commercial metals except cast iron are quickly and homogeneously welded together, the joint being raised to incandescence by the flow of the electric current. This process has had a very successful commercial development, and is now used for making thousands of welds daily. The electric welding processes are essentially "autogenous," an expression that will be explained further on.

The thermit process developed by Goldschmidt is unique. Intense heat is produced by the chemical reaction of pure aluminum and iron oxide in a finely divided state, the temperature rising as high as 5,400 degrees F. One product of the reaction is pure molten iron or mild steel so hot that when poured upon the broken ends of a forging, surrounded by a suitable mold, the parts are instantly melted, and the whole fushed together with a mass of hot metal which, as it cools, binds the joint together with a perfectly homogenous union.

The latest development in the joining of metals, which is now assuming the proportions of an important commercial development, is the so-called autogenous gas flame process. The term autogenous welding is in some danger of becoming applied exclusively to various systems of gas flame welding. The flame produced by the combustion of hydrogen and oxygen, or acetylene and oxygen, is so hot that the parts adjacent to the metal joint are quickly melted together, forming a perfect union; but the meaning of autogenous welding is simply a welding of its own kind, the parts being joined together without the introduction of spelter, solder or any foreign material. Hence any method of joining metals by fusion of the joint which does not require the introduction of foreign material to make the weld is autogenous. Right here it may be said that the autogenous weld is the only reliable joining of aluminum parts that has been discovered.

An autogenous joint, when properly made, must be as strong as the adjacent metal, provided no change has been made in the charactertics of the metal because of the heat. A broken forging that has been subjected to special heat treatment to improve its physical characteristics could not be autogenously welded and made as strong in the joint as before, without, of course, again being heat treated. The importance of gas flame autogenous welding in jointing thousands of manufactured articles, which are now brazed, riveted or bolted together, is obvious.

CHAPTER I

THE OXY-ACETYLENE AND OXY-HYDROGEN PROCESSES OF METAL CUTTING AND AUTOGENOUS WELDING

Within the past few years a valuable tool, unique in its characteristics, has been developed for cutting, shaping, and welding metals. This is the oxy-acetylene "torch," which now is so well advanced that it bids fair to displace other emergency cutting and welding means to a large extent. The oxy-acetylene process had its inception in France, the first experimenter being Mr. Edmund Fouche, of Paris, who began his work on it in 1901. The principle of the oxy-acetylene torch or burner is essentially the same as that of the oxy-hydrogen blow-pipe, which has been used for many years for generating intense heat. But though the oxy-hydrogen flame is intensely hot, the flame produced by the oxy-acetylene torch is so much hotter that the two are not in the same class. The temperature produced by the oxy-hydrogen flame is rated by authorities at about 4,000 degrees F., while that of the oxy-acetylene flame is estimated at about 6,300 degrees F. Not only is the flame of acetylene much hotter than hydrogen, but the number of B. T. U. per cubic foot is about five times as great, being as 330 to 1600. Hence both the intensity and amount of heat is greatly increased in the flame of the oxy-acetylene torch. A comparison between the two instruments has been aptly put as like that of "a finely pointed tool and a blunt instrument."

Definition of Autogenous Welding—Brief Explanation of Method

As already mentioned in the introductory paragraphs, the process of fusing and uniting metals by the application of intense heat without compression or the use of a flux is termed "autogenous welding." The temperature required is obtained by the combustion of a mixture of gases, such as oxygen and acetylene or oxygen and hydrogen. One or both of these gases may be under pressure. The gases are mixed in the nozzle of the torch prior to combustion. Ordinarily, the weld is formed by fusing in additional material between the surfaces of the joint. This material is in the form of a rod or wire and may or may not be of the same composition as the material being welded.

Development of Oxy-acetylene Process

The commercial development of metal-cutting and autogenous welding has been taken up by several concerns in the United States and Europe. The processes are essentially the same, the difference being in the construction of the torches and the manner in which the gases are generated. Great difficulties were at first met with in cheaply producing pure oxygen gas. The cheap production of acetylene had, to a great extent, been satisfactorily solved in the extensive development of acetylene lighting, but even this art had to be further developed to meet all the requirements of metal welding and cutting work. There are four or five commercial means of making oxygen, these being principally the oxone or barium process, the liquid air process, the epurite process, and the chlorate of potash process. The latter process is used by the Davis-Bournonville Co., New York, and the following notes relate to the development of the art of metal cutting and autogenous welding, as reached by this concern.

A few of the purposes for which cutting and welding torches are commonly used are as follows: For cutting steel wreckage, steel piling, steel beams in structural work, risers from steel castings, openings through steel plates, etc.; for welding seams, reclaiming cracked castings, filling blowholes in castings, adding metal to worn surfaces to secure the original thickness, welding piping without removal, filling holes that have been incorrectly located, replacing broken gear teeth by welding in new material, sealing riveted seams to secure tight joints without calking, etc.

Generating the Oxygen and Acetylene

The chlorate of potash process of generating oxygen is well known, being perhaps the simplest method. It will be found described in elementary works on chemistry. The oxygen of chlorate of potash can be driven off by gentle heat, and, in practice, the potash is placed in a closed retort and subjected to a comparatively low temperature. The reduction is facilitated by the addition of black dioxide of manganese in the proportion of 14 pounds of manganese to 100 pounds potash. The oxygen gas is passed through scrubbers and is pumped into receivers. The pressure in the receivers is varied according to the use, it being desirable to compress from 125 to 150 pounds per square inch for metal cutting, while 15 pounds pressure suffices for autogenous welding. The acetylene gas is produced in the Davis generator which is adapted to all pressures up to 15 pounds per square inch. The machine is automatic and feeds lump carbide perfectly up to sizes that pass through 1-inch screen. The theoretical quantity of water to carbide is about ½ pound to 1 pound carbide, but to absorb the heat of the chemical transformation the generator is required to have a water capacity of 1 gallon water to 1 pound carbide. For repair shops and work outside of the shop, a portable apparatus is required, and for such purposes the oxygen and acetylene gases are stored in small cylinders. The storage of oxygen is a simple matter of pumping the gas into the cylinders until the required pressure has been reached. The storage of undiluted acetylene under pressure in tanks is impracticable, but fortunately, it was discovered in 1896 by Claude and Hesse, two French engineers, that acetone, a fluid derived from the dry distillation of wood, is a remarkable solvent for acetylene, being capable of absorbing 25 times its volume at 60 degrees F. for each atmosphere. At ten atmospheres, or 150 pounds pressure per square inch, a gallon of acetone absorbs 250 gallons of acetylene gas. When absorbed by acetone, acetylene is non-explosive under heavy pressure. A red-hot wire might be thrust into the receiver with absolutely no effect, provided there is no free space occupied by acetylene gas. To prevent the possibility of there being free spaces for the accumulation of gas, acetylene storage tanks were designed by Mr. Edmund Fouche, which are packed with porous brick, asbestos or other neutral porous material, thus filling the entire free spaces and affording storage for the acetone and acetylene gas only in the cells of the filling.

Impurity of Oxygen

It is of considerable importance to understand the effect of impure oxygen. The impurities which have any especial claim to attention are those which arise through the presence of nitrogen or hydrogen. If the oxygen is prepared by the liquefaction of air, some percentage of nitrogen will be very sure to be present. Nitrogen itself seems to be harmless, in so far as any ill effect on the metal is concerned. It is, however, practically unburnable, and so clogs the action of the oxygen. It probably also tends to cool the heating flame and thus retard the work. In the manufacture of oxygen by the electrolytic process, the principal impurity will probably be hydrogen. As hydrogen is a gas that is readily combustible it has but little effect on the heating flame, but in the cutting stream of oxygen its presence doubtless gives rise to a clogging effect similar to that of nitrogen. At all events, whether we account for the result in one way or another, the presence of nitrogen or other impurities in the oxygen supply has the effect of retarding the cutting operation. This retardation means a labor loss in addition to a gas loss, besides hindering output. Certain experiments carried out abroad will assist us in seeing just how serious the retardation is.

Table 1 gives the results of twenty-six experiments, all tried on sheets of the same kind, of the same thickness, and with the same style of torch.

It will be seen at once that the purity of the oxygen plays a most important part in the efficiency with which cutting may be accomplished. With oxygen 85.5 per cent pure, it requires three times as

TABLE I. TIME REQUIRED FOR OXY-HYDROGEN CUTTING OF METALS

Siemens-Martin sheet steel, 1.18 inch thick. Oxy-hydrogen procedure. Gas consumption per minute: Hydrogen, 1.06 cubic foot; oxygen, 0.28 cubic foot. Oxygen pressure = 1.5 atmosphere = 22 pounds per square inch.

Purity of Oxygen, expressed as Percentage	Length of Cut, in Inches	Time required in Making Cut, in Seconds	Time required to Cut One Foot, in Minutes	Average Time required to Cut One Foot, in Minutes
99.00	28.0	182	1.30	1.30
99.00	21.3	140	1.31	
99.00	18.9	120	1.27	
99.00	34.3	228	1.33	
99.00	29.9	196	1.31	
98.50	31.5	210	1.33	1.53
98.50	41.7	330	1.58	
98.50	41.7	320	1.53	
98.50	39.4	310	1.58	
98.50	27.6	225	1.63	
98.50	18.9	150	1.58	
95.50	44.5	426	1.91	1.91
95.50	32.3	295	1.91	
94.75	25.2	270	2.14	2.21
94.75	21.7	240	2 21	
94.75	33.9	364	2.15	
94.75	23.6	270	2.29	
94.75	41.6	475	2.28	
90.50	34.3	480	2.80	2.88
90.50	36.6	500	2.73	
90.50	32.7	480	2.94	
90.50	35.4	495	2.80	
90.50	29.9	470	3.14	
85.50	43.3	870	4.02	3.99
85.50	21.7	420	3.87	
85.50	23.6	480	4.07	

Machinery

long to cut the 1.18-inch plate as with oxygen 99 per cent pure. This means that the cost is three times as much. Exen the one-half of one per cent drop from the 99.0 per cent oxygen to the 98.5 per cent quality means an increase in the expense amounting to 16 per cent. So even if the better grade of oxygen should cost more, we see from the foregoing that it would have to cost a great deal more to make it a matter of no importance which grade of oxygen is used.

In Table II the same kind of steel and the same thickness of sheets are to be understood as in Table I. The pressure of the oxygen is increased, however. Note especially that here we have the alternative procedure with acetylene gas.

It will be noted that we do not have any experiments here with 99 per cent oxygen. Comparing the 98.5 per cent purities in Tables I and II, we see that the acetylene cutting has the advantage. The result with 94.75 per cent oxygen, hydrogen cutting, when compared with

TABLE II. TIME REQUIRED FOR OXY-ACETYLENE CUTTING OF METALS

Siemens-Martin sheet steel, 1.18 inch thick. Oxy-acetylene procedure. Acetylene consumption per minute: 0.153 cubic foot. Oxygen pressure: 2 atmospheres = 29.4 pounds per square inch.

Purity of Oxygen, expressed as Percentage	Length of Cut in Inches	Time required in Making Cut, in Seconds	Time required to Cut One Foot, in Minutes	Average Time required to Cut One Foot, in Minutes
98.50	17.3	123	1.42	1.40
98.50	28.3	192	1.36	
98.50	32.3	228	1.41	
98.50	33.9	230	1.36	
98.50	28.3	200	1.41	
98.50	28.3	202	1.43	
96.50	33.9	255	1.50	1.63
96.50	45.3	360	1.59	
96.50	47.2	380	1.61	
96.50	37.8	320	1.69	
96.50	58.3	480	1.65	
96.50	44.1	370	1.68	
96.50	41.7	340	1.63	
96.50	30.7	245	1.60	
96.50	44.9	380	1.69	
94.50	34.6	400	2.31	2.33
94.50	43.3	510	2.36	
94.50	43.3	520	2.40	
94.50	35.4	400	2.26	

Machinery

the work done with 94.50 per cent, acetylene cutting, indicates that the efficiencies at this degree of impurity are about the same. This would become all the clearer by drawing curves illustrative of the last columns in Tables I and II and then superimposing them on each other. It must be borne in mind, however, that the oxygen pressure is distinctly higher with the acetylene experiments.

The Oxy-acetylene Torch

Fig. 1 shows the Davis-Bournonville Co.'s cutting and welding torches. The upper illustration is the cutting torch and differs from the welding torch shown in the lower illustration simply in that it has an auxiliary detachable oxygen tube secured to the side. The welding torch has an acetylene gas tube and an oxygen tube which combine in a tip or nozzle from which the united gases flow and burn. The upper tube in each illustration is for oxygen, while the lower tube is for acetylene, the two gases uniting at the end of the removable tip within the body of the torch.

In Fig. 2 is shown a line engraving of a standard oxy-acetylene torch for medium and heavy welding. As will be seen, there are two small pipes which have hose connections at one end. The opposite ends are attached to a head which holds the torch tip or nozzle. The pipe for acetylene opens into a cylinder which serves as a handle and is packed with a porous material that makes it impossible for the flame to pass this point. However, "flash back" is not likely to extend back of the tip. The tips are interchangeable, different sizes being

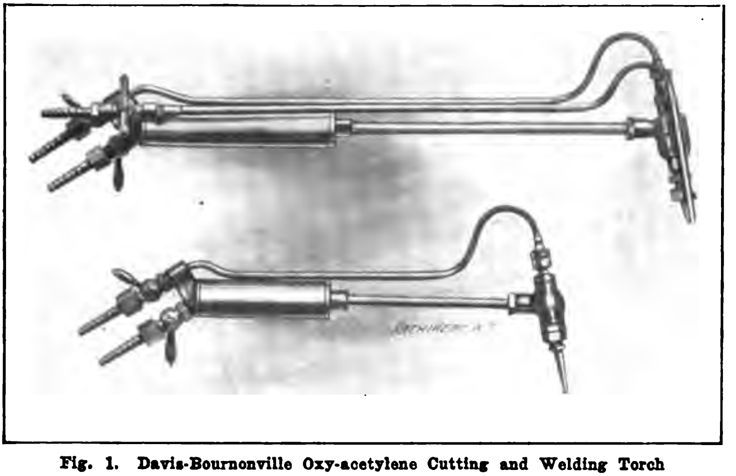


Fig. 1. Davis-Bournonville Oxy-acetylene Cutting and Welding Torch

required for various classes of work. The mixture of the oxygen and acetylene gases takes place within the tip. The acetylene is admitted under lower pressure than the oxygene, and through inlets at right angles to the oxygen inlet to insure thorough mixing. Regulators on the storage tanks serve to control the working pressures of both gases.

Adjusting the Torch

Before lighting the torch, the regulator on the oxygen tank should be set to give the required pressure. The average pressures used for welding different thicknesses of metal are given in Table III. The acetylene is lighted first, the regulator being adjusted so that there is a fairly strong flame. The full pressure of the oxygen is then turned on, after which the acetylene pressure is varied by means of the regulator until the two cones which appear in the flame at first are merged into one smaller cone. After this cone is formed, no more oxygen should be added. It is also well to occasionally test the cone by increasing the acetylene pressure slightly, which will immediately cause an extension at the point of the cone. When the cone is properly formed, it will be neutral, so that it will neither oxidize (burn) or carbonize the metal. An excess of oxygen will cause burning and oxidation, whereas an excess of acetylene will carbonize the metal. The tip of the cone should just touch the metal being welded, but not the point of the torch, as this might cause a "flash back." An excessive discharge of sparks indicates that too much oxygen is being used and that the metal is being burned or oxidized, although when welding thick metals, there will be a considerable volume of sparks, even though the flame is neutral.

Size of Torch Tip

The proper size of tip to use for welding depends upon the thickness of the work and the rate at which the heat is dissipated. Sometimes the rate of conduction and radiation is affected by the location of the parts to be welded. In general, heavy parts will conduct the heat more rapidly from the working point, and to offset this loss of heat a larger

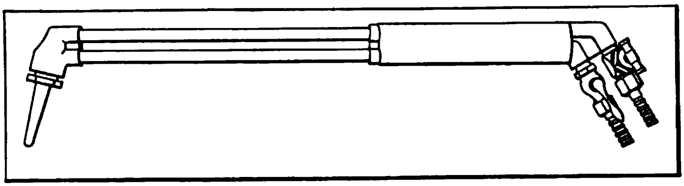


Fig. 2. Oxy-acetylene Torch for Medium and Heavy Welding

tip is used. In any case, the tip should be as small as is compatible with good work, to economize in the use of gases. If the flame is too small for the thickness of metal being welded, the heat will be radiated almost as fast as produced; hence, the flame will have to be held so long at one point to effect a weld that the metal will be burned. On the other hand, if the flame is too large, the radiation may be insufficient to prevent burning the molten metal. The tip should give a flame that will reduce the metal to a plastic, molten condition (not too fluid), covering a width approximately equal to the thickness of the metal being welded.

High- and Low-pressure Torches

The difference between high- and low-pressure oxy-acetylene welding and cutting torches, according to the generally accepted meaning of these terms, is in the pressure of the acetylene gas. The oxygen, in each case, is under a pressure of one or two atmospheres. With a high-pressure torch, the acetylene gas has a working pressure of one pound or more (depending upon the nature of the work); in the low-pressure type, the acetylene gas only has a pressure of a few ounces. The operation of the low-pressure torch is on the principle of an injector, in that the jet of oxygen draws the acetylene into the mixing chamber which is in the torch tip. The proportion of oxygen to acetylene varies somewhat with different torches; it usually ranges between 1.14 to 1 and 1.7 to 1, more oxygen being consumed than acetylene.

Making Autogenous Welds

To become proficient in the art of autogenous welding requires experience and practice, but a knowledge of some of the fundamental principles will enable the operator to make more rapid progress. It is advisable to begin by welding thin strips of iron or steel not over ⅛ inch in thickness. Such light metals can be welded without the addition of a filling-in material. The torch should be given a rotary motion accompanied by a slight upward and forward movement with each rotation. This movement tends to blend the metal and reduces the liability of overheating. If comparatively thick materials are to be welded, the edges should be beveled (by chipping, or in any other convenient way), as shown in Fig. 3. The beveled surfaces are then heated by a circular movement of the flame, care being taken to melt them to a soft, plastic state without burning the metal. Wherever fusion occurs, new metal should be added from a "welding rod," the composition of which is suitable for the work in hand. In continuing

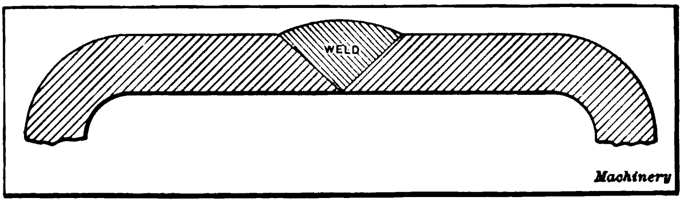


Fig. 3. Method of Welding Thick Materials

the heating operation, the flame should be swung around in rather small circles and be advanced slowly to distribute the heat and prevent burning. The surface should be thoroughly fused before adding metal from the welding stick, and the latter should be held close to, or in contact with, the surface. The heat is then radiated from the welding rod to the work, whereas if the metal were allowed to drop through the flame, it might be burned to an injurious extent. When the weld is completed, it is advisable to pass the torch over it, so that all parts will cool from a nearly uniform temperature.

When welding two parts together, it is important not to heat one more than the other, because the hottest piece will expand most and the weld may crack in cooling as the result of uneven contraction. When making heavy welds, the parts should be brought to a red heat for a distance of about three times the thickness on each side of the weld, for thicknesses up to one inch, the distance being increased somewhat for heavier parts. The following suggestions are given by the Davis-Bournonville Co., and apply to the welding of various metals.

Welding Cast Iron

If the work is in such a form that it may crack in cooling, it should be pre-heated, but not enough to warp the metal, no part being heated to a dark red except at the welding point. (See Chapter II.) Whether the metal is pre-heated or not, it should be covered as soon as the weld is finished and be allowed to cool slowly. If the metal is more than ¼ inch thick, the edges should be beveled at an angle of about 45 degrees on each side. For comparatively heavy welds, it is well to leave three small points of contact for aligning the broken parts in the original position. To make the weld, the flame should be passed for some distance around the fracture and then be directed onto it until the metal is cherry-red. When this occurs, have an assistant throw on a little scaling powder, and when the metal begins to run, add cast iron from the cast-iron "welding stick," which should be of specially refined material. Powder should only be added when the metal does not flow well, as little as possible being used. Never attempt to re-

TABLE III. APPROXIMATE HOUR COST OF OXY-ACETYLENE WELDING
(Davis-Bournonville Co.)
Oxygen at 3 cents per cubic foot, acetylene at 1 cent per cubic foot

Tip No.	Thickness of Metal, Inches	Acetylene Pressure, Pounds	Oxygen Pressure, Pounds	Cubic Feet per Hour		Lineal Feet Welded per Hour	Cost of Gases	Cost of Labor	Total Hour Cost	Cost per Lineal Foot
				Acetylene	Oxygen					
1	1/32	1	2	3.21	3.65	30	$0.142	30 cents per hour	$0.442	$0.015
2	1/16	2	4	4.84	5.50	25	0.213		0.513	0.020
3	3/32	3	6	8.14	9.28	20	0.360		0.660	0.033
4	1/8	4	8	12.50	14.27	15	0.553		0.853	0.057
5	3/16	5	10	17.81	21.32	9	0.818		1.118	0.124
6	1/4	6	12	24.97	28.46	6	1.103		1.403	0.234
7	5/16	6	14	33.24	37.90	5	1.469		1.769	0.354
8	3/8	6	16	41.99	47.87	4	1.856		2.156	0.539
9	1/2	6	18	57.85	65.95	3	2.557		2.857	0.952
10	5/8	6	20	82.50	94.05	2	3.646		3.946	1.973

weld pieces that have been previously welded or brazed, without first cutting away all of the old metal.

Welding Steel

Steel less than ⅛ inch thick can be welded without the addition of any welding metal. If the thickness exceeds ⅛ inch, the edges should be beveled or chamfered. It is very important not to add the welding material until the edges are fused or molten at the place where the weld is being made. The welding metals should be of special wire, and in no case should the flame be held at one point until a foam is produced, as this is an indication that the metal is being burned. Do not hold the flame steadily in the center of the weld, but give it a circular motion with an uplifting movement at each revolution, the object being to drive the molten metal toward the center of the weld. When welding a crack located in the middle of a heavy steel sheet, begin by chamfering the metal on each side of the fracture at an angle of 45 degrees, the slope extending to the bottom; then apply the welding torch to the sheet beyond the end of the crack, until there is sufficient expansion to open the crack perceptibly. The weld should then be made, and, as a rule, it will be found that the expansion will compensate for the contraction when cooling. A slight excess of oxygen is less harmful than an excess of acetylene, but it is important to so adjust the gases that the flame is neutral. When the weld is completed, pass the torch over it and the surrounding metal, as previously mentioned.

Welding Aluminum

Aluminum that is to be welded should be scraped and cleaned, and if the stock is more than 1/4 inch thick, it is advisable to chamfer the edges. The oxy-acetylene flame can be reduced or "softened" by using an excess of acetylene to a degree which will be indicated by the extension of the acetylene cone from 1 to 1 1/2 inch beyond the white cone. This excess of acetylene does not injure aluminum, but lowers the flame temperature which is desirable when welding aluminum. Before welding this metal, heat the entire piece in a charcoal fire or furnace to about 300 or 400 degrees below the melting point. Then cover it with asbestos or other material (leaving an opening where the weld is to be made), in order to keep the work hot until the weld is completed. When the weld is made it should be covered completely, as a protection against drafts, to insure slow cooling and prevent shrinkage cracks. Many aluminum parts can be welded without pre-heating, such as lugs or projecting pieces broken off completely. When a welding flame is applied to aluminum, it will be noticed that the metal does not run together. A flattened iron rod should be used to puddle the aluminum, and this rod should be wiped frequently, so that it will not become coated. The rod should not be allowed to reach a red heat, thus causing oxide of iron to form on it, as this would cause a defective weld. A good aluminum flux will be found advantageous. The aluminum to be added should be in sticks of special composition, obtainable from the makers of welding apparatus. The quality of the welding metal has much to do with the quality of the weld.

Welding Brass and Copper

For brass, adjust the flame until there is a single cone, as for steel welding. Keep the point of the white flame slightly away from the weld, according to the thickness of the piece, so that the heat will not be sufficient to burn the copper in the brass or volatilize the zinc. If a white smoke appears, remove the flame, as this indicates excessive heat. A little borax should be used as a flux. For brass welding, it is advisable to use a tip about one size larger than for the same thickness of steel. As the weld is really cast brass, it will not have the strength of rolled sheet brass. Do not breathe the fumes while welding brass.

To weld copper use the same kind of flame as for steel, but a much larger tip for corresponding dimensions, because of the great radiating property of copper. Pre-heating is neessary when a large piece of copper is to be welded, as otherwise so much heat from the torch will be dissipated by radiation that little will be left for fusing the metal. Copper will weld at about 1930 degrees F.; hence, the flame need not have so high a temperature as for steel and it must not be concentrated on so small a surface. On account of the radiation, however, the total quantity of heat must be greater. Welded copper has the strength of cast copper, but can be rendered more tenacious by hammering. The radiation of heat from copper can be considerably lessened by covering it with asbestos sheets while heating. To weld copper to steel, first raise the steel to a white heat (the welding

Fig. 4. Welding together the Parts of a Drawn Steel Retort. The Operator feeds the Joint with a Special Grade of Iron Wire

point); then put the copper into contact with it and the two metals will fuse together. When the copper begins to flow, withdraw the flame slightly to prevent burning.

Welding Miscelianeous Metals

To weld high-speed steel to ordinary machine steel, first heavily coat the end of the high-speed steel with soft special iron, obtainable from the makers of welding outfits. This can be done without heating the high-speed steel to the burning point. After cooling, the high-speed steel can be welded to ordinary machine steel without burning, but experience is required to make a good weld of this kind.

To weld cast iron to steel, cast-iron rods are used as welding material. The steel must be first heated to the melting point, as cast iron melts at a lower temperature. A very little scaling powder should be used.

The welding of malleable iron is difficult for several reasons. If malleable iron is raised to the melting point and kept there for any length of time, the metal becomes spongy and changes to what is practically cast iron. To weld it, coat the edges with soft special iron, using a little scaling powder, and then finish the weld by the addition of special iron. To fill blowholes in malleable iron, use cast iron for a filler, and to avoid hard spots, pre-heat the metal so that the oxy-acetylene flame is used as little as possible.

Certain grades of cast steel can be welded more easily than ordinary rolled steel, but other grades, especially of high-carbon composition, are very difficult to weld and some cannot be welded at all. When difficulty is experienced, the addition of one or two drops of copper, melted into the weld, will cause the metal to flow and a fairly good weld can be made, but copper is likely to harden the metal so that it cannot be machined except by grinding.

Filling Blowholes

To fill large blowholes in brass or copper castings, pre-heat the casting to a temperature between 200 and 400 degrees F. below the melting point, or to a bright red color. Have some of the same metal melted in a crucible ready to pour; then apply the torch to the blowhole to be filled and when the walls of the hole have been brought to the melting point, gradually pour in the metal, keeping the walls fused by using the flame. Continue mixing the poured metal with the molten metal of the walls, until the blowhole is filled.

Spots in Welding

When making heavy welds, there often is a spot in the middle of a weld where the metal refuses to flow, because the metal is not hot enough surrounding this spot, the heat being absorbed by the cold metal; consequently, the added metal is chilled. To remedy this, play the flame in a radius of from ½ to 1 inch, around the refractory point until the surrounding metal is at a white heat; then apply the flame to the spot itself and it will quickly unite with the other molten metal.

Examples of Welding Operations

Fig. 4 illustrates the welding of thin steel retorts for generating oxygen gas. The material for the retorts is bought in drawn shape, one part being made with a collar and the other having a rounded bottom. The length of the retort is too great to permit its being drawn in one piece, hence the necessity of welding the two parts together near the center. The following is the approximate cost of welding 1/16-inch metal. The consumption of acetylene is 2.8 cubic feet per hour; of oxygen 3.6 cubic feet at a pressure of 8 to 10 pounds. The rate of welding is about 50 feet per hour, and with labor at 30 cents per hour, the total cost per hour is 43.6 cents, or less than 9/10 per cent per lineal foot. The cost of welding increases with the thickness of material, of course, reaching an estimated cost of 80 to 95 cents per lineal foot for 7/16- to ½-inch thick metal.

In Fig. 5 is illustrated the welding of a broken flange on a casting. This job, which would have been difficult and expensive by brazing, was easily accomplished. In this illustration, as in Fig. 4, the operator is shown feeding material into the weld, the same as a tinner feeds solder when soldering. For welding steel and wrought iron a special iron wire is used as already mentioned, and for welding cast iron, rods of cast iron.

Pre-heating

Parts to be welded together autogenously are often pre-heated by the use of a blow-torch, gas furnace, charcoal fire, etc. This pre-heating

Fig. 5. Welding the Broken Flange of a Cast-iron Base. The Operator feeds the Joint with a Cast-iron Rod

is done either to economize in gas consumption or to expand the metal before welding, in order to compensate for contraction in cooling. Usually it is advisable to pre-heat comparatively heavy, thick metals (especially if cast) before welding. This equalizes the internal strains, and very materially reduces the cost. In many instances, it is much better to produce expansion before welding, than to attempt to care for the contraction afterward. When there is a straight crack, it can usually be opened uniformly by heating the metal at each end and keeping it hot while the weld is being made. As a rule, the expansion obtained by heating at the ends will compensate for the contraction which accompanies cooling. When a part has been pre-heated, it is well to place sheets of asbestos over it to protect the operator and prevent heat radiation, the surface to be welded being exposed. Where a piece of metal has been severed completely or a projection has been broken off, pre-heating will not be necessary. This subject will be dealt with in detail in a following chapter.

Cutting Metals with Oxidizing Flame

The oxy-hydrogen and oxy-acetylene flames are especially adapted to cutting metals. When iron or steel is heated to a high temperature, it has a great affinity for oxygen and readily combines with it to form different oxides which causes the metal to be disintegrated and burned with great rapidity. The metal-cutting torch operates on this principle. Ordinarily, two jets or flames are used: First there is an ordinary welding flame for heating the metal, and this is followed by a jet of pure oxygen, which oxidizes or burns the metal. The kerf or path left by the flame is suggestive of a saw cut. On some torches the oxygen jet is obtained by the application of a separate cutting attachment to a regular welding torch. This attachment is little more than a pipe containing a tip, which supplies a pure oxygen jet located close to the regular heating flame. Torches are also designed especially for cutting.

Operation of Cutting Torch

When starting a cut, the steel is first heated by the welding flame; then the jet of pure oxygen is turned on. The flame should be directed a little inward, so that the under part of the cut is somewhat in advance of the upper surface of the metal. This permits the oxide of iron produced by the jet to readily fall out of the way. If the flame were inclined in the opposite direction or in such a way that the cut at the top were in advance, the oxide of iron would accumulate in the lower part of the kerf and prevent the oxygen from attacking the metal. The torch should be held steadily and with the cone of the heating flame just touching the metal. When accurate cutting is necessary, some method of mechanically guiding the torch should be employed.

Thickness of Metal to be Cut

The maximum thickness of metal that can be cut by these high-temperature flames depends largely upon the gases used and the pressure of the oxygen; the thicker the material the higher the pressure required. When using the oxy-acetylene flame, it might be practicable to cut iron or steel up to 7 or 8 inches in thickness, whereas with the oxy-hydrogen flame the thickness could probably be increased to 20 or 24 inches. The oxy-hydrogen flame will cut thicker material principally because it is longer than the oxy-acetylene flame and can penetrate to the full depth of the cut, thus keeping all the metal in a molten condition so that it can easily be acted upon by the oxygen cutting jet. A mechanically-guided torch will cut thick material more satisfactorily than a hand-guided torch, because the flame is directed straight into the cut and does not wabble, as it tends to do when the torch is held by hand. With any flame, the cut is less accurate and the kerf wider, as the thickness of the metal increases. When cutting light material, the kerf might not be over 1/16 inch wide, whereas, for heavy stock it might be ¼ or ⅜ inch wide.

Cutting Metal under Water

A German engineer has designed a burner which makes it possible to use the hydrogen-oxygen flame for cutting metals under water. The burner consists of a bell-shaped head which is screwed onto an ordinary burner and which allows the flame to continue to burn below

Fig. 6. Cutting Off Steel Sheet Piling with Oxygen Cutting Torch showing Portable Apparatus

the water in a supply of compressed air. This process has been so improved of late that the cutting of metals under water is claimed to be effected almost as quickly as above the surface. At tests made with the new apparatus at the harbor at Kiel, before prominent engineers and representatives of the German government, a diver went down into the sea to a depth of about 16 feet, and, after boring a hole into an iron bar 2½ inches square, cut off the bar in about thirty seconds. An iron sheet ⅞ inch thick was drilled through and cut for a distance of one foot in ninety seconds.

Example of Metal Cutting

Fig. 6 illustrates the use of the cutting torch cutting off steel sheet piling. This work is done with rapidity, and is a very spectacular performance. In the case of cutting, the combustion of the steel materially raises the temperature and assists in the work. This was pointed out by Chevalier C. de Schwarz in a paper read before the May, 1906, meeting of the Iron and Steel Institute, and it gives one a startling idea of the power of the oxygen cutting flame when the concentration of the heat units produced is known. Burning 1 pound of acetylene with oxygen produces from 18,250 to 21,500 B.T.U. The mean value may be taken as about 19,750 B.T.U. per pound, and the number of cubic feet at atmospheric pressure at about 14½. Now, the burning of 1 pound of steel with oxygen produces approximately 2,970 B.T.U., but at atmospheric pressure 1 pound of acetylene gas fills 6,750 times the space of 1 pound of steel. Hence, the intensity of the heat with perfect combustion of the steel in oxygen will be, theoretically, $\frac{6750 \times 2970}{19,750} = 1,015$ times the intensity of heat of the oxy-acetylene flame. As a matter of fact, of course, this enormous temperature is not even remotely approached, because the metal dissolves at a far lower temperature and passes off in sparks, which are speedily cooled by the atmosphere.

Cost of Cutting Metals with the Oxy-acetylene and Oxy-hydrogen Flame

The following figures will give an idea of the cost of cutting metals by the processes described. Assuming oxygen at 3 cents per cubic foot and acetylene at 1 cent per cubic foot, 2 feet of ¼-inch thick steel can be cut per minute at a cost of 1.3 cent per foot, and 1 foot of 1½-inch thick steel can be cut per minute at a cost of 7.6 cents per foot. This cost is for gas alone; the cost of labor must, of course, be added. The figures given are for machine-guided torches. When cutting with a hand-guided torch, the gas consumption will be approximately one-third more and the number of feet cut per hour, one-third less, than when the torch is mechanically guided by a special cutting machine. The variation, of course, depends to some extent upon the skill of the operator.

When cutting with the oxy-hydrogen flame and assuming the cost of oxygen at 3 cents per cubic foot and the cost of hydrogen at 1¾ cent per cubic foot, the cost of the gas per foot for cutting ¼-inch thick steel is about 7 cents and the cost of cutting 1½-inch thick steel, about 18 cents per lineal foot. Cutting with a hand torch increases the cost slightly. While the oxy-hydrogen process is thus more expensive than the oxy-acetylene process for thin stock, it has the advantage that it can be used on much heavier material than the oxy-acetylene flame, as explained in a previous paragraph.

CHAPTER II

PRE-HEATING METALS TO BE WELDED BY THE OXY-ACETYLENE PROCESS

The use of the oxy-acetylene torch for heating the work from the ordinary open-air or room temperature to that of, say, red heat, is a rather wasteful method. It is frequently more economical to do this pre-heating by some cheaper method and then to complete the heating with the torch. Various methods are used for pre-heating; as a rule these methods are comparatively simple. A number of examples will be described in the following.

In pre-heating a large cast-iron kettle, a charcoal fire was employed. The kettle weighed about 18,000 pounds and the metal around the crack, which was about two feet long, was several inches thick. The crack was in the bottom and so the kettle was overturned in order to make the crack more easily accessible. The pre-heating was then done from within the kettle, and, in this case, was not only economical but probably essential, as it would have been difficult to obtain the required amount of heat by the torch flame alone. Asbestos sheeting was employed to protect the operator from the heat radiation.

Repairing a Locomotive Cylinder

In repairing a break in a locomotive cylinder, Fig. 1, the pre-heating was also done with charcoal, a temporary oven having been built up of loosely laid bricks, as shown in Fig. 2. The fire was kept going for two and one-half hours, at which time a dull red heat was secured. This condition was maintained for six hours longer during the welding operation. It is often possible to use an ordinary blacksmith's forge for the pre-heating, and if a great many similar parts are to be handled, a special forge and bellows may be found of advantage. In addition to the use of charcoal, torches using illuminating, producer, or natural gas, oil, or gasoline, may be employed; in fact, any method for obtaining a large amount of heat, but not necessarily a high temperature, can be employed. In one case, in welding a break in a locomotive engine frame, a gasoline torch was employed for the pre-heating, the torch being applied throughout the welding operation. In cases of repetition work, special arrangements of pipes and burners may be advisable.

Various Methods of Pre-heating

In one plant in Europe, where tubing is manufactured with the aid of power-driven gas-welding machines, provision is made for the rolled but unwelded tube to pass through a muffle just before reaching the torch, so that the tube is bright red when passing under the torch. Sometimes the outer flame of the torch itself may be used for pre-

Fig. 1. The Broken Cylinder

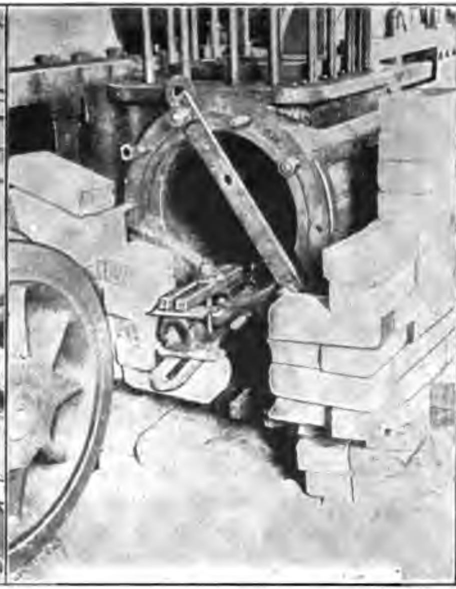


Fig. 2. Arrangement for Pre-heating

Fig. 3. After Welding, before Cleaning Weld

heating. Thus the Edison Storage Battery Co. employs a machine in welding a straight seam on the containing cans of their batteries. The torch, the work, and the clamping devices are so arranged that the outer flame of the oxy-acetylene jet is divided into two long streamers. One of these impinges upon the seam several inches ahead of the place where it is reached by the working flame. It is possible that this arrangement was not provided with a view to pre-heating, but that is the effect, and a consequent economy in gas consumption is the result.

The use of the outer flame for pre-heating may come to be an important factor. A large quantity of heat is generated by this flame. In the machine referred to, the clamps arranged along the sides of the seam are beveled to afford access to the torch, the bevels being quite steep—about 60 degrees. The writer would suggest that similar clamping bars be formed in connection with regular hand-welding work, so as to provide a canyon-like working groove. In hand-welding larger sizes of tubing, it would also be practicable to provide a series of gas jets on a single supply pipe beneath the joint. In this way the edges could be pre-heated with cheap gas.

Pre-heating to Prevent Unequal Expansion or Contraction

Pre-heating is often resorted to for reasons other than those of economy of gas consumption. It is used where the effects of expansion and contraction are objectionable. The rise of 2000 degrees in the temperature of a metallic body occasions considerable expansion in every direction. For example, a 12-inch steel bar will lengthen about 5/32 inch. It is easily seen that the sudden swelling and resultant shrinking of only a small part of the work may, at times, have disastrous results. Take as an example the spoke of a fly-wheel with a piece broken out. This piece just fits into its place. If we repair this by making the required grooves and then filling them with new metal, thus producing an apparently good weld, we will find that, upon cooling, a break will frequently occur in the weld or at some other point, due to the contraction. A similar case is met with in a crack in a casting. It is chipped out in order to obtain beveled edges for the flame, the faces are heated, and new molten material filled in. When the weld cools off, however, the new material is likely to shrink away from the walls of the crack.

Now what can be done to meet this condition? If we could uniformly heat the whole piece inside and outside, we should probably have an ideal solution, but one of the great objects in oxy-acetylene welding is to localize the heating. We can, however, pre-heat a larger portion of the whole body than is required for the welding alone, and in this way distribute the stresses. In the case of the flywheel, the broken spoke, the adjacent spokes, and the intervening rim may be heated to a red heat, gradually diminishing toward the other parts of the wheel, so that the pre-heating itself does not introduce new stresses. When the new material for making the joints is filled in, the spoke is naturally longer than it will be at ordinary temperatures, and while there is a local contraction of the weld, there is also a general contraction of the whole spoke and those adjacent, which diminishes the effect. In the case of a cracked cylinder casting, the pre-heating of the metal beyond each end of the crack, if properly done, will ordinarily open up the crack so that when it is filled with new metal, the amount which is used will be sufficient, when the cylinder cools off, to fill the original space. Ordinarily, the walls of the crack should be held apart until the weld is completed, so that the width of the crack and the new metal will contract together. If the crack runs from a point within the periphery all the way to the edge it may be opened up by heating at a point a little further in than the beginning of the crack. The welding is begun at the inner end of the crack, working toward the edge.

The pre-heating should ordinarily be done rather slowly so as not to introduce sudden temperature changes and stresses. Slow heating is especially to be advised when there is a combination of thin and heavy parts. Similar remarks apply to the cooling, which should be slow to be safe; the cooling may be retarded by the use of asbestos sheeting or by packing the object in heated ashes or heated slaked lime.

Temporary Furnace for Pre-heating

When it is possible to pre-heat the entire casting, this seems to be the best way of taking care of expansions and contractions. Castings

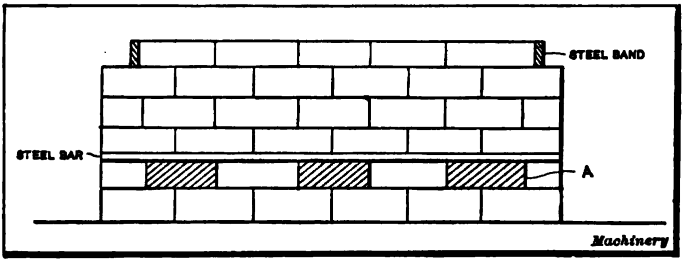


Fig. 4. Arrangement of Temporary Brick Furnace

the size of which makes necessary special arrangements may be placed on a bed of fire-brick arranged with spaces between them. A temporary wall or furnace is then built around the whole, fire-brick being used for this also. These are arranged, of course, without the use of mortar, with very narrow openings between them, one method of constructing such a wall being shown in Fig. 4.

Flat steel bars may be employed just above the separated course of bricks *A*. The top course may be held in place by a steel band. The object of the open spaces is to provide a draft. Charcoal is now filled in between the casting and the wall and the fire started. A sheet of asbestos is used as a cover. This cover should contain a number of holes so as to provide an exit for the gases.

Hood used for Pre-heating Operations

Another method is to make a hood of a material that is a poor conductor of heat. Such a hood is shown in vertical section in Fig. 5. The walls consist of two sheets of wire netting with an intervening space filled with asbestos. A hole, the wall of which is made of sheet iron, is provided at the top. Another aperture also lined with sheet iron is provided on one side of the vertical cylindrical wall. The bottom of the hood is furnished with an annular base ring of sheet iron, the netting and sheet iron being joined by welding. Provision should be made for lifting and lowering the hood, so that it can be let down over the casting which is to be pre-heated. To make a tight joint with the floor, some loose asbestos may be used as a foundation for the hood. A kerosene or other torch may now be inserted through the aperture in the side. Some kind of shield may be used just inside of the side opening to divide the flame, so that, as far as possible, the casting will be encircled by it. Sometimes it is advisable to use auxiliary fires on shelves above the main fire at the bottom. This is especially to be recommended for tall castings, so that there will be

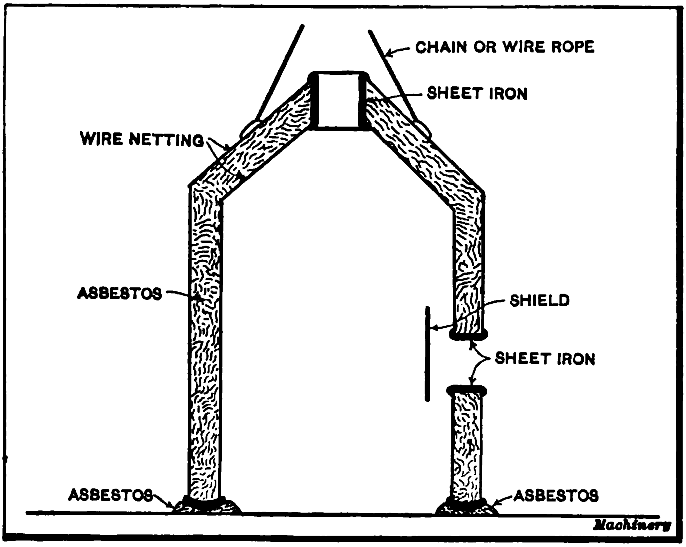


Fig. 5. Hood used for the Pre-heating Operation

no severe concentration of heat at one point. As already mentioned, the heating should be done slowly, the fires being started in a moderate way and gradually increasing in intensity. During the welding the hood must, of course, be raised, and when the welding is completed the hood may again be lowered into position in order to retard the cooling. The oil torch should be brought into service again for a short period. It may then be shut off and the openings of the hood covered. In this way, slow and even cooling is assured.

In general, after a welding operation, the casting should be reheated as soon as the welding is completed, and then covered with asbestos wool or scrap asbestos. The casting may also be buried in any of the materials ordinarily used for retarding the cooling of steel which is to be annealed. If the casting is of such a shape that it is not likely to crack, it may be cooled in the bed of charcoal in which it has been heated.

Pre-heating Temperatures

Cast iron may be pre-heated to about 700 to 1000 degrees F. Generally speaking, the higher the temperature of pre-heating, the less the danger of cracking when cooling. Aluminum castings should be preheated to about 600 or 700 degrees F., the heat if possible being maintained during the entire time of welding. To accomplish this, it is often advisable to cover the casting with asbestos and to leave only the working area exposed. Asbestos sheeting will be found satisfactory for keeping any class of work hot during the welding.

Example of Repair Work by Oxy-acetylene Welding

It may be of interest to refer to a specific case of welding performed by the Pullman Co. of Chicago. The bed of a hydraulic press was cracked; the casting weighed about 10 tons, and the crack was about 10 inches long and 26 inches deep. The material of the bed was cast steel. The casting was placed on supports of brick about 14 inches high and a fire of wood and charcoal was maintained during the night, with the result that when the welding was begun the metal was at a red heat. A No. 10 Davis-Bournonville tip was used with a soft steel welding rod, two workmen carrying out the work. The time consumed for the welding operation was about five hours. The necessary enlargement of the crack was made by the oxy-acetylene flame. The expense was estimated at $19.16, and the result of the welding was very satisfactory. As the gas cost of the Pullman Co. is extraordinarily low, for ordinary conditions the expense would, perhaps, be as follows:

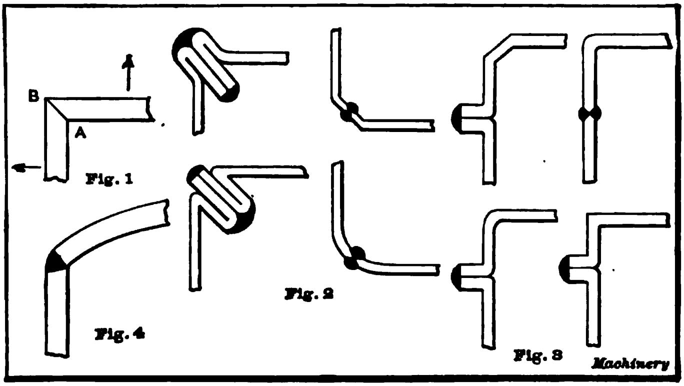
357 cubic feet of oxygen at 3 cents per cubic foot......	$10.71
143 cubic feet of acetylene at 1 cent per cubic foot......	1.43
Labor	7.40
Fuel for pre-heating and annealing....................	4.00
	$23.54

The expense of replacing the casting by a new one would have been about $600.

CHAPTER III

OXY-ACETYLENE WELDING OF TANKS AND RETORTS

One of the most important applications of the oxy-acetylene welding process is in connection with the manufacture of tanks and cylinders from sheet metal. In this field the new process promises to supersede soldering and riveting to a very large extent. The advantage over soldering consists principally in the increased strength of the joint and the equality of the expansion and contraction of the metal in the seam and in the work. There is also much less likelihood of the occurrence of poisonous corrosions.

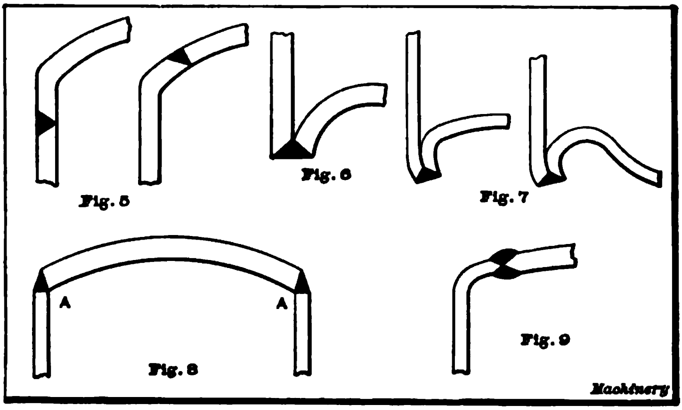


Figs. 1 to 4. Illustrations showing Various Methods of Making Welded Joints

In constructing vessels of sheet metal which are subjected to alternations of high and low internal pressures, it is generally advisable to use special forms of joints at the corners or to avoid corner joints entirely. The stresses on the corner joints become very severe if the corners are of right-angled shape. If the corner is rounded, the effect of the internal pressure at the joint is reduced. In Fig. 1, for example, if the welded joint is made at the square corner *AB*, it will be located at the point where the stresses on it, acting as indicated by the arrows, will be most severe. By forming the joint in the various ways shown in Fig. 2, the weld will be considerably strengthened as compared with a weld that merely joins the two sides at the corner *AB* in Fig. 1. It is still better, however, to remove the joint from the corner altogether. In Fig. 3 are shown the methods used for doing this. The best method of all to relieve the welds of the excessive corner stresses is, of course, to change the horizontal section to that of a circle.

Tops and Bottoms of Sheet-metal Vessels

One of the most difficult operations in the welding of tanks and retorts is the attaching of the tops and bottoms to cylindrical vessels. One of the first methods employed was that of making a joint as shown in Fig. 4. The welding was done from the outside and could be well finished. However, when the vessel was subjected to pressures from within, a combination of compressive and tensional stresses was produced at the weld, thus causing cracks. To overcome this difficulty, joints as indicated in Fig. 5 were made. Where the metal is quite thin, sufficient contact of the surface can be secured by bending the metal outward to form a kind of a flange. By using more welding material than necessary to produce a joint flush with the adjoining surfaces, a stronger weld can also be made.



Figs. 5 to 9. Methods of Welding Tops and Bottoms to Cylindrical Shells

In all these cases, the top or bottom is assumed to be convex on the exterior. Another method, shown in Fig. 6, is to make it concave on the outside. Such forms are especially suitable for bottoms. In Fig. 6 the rim of the bottom is bent and the edges of the bottom and of the cylinder are both beveled to provide a welding groove. Another method which does not necessarily include concaving is to bend up the rim of the bottom for a short distance, the dimensions of the piece being such that this rim snugly envelops the cylinder; the two may then be welded together.

The use of flat tops and bottoms should, of course, be avoided. The expansion and contraction of these during welding are different from those of the cylinder. The flat piece does not yield to the cylinder, and, hence, the work is likely to be distorted. The convexing and concaving of the tops and bottoms provides a suitable margin for yield. Two forms of bottoms are shown in Fig. 7, in both of which elasticity in the diameter is provided for. The bending in of the edges enables the cylinder wall to support the bottom when the latter is under pressure from within. In some cases it may be necessary to prevent diametral expansion of the cylinder when welding. A heavy removable band of metal in the form of a hoop may be used for this purpose. It is placed close up to the location of the seam. Most of the heat from the cylinder will then be absorbed and dissipated by this hoop.

An interesting example of the application of the foregoing principles is afforded by a large containing vessel constructed by Munk & Schmitz, Cologne-Bayenthal, Germany. This vessel is a cylindrical shell, closed at top and bottom, and is formed of sheets 0.40 inch thick in the cylindrical portion and 0.83 inch thick in the end portions. The vessel is 15 feet high and over 9 feet in diameter. All joints were made by the oxy-acetylene torch and the vessel successfully withstood, when tested, a pressure of 90 pounds per square inch.

General Considerations in Welding Tops and Bottoms to Cylindrical Vessels

If the joining of the top to the cylindrical shell were made at the precise point where geometrically the side of the wall joins the top, as shown in Fig. 8, an outward pressure exerted from within and tending to produce a spherical shaped bottom would tend to make the angles at *A* more obtuse and would thus produce a tensional stress on the inner portion and a compressive stress on the outer portion of the weld. Hence, it should be carefully noted that this method of joining ends to cylindrical shells is objectionable, and that the methods shown in Fig. 5 should, in general, be adopted.

It is also very important in forming welds of the type described not to forget the effects of expansion and contraction. It is recommended that the weld be hammered during the cooling-off process. The hammering should be discontinued while the metal is still quite hot, and should not be continued below the point where a horse-shoe magnet attracts the iron; in fact, at this point, one has perhaps gone a little too far. Subsequent to the cooling, the region that has been exposed to the high temperature should also be well annealed. This may be done by using two oil torches for gradual re-heating, one from the inside and one from the outside. Incidentally it might be mentioned that in performing the welding operation it is also often advisable to use two welding torches, in which case a weld of the double-V character, as shown in Fig. 9, will be produced. The bottom of such a vessel should be so arranged that the weld is not located where the weight of the vessel itself comes upon it.

As an interesting practical example, the illustrations Figs. 11, 12 and 13 are shown, indicating the progressive steps in welding a cylindrical shell, as well as the welding of a top and bottom to it. A diagrammatical view of a section of the welded container is shown in Fig. 10, the work being done by the Vilter Mfg. Co., Milwaukee, Wis. It will be seen that the top is convex and the bottom concave, as viewed from the outside. The shell is of 3/8-inch boiler iron; the metal in the heads is 1/2 inch thick. The tank is 20 inches in diameter and 24 inches long. Both heads fit the inside of the shell as indicated.

After welding, this tank was tested at a pressure of 1200 pounds per square inch. For carrying out the test, a hole was drilled on one side of the shell and a nipple inserted after tapping. The tank was then connected with a hydraulic press pump. At 1100 pounds pressure the nipple started to leak, but there was no leak at the welded joints. A No. 7 Davis-Bournonville tip was employed in making the straight weld in the shell, and a No. 8 tip was used for the ends. The straight weld was made in 45 minutes at a cost of $1.62 (exclusive of labor, but including depreciation); the circular weld at the convex end required 2.67 hours and cost $6.99; the circular weld at the concave end required two hours and cost $5.24. At thirty cents per hour, the labor cost would be about $1.63, making a total cost of $15.48. These tanks are used at a maximum working pressure of three hundred pounds per square inch. A water cooled torch was employed in part of this work.

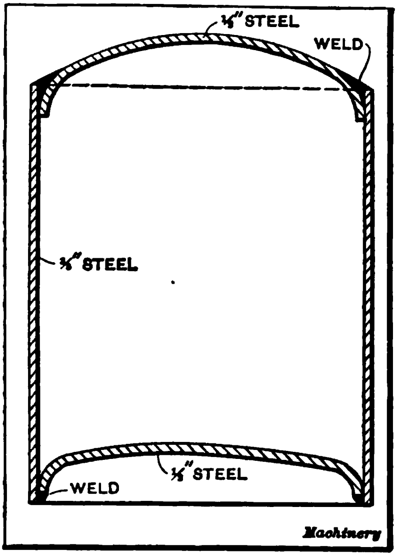


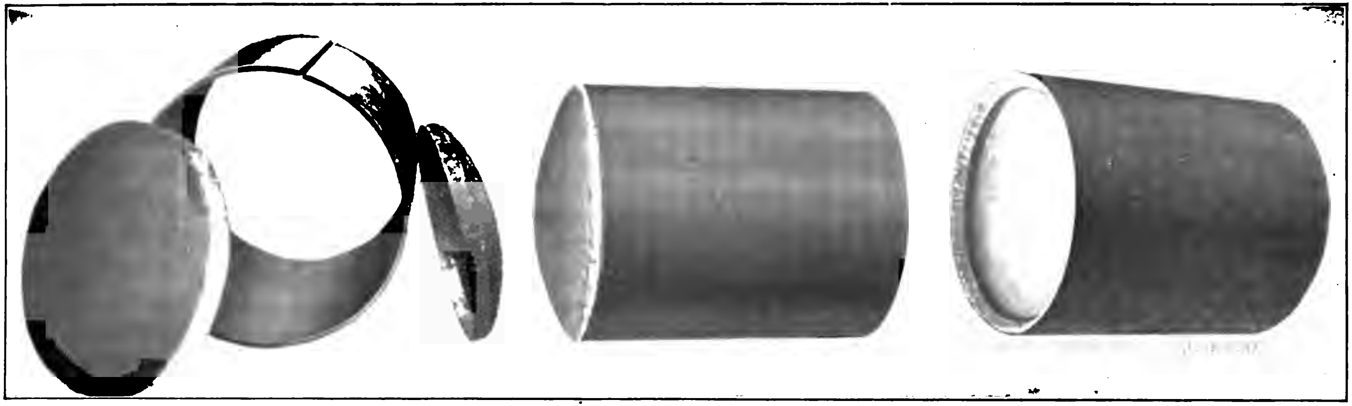
Fig. 10. Example of Tank welded by the Oxy-acetylene Process

Autogenous Welding of Copper

While copper is normally tough and ductile, it enters a brittle stage when heated to about 1650 degrees F. This brittleness continues up to the melting point (at about 1930 degrees F.) In order to weld copper it must be heated to this critical stage. At these high temperatures copper possesses a remarkable capacity for absorbing certain gases. If exposed to the atmosphere while at a white heat it absorbs oxygen.

Another quality of copper is that when heated to a high temperature, quenching in water has a softening or annealing effect. Copper that has been highly heated and oxidized will, however, begin to fracture when one commences to hammer it, even if it has been annealed; hence, it is very important to prevent oxidation when welding, and by proper management of the outer flame of the oxy-acetylene torch the operator may succeed in preserving the new copper in the weld from oxidation. To make perfect work, however, it is necessary also to preserve the old copper, and here is where difficulties are met with. On account of the great heat conductivity of copper, a high temperature will be found for some distance on either side of the joint to be welded. Unless the operator can protect this outlying region, the results will not be satisfactory.

It is well known that phosphorus has a great avidity for oxygen. If, then, instead of a very pure copper we use a phosphor-copper alloy



Figs. 11, 12 and 13. Progressive Steps in Making the Tank shown in Fig. 10

when welding, good results may be expected. A welding powder containing a percentage of phosphorus may also be used to secure a deoxidation. Investigations along these lines have been carried on in Germany; it can be stated, in a general way, that good welding powders for copper can be made of such mixtures as borax, phosphor-natrium and prussiate of potash. The borax is not commercial borax, but that which has been subjected to a high temperature in a crucible and has then been pulverized.

Boracic acid may be used instead of borax. The powder is prepared by mixing the boracic acid and the phosphor-natrium. Welding powders of this description form a film over the work and thus exclude the atmosphere. It is recommended when welding copper sheeting to spread the powder containing phosphorus for about 1½ inch on either side of the joint. This powder is then melted before the welding operation proper is begun. As there is some possibility of blowing away some of the powder when used in this way, it would seem desirable to apply it in the form of a paste.

See also the section "Welding Brass and Copper" in Chapter I, where some additional information on this subject is given. It is also well to consult the catalogues of firms making autogenous welding outfits.

The Welding of Aluminum

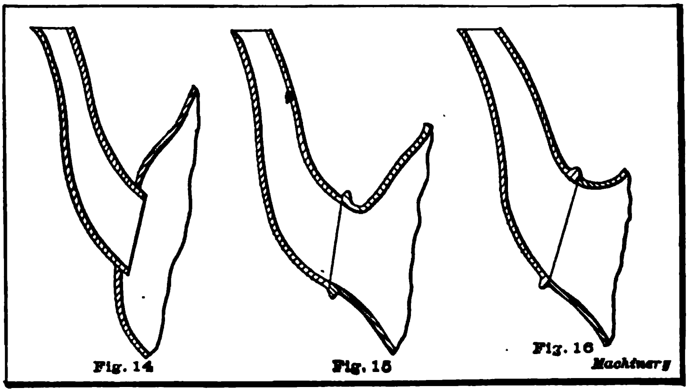
The coefficient of expansion of aluminum is equal to twice that of steel and its melting point compared with that of copper and steel is rather low, being about 1215 degrees F. It is also comparatively weak in tension. Cast aluminum resists a tensional stress of about 10,000 pounds per square inch. Because of this weakness, and on account of its high rate of expansion and contraction, it is a difficult material to weld. As its heat conductivity is high, it is also difficult to localize the region of the high temperature. Oxidation of aluminum, however, can be avoided by the use of a proper flux.

While the total expansion and contraction from 100 degrees F. to the fusion point or welding temperature is about the same for cast iron and aluminum, because of the fact that the fusion point of cast iron is at a temperature about twice that of the fusion point of aluminum, the expansion and contraction, due to temperature changes, take place much more rapidly with aluminum, and the operator must use special care on this account. The low temperatures dealt with when welding aluminum make the pre-heating easier, but the operator must guard against not exceeding the fusion temperature. It is sometimes possible to make slight saw cuts here and there, and thus assist in making the effects of expansion and contraction harmless. These cuts, of course, must be repaired when the main operation is completed. Aluminum should never be welded without a flux. If welding is attempted without a flux, little globules consisting of aluminum within and a coating of alumina (oxide of aluminum) will appear. In order to eliminate these by heat, it would be necessary to raise the temperature to the melting point of the oxide of aluminum, which is about 5400 degrees F. A flux consisting of the following ingredients has been recommended: chloride of sodium, 30 parts; chloride of potassium, 45 parts; chloride of lithium, 15 parts; fluoride of potassium, 7 parts; and bisulphate of sodium, 3 parts.

When melting new metal from a rod, it is good practice to keep the rod constantly submerged in the molten bath of the metal in the welding groove, which for aluminum should be much larger than usual. If no powder is used, the oxidation is then confined to the upper surface. The main point to remember when welding aluminum is that the fusion point of this metal is very low; hence, the working flame should be kept further away from the metal than is usually the case when welding cast iron and steel. The torch should be so adjusted as to furnish an excess of acetylene. There need be but little fear of carbonizing the metal, for the reason that the temperature of the work is comparatively low.

The Welding of Household Utensils

Some forms of household utensils, such as, for example, coffee and tea pots, cause considerable difficulties in their manufacture, particularly in connection with the attachment of the spout. Soldering has been used to a great extent in making these joints. However, the basic material of the solder is altogether different from the material united. The uses to which the vessels are put expose the joints to the action of acids, and galvanic currents are set up which injure the joint. Aluminum vessels are especially exposed to the action of these currents, because this metal is electro-positive to nearly all of the common metals. One means to obviate the difficulty is to bend the metal of the main vessel or body inwards at the hole for the spout. The material of both body and spout is then bent into a fold on the interior, no soldering material being used. The presence of this fold on the inside, however, is very objectionable. Even though it is closed when the vessel is new, the effect of repeated heatings is liable to open it, and the crevice becomes a trap for various small particles,



Figs. 14, 15 and 16. Methods of Welding Spouts to Household Utensils

which prevents effective cleaning. The oxy-acetylene welding presents the best solution of the foregoing difficulties.

When seeking to unite the spout and body by the oxy-acetylene torch, the worker is, however, confronted with several difficulties, especially if the sheet metal be aluminum. The expansion and contraction of aluminum, due to temperature changes, as already mentioned, is very rapid, so that the operator must guard against distortions of the work. The melting point of the metal is low, so that holes are apt to be made in thin metal. Heated aluminum is very readily oxidized with the result that a proper intermingling of the material is difficult. In view of these facts, it is recommended that the joint be placed away from the main body, that welding wire be dispensed with, and that a suitable flux be employed. In Fig. 14 is shown a joint which eliminates the necessity for the welding wire; the spout fits closely into the hole and is introduced far enough to protrude about ⅛ inch into the interior, the projection thus furnishing the welding material. There is considerable advantage, of course, in thus eliminating the handling of the wire as far as the worker is concerned, and another advantage is that the welding material is precisely the same as the material of the work. It is difficult, however, to operate on the interior, but this difficulty may be reduced by using a tip of special form. The appearance of the exterior, however, is good.

Another form of joint is shown in Fig. 15. Here the diameter of the hole is first made smaller than the interior diameter of the lower end of the spout. The material is then bent outwards to form a ridge of

Fig. 17. Example of Welding Copper. Kettle is 5 feet 6 inches in Diameter, 31 inches deep and used under Pressure. All seams are welded on Both Sides

the same diameter as that of the spout end. The body and spout can then be butt-welded by using welding wire. It is preferable, however, to bend the edge of the projection from the vessel outward, thus supplying the needed welding metal, or the auxiliary metal may be provided by bending the edge of the spout outwards, a joint of this kind being shown in Fig. 16. In either case, the ring of metal protruding at the joint will not be thicker than 1/8 inch in a radial direction. In both cases, the interior is smooth.

CHAPTER IV

AUTOGENOUS WELDING AS A MEANS OF REPAIRING CYLINDERS

Breakages in automobile cylinders can be divided into three main classes which cover at least ninety per cent of the cases. The majority of these breakages can be satisfactorily repaired by means of the oxy-acetylene flame, the cylinder being as good as new. Additional metal is added where necessary from a rod of the same material, and the process consists in practically recasting the part locally.

Autogenous welding is proving a great boon to those who are unfortunate enough to have their automobile cylinders broken, as they can be satisfactorily welded and in the majority of cases, with a little trimming off, the repairs will not show. Cylinders with cracks are sometimes brazed, but owing to the necessity of heating the whole cylinder to a good red heat to even up the contraction strains, so as not to crack when cooling, the bore of the cylinder is generally warped, and the job requires a lot of finishing as the spelter and flux spread considerably and are difficult to remove. Also, owing to the dirt and rust in the crack it is difficult to get the brazing below the surface; the high temperature necessary will sometimes crack the cylinder elsewhere.

Water Jackets Broken by Freezing

The largest class of cylinder breakages—mainly due to carelessness or misfortune, probably in most cases the former—is caused by allowing the water jacket to freeze, resulting in the breaking of the water jacket wall. Also, it has frequently happened that when shipping a car by rail in winter the drain cocks were opened, but due to some pocket in the water system (in some cases very small ones) which did not drain, the cylinders have become fit subjects for the autogenous welder.

Curiously enough the majority of cylinders cast from the same patterns will break in just the same place when frozen. In a number of cases the break causes a piece of the wall of the water jacket to be entirely detached, and the breaks occur so nearly alike, in similar cylinders, that it would be possible to take the detached piece from one and weld it into another, even the smaller irregularities coinciding.

When a break of this nature is autogenously welded, by means of the oxy-acetylene flame, the crack or edge of the broken part is prepared so as to leave a groove nearly through the metal. The whole part is then uniformly heated to about five hundred degrees F. This temperature is not high enough to warp the bore, as has been repeatedly proved by careful measurements before and after treatment. The sides of the groove are fused together and filled from a rod of cast iron. The resulting weld is very neat in appearance; it generally requires no finishing and is as strong as the original wall. As a very small number of heat units are absorbed by the part, owing to the intense heat of the flame fusing the metal before the heat has time to spread, there is seldom any trouble with cracks when the metal contracts in cooling. The cylinders *A* and *B*, Fig. 1, show common types of breakages which are being satisfactorily welded every day. The crack in *A* is seventeen inches in length. Both cylinders are grooved out ready for welding.

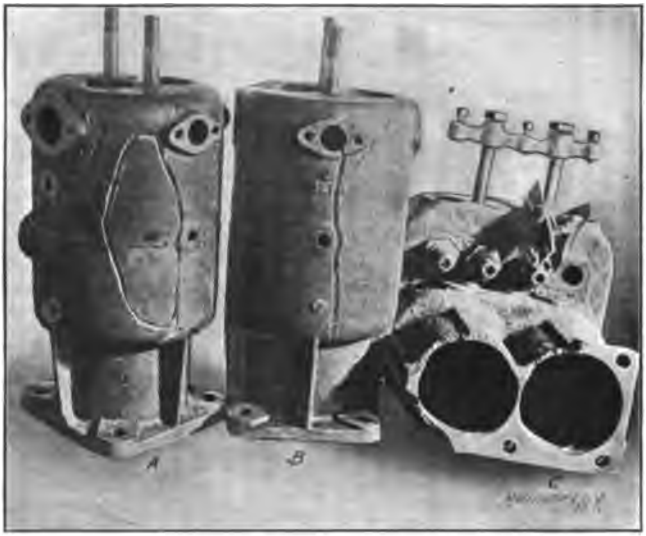


Fig. 1. Two Cylinders with Cracked Water Jackets prepared for Welding. Twin Cylinders with Broken Flanges to be Welded

Cylinder Wall Broken

The next class of breakages, in order of frequency of occurrence, is that in which the wall of the cylinder, combustion or valve chamber, is broken or cracked. These breaks are, in most cases, due to freezing, but a certain number of them are due to the designer making a large flat surface without adequate ribbing to support the pressure of the explosion.

Another cause is the breakage of the connecting-rod, allowing the piston to strike the top of the cylinder. Serious damage from this cause occurs most frequently in two-cycle engines as the deflector on the piston readily punches a hole in the combustion chamber wall.

This class of breakages is the most difficult to repair, as it is necessary in most cases to cut out a section of the water jacket to be able to work on the inner wall, the only exception occurring when the break happens to be opposite a large hand hole. This operation has a singular resemblance to the well-known trepanning operation performed upon the human skull.

It can be readily seen that it is practically impossible to make a repair when the break occurs between two cylinders or behind the valve chamber, as these parts cannot be reached with the small flame. If the crack occurs in the bore, it is necessary to carefully weld to within a sixteenth inch of the bore, or the finished surface will be spoiled; the crack left in this way is of small importance, as sufficient metal can be built on the outside so that there is no doubt about the strength. After welding the break, the section of the water jacket which was removed is welded back in place.

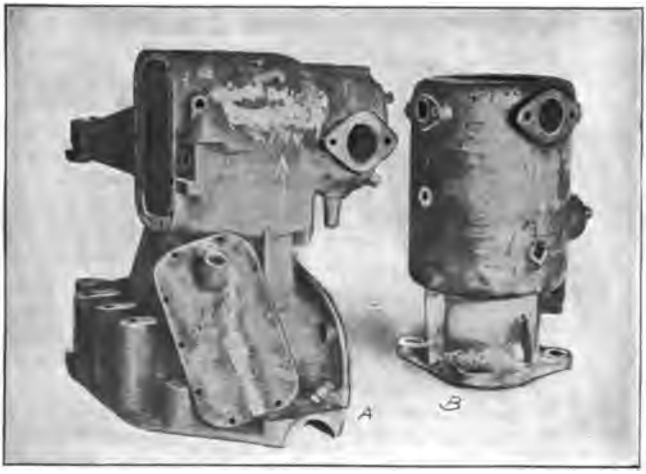


Fig. 2. Cylinder A repaired by inserting a Steel Piece, bent to Shape, and autogenously welded in Place. Cylinder B has had Flange repaired

As it often is impossible to determine the length or exact locality of the cracks before cutting away the jacket and as it is desirable to remove as small a section as possible, it often is found necessary to cut additional pieces out, thus necessitating welding a number of small pieces back in place when finishing the job. To restore these pieces sometimes is impracticable, and a sheet steel substitute must be hammered out and welded in place. With care this piece can be shaped so as to coincide with the piece removed, and cannot be detected when welded in place. The part cut away was thus neatly replaced by sheet steel, as shown at *A*, Fig. 2.

The water in freezing will often crack both the water jacket and cylinder wall. The former being readily seen is generally thought to be the full extent of the damage, particularly as it is practically impossible to make a test until the crack is repaired. The work may then have to be cut out to find further defects.

The cover plate on the cylinder shown in Fig. 2 was also broken in freezing, at the same time as the cylinder wall was broken, and is shown welded.

Fig. 3 shows a cylinder having a crack eight inches long, located at the corner of the combustion head, that was welded. The part cut out of the water jacket is also shown. It will be noticed that this operation required cutting through a supporting lug.

Broken Flanges

The next order of breakages in point of number are those in which all, or a portion of the flange, which holds the cylinder to the crank case is broken away, due either to insufficient metal to withstand the strain or to carelessness in assembling.

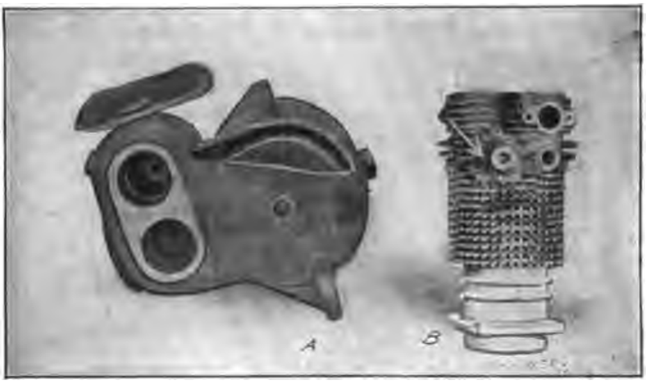


Fig. 3. Cylinder Cracked in Inner Wall, showing Large Section of Outer Wall removed to weld the Crack

Fig. 4. Air-cooled Cylinder on which Boss for Ignition Plug was autogenously welded

These breakages occur in two ways; the wall of the cylinder may be broken away or part of the flange may be cracked off. In the latter case it is an easy matter to make the repair, but when the break runs through into the bore of the cylinder considerable care is required. First it is necessary to consider whether it is desirable to weld in the bore which would then require machining or at any rate filing out, or only groove and weld from the outside to within a sixteenth inch of the bore, sufficient metal being added to the outside to insure strength. The latter method, of course, leaves the crack on the inside, which can, however, be smoothed down and is not objectionable for a repair job, as it does not interfere with the satisfactory operation of the motor in any way.

In addition to these three classes, there is a large variety of other breakages, no two of which are alike, that can be repaired successfully by the oxy-acetylene torch. Considerable welding can also be carried out by the manufacturer, such as the welding on of additional bosses for dual ignition systems, as shown in Fig. 4, building up bosses that did not "fill" in castings, etc.

CHAPTER V

MANUFACTURE OF TUBING BY AUTOGENOUS WELDING

The trend of industrial processes, today, is in the direction of continuity. If a process can be made continuous, a great advantage is gained, other things being equal. It is no wonder, then, that in consequence of the enormous demand for water, gas and steam piping, very determined efforts have been made to produce tubing by the process of rolling. The efforts have been successful, and steel

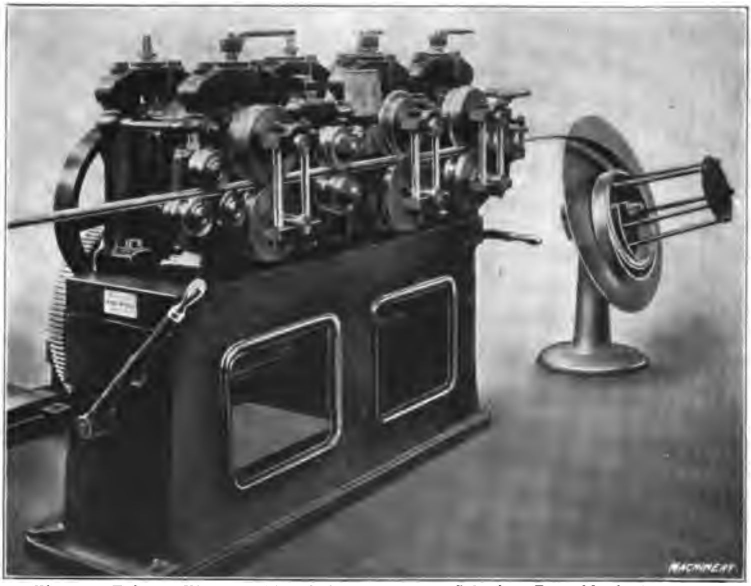


Fig. 1. Tube Rolling Machine built by August Schmitz, Dusseldorf, Germany

tubing is now made in large quantities by this method. Strips of flat steel are rolled longitudinally between successive pairs of rolls until the edges meet or overlap. They are then butt- or lap-welded.

In Germany, tubing is being made by the rolling of sheet metal and the subsequent welding with oxygen and acetylene, the process being continuous, and a special welding machine being used. The rolling machine is of the type shown in Fig. 1. This machine receives the metal in long flat strips, which have either been specially rolled or cut to the required width. The first operation is accomplished by a pair of rolls which bend the longitudinal edges upward. These bent-up edges will ultimately form the "roof" of the tube. It is important that the degree of curvature of the bends shall be precisely that of the finished tube. Another pair of rolls just ahead receives the strip and bends it into a U-shaped form; the upper ends of the U-curve, however, are bent toward each other because of the side bends formed by the previous pair of rolls. Another pair of rolls is now employed to receive the U-shaped strip and cause it to approximate still more closely the tube-shape. Finally, another pair of rolls complete the bending to shape; a mandrel is employed with this pair. In case very elastic material is employed, it is advisable in the first pass to bend the axial portion so that when the tube is shaped it will point in toward the inside of the tube. In the last operation, this bend will be eliminated by the mandrel. The object is to obtain a joint with no tendency to open.

When a strip which has been cut from a sheet in the ordinary way is thus bent together, there will be a V-shaped groove along the joint.

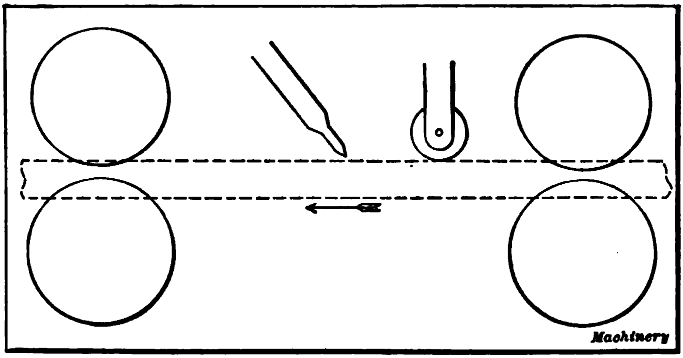


Fig. 2. Principle of Autogenous Tube-welding Machine

The reason for this is that the external circumference of an annular ring is longer than the internal one. The strip is of the same width on both sides, so that when one side is bent to form a complete inner circle there is not enough material for the outer circle. The weld can still be made, but as machine welds use no additional metal, the section at the weld will be thinner than it ought to be. If the tubing is made of quite thin metal, no especial difficulty will arise from the formation of a groove; but when the wall is rather thick, strips which have been especially rolled to provide a greater width on one side than on the other should be used. When such a strip is bent to the final shape, we have a narrow V-shaped groove with ridges on each side. A narrow groove is advisable, because it admits the flame to the entire depth of the joint.

The welding machine is rather simple. Two pairs of compression rolls are placed a short distance apart, as indicated in the diagrammatical view, Fig. 2. These rolls carry the tube along, the one pair receiving it from the tube rolling mill. Between the two pairs of rolls a standard is placed to which is secured the device which holds the torch. This latter has its tip directed downward and toward the unwelded joint. The angle of inclination is about 45 degrees. The tubing, as it is fed along by the first pair of rolls, can scarcely be depended upon to keep its unwelded joint in a constantly uniform position. It is, however, necessary that the working flame of the torch and this joint shall be in an exact relation to each other. Therefore, a holder is provided which carries a roll or wheel having a thin edge or projection on its periphery. This edge enters into the groove at the joint and controls its position just before it reaches the torch. This machine is made of the duplex type, so that two welding operations may be handled at the same time; a torch and the necessary rolls are arranged on each side of the bed. Comparatively thin tubing, say 0.04 inch in thickness, can be welded at the rate of about 8 inches per second, or about 40 feet per minute.

It is frequently the custom in the bicycle industry to draw tubing to an oval or elliptical section. The most severe stresses to which such elliptical tubing is subjected would tend to injure the weld if the latter should be located at the end of either axis of the ellipse. It has been found advisable, therefore, to locate the seam to one side of the "sharp" end of the ellipse. A Swedish charcoal iron, containing very little carbon, is said to be most suitable for this class of work.

In the rolling of tubes of small diameter, it is permissible to roll in a longitudinal direction, but when we come to greater diameters, it becomes necessary, or at least advisable, to discard the continuous method and use rolls or other devices whose axes are parallel with that of the tube. Machines specially built for this service bend the sheets quickly to the required cylindrical form. Diameters of 3 to 10 inches are readily handled, the material having a thickness up to ¼ inch. The forming process requires from 7 to 12 minutes for each section of tubing, according to the length. Large tubes are usually welded autogenously by hand.

That large pipe made by the oxy-acetylene process is reliable is indicated by the following test: Two sections of such pipe, each about 39 feet long and 35 inches inside diameter had their flanges bolted together to form a single length of nearly 80 feet. The supports were placed at the ends so that the full length between them was unsupported. Then the double length of tubing was loaded with about thirty men, or, in other words, a load of more than two tons was supported. Of course this test does not take into account the question of the "water-tightness" of the weld. However, a test was carried out upon another piece of welded tubing—this time a bend—of about 2 feet inside diameter. The tube did not leak under a pressure of about 365 pounds per square inch. Another piece of tubing about 31 or 32 inches in diameter has been made by the welding process from material which was about 0.4 inch thick. A drainage system for a lock of the Kaiser-Wilhelm canal contains about 2000 feet of pipe welded by the autogenous process. One German firm is manufacturing hot water heaters by the same process.

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CHAPTER I

DRAWING AND FORMING DIES

Comparatively little information has been published in book form relating to the subject of drawing dies. This depends partly upon the fact that this line of work in some respects is still in its infancy. While an enormous amount of this kind of work is done daily in hundreds of shops in the country, yet there is a scarcity of definite information as to the fundamental rules that govern this class of work. Some day some one will take up this subject in a manner similar to that in which Mr. F. W. Taylor investigated the art of cutting metals, and then we may be able to lay down exact rules and formulas governing the drawing of metal sheets into shells. At present we must content ourselves with studying a few general principles based upon experience. By giving a great number of examples of work that has been accomplished in practice, the possibilities in this class of work may, however, be indicated.

A large majority of work which, in the past, has been made from castings is now made from sheet steel by drawing up bosses and reinforcing ribs to strengthen the work. The development in the art has been rapid, but has proceeded almost entirely along cut-and-try methods. The definite information that is available, however, relating to the diameters of shell blanks, the depth and diameter reductions of drawn shells, the lubrication of dies, etc., will be given in the following. In addition, a number of practical hints for die-makers in the making of forming dies will be presented, and numerous examples of successful designs of drawing, forming and bending dies. This will give the reader a comprehensive view of the present state of the art.

Diameters of Shell Blanks*

The diameters of blanks for drawing plain cylindrical shells can be obtained from the accompanying table, which gives a very close approximation for thin stock. The blank diameters given in this table are for sharp cornered shells and are found by the following formula:

$$D = \sqrt{d^2 + 4\,dh}, \qquad (1)$$

in which D = diameter of flat blank; d = diameter of finished shell; h = height of finished shell.

Example.—If the diameter of the finished shell is to be 1.5 inch, and the height, 2 inches, the trial diameter of the blank would be found as follows:

$$D = \sqrt{1.5^2 + 4 \times 1.5 \times 2} = \sqrt{14.25} = 3.78 \text{ inches.}$$

For a round-cornered cup, the following formula, in which r equals the radius of the corner, will give fairly accurate diameters, provided

*From MACHINERY'S HANDBOOK, page 979.

the radius does not exceed, say, ¼ the height of the shell:

$$D = \sqrt{d^2 + 4\,dh} - r. \qquad (2)$$

These formulas are based on the assumption that the thickness of the drawn shell is the same as the original thickness of the stock, and that the blank is so proportioned that its area will equal the area of the drawn shell. This method of calculating the blank diameter is quite accurate for thin material, when there is only a slight reduction in the thickness of the metal incident to drawing; but when heavy stock is drawn and the thickness of the finished shell is much less than the original thickness of the stock, the blank diameter obtained from Formulas (1) or (2) will be too large, because when the stock is drawn thinner, there is an increase in area. When an appreciable reduction in thickness is to be made, the blank diameter can be obtained by first determining the "mean height" of the drawn shell by the following formula. This formula is only approximately correct, but will give results sufficiently accurate for most work:

$$M = \frac{ht}{T} \qquad (3)$$

in which M = approximate mean height of drawn shell; h = height of drawn shell; t = thickness of shell; T = thickness of metal before drawing.

After determining the mean height, the blank diameter for the required shell diameter is obtained from the table previously referred to, the mean height being used instead of the actual height.

Example.—Suppose a shell 2 inches in diameter and 3¾ inches high is to be drawn, and that the original thickness of the stock is 0.050 inch, and thickness of drawn shell, 0.040 inch. To what diameter should the blank be cut? Using Formula (3) to obtain the mean height:

$$M = \frac{ht}{T} = \frac{3.75 \times 0.040}{0.050} = 3 \text{ inches.}$$

According to the table, the blank diameter for a shell 2 inches in diameter and 3 inches high is 5.29 inches. This formula is accurate enough for all practical purposes, unless the reduction in the thickness of the metal is greater than about one-fifth the original thickness. When there is considerable reduction, a blank calculated by this formula produces a shell that is too long. This, however, is an error in the right direction, as the edges of drawn shells are ordinarily trimmed. If the shell has a rounded corner, the radius of the corner should be deducted from the figures given in the table. For example, if the shell referred to in the foregoing example had a corner of ¼-inch radius, the blank diameter would equal 5.29 — 0.25 = 5.04 inches.

Another formula which is sometimes used for obtaining blank diameters for shells, when there is a reduction in the thickness of the stock, is as follows:

DIAMETERS OF BLANKS FOR DRAWN SHELLS

Diameter	Height of Shells																							
	¼	½	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6
¼	.56	.75	.90	1.03	1.14	1.25	1.35	1.44	1.52	1.60	1.68	1.75	1.82	1.89	1.95	2.01	2.08	2.14	2.19	2.25	2.30	2.36	2.41	2.46
½	.87	1.12	1.32	1.50	1.66	1.80	1.94	2.06	2.18	2.29	2.40	2.50	2.60	2.69	2.78	2.87	2.96	3.04	3.12	3.21	3.29	3.36	3.44	3.50
¾	1.14	1.44	1.68	1.89	2.08	2.25	2.41	2.56	2.70	2.84	2.97	3.09	3.21	3.33	3.44	3.54	3.65	3.75	3.85	3.95	4.04	4.13	4.22	4.31
1	1.41	1.73	2.00	2.24	2.45	2.65	2.83	3.00	3.16	3.32	3.46	3.61	3.74	3.87	4.00	4.12	4.24	4.36	4.47	4.58	4.69	4.80	4.90	5.00
1¼	1.68	2.01	2.30	2.56	2.79	3.01	3.21	3.40	3.58	3.75	3.91	4.07	4.22	4.37	4.51	4.64	4.77	4.91	5.03	5.15	5.27	5.39	5.50	5.62
1½	1.94	2.29	2.60	2.87	3.12	3.36	3.57	3.78	3.97	4.15	4.33	4.50	4.66	4.82	4.98	5.12	5.27	5.41	5.55	5.68	5.81	5.94	6.06	6.18
1¾	2.19	2.56	2.88	3.17	3.44	3.68	3.91	4.13	4.34	4.53	4.72	4.91	5.08	5.26	5.41	5.58	5.73	5.88	6.03	6.17	6.31	6.45	6.58	6.71
2	2.45	2.83	3.16	3.46	3.74	4.00	4.24	4.47	4.69	4.90	5.10	5.29	5.48	5.66	5.83	6.00	6.16	6.32	6.48	6.63	6.78	6.93	7.07	7.21
2¼	2.70	3.09	3.44	3.75	4.04	4.31	4.56	4.80	5.03	5.25	5.46	5.66	5.86	6.05	6.23	6.41	6.58	6.75	6.91	7.07	7.23	7.39	7.54	7.69
2½	2.96	3.36	3.71	4.03	4.33	4.61	4.87	5.12	5.36	5.59	5.81	6.02	6.22	6.42	6.61	6.80	6.98	7.16	7.33	7.50	7.66	7.82	7.98	8.14
2¾	3.21	3.61	3.98	4.31	4.62	4.91	5.18	5.44	5.68	5.92	6.15	6.37	6.58	6.79	6.99	7.18	7.37	7.55	7.73	7.91	8.08	8.25	8.41	8.58
3	3.46	3.87	4.24	4.58	4.90	5.20	5.48	5.74	6.00	6.25	6.48	6.71	6.93	7.14	7.35	7.55	7.75	7.94	8.12	8.31	8.49	8.66	8.83	9.00
3¼	3.71	4.13	4.51	4.85	5.18	5.48	5.77	6.04	6.31	6.56	6.80	7.04	7.27	7.49	7.70	7.91	8.11	8.31	8.50	8.69	8.88	9.06	9.24	9.41
3½	3.97	4.39	4.77	5.12	5.45	5.77	6.06	6.34	6.61	6.87	7.12	7.36	7.60	7.83	8.05	8.26	8.47	8.67	8.87	9.07	9.26	9.45	9.63	9.81
3¾	4.22	4.64	5.03	5.39	5.73	6.05	6.35	6.64	6.91	7.18	7.44	7.69	7.92	8.16	8.38	8.61	8.82	9.03	9.24	9.44	9.63	9.83	10.02	10.20
4	4.47	4.90	5.29	5.66	6.00	6.32	6.63	6.93	7.21	7.48	7.75	8.00	8.25	8.49	8.72	8.94	9.17	9.38	9.59	9.80	10.00	10.20	10.39	10.58
4¼	4.72	5.15	5.55	5.92	6.27	6.60	6.91	7.22	7.50	7.78	8.05	8.31	8.56	8.81	9.04	9.28	9.50	9.72	9.94	10.15	10.36	10.56	10.76	10.96
4½	4.98	5.41	5.81	6.19	6.54	6.87	7.19	7.50	7.79	8.08	8.35	8.62	8.87	9.12	9.37	9.60	9.84	10.06	10.28	10.50	10.71	10.92	11.12	11.32
4¾	5.22	5.66	6.07	6.45	6.80	7.15	7.47	7.78	8.08	8.37	8.65	8.92	9.18	9.44	9.69	9.93	10.16	10.40	10.62	10.84	11.06	11.27	11.48	11.69
5	5.48	5.92	6.32	6.71	7.07	7.42	7.75	8.06	8.37	8.66	8.94	9.22	9.49	9.75	10.00	10.25	10.49	10.72	10.95	11.18	11.40	11.62	11.83	12.04
5¼	5.73	6.17	6.58	6.97	7.33	7.68	8.02	8.34	8.65	8.95	9.24	9.52	9.79	10.05	10.31	10.56	10.81	11.05	11.28	11.51	11.74	11.96	12.18	12.39
5½	5.98	6.42	6.84	7.23	7.60	7.95	8.29	8.62	8.93	9.23	9.53	9.81	10.08	10.36	10.62	10.87	11.12	11.37	11.61	11.84	12.07	12.30	12.52	12.74
5¾	6.23	6.68	7.09	7.49	7.86	8.22	8.56	8.89	9.21	9.52	9.81	10.10	10.38	10.66	10.92	11.18	11.44	11.69	11.93	12.17	12.40	12.63	12.85	13.08
6	6.48	6.93	7.35	7.75	8.12	8.49	8.83	9.17	9.49	9.80	10.10	10.39	10.68	10.95	11.23	11.49	11.75	12.00	12.25	12.49	12.73	12.96	13.19	13.42

$$D = \sqrt{a^2 + \left(a^2 - b^2\right) \frac{h}{t}} \qquad (4)$$

In this formula D = blank diameter; a = outside diameter; b = inside diameter; t = thickness of shell at bottom; h = depth of shell. This formula is based on the cubic contents of the drawn shell. It is assumed that the shells are cylindrical, and no allowance is made for a rounded corner at the bottom, or for trimming the shell after drawing. To allow for trimming, add the required amount to depth h. When a shell is of irregular cross-section, if its weight is known, the blank diameter can be determined by the following formula:

$$D = 1.1284 \sqrt{\frac{W}{wt}} \qquad (5)$$

in which D = blank diameter in inches; W = weight of shell; w = weight of metal per cubic inch; t = thickness of the shell.

In the construction of dies for producing shells, especially of irregular form, a common method of procedure is to make the drawing parts first. The actual blank diameter can then be determined by trial. One method is to cut a trial blank as near to size as can be estimated. The outline of this blank is then scribed on a flat sheet, after which the blank is drawn. If the finished shell shows that the blank is not of the right diameter, a new trial blank is cut either larger or smaller than the size indicated by the line previously scribed, this line acting as a guide. If a model shell is available, the blank diameter can also be determined as follows: First cut a blank somewhat large, and from the same material used for making the model; then reduce the size of the blank until its weight equals the weight of the model.

Depth and Diameter Reductions of Drawn Shells

The depth to which metal can be drawn in one operation depends upon the quality and kind of material, its thickness, the slant or angle of the dies, and the amount that the stock is thinned or "ironed" in drawing. A general rule for determining the depth to which cylindrical shells can be drawn in one operation is as follows: The depth or length of the first draw should never be greater than the diameter of the shell. If the shell is to have a flange at the top, it may not be practicable to draw as deeply as is indicated by this rule, unless the metal is extra good, because the stock is subjected to a higher tensile stress, owing to the larger blank which is necessary for forming the flange. According to another rule, the depth given the shell on the first draw should equal one-third the diameter of the blank. Ordinarily, it is possible to draw sheet steel of any thickness up to ¼ inch, so that the diameter of the first shell equals about six-tenths of the blank diameter. When drawing plain shells, the amount that the diameter is reduced for each draw must be governed by the quality of the metal and its susceptibility to drawing. The reduction for various thicknesses of metal is about as follows:

Approximate thickness of sheet steel....	1/16	1/8	3/16	1/4	5/16
Possible reduction in diameter for each succeeding step, per cent..........	20	15	12	10	8

For example, if a shell made of 1/16-inch stock is 3 inches in diameter after the first draw, it can be reduced 20 per cent on the next draw, and so on until the required diameter is obtained. These figures are based upon the assumption that the shell is annealed after the first drawing operation, and at least between every two of the following operations. Necking operations—that is, the drawing out of a short portion of the lower part of the cup into a long neck—may be done without such frequent annealings. In double-action presses, where the inside of the cup is supported by a bushing during drawing, the reductions possible may be increased to 30, 24, 18, 15 and 12 per cent, respectively. (The latter figures may also be used for brass in single-action presses.)

When a hole is to be pierced at the bottom of a cup and the remaining metal is to be drawn after the hole has been pierced or punched, always pierce from the opposite direction to that in which the stock is to be drawn after piercing. In extreme cases, it is necessary to machine the metal around the pierced hole in order to prevent the starting of cracks or flaws in the subsequent drawing operations.

The foregoing figures represent conservative practice and it is often possible to make greater reductions than are indicated by these figures, especially when using a good drawing metal. Taper shells require smaller reductions than cylindrical shells, because the metal tends to wrinkle if the shell to be drawn is much larger than the punch. The amount that the stock is "ironed" or thinned out while being drawn must also be considered, because a reduction in gage or thickness means greater pressure of the punch against the bottom of the shell; hence the amount that the shell diameter is reducd for each drawing operation must be lessened when much ironing is necessary. The extent to which a shell can be ironed in one drawing operation ranges between 0.002 and 0.004 inch per side, and should not exceed 0.001 inch on the final draw, if a good finish is required.

Prevention of Wrinkles in Drawn Work

The formation of wrinkles in drawing operations is a source of great trouble, and there are many pieces of drawn work which could be performed in a single operation were it not for the wrinkles that would inevitably appear. In drawing operations, the tendency to wrinkle starts with the first contact of the punch upon the metal.

The usual method of preventing wrinkles is to provide the punch with a blank-holder which is operated by springs of sufficient tension to allow the metal to be pulled from beneath it for drawing, but maintaining pressure enough to keep the metal free from wrinkles. At *A*, in Fig. 1, is shown a section of a simple drawing die in which it will be noticed that the die is provided with a raised ridge around its opening, the blank-holder having a corresponding depression. Consequently, the sheet metal being drawn is pulled over this ridge, and as the space between the blank-holder and the top of the ridge is purposely made slightly less than the thickness of the metal, it will be seen that as the stock passes through this opening any wrinkles are "ironed out." At *B*, the shell from the dies at *A* is shown undergoing a second operation.

For strength and protection in hardening, as well as to facilitate the drawing operation, the ridge is provided with a fillet where it joins the flat surface of the die. It is obvious that the addition of this ridge to the drawing die occasions a little extra work in the die-making, but this work is offset by the fact that the blank-holder and upper surface of the drawing die do not have to be ground perfectly smooth and parallel, as is ordinarily required. The size of the ridge around the die should be in proportion to the diameter of the shell. A shell 4 inches in diameter is most easily drawn with a die having a ridge of

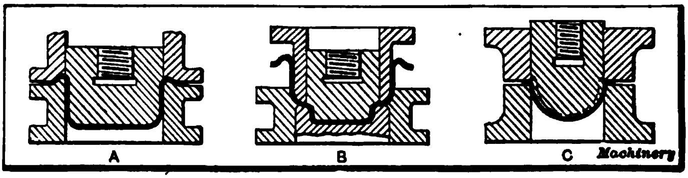


Fig. 1. A Method of Drawing Sheet Metal by Means of which Wrinkling of the Stock is avoided

7/16 inch radius. For a shell of 8 inches diameter the radius of the ridge should be ½ inch. For a shell 12 inches in diameter the radius of the ridge should be ⅝ inch. For a shell 16 inches in diameter the radius of the ridge should be ¾ inch, and a shell 20 inches in diameter would require a ridge having a radius of 1 inch.

It is obvious that the completed shell will have a ridge left at the edge. On work which is to be wired or for work on which the edge is to be turned over, this additional ridge is no detriment as it can be made use of directly. Moreover, if a succeeding operation is to follow, deepening the shell slightly, this ridge will provide the surplus metal required. This point is illustrated at *C*. In other cases, the extra metal left at the edge may be removed when the shell is trimmed. It is claimed that this improvement in drawing dies is being employed with success. By its use, wrinkles are absolutely prevented, and, moreover, the drawing operation puts less stress upon the metal.

Practical Hints for Diemakers in making Drawing and Forming Dies

In making templets and blanks, always file them straight and square across the edge. In developing the blank always keep a templet or reference blank, so that it will be at hand if alterations are found necessary. Each time a change is made the previous blank which was kept for reference is marked to designate it from others. The marks may be "M" for model or "S" for sample. It should be remembered that metal will not draw around sharp corners, and that corners over which the metal is to be drawn should be rounded to a true radius. In all cases when making blanks for forming punches and dies consider the thickness of the metal.

In forming blanks they should always be bent with the grain of the metal and not across it, particularly on sharp bends. By the "grain" is meant the way in which the metal is drawn when passing through the rolls. If it is required to make bends at right angles to each other or approximately so, the blanks should be punched out diagonally across the grain. It is sometimes found necessary to form blanks from unannealed stock, that is stock which has been rolled to a certain degree of hardness. In bending this metal it springs back more or less after being struck in the die. This makes it necessary to make a more acute angle or a smaller radius on the punch and die, than is required on the finished product. This difference can be ascertained only by the cut-and-try method. When producing a short bend in blanks in such a position and of such a nature that the blank slips away from under the punch when it is descending into the die, a spring pad is fitted into the die with the lower part of the bend shaped into it, and flush with the top surface of the die. This holds the metal securely against the punch in its descent into the die and insures perfect duplicates of the product. Where holes in a blank come near a bend, a strain in the metal is set up during the bending operation which elongates the holes. This makes it necessary sometimes to pierce the holes slightly oval in the opposite direction before forming. In testing the shape of a forming die before it is hardened, always apply a small amount of oil to the surface so that the blank will not bruise or scratch the die, which would be the case if the die were left dry.

Never leave the inside corners of a die sharp when they can just as easily conform to the radius formed by bending the stock around the punch. This will strengthen the die and lessen the possibility of its cracking when hardened. When necessary, one forming die can be made to form bends in several pieces which have the same form but are of different lengths. This is accomplished by equipping the die with interchangeable gages or guide strips. Never leave any file marks on the working portions of the punch or die, as these will be reproduced on the blank. A screw hole in a die should be tapped a little larger than the screw, as the die shrinks somewhat in hardening.

When a punch or die is heated in a charcoal or a soft coal fire, the dust and ashes should be thoroughly scraped off the working portion before dipping, so that the water will have a free action upon the steel. Bending and forming dies, unless there is danger of cracking or breaking of weak parts, should be as hard as fire and water will make them. After hardening they may be warmed over a slow fire until water "sizzles" on them. Some toolmakers, when hardening a punch or die, apply cyanide of potassium to the working portions of the steel before dipping. They claim for this that the outer surface of the steel is rendered harder by the application of this casehardening substance and thus will be better fitted to withstand the wear to which it is subjected. This practice is strongly condemned for this reason: If, as is often the case, the tool should fail to harden, this fact will be concealed by the casehardened outer coating, and the tool will respond to the file test as being hard whether it is or not.

Gage plates should never be secured with two screws and one dowel pin. It is far more practical to use one screw and two dowel pins in most cases. A good method of holding gage plates before their exact position is determined is to clamp them to the die with fillister screws having washers under their heads, and to drill the holes in the gage plate about 1/16 inch larger than the diameter of the screws, so that the gage plate may be shifted around. Always drill the screw holes for the gage plates through the die so that in case a new gage plate is required the holes will be spotted from the die. Whenever the gage plate comes close to the working portion of the die, cut the punch back far enough so that the body of the punch will come within 1/8 or 1/4 inch of the gage plate. In making gage plates for locating large blanks of irregular shape, they should be made to fit the blank only at the point where accuracy is essential, and not to conform exactly to the irregular shape of the blank.

Wood fiber may be formed in the press into almost any shape, but before shaping, it should be immersed in a solution of hot water and soda for a few minutes and then subjected to heavy pressure in the press.

When setting up a press for forming operations the blank as formed by the tools is used to locate the punch in the die before securing the die to the press. If the tools are being tried out for the first time and no sample has been made, they may be set with strips of metal cut from the stock to be formed. When setting the die for a piece in which the bends are not parallel but off at an angle, it is usually impracticable to set them with a previous blank, because when the punch is brought down, the tendency is to push both die and blank away. The more practical method is to locate it approximately with the blank and slightly tighten the screws in the press bed; then with two strips of metal the same size as the blank, gage the exact distance, after which the die can be secured to the press.

Do not assume that a die is certain to be satisfactory when the samples have been produced by bringing down the press slowly by hand, as there is sometimes more or less variation in what the tools will do when operated by hand and when operated by power.

Lubricants for Drawing and Forming

For drawing steel, the following mixture is recommended as a lubricant: 25 per cent flaked graphite; 25 per cent beef tallow; and 50 per cent lard oil. This mixture should be heated and the work dipped into it. Oildag mixed with heavy grease is also used for steel, and a thin mixture of grease (preferably tallow) and white lead has proved satisfactory. The following compound is also used for drawing sheet steel of a mild grade: Mix one pound of white lead, one quart of fish oil, three ounces of black lead, and one pint of water. These ingredients should be boiled until thoroughly mixed. For working brass or copper, a solution composed of 15 pounds of Fuller's soap to a barrel of hot water (used hot), or any soap strong in rosin or potash, is cheaper and cleaner than oil. The stock should pass through a tank filled with this solution before entering the dies. For cutting aluminum, use kerosene, and for drawing aluminum, use vaseline of a cheap grade. Lard oil is also applied to aluminum when drawing deep shells. Aluminum should never be worked without a lubricant. For many classes of die work, no lubricant is required, especially when the metal is of a "greasy" nature, like tin plate, for instance.

Annealing Drawn Shells

When drawing steel, iron, brass or copper, annealing is necessary after two or three draws have been made, as the metal is hardened by the drawing process. For steel and brass, anneal between every other reduction, at least. Tin plate or stock that cannot be annealed without spoiling the finish must ordinarily be drawn to size in one or two operations. Aluminum can be drawn deeper and with less annealing than the other commercial metals, provided the proper grade is used. In case it is necessary to anneal aluminum, this can be done by heating it in a muffle furnace, care being taken to see that the temperature does not exceed 700 degrees F.

Drawing Brass

When drawing brass shells or cup-shaped articles, it is usually possible to make the depth of the first draw equal to the diameter of the shell. By heating brass to a temperature just below what would show a dull red in a dark room, it is possible to draw difficult shapes, otherwise almost impossible, and to get shapes with square corners.

Drawing Rectangular Shapes

When square or rectangular shapes are to be drawn, the radius of the corners should be as large as possible, because it is in the corners that defects occur when drawing. Moreover, the smaller the radius, the less the depth which can be obtained in the first draw. The maximum depths which can be drawn with corners of a given radii are approximately as follows: With a radius of 3/32 to 3/16 inch, depth of draw, 1 inch; radius 3/16 to 3/8 inch, depth, 1½ inch; radius ⅜ to ½ inch, depth, 2 inch; radius ½ to ¾ inch, depth, 3 inches. These figures are taken from actual practice and can doubtless be exceeded slightly when using extra good metal. If the box needs to be quite deep and the radius is quite small, two or more drawing operations will be necessary.

Drawing a Flanged and Tapered Cylindrical Shell

In the production of cylindrical shells from flat stock, the construction of the tools and the number of operations or steps in their development depend entirely upon what the ultimate shape is to be. Thus, when it is desired to produce a straight cylindrical shell of a depth not exceeding, say, twice the diameter, the first operation may be accomplished in a combination blanking and drawing die, which will cut the blank and draw it to a height almost equal to the diameter. If a flange is left around the shell, the die can be used in a single-action press, a rubber spring barrel being used to create pressure on the blank. If no flange is left on the shell, a double-action press is uscd and all of the blank area worked into the shell, the metal being drawn through the die, and the shell stripped on the under edge of the drawing die at the commencement of the return stroke. After this first operation, two, or at the most, three redrawing operations, each accomplishing an approximately equal reduction in diameter and increase in depth, will attain the desired result. In such work, the evolution of the shape and the dimensions can usually be planned accurately without trouble before starting the construction of the tools, and the blanking die can be made to size with the certainty that just the right amount of stock will be contained in the blank to produce a shell of the required form, diameter and depth.

When the shell height does not exceed the shell diameter, only a slight variation will take place in the thickness of the wall, and the final thickness will not differ materially from the original blank thickness, that is, if the metal drawn is perfectly soft to commence with and the product of each drawing operation is annealed before reducing. If the holes in the drawing dies are lapped, the punches fitted properly and given just sufficient taper to allow the shell to be stripped without collapsing the rim, an elegant surface will be attained and the shell diameter will be true.

In drawing tapered cylindrical shells with flanges, the requirements for the construction of the dies and the evolution of the shell shapes are different. When the taper in the finished shell is considerably acute in comparison with the height and diameter, the desired result can only be accomplished as shown in Figs. 2 to 6 inclusive. To attain these results, it is first necessary to bring the blank into a cylindrical shape, the area of which will just equal that of the metal required in the finished shell. When trouble is experienced in drawing tapered shells, it is almost invariably caused through the diemaker endeavoring to generate the acute taper in the first operation, or to draw it directly from the flat blank. When this practice is followed the shell is either split at the bottom, or waves and wrinkles are formed in the wall of the shell which cannot be removed. Another frequent cause of trouble lies in having a surplus of metal in the shell, and the consequent inability to distribute it in the finishing operation or to return it to the flange from which it was drawn.

When the proper amount of metal is contained in the shell form

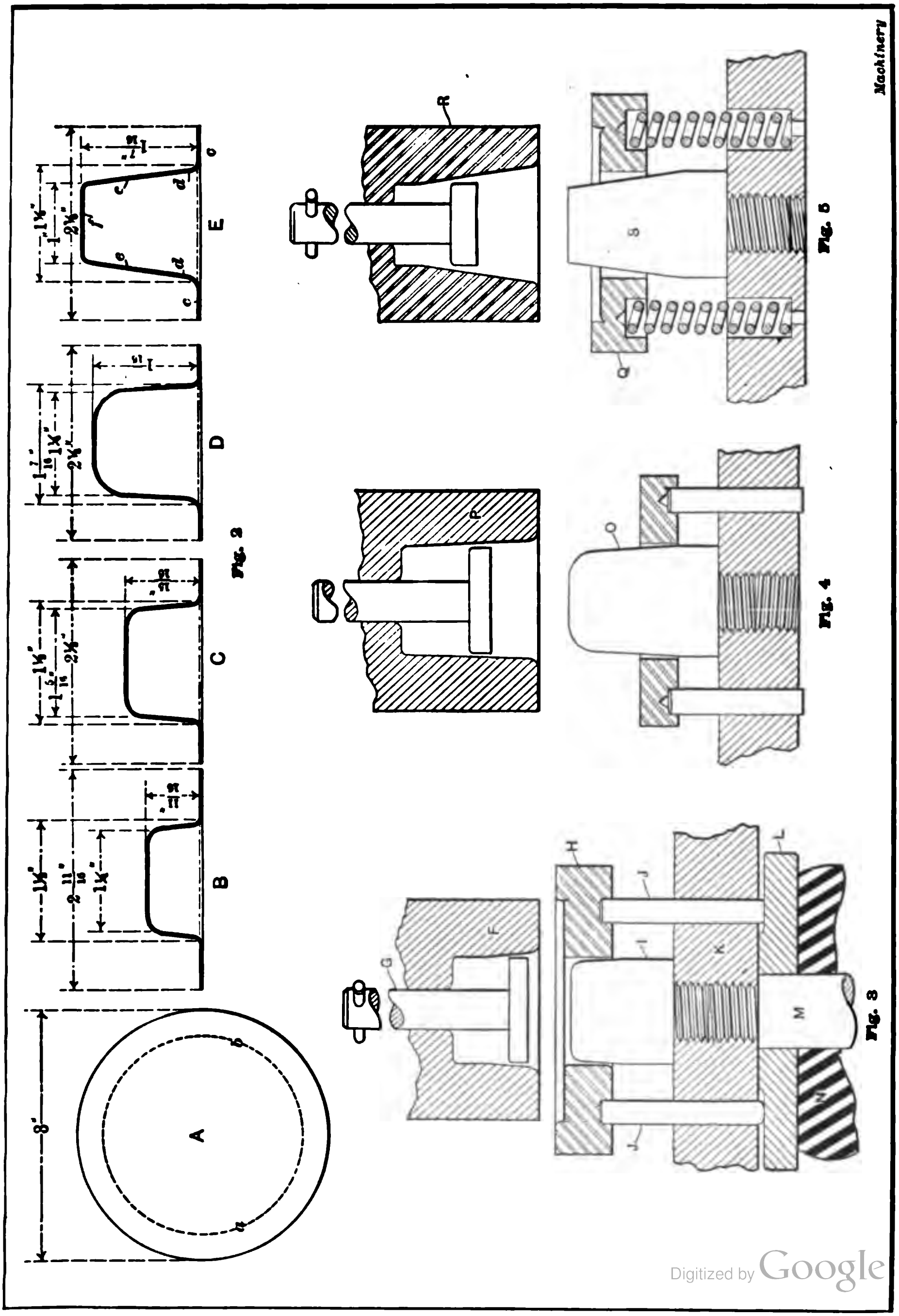


Fig. 2. Development, Evolution and Dimensions of a Flanged and Tapered Cylindrical Shell. Fig. 3. The Drawing Punch and Die for the Cups shown at B and C, Fig. 2. Fig. 4. Redrawing Punch and Die for Operation shown at D. Fig. 5. The Finishing Punch and Die for Operation shown at E

as shown at *D*, Fig. 2, with slightly tapering walls, a succeeding operation of reforming—not drawing or reducing through friction—will shape the cylindrical shell to the desired taper. The reason for this practice is that in drawing a straight cylindrical shell or even one slightly tapering, the metal is confined at all times during the process of drawing between the die and punch surfaces, making the inception of wrinkles impossible and the flow of metal equal and constant during the entire operation. When the depth to be drawn is quite shallow as compared with the shell diameter, even acute tapers can sometimes be accomplished in one operation.

Fig. 6 shows clearly the result of each operation, while Fig. 2 illustrates the various steps necessary to develop the final form completely. In Fig. 2, *A* is the blank, 3 inches in diameter by 0.032 inch thick—No. 20 Brown & Sharpe gage. The blank was cut in a plain blanking die in an automatic press. *B* is the result of the second operation, and is accomplished in the die shown in Fig. 3, as is also the redrawing operation *C*, the die remaining unchanged, except that a thinner locating pad and blank-holder was substituted for the one shown at *H*. In Fig. 3, *F* is the drawing die, *G* the shell ejector, *H* the blank-holder and locater, *I* the drawing punch, *J* two of five spring barrel pins, *K* the die-bolster, *L* one of the two spring barrel-washers, *M* the barrel stud, and *N* the rubber spring barrel, only a section of which is shown, it being circular, 4 inches in diameter by 6 inches high with a 1-inch hole through it.

At *C* in Fig. 2, it will be noticed that an increase of ¼ inch in height and 1/16 inch in top diameter is attained. At *D* the height is increased to 1 5/16 inch—a gain of 3/8 inch—and at *E* the shell is completed to a height of 1 7/16 inch, the smallest diameter being 1 inch and the largest 1⅜ inch with a flange diameter of 2⅜ inches. The dotted line *a b* at *A* in Fig. 2 shows the amount of metal drawn from the blank to form the entire cone of the shell at *E*.

Fig. 4 shows the tools used for accomplishing the operation shown at *D* in Fig. 2. A spring buffer, not shown, is used as in Fig. 3, and the cup *C*, Fig. 2, is located on the punch *O*, the die *P* descending and drawing the cup to the shape shown at *D*.

In the finishing punch and die shown in Fig. 5, no drawing of the metal takes place, the displacement of the wall of the shell and reshaping alone being accomplished. Only a slight description is necessary to understand the operation of the die shown in Fig. 5. The shell *D* is located in a seat in the holder *Q*, and the die *R* descends, holding the flange of the shell tightly between the faces of *Q* and *R*, while the punch *S* forms the shell into the tapered shape shown at *E*. At the bottom of the stroke, pressure occurs on all surfaces of the shell, shaping it to a tapered and cylindrical form.

In the evolution of the finished shell the following changes take place in the wall and flange thickness: At *c* (see *E* Fig. 2) the metal is reduced to 0.030 inch, at *d* to 0.022 inch, at *e* to 0.018 inch, and at *f* to 0.021 inch. It was necessary to anneal the shell twice, after

Fig. 6. The Successive Operations in the Production of a Flanged and Tapered Cylindrical Shell

the first draw and after the third or redrawing operation. To secure satisfactory results the annealing has to be accomplished without producing a surface scale, as the scale would prevent the attainment of smoothness and accuracy in the finished product.

Thin lard oil was used as a lubricant during the first two drawing operations, and then the shells were run dry and clean through the last two operations. No fractured shells came through, and the tools produced a large quantity of the shells which were used in molding fixtures for brass articles reinforced with cement. The drawing pads, punches and spring buffer pins used in the dies shown in Figs. 3 and 4, were made of steel, the other parts being made of cast iron. For the finishing die, Fig. 5, steel was used throughout for all the working parts, and the pad and die surfaces were hardened and lapped to a finish.

In drawing tapered shells of the type shown in Figs. 2 and 6, in which a uniform thickness of wall throughout is not demanded, a slight insufficiency of metal in the product of the next to the last operation is best, as the finishing tool can then stretch the metal so as to bring the surface and diameter perfectly smooth and true.

Dies for Drawing a Deep Steel Shell

Figs. 8 to 11 show a set of drawing dies made for producing a steel can 4 inches in diameter and 8⅝ inches long, with a 3/32-inch shoulder formed at an angle of 15 degrees with the sides. Fig. 7 shows the blank *A* and the successive drawing operations. The blank is made from sheet steel, 1/16 inch thick, and is 12¾ inches in diameter.

The first drawing or cupping die is shown in Fig. 8, and the cup produced in this die is shown at *B* in Fig. 7. The die bed *A*, Fig. 8, is made from cast iron, while the drawing die *B* is made from machine steel, pack-hardened. The punch *C* is also made from machine steel, and pack-hardened, and the blank-holder *D* is made from cast iron, faced with a hardened machine-steel ring *E*. The cup is stripped from the punch by means of the finger *F*, acted upon by the spiral spring shown.

The construction of the second drawing die, shown in Fig. 9, is substantially the same as that shown in Fig. 8, except that it is provided with a gage-plate *G* for holding the cup. The length of the shell produced by the die shown in Fig. 9 is indicated at *C* in Fig. 7. After these two drawing operations the shell is annealed, and then put through the die shown in Fig. 10. The construction of this die is similar to that shown in Fig. 9.

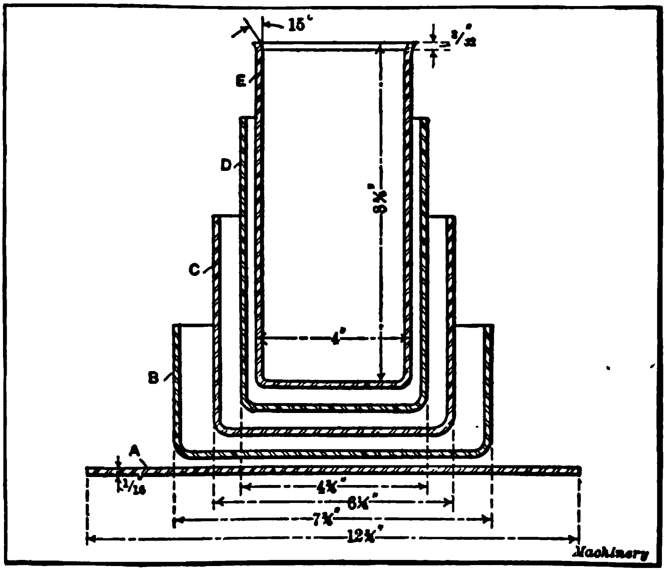


Fig. 7. The Blank and the Successive Drawing Operations

The cup *D*, after the third drawing operation, was too long to be inserted in the press available for the fourth drawing operation, and had to be trimmed down to 7½ inches. The shell is kept in an upright position in the die, Fig. 11, by a ring gage or guide *A*, which fits in the top of the shell when it is located in the die, and holds it while the punch forces it through. The distance between the bed and the ram of the press was not sufficient to allow the use of this guide without trimming the shell, which operation could have been dispensed with if a suitable press had been available.

The shell was annealed after the third drawing operation, and then put through the finish-drawing die shown in Fig. 11, after which it was trimmed to the required length. The last drawing die, Fig. 11, is provided with a knockout *B*, which was necessary, as it was impossible to force the shell through the die in this operation, on account of the

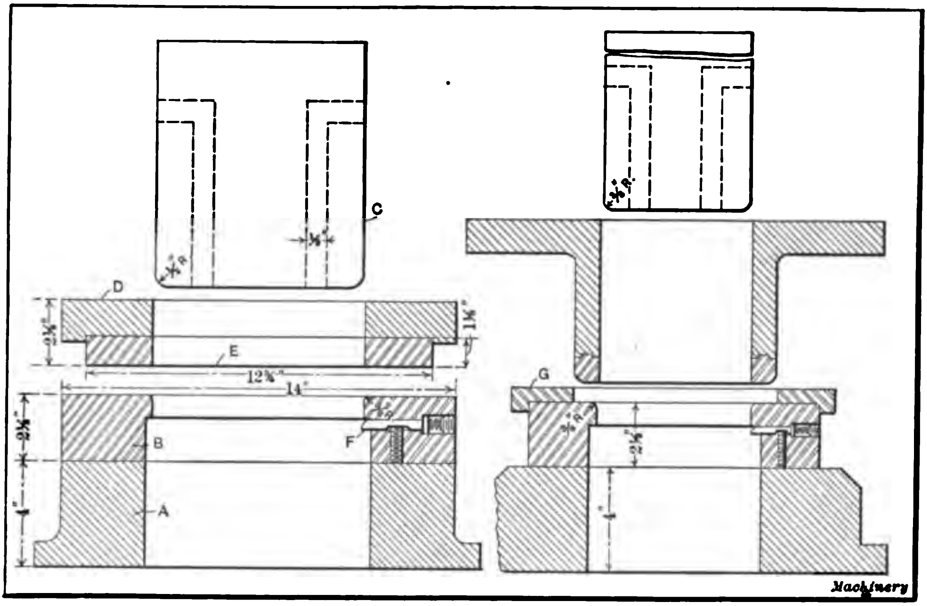
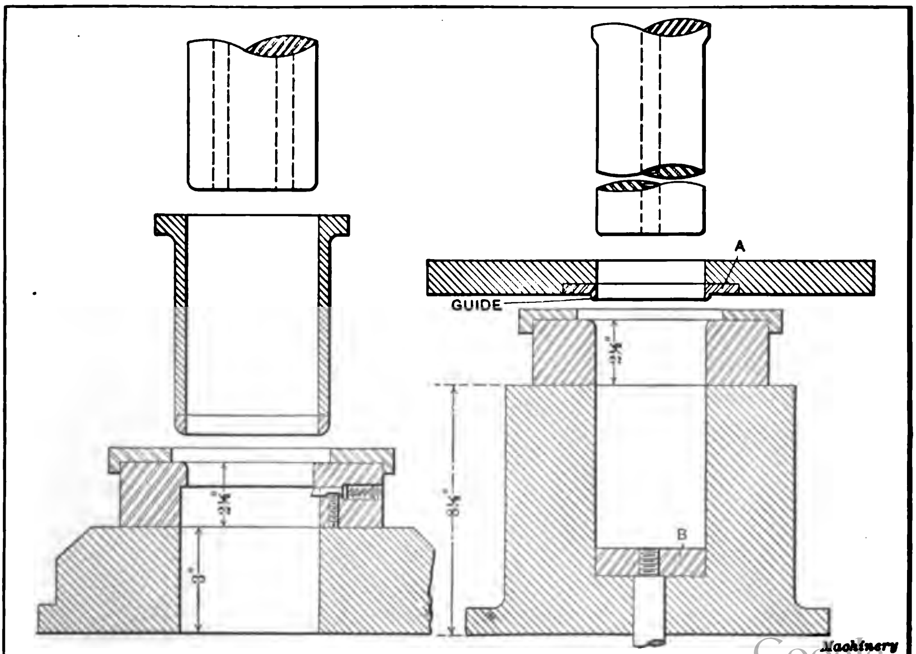


Fig. 8. Punch and Die for Forming the Cup **Fig. 9. Punch and Die for Second Operation**



Figs. 10 and 11. Punches and Dies for the Third and Fourth Drawing Operations

punch forming a flange on it, as shown at *E* in Fig. 8. All the drawing punches were provided with air passages, and the drawing faces of the blank-holders were made from tool steel and hardened.

Drawing a Cold-rolled Steel Shell

In Fig. 12 is shown a cold-rolled steel shell to be drawn. The following sizes of dies for the various drawing operations will be found

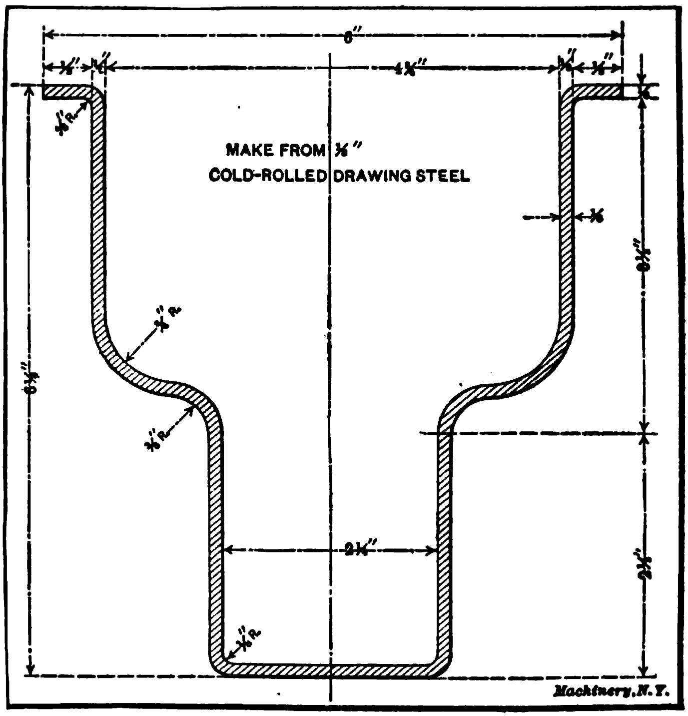


Fig. 12. Steel Shell to be drawn

suitable for making this shell:

Diameter of first drawing die	= 9⅛ inches,
Diameter of second drawing die	= 7½ inches,
Diameter of third drawing die	= 6⅛ inches,
Diameter of fourth drawing die	= 5 inches,
Diameter of fifth drawing die for reducing shoulder	= 4 inches,
Diameter of sixth drawing die for reducing shoulder	= 3¼ inches,
Diameter of seventh drawing die for reducing shoulder	= 2 9/16 inches,
Finished drawing die for shoulder	= 2½ inches.

All these drawing dies are of the same type as those used in a double-action drawing press. The dies are made from cast iron with hardened steel drawing surfaces, and the shell is shoved through and not returned, to avoid scratching, except in the operations for reducing the shoulder or lower part of the shell where it is necessary to remove the shell by the knock-out. In the drawing operations previous to reducing the shoulder, the shell is stripped from the punch by projection *F* on the die (see Fig. 14).

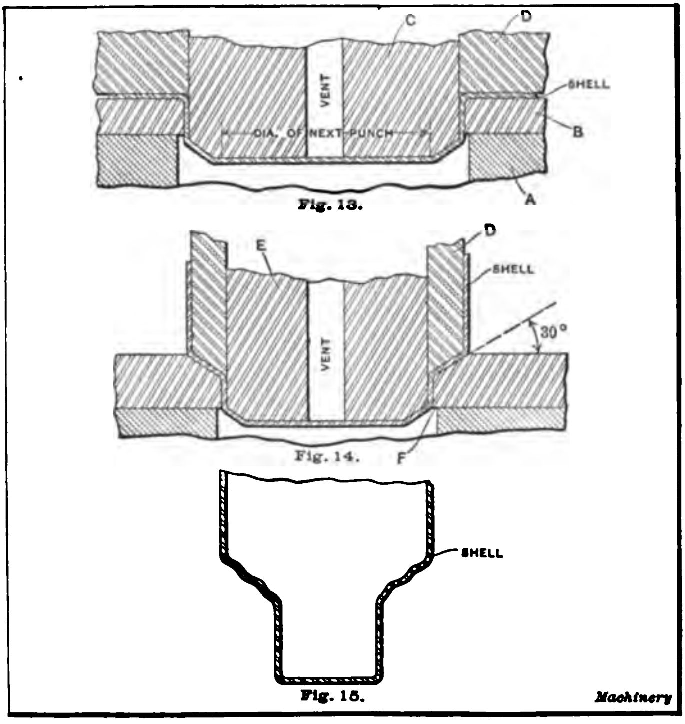


Fig. 13. First Drawing Die. Fig. 14. Redrawing Die. Fig. 15. Shape of the Shell after Reducing the Shoulder

The first drawing die is shown in Fig. 13, where *A* is the cast-iron base, *B* the tool-steel face, *C* the punch, and *D* the double-action blank holder which has a steel face. The punch is provided with a vent hole, as in the case with all the other drawing punches. The correct shape of the punch is shown in the illustration. In Fig. 14 the redrawing die is shown. This die is of the same construction as that shown in Fig. 13, except that it is provided with a drawing angle of 30 degrees, which facilitates the drawing or "flowing" of the metal. The shell, in this case, is held by a blank holder *D*, which is actuated by the double-action of the press, and holds the blank with sufficient pressure to prevent it from buckling when being drawn out by the punch *E*. The dies for the successive redrawing operations up to the point where the shoulder is reduced, are of similar construction to that shown in Fig. 14. The redrawing dies for the reducing of the shoulder are also somewhat similar in design to that shown in Fig. 14, except that the shell is not forced through the die, but is returned by the knock-out bar of the press.

The punch and die for finish drawing and "ironing" out ridges in the shell is shown in Fig. 16. The die *G* is made of tool steel, as is

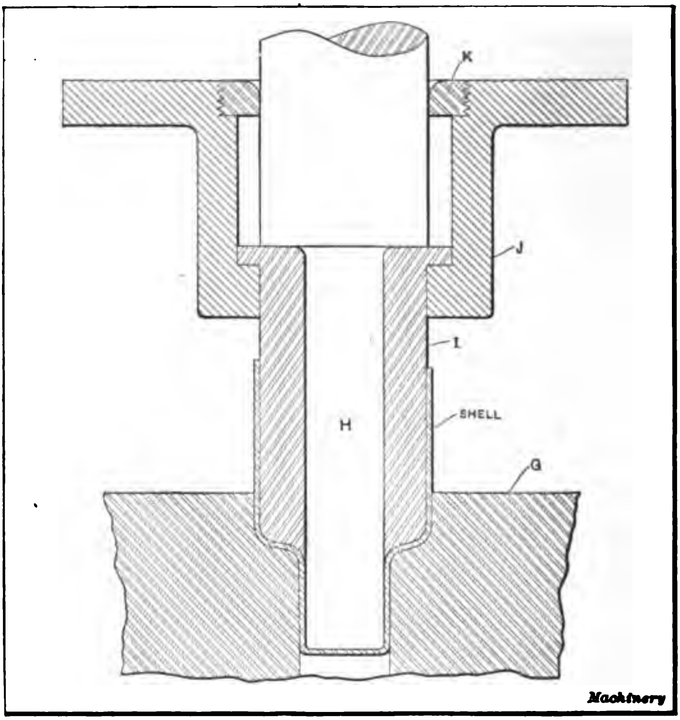


Fig. 16. Punch and Die for Finish Drawing

also the punch *H* and the double-action blank holder *I*. The blank holder *I* is held in a bolster *J*, which, in turn, is fastened to the ram of the press. A collar *K* is screwed into the top of the bolster to stop the upward stroke of the blank holder until the shoulder on the punch comes in contact with it. The idea of using a double-action press and a die along the lines shown in Fig. 16 is to throw the blow on the punch and crankshaft of the press, instead of on the toggles. This also insures the stripping of the shell from the punch, as the small end of the shell, which is brought down to size, is likely to stick in the die in this operation. Having a die of this construction also facilitates the stripping of the shell from the blank holder. The shape of the shell up to and beyond the shoulder is indicated in Fig. 15 where slight ridges are shown at the shoulder. These ridges are caused by the successive re-drawing operations.

The writer would call the reader's attention to the gradual decrease in the metal after each successive drawing operation. It is evident, of course, that the diameter of the shell must become less as it is reduced, so that the metal will not be subjected to excessive strain. The second drawing operation, that is, the first operation after the cup has been formed, reduces the shell from 9⅛ inches to 7½ inches or

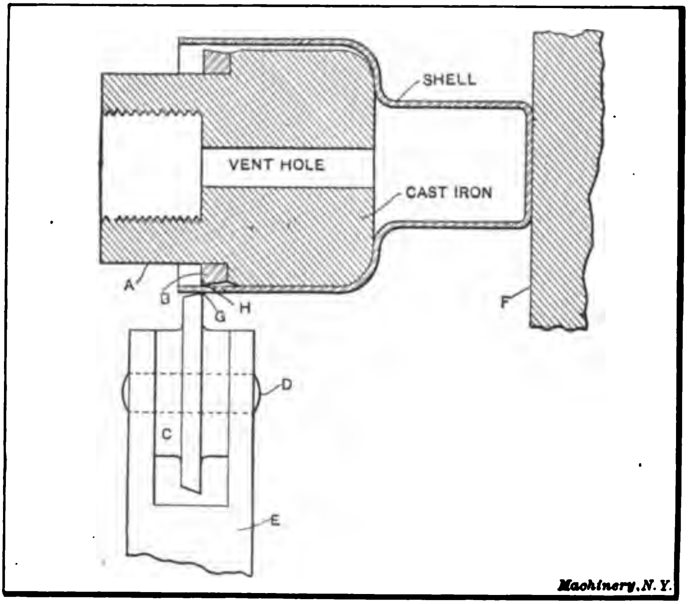


Fig. 17. Trimming the Shell to Length

1⅝ inch in diameter. For the following drawing operations, the reductions are as follows:

Third drawing operation reduces the shell from 7½ to 6⅛ inches or 1⅜ inch in diameter.

Fourth drawing operation reduces the shell from 6⅛ inches to 5 inches or 1⅛ inch in diameter.

Fifth drawing operation reduces the shell from 5 inches to 4 inches or 1 inch in diameter.

These are the reductions in size of the upper part of the shell. The reductions in the re-drawing operations for the lower part of the shell are still less than those for the upper part, as follows:

For the first drawing of shoulder the shell is reduced from 4 to 3¼ inches or ¾ inch in diameter.

For the second drawing operation of shoulder, the shell is reduced from 3 1/4 to 2 9/16 inches, or 11/16 inch in diameter.

For the third drawing operation of shoulder, the shell is reduced from 2 9/16 to 2 1/2 inches, or 1/16 inch in diameter.

It is absolutely necessary that all the drawing punches have vent holes in them, so that the shell, when drawn, will not stick to the punch or die and work havoc with the press. Another point which should be carefully considered is the diameter of the blank. The blank should be made of such a size, that when the cup is finish drawn there will be from 3/8 to 1/2 inch to trim off. The reason for this is that the upper or open end of the shell becomes hard and crystallized, owing to the excessive drawing, and extremely brittle.

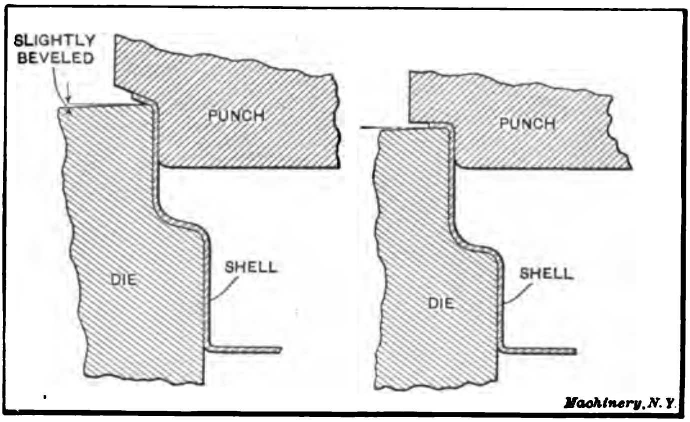


Fig. 18. Punch and Die for Starting the Flange Fig. 19. Punch and Die for Finishing the Flange

The crystallized part of the shell should be entirely removed so that, in flanging, the shell will not split or crack at the top edges. The writer would suggest that the shell, during the drawing operations, should pass through several annealing and pickling operations, so as to make it more ductile.

After the shell has been drawn to the correct length, it is ready to be trimmed. This is done before the flanging and is usually accomplished in a lathe of the roller-spindle variety. A method which could be used in trimming this shell is shown in Fig. 17. The shell is placed on a cast-iron chuck *A* which is screwed to the nose of the spindle. This cast-iron chuck is made slightly smaller in diameter than the inside of the shell. A hardened steel ring *B* is driven on the cast-iron chuck, and acts as a cutting edge. The shell is cut off by means of a hardened roller *C*, which is made circular in shape but has no cutting teeth. It is held on a pin *D* which is driven into a holder *E*. This holder is held in the toolpost of the lathe. The shell is held on the chuck by means of a revolving backplate *F* which, in turn, is held in a holder fitted to the tailstock of the lathe. The edges *G* and

H of the roller and hardened ring, respectively, are set so that they will slide freely past each other. The shank of the chuck is made considerably smaller than the shell, so that the part cut off can be easily removed.

The flanging of the top of the shell is the next operation. This can be done in two ways, one of which is shown in Figs. 18 and 19. This method requires two punches, both of which have hardened steel faces, but the same die can be used for both operations. The first punch, as shown in Fig. 18, starts the flange, and the second punch, as shown in Fig. 19, flattens it. The top face of the die is made of hardened steel, and is beveled slightly to allow for the spring in the material. The other method of forming the flange is shown in Fig. 20. This the writer considers better and more satisfactory than the

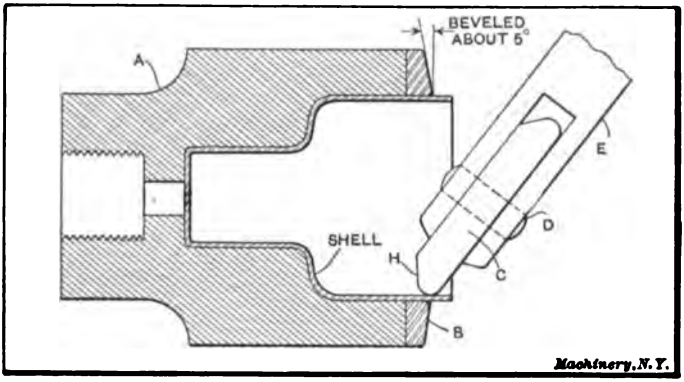


Fig. 20. Another Method of Flanging the Top of the Shell

one shown in Figs. 18 and 19. The flanging is accomplished in the lathe, the shell being held in a cast-iron chuck *A* which is screwed to the nose of the spindle. A tool-steel face *B* is fastened to the cast-iron chuck, over which the flange is bent by means of the hardened roller *C*. This roller is held on a pin *D* which is driven into a holder *E*, the latter being held in the toolpost of the lathe. The roller is applied in the manner shown in the illustration, and is brought from the inside out along the face. The face of the tool-steel ring *B* is beveled at about 5 degrees, to allow for the spring of the metal. Care should be taken to turn the flange over evenly and without buckling. The roller should be held at the correct angle to the work, to give the best results. When the flange is turned over, it is flattened down by the flat face *H* on the roller. If the suggestions given are carefully followed no difficulty should be encountered in making this shell.

Making a Ferrule in One Operation

Figs. 21 to 23 illustrate a ferrule and the method of blanking, drawing, redrawing and finishing the hole in the bottom, in one operation. The die, which is shown in Fig. 21, is not a complicated one, nor is it difficult to construct. That it is practical is obvious from the fact that it is producing ferrules at the rate of 1080 per hour. This shows the possibility of combining several operations in one.

The punches and dies were made of 0.12 point carbon steel, and used in a No. 3½ Bliss double-acting press. This press was used because there was no smaller press available in which the dies could be

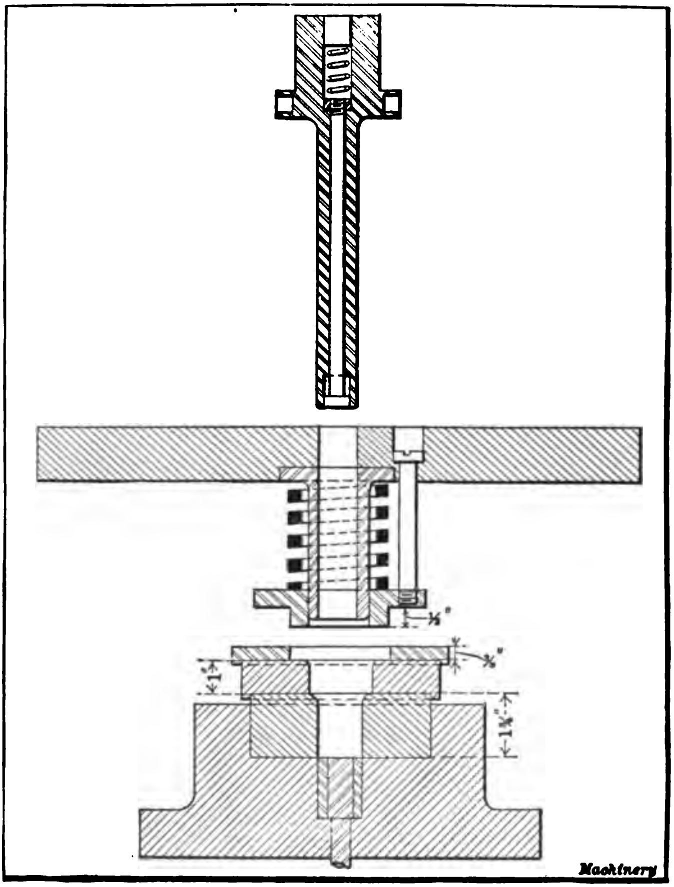


Fig. 21. Die for Blanking, Drawing, Redrawing and Punching the Hole in a Ferrule in One Operation

used. The tools, on account of their small size, were made from bar stock, but in general, drawing punches and dies, except for small work, should be made either of cast iron or cast steel. In some cases a cast-iron die is just as efficient as one made of tool steel. It is the writer's practice to make a pattern and cast the die, punch or blank-holder as nearly to size as possible, thus dispensing with the machining and bench work. In making this die, the first thing done by the bench-hand was to make male and female sheet-metal gages, about 1/16 inch thick. These gages must be full size, not half gage, as it is very easy for a lathe-hand to misread his micrometer one turn, 0.025 inch, but there is no excuse for a workman not making a part right when he has gages to work to, and, moreover, it is quicker to work to the gages.

This set of tools, as can be seen at a glance, requires only straight lathe and grinder work; therefore, after the bench-hand had made the templets, he had no more to do with the tools until they were turned, hardened and ground and came back to be assembled. The cutting punch was only hardened on the end, leaving the shoulder soft, thus making it possible to get a perfect alignment for the two 5/8-inch

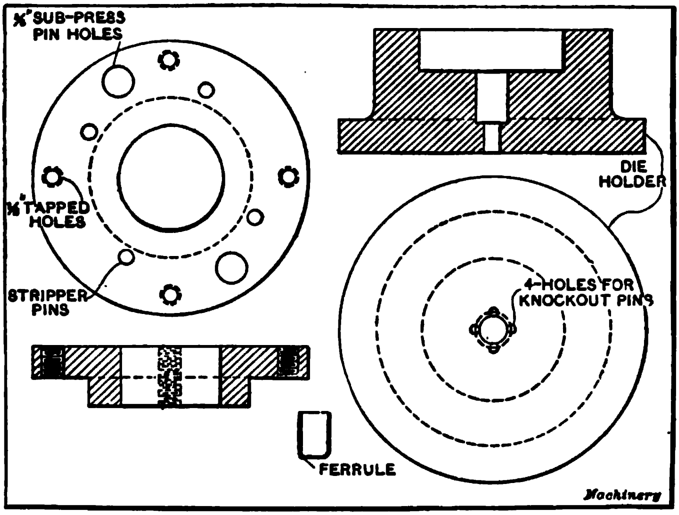


Fig. 22. Blanking Punch and Blank Holder. Fig. 23. Die-holder

sub-press pins, after the die and punch were hardened and ground. The blanking die, as well as the first and second drawing dies, had to be true with the outside diameter, as each in turn was recessed out for the other.

The second operation drawing punch, which is also the re-punching die, is provided with a spring stripper. This stripper has a rod passing through the punch, held in place by a nut. Behind the stripper is a spring, held in place by a blind screw. Six 5/16-inch holes are drilled in the shoulder of this punch, for holding the punch to the ram of the press. By making the spring stripper in this manner, the scrap from the ¾-inch hole in the bottom of the ferrule is retained on the inside of the shell when it is ejected. The spring stripper which operates the blanking punch is turned down, so as to take up as little room as possible. Figs. 22 and 23 show the construction of the blanking punch and the die-holder, respectively.

CHAPTER II

EXAMPLES OF DRAWING, FORMING AND BENDING DIES

The shell shown in section in the dies at *C* in Fig. 24 is an unusually difficult piece to draw from thick brass, the principal difficulty being due to the fact that the metal will not draw over anything approximating a sharp corner. The usual method of producing a shell of this kind—reducing it from larger cups by successive drawing operations—was tried without success. Finally the method shown in the illustration was tried, and it was found that satisfactory results could thus be obtained. This makes the operation akin to squeezing

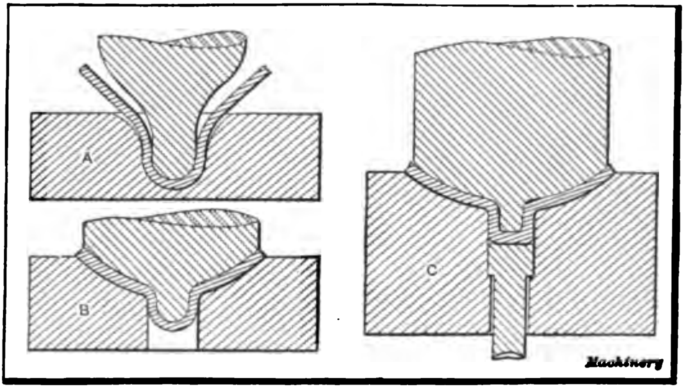


Fig. 24. The Three Dies used to produce the Shell

rather than drawing, the point being to protrude enough metal in the first and second operations to allow pressure from below to be applied in a third operation, shaping the stock and setting it to the required dimensions.

In the dies shown at *A* the object is to start the thick metal in a downward direction by means of the comparatively loose fitting punch and die shown. The edge of this die is very gradually rounded so that the metal will slide over easily. The second operation, which is performed in the dies at *B*, consists of shaping the shell around the depression already made, and the finished shape is the result of the operation performed in the dies at *C*.

The shell is started from a round blank, and two annealings are required to bring the metal to the finished shape. Subsequent piercing and cutting operations are afterward performed on the piece, but these do not differ from the general run of such operations.

Drawing Rounding Covers in One Operation

Figs. 25 to 28 show a punch and die for drawing rounding covers to the full depth in one operation, without leaving a wrinkle, finishing them four at a time. As is well known, it is a difficult propo-

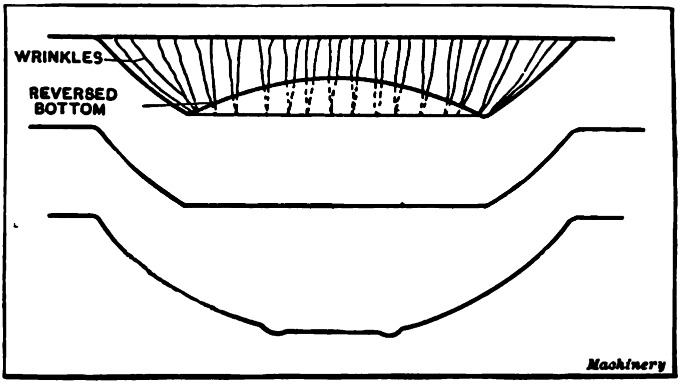


Fig. 25. Top View: Cover produced by Old Method of Drawing in One Operation, causing Wrinkles, even with Reversed Bottom. Middle View: First Stage in Drawing Cover in One Operation. Lower View: Finished Cover

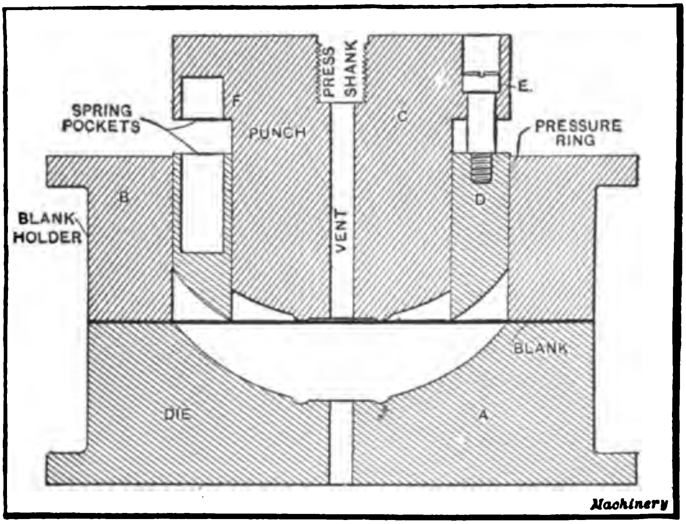


Fig. 26. Cover Blank Gripped by Blank-holder preparatory to the Drawing Operation

sition to draw a shell to the shape shown; such a cover cannot be drawn in one operation by the standard double-action method, for the stock would wrinkle and tear, making it necessary to spin out the wrinkles, as the punching would not stamp them out. An additional operation is required to finally stamp them all uniformly.

Fig. 25 shows at the top a view of the old-style method of making this cover which shows how the bottom has been reversed to stretch the metal and give enough stock for the crown and sides, the latter being very much wrinkled and sometimes "lapping." Considering the fact that these covers are of large size, ranging from 15 to 22 inches in diameter at the edge of the rounding top, and that each time the blanks "lapped" it meant a loss of four, this proved to be a costly method. When they did come through all right, not only did the wrinkles have to be rolled out, but the blanks had to be stamped besides to bead them and reverse the shell.

To overcome these drawbacks and to eliminate the numerous handlings, a triple-acting die for use in a double-action press was designed.

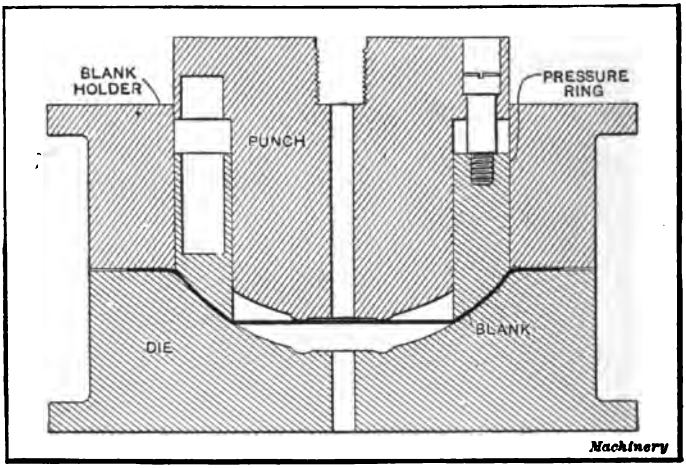


Fig. 27. First Step in the Operation, the Pressure Ring drawing the Blank to the Form shown in Middle View, Fig. 25

This made the complete shell, four at a time, in one operation to the shape indicated in Fig. 25 at the bottom. Fig. 26 is an assembled view of the die, showing all its parts. A blank is shown in position for drawing, being held by the blank-holder and die in regular double-action fashion, with the punch just touching. The die A is an ordinary double-action drawing die, made of cast iron, formed to the exact shape of the finished rounding cover, with a vent hole through the center of the bottom through which the ejector works. The drawing faces of both the die and the blank-holder are the exact size of the blank; the blank-holder *B* is of the regulation, double-action type, made of cast iron, with an opening through the center to allow the drawing punch to slide through easily. Both the die and the blank-holder are secured to the press by means of a clamping flange. The punch *C*, it will be noted, contains the special feature that made the drawing of the finished shell a possibility. The punch, itself, is made of cast iron and is tapped at its base and thereby secured to the shank of the press. The outside diameter of the punch is just large enough to slide through the blank-holder easily. A shoulder is turned around the body of the punch over which there is a sliding pressure ring *D*, held in position by several shoulder screws *E*, between which are spring pockets containing heavy spiral springs of sufficient strength to draw the shell to the shape indicated in the middle view in Fig. 25; the punch has corresponding spring pockets. When making the punch, this ring *D* was held back against the shoulder of the punch *C* and both faces were machined while in this position to give the internal form of the rounding cover. The normal position and appearance of the punch and ring are shown in Fig. 26.

The action of the punch and die in drawing the shells is as follows:

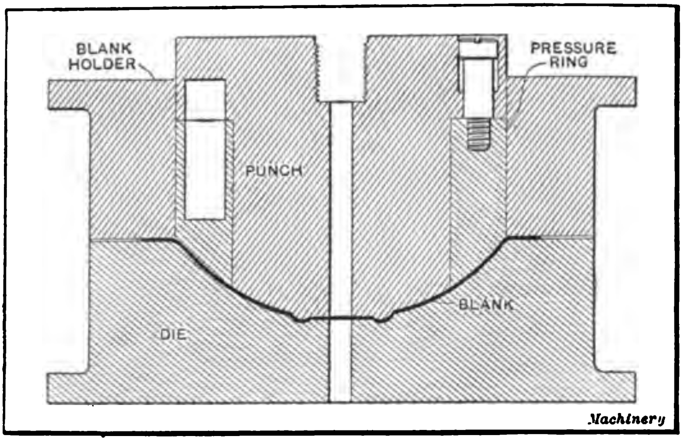


Fig. 28. Final Step in the Operation, the Punch descending within the Pressure Ring to form the Bottom, leaving Blank as shown in the Lower View, Fig. 25

After the blanks have been placed in position on the top face of the drawing die *A*, the blank-holder *B* attached to the pressure part of the double-action press descends until it holds the blanks firmly against the die face. The punch pressure ring *D* then comes down, the heavy springs in the pockets being sufficiently strong to perform the first drawing operation which brings the blank to the shape shown in the middle view in Fig. 25; Fig. 27 shows the punch and die after this operation, when the pressure ring has bottomed in the die, acting as an inner blank-holder while the punch descends still further to form the central part of the blank. The cover finally assumes the shape indicated in the lower view in Fig. 25, the relative positions of the members of the punch being shown by Fig. 28. Altogether, the action was perfect and no defective shells were produced, the drawing being easy and uniform.

The examples of drawing and forming shown on the previous pages have been selected from a great variety of punch and die constructions, because they exhibit clearly the principles involved.

Some Interesting Drawing and Curling Dies

The following interesting examples of drawing and curling die work were obtained in the shop of the Budd & Ranney Mfg. Co., Columbus, Ohio, manufacturers of Budd & Ranney gas engines, special machinery, tools, and all sorts of punch press work. The firm devotes the greater part of its attention to the manufacture of special tools, punches and dies, etc. Some of the punch and die problems submitted to it and successfully solved are described in the following.

Fig. 29 shows a drawing punch and die which was made for producing the brass top for a wire gas globe shown assembled at *A* in

Fig. 29. Drawing Die and Punch and Brass Top after Drawing and Trimming Operations

Fig. 30. This globe is a recently patented protector for gas mantels. The wire mesh permits a free circulation of the air around the burner. This globe fills the additional function of a fire prevention device, because if the mantel should break, it is caught and held by the wire basket.

The top for this wire gas globe is made from 0.010 inch thick sheet brass and is blanked and drawn up completely to shape in one operation. The piece is shown after this operation at *A* in Fig. 29, and also at *B* in Fig. 31. The die and punch used for this purpose are shown at *B* and *C* in Fig. 29, and are used in a single-action punch press. As indicated in Fig. 31, this brass top is produced inverted and not drawn through a die in the usual manner.

The die *B*, Fig. 29, consists of a cast-iron bolster *a*, bored to receive the blanking die *b* which has an irregular top face providing for a shearing cutting edge. This blanking die is held in place by ring *c* and the screws shown. The forming part of the die proper consists of a circular form *d*, made to suit the internal diameters and shape of the brass top, and held in the recess in the bolster by screws and dowels. Projecting through from the base of the die bolster are eight pins *e* which rest on a steel ring bearing on top of a rubber spring pad, 10 inches long and 6 inches in external diameter, having

Fig. 30. Curling Die and Punch for a Steel Ring; Ring in its Various Stages of Formation; and Complete Wire Gas Globe in which Ring is used

a 3½-inch hole. This rubber spring pad is held on a bolt screwed into the bolster.

When in operation, pad *f* (shown removed in Fig. 29), rests on pins *e* and provides a support for the sheet while the blank is being cut by the outer edge of the punch *C*. Then, as the ram of the press continues to descend, pad *f* is forced down by punch *C*, compressing the rubber spring pad and at the same time allowing the recess in

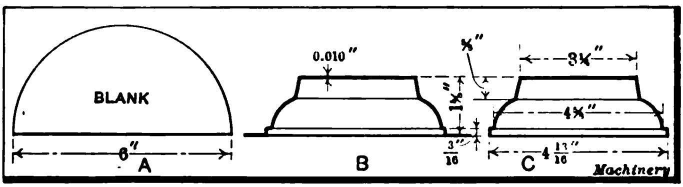


Fig. 31. Successive Drawing Operations on a Brass Top for a Wire Gas Globe

the punch (made to suit the outside diameters and shape of the brass top) tc force the work over forming die *d*, thus producing the desired shape. The bar *g* is used as a guide for the sheet, while the finger *h* locates the sheet for each successive blank.

It will be seen from Figs. 29 and 31 that there is considerable excess material left around the edge of the brass top after it has been formed to the desired shape. The chief reason for this is that the brass top, which is made from comparatively thin stock, can then be nicely trimmed in a succeeding punch and die with little difficulty. On the other hand, if this excessive material were not provided for, it would be much more difficult to draw the cup successfully, and would also increase the difficulty of trimming. As it is also necessary to cut out the bottom of this brass top in a succeeding operation, the trimming and blanking can be done in the same die.

The punch and die used for trimming the wire gas globe is shown in Fig. 32. This punch and die is also held in a single-action press, the punch being held to the ram, while the die is held in a bolster on the bed of the press in the usual manner. The trimming die consists of two steel rings or dies; the larger one *A* is doweled and screwed to the top face of the bolster *B*, while the trimming ring for the bottom of the brass top is let into the bolster. The distance between the top faces of the two trimming rings is slightly greater than the corresponding distances on the brass top.

Fig. 32. Trimming Punch and Die for Brass Top set up on a Single-action Press

The punch consists of two main parts *C* and *D*. The lower part *C* which continues up, in shank form, into the ram of the press, is used to cut out the bottom of the brass top. Part *D* is in the form of a ring surrounding punch *C*, and is held down on a shoulder on the latter by stiff coil springs located between the rings *D* and *E*, the latter of which bears against the lower face of the press ram.

The operator places the work in the die, as shown in Fig. 32, and then trips the press, when punch *C* descends and cuts out the bottom of the brass top. Upon further downward movement of the ram, punch ring *D* comes in contact with the flange on the work, pressing it tightly against the die ring *A* and compressing the coil springs. This action continues until punch ring *D* comes into contact with ring *E*, when further upward movement of the punch ring is prevented, and the excess metal is sheared from the brass top. The disk cut out from the bottom of the work falls to the floor, while the ring and top are removed from the die by the operator with the stick shown lying on the bolster of the press. A pile of finished pieces is shown at *F*, Fig. 32, and one single top at *D* in Fig. 29. In this single-action press it is possible to turn out 4000 wire gas globe tops in 10 hours, this production including both operations—drawing or forming, and trimming.

Another interesting example of press drawing of sheet metal is shown in Figs. 33 and 34. Fig. 34 shows the various press operations diagrammatically, and illustrates the successive steps followed in the production of a steel cup. The most remarkable feature is that this cup is completed in four operations without annealing. The material used is mild steel 0.042 inch thick. Upon referring to *B* and *C* in Fig. 33, and also to *C* and *D* in Fig. 34, it will be seen how

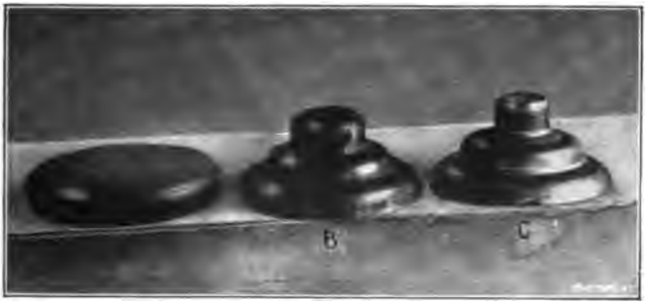


Fig. 33. Successive Drawing Operations on a Steel Cup, which is drawn to Shape without annealing (Last Operation not shown)

this feat is accomplished. Instead of endeavoring to produce square shoulders and straight sides in the preliminary drawing operations, the corners are formed with liberal radii and the sides inclined at an angle with the axis of the cup. The object in making the cup of this shape is to assist the metal in "flowing," anad to distribute the strains throughout the greater portion of the blank.

Sharp corners and straight sides tend to put all the strain on the corners and cause rupture at these points. Furthermore, by forming the cup in the manner shown, the final operation simply shapes the work by stretching it at the corners, without increasing its length to any perceptible extent. Upon cutting one of these cups in two, it was found that the metal was only slightly reduced in thickness at the point *a*, in section *E*, Fig. 34, the remainder of the cup being practically of uniform thickness. As the top of the cup had to be of an exact diameter externally, the metal was drawn more at this point, to remove what spring still remained in it. This steel cup was produced in dies of practically the same construction as those shown in Fig. 29, in a single-action punch press.

It is the practice in one shop in making drawing dies, to calculate roughly the diameter of the blank required and to make the

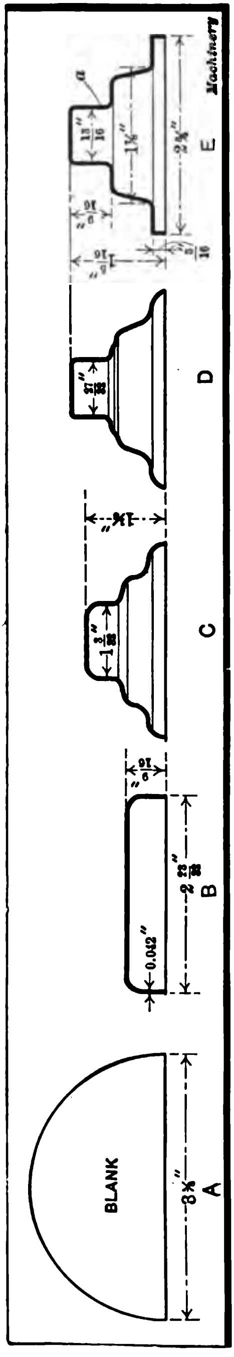


Fig. 34. Press Operations on the Steel Cup also shown in Fig. 33

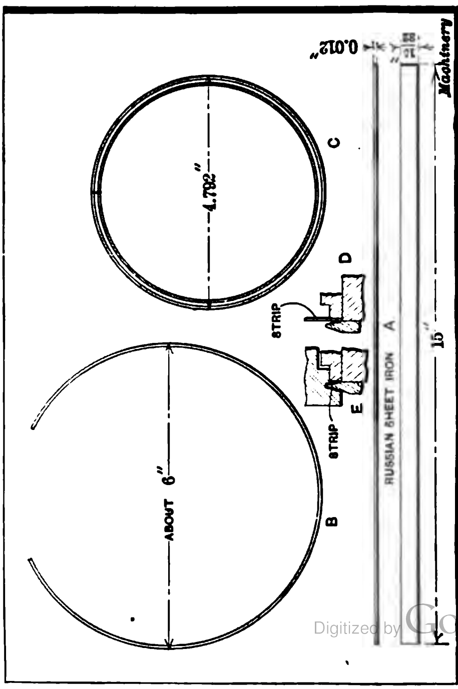


Fig. 35. Steel Ring in Various Stages of Formation, and Diagram illustrating how it is held and curled

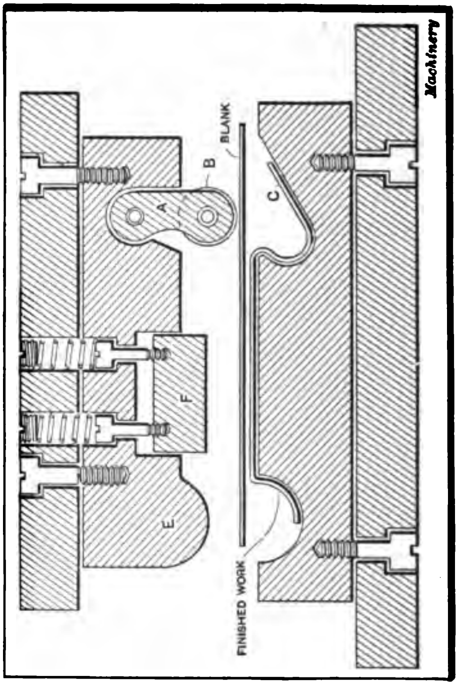


Fig. 36. Novel Form of Bending Die

successive drawing and redrawing dies before making the blanking die. A simple method of obtaining the approximate diameter of the blank is to multiply the circumference of the finished cup by the height, and then add the area of the bottom, which gives the area of the blank; then find the diameter of a circle whose area equals this area. This rule applies to cups that must be made of a uniform thickness on the sides and bottom and that are of approximately cylindrical shape. For irregular shaped cups the usual practice is to take the mean diameter and use the rule previously given.

It is impossible by any known method to calculate the exact diameter of blank required, as the "stretch" of the material cannot be definitely determined except by trial. Considering this, it is good practice to follow the method suggested—that is, making the successive drawing dies before the blanking die. A blank can be cut out and filed to the approximate diameter in a short time, then passed through the drawing dies, and when completely formed, if found to be of the required length, the blanking die can be made to the same diameter as was this trial blank. If, on the other hand, the shell is too short or long, the diameter of the blank can be increased or reduced accordingly, and the same procedure followed until the exact diameter of the blank is obtained.

An interesting curling die for forming the ring *B*, Fig. 30, used in holding the wire mesh in the gas globe shown at *A*, is shown in the same illustration. The ring is shown in its successive forming steps at *A*, *B* and *C* in Fig. 35; *A* is the strip from which the ring is made, cut from a sheet of Russian iron to the dimension shown. The first step is to bend the blank into a hoop in a pair of bending rolls, bringing it to the shape shown at *B*, and also at *D* in Fig. 30. It is now ready for the curling die, which is held in the press shown in Fig. 32.

Referring to Fig. 30, the curling die shown at *F* consists of a bolster *a* having a projection around which the forming ring or die *b* is held. Retained inside the forming die, by a ring *c* and four screws *d*, are four jaws *e*. These jaws are provided with elongated holes in which screws *d* fit, and are acted upon by open-wound coil springs located in front of the eight headless screws *f* placed equidistant around the die ring. The inner sides of the jaws are provided with a projection and form a tapered hole into which the tapered spring-operated pin *g*, held in punch *G*, fits.

In operation, punch *G* is held in the ram of the press and die *F* is fastened to the bed. The operator grasps the partly bent band *D* with both hands, placing it between jaws *e* and die ring *b*, as illustrated diagrammatically at *D* in Fig. 35. Then when the ram of the press descends, the tapered pin *g* comes in contact with jaws *e*, forcing them out and thus gripping the hoop securely. As the ram continues to descend, the tapered pin recedes, allowing the groove *h* in punch *G* to force the band over the die ring in the manner shown at *E* in Fig. 35. When the ram of the press ascends, the jaws are returned to their normal position by the eight coil springs, thus freeing the ring and allowing it to be easily removed by the operator.

A Bending Die

Fig. 36 shows a die designed for the Eagle Tool Co., Cincinnati, Ohio, to meet the requirements of a certain bending operation on 16 gage sheet metal. It will be seen from the illustration that a swinging arm *A* is pivoted at one end of the punch; this arm carries a steel roll *B*. When the punch descends this roll bends the stock down into the die at *C;* when the downward travel of the roller is checked by the die, the arm *A* swings to the left and continues to move in this direction until the roller has formed the work in the die as shown. The left hand end of the work is formed between the die and the extension *E* on the punch. Before the punch has reached the end of its

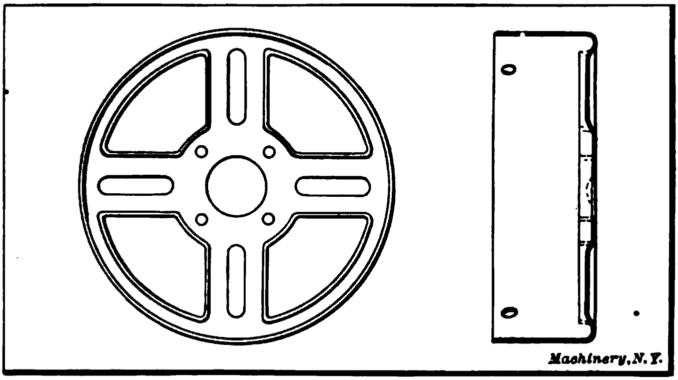


Fig. 37. Aluminum Shell to be made

downward travel, the gripper *F* engages the work and holds it in position through the tension of the two springs shown in the illustration. This prevents any movement of the work during the final stages of the bending operation.

Press Tools for Aluminum Shell

The spoked aluminum shell shown in Fig. 37 is about four inches in diameter and one inch deep. It has four spokes, or arms, radiating from a hub in which a shaft hole and four rivet holes are punched. These holes are used for attaching the aluminum shell to the bearings of the hub on which it is used. Stiffening "lips" around the openings and spokes are formed, and the ribs or spokes themselves are embossed to add to the strength of the shell. Four rivet holes punched through the rim of the shell serve to attach it to an exterior band.

This shell was made in the following manner and with excellent results: The blanking, drawing and embossing is done in one operation in a double-action press, using the die shown in Fig. 38. The blank-holder *A* is made of cast iron, and a hardened tool-steel blanking die *D* is fastened to it, which not only acts as a die, but also serves to hold the blank in position while the drawing operation is taking place. *B* is the cast-iron drawing punch, to which is attached a hardened steel face *K*. This face *K* contains the embossing recess

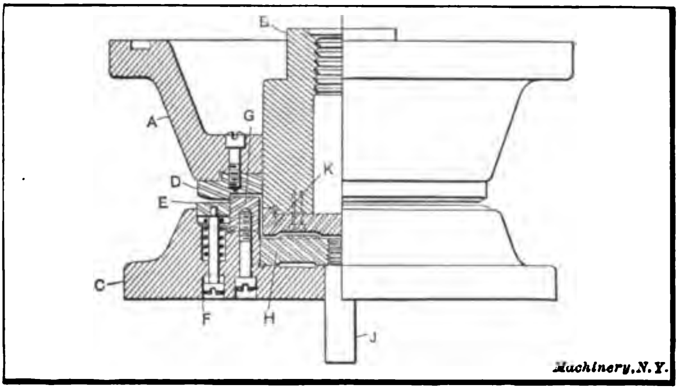


Fig. 88. Combination Blanking, Drawing and Embossing Die for the Shell

for the spokes, into which the metal is forced by the embossing punch *H* held to the lower member. The punch *H* also acts as an ejector after the drawing and embossing operations have been completed, and is actuated by the stem *J* and the knock-out mechanism of the press.

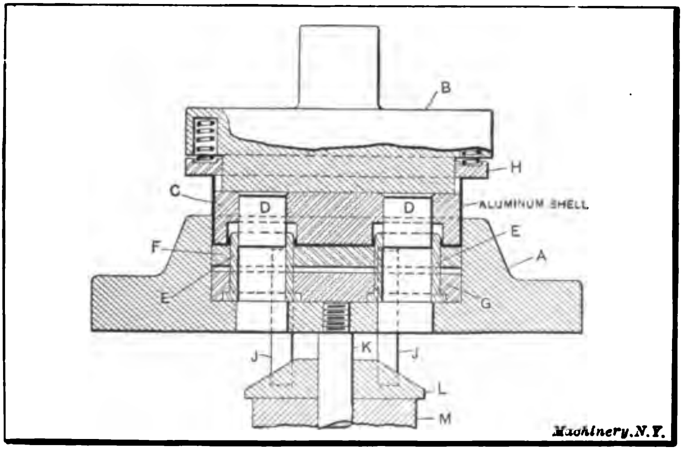


Fig. 89. Combination Piercing and Ribbing Die

The die-shoe *C* is made of cast iron, and is bored out to receive the blanking punch *G* over the inner edge of which the shell is drawn after blanking. The stripper ring *E*, which is made of soft steel and passes around the periphery of the die *G*, is limited in its travel by the shouldered screws *F*, and acted upon by six helical springs. There are several vent holes in the drawing punch and through the plate *H* and the base of the die-shoe, the purpose of which is to allow the air to escape while drawing, and enter while stripping and ejecting the shell. The shell is drawn entirely into the ring *G*, and of course, must be trimmed afterward. This is performed in a trimming lathe, although similar shells are sometimes drawn to the depth required, and a flange left on them, so that they may be trimmed off by a simple blanking die. However, the method of handling this operation lies entirely with the designer, although it should be governed to some extent by the requirements of the shell.

After the shell is drawn into cup form, the next operation is to pierce the openings to form the spokes, and turn up the "lips" around these openings. Both these operations are performed in the die

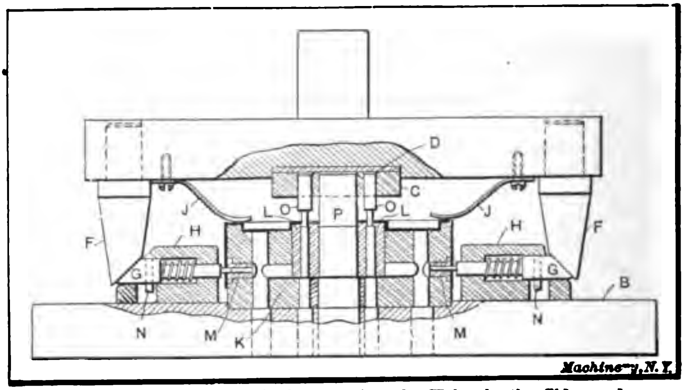


Fig. 40. Punch and Die for Piercing the Holes in the Sides and Bottom of the Shell

shown in Fig. 39, which is held in a single-action press. The die-shoe *A* and the punch-holder *B*, respectively, are made of cast iron, the die-shoe being bored out to receive the soft-steel die carrier *G*, and the ejector plate *F*, which is also made of soft steel and is actuated by four studs *J* resting on a cast-iron plate *L*. This cast-iron plate *L* is pressed upward by a rubber pad *M* which slides on stud *K*. The die-bushings *E* are flanged on the bottom, as shown, and are held in the carrier plate in the usual manner. They serve not only as dies for piercing, but also as drawing punches to draw the stiffening "lips" on the shell. The drawing die *C* is held on the punch-holder *B*, and carries the piercing punches *D*, which are set ahead of the drawing die so that they will pierce the stock before the die begins to draw the "lips." A stripper ring *H*, actuated by coil springs as shown, is limited in its travel by the drawing die *C* upon which it comes to rest on the up-stroke of the ram. All the screws and dowel pins used for holding the various members in their respective holders are omitted for the sake of clearness.

The shell is now ready to have the holes around the rim and the small holes in the bottom pierced. These operations are accomplished in the die shown in Fig. 40 which is held in a single-action press. A circular disk *B* of cast iron serves as a base for the die, and to it is attached the die-anvil *K*, of soft machine steel. Die-bushings *L* and *M* are driven into the anvil *K* for piercing the holes in the rim and in the bottom of the shell. Recesses are cut in the block *K* to receive the "lips" around the spoke openings. The cast-iron punch-holder carries two flat springs *J*, which serve to hold the shell on the anvil when the holes are being pierced. The punch-holder also carries four studs *F* (only two of which are shown) that operate the piercing punches *G*. These piercing punches *G* fit in blocks *H* held to the die-bolster, and are retained in the blocks *H* by the small studs *N*

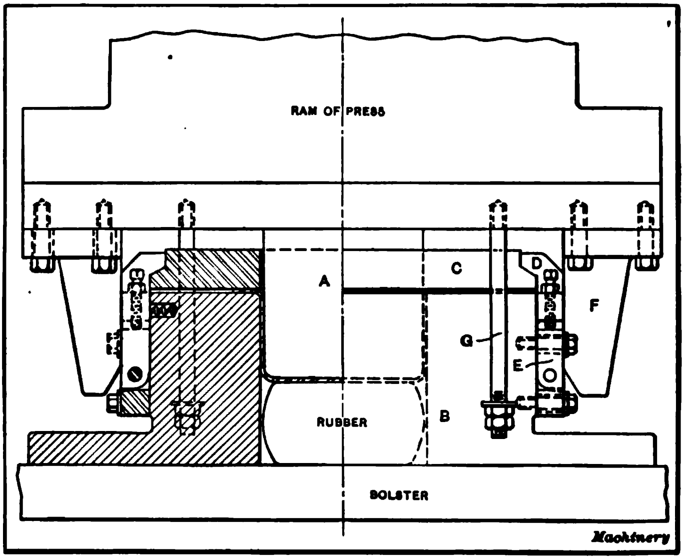


Fig. 41. Die for drawing Cups in a Long-stroke Single-acting Press

working in elongated holes in the block. These small studs or pins *N* also serve to prevent the punches *G* from turning around, so that their beveled ends are always presented properly to the studs *F*. The punches *G* are withdrawn when the ram of the press ascends, by coil springs, as shown. The punches *O* and *P*, for piercing the holes in the bottom of the shell, are held in a machine-steel block *C*, which is backed up with a hardened tool-steel block *D* inserted in the punch-holder. The blocks *C* and *D* are doweled together and held to the punch-holder.

Making this aluminum shell in the manner described, gives a uniform product, and the tools are of such a character that they are easily repaired and are not very costly. While these tools are of a special character, a number of the features incorporated in them could be used for a variety of purposes.

Drawing in a Single-Acting Press

Fig. 41 shows a method for drawing steel cups, such as would usually be made on a double-acting press. No double-acting press was available, but only a long-stroke single-acting press of sufficient capacity to do the job. The die was made as follows: On the die *B* were bolted some U-shaped pieces *E* which carried the holding hooks *D*. These hooks *D* could be adjusted to any desired degree of tightness by setting down the pieces *E* with the set-screws provided and then clamping them securely in place. The blank-holder *C* was suspended on four bolts *G*, and these bolts were adjusted to the proper length so that the blank-holder *C* was laid on the blank early in the stroke; then closing lugs *F* engage the holding hooks *D* and force them in on the beveled ledge of the blank-holder. The lugs *F* then slide along the back of hooks *D* during the remainder of the stroke.

On the up stroke the closing lugs leave the hooks *D* which are immediately thrown open by springs provided for this purpose, and then the blank-holder *C* is lifted up by the suspension bolts *G*. The formed piece is loosened in the die by the rubber block, or, if necessary, a positive stripper can be provided. At first the closing lugs *F* were made solid with the punch-holder, but after several were broken by dirt or other foreign substances getting under the blank, a new holder was made with the lugs bolted on, so that the bolts would allow the lugs to give enough to prevent breakage.

This die is more expensive than would be required for a double-acting press, but works nearly as well and makes it possible to do the work with the equipment at hand.

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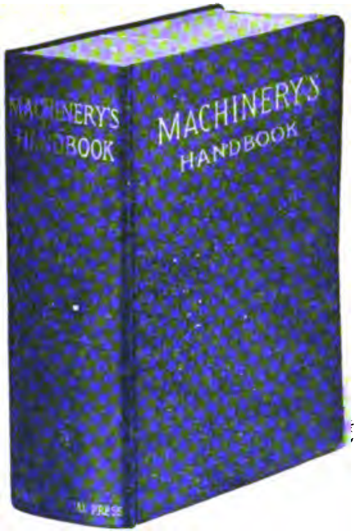

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ELECTRIC WELDING PROCESSES

Although the electric welding process passed out of the experimental into the practical stage some years ago, electric welding is still a rather vague subject to most mechanics. Electric welding, however, plays an important part nowadays in the manufacture of a great many articles, and several companies have been formed which devote their entire attention to the manufacture of articles in which electric welding is an integral part of the manufacturing process. Without the process of electric welding, many of these products would have to be manufactured in an entirely different way, and in many cases at a greatly increased cost.

There are at least five distinct processes of electric welding in use at the present time. These processes are commonly known as the Zerener, the Benardos, the Strohmenger-Slaughter, the La Grange-Hoho, and the Thomson processes.

The Zerener Process

In the first process mentioned above, the Zerener process, perhaps more commonly known as the electric blow-pipe method, an electric arc is drawn between two carbon electrodes. This arc is then caused to impinge upon the metal surfaces to be welded by means of an electro-magnet. This welding system was introduced by Dr. Zerener of Berlin, Germany, some twenty years ago. No current passes through the work in this case.

The Zerener system, as well as all arc-welding systems, is based upon the fact that when two rods of carbon, connected by suitable means to the poles of a dynamo or to the terminals of current supply cables, are brought into contact, a flame is caused to play between them, this flame being known as an arc. Variations in the gap or distance between the carbon electrodes, or the interposition of resistances of varying intensity, increase or decrease, as the case may be, the amount of current passing through the electrodes, and thus alter the size of the flame or arc.

In an improvement on this method, known as the Voltex process, the carbons contain a small percentage of metallic oxides—oxide of iron, for instance—which is converted by the heat generated into its metallic form and then vaporized. The vapor tends to increase the size of the arc and minimizes or prevents the carbonization of the work by the carbon of the electrodes at the welding point.

The various systems of electric arc welding are especially valuable when the parts to be welded must, after welding, retain their original positions or relationship with reference to each other. A crack in a machine part illustrates such a case. These methods are also applicable when making an abrupt joint between two plates, filling up holes in castings and generally for any work in which it is necessary to add metal to form the joint.

In arc welding the temperature of the arc is practically impossible of control; to avoid melting, then, even in cases where melting is unnecessary, which not often is the case, it would be compulsory to remove the work or arc at the very instant welding heat was attained, a point not readily determined, having regard to the intense light at the arc necessitating the use of almost opaque spectacles, which not only obscure the vision, but result in severe eye-strain. The heat generated is so intense that it is necessary also to guard the hands and face to avoid burning.

In the case of the iron alloys, the arc method is often open to the objection that it demands infallibility on the part of the operator. While a good weld is almost as good as original continuity, the fact that this is only possible when the pieces are heated to a definite temperature, renders the method less satisfactory than the Thomson process yet to be described. From the point of view of perfection of product, the process is lacking, for the reason that the temperature of the arc—between 5000 and 7000 degrees F.—is far in excess of the melting-point of the iron alloys, and is extremely difficult to control.

The Benardos Process

The Benardos process is also based upon the use of the electric arc, the characteristic principle of this process being that the electric arc is drawn directly between the metal to be welded, which itself forms one electrode for the electric current, and the carbon electrode, which forms the other terminal of the circuit. In this process, the pieces of metal to be welded are melted on their faces together with a small iron rod which acts as a kind of solder and flows in between the two surfaces to be joined together by the welding process. This system, if properly adapted to the work to be done, and with a plant well designed for generating, distributing and regulating the current, is practical, simple and effective. The quantity of current used depends on the thickness to be welded and may, in ordinary practice, range from 200 to 500 amperes. The arrangement of using the metal to be welded as one electrode for the electric circuit makes it possible to obtain a great amount of heat in the weld.

In the Benardos process, the direction of flow of the electric current may be in either direction, but, as a rule, the work or metal electrode is the positive and the carbon electrode the negative pole. In case the flow is reversed, the arc will be shorter and the carbon from the electrode is more liable to enter the weld, thereby hardening the material and rendering it brittle. In commencing the weld, the carbon electrode is brought into contact with the work, thus causing an electric current to flow, but is quickly withdrawn, introducing a resistance which produces an arc of high temperature.

In all arc-welding systems, it is difficult to absolutely prevent the introduction of carbon into the work. An improvement, known as the Slavianoff system, in which a very small arc is used, and which, for that reason, is much slower, prevents, to a large extent, the introduction of carbon into the work, and is therefore preferred, particularly for small work. In this process the electrode is of the same metal as the work.

When a number of welding machines working according to the Benardos system are employed, it is necessary that the current be supplied in such a manner that one machine will not affect the arc of another. This is effected very simply by generating in a compound-wound dynamo of ample capacity, and the machine should be slightly over-, rather than under-, compounded. By this arrangement an increase of load does not lower the voltage. In a well-designed machine the voltage scarcely varies, provided the engine driving it is efficient to maintain its speed. The arcs are arranged in parallel, and each arc is provided with a regulator to adjust the current to the work to be done. The rod of carbon forming the negative electrode is fastened in an insulated holder of light construction. The workman holds this in his hand, strikes the arc by placing the carbon in contact with the work, and manipulates it so as to spread the arc and heat the work at and near the point to be welded with what is described as a soaking heat. When the welding heat is attained, the work is hammered or not according to circumstances. Screens with colored glass windows are used to protect the eyes and skin of the workman from the effect of violet rays.

The Strohmenger-Slaughter System

The Strohmenger-Slaughter system, also an arc-welding system, may be worked with either direct or alternating current. It is generally assumed that the alternating current is preferable for this purpose. The voltage need not be very high and the amount of the current within limits is not important. Successful welding has been carried out with 85 volts used with direct current and 220 volts with alternating current. The quantity of the current depends upon the nature of the work. The parts to be welded are placed in the required position and an electrode is laid upon and along the welding line. This electrode consists of a soft iron rod covered all over except at the extreme ends with a flux suitable for the metal to be welded. Then the work and one end of the electrode are brought into contact, causing, by a series of arcs along the welding line, the electrode to melt and to coat the weld with the flux, thereby preventing oxidation. The flux will flake off when the metal cools. It is claimed that this system is used successfully in the welding of rails and in other repairs by building up worn places, but it is not as generally known as the other systems.

The La Grange-Hoho Process

The La Grange-Hoho system, commonly known as the "water pail" forge, is distinctly different from all other processes in principle as well as in its practical application, and is, properly speaking, only a heating process replacing the blacksmith's fire. A wooden tank is filled with a bath containing a solution of borax and potassium carbonate in water. In this bath, the positive electrode of the electric circuit is placed. The negative electrode is connected to the metal to be forged or welded, which is then also immersed in the fluid in the tank. The metal is then permitted to remain in the fluid until it has reached the welding temperature. The object to be welded is then removed and the actual forging or welding process is carried out in the usual manner on the anvil under a hammer. Strictly speaking, therefore, this is not an electric welding process, but merely an electric heating process for bringing the metal to a welding heat.

The Thomson Process

In the Thomson process, also known as the incandescent or resistance process, the metals to be welded are brought into intimate contact, being usually held closely together by metal clamps actuated by springs so as to permit a permanent pressure on the parts even when the metal at the welding surfaces commences to melt. By this contact, the parts to be welded complete an electric circuit, and the resistance at the points of contact between the metals produces a welding temperature in a very few seconds, at the same time as the two metals are, by the spring-actuated clamps, forced together automatically, and welded. A distinct feature of this electric welding process is that the interior is raised to a welding temperature before the surface reaches that heat. When heated in the forge for welding, the opposite conditions take place. In the process of electric welding, if the exterior surfaces weld, the operator is sure that the interior is also welded, since it must, by necessity, be of a somewhat higher heat. With ordinary forge welding the surfaces may present a perfect weld and still cover an imperfect joint inside.

A few years ago it was thought that electric welding would be practical only for very small objects, on account of the high amperage required, but since that time the process has been developed so that it is now possible to electrically weld parts of considerable size. The process is particularly suited for the manufacture of automobile and bicycle parts, carriage hardware, and mechanics' tools of various descriptions.

When, as mentioned above, the two parts to be welded have been placed against each other, in the electric circuit, which heats the metal at the juncture to a molten state, the separate parts will be united into one piece in such a manner that the joint is practically imperceptible, but at first a burr or upset is produced around the welded surface, composed of the expelled oxidized and otherwise inferior metal. This oxidation is, of course, removed, and then a perfect joint is the result.

One very important question in regard to electric welding, and for that matter any other process for joining metallic parts, is whether the joint is sound. Experiments and tests, as well as use of electrically welded joints, have unquestionably demonstrated its reliability. In the case of electric welding, the great variety of parts so joined has shown, beyond doubt, that the joint is practically as sound as the solid sections in the parts so joined. Very commonly the parts which are welded by the electric process are subjected to abuse and rough handling, or to heavy stresses. Especially is this so in automobile work. The results obtained have been so satisfactory as to place the art among the most useful of the applications of electricity.

In this connection, it may be well to mention that the Thomson process, while originally an American invention, has also received considerable attention in England. A writer in the *London Times* some time ago, called attention to the fact that the system has caused a complete revolution in existing methods of manufacture in many industries, and that electric welding had created some entirely new manufactures. As to the reliability of these joints, this writer also mentioned that tests had been carried on regarding the comparative strength of electric and ordinary forged welds, and that these tests show that while the ordinary forge weld of iron bars shows an average strength of 89.3 per cent, as compared with the strength of the solid, electrically welded joints show a strength of 91.9 per cent.

In giving a summary of the advantages which can, with propriety, be claimed for the electric welding process, the following may be stated as being the most important: Finished or nearly finished work may be welded and repaired without damage; the welding operation can be closely watched as it proceeds, and faulty welds prevented; the process is carried out with great rapidity, occupying only a few seconds, and in small work it is performed almost instantaneously; and, finally, impurities are expelled from the joint, and a perfectly homogeneous weld is obtained. The cost for the generation of heat, generally speaking, is probably the same for forge and electric welding, but with the electric process the cost of labor is greatly reduced.

In the following chapters the more important of these welding processes will be dealt with in detail, the methods connected with each being explained and the advantages pointed out.

CHAPTER II

ELECTRIC RESISTANCE PROCESS OF WELDING

In a paper read before the American Society of Mechanical Engineers by Mr. W. A. Hodges, the most important features of the electric resistance process—also known as the Thomson process—of welding were pointed out. This process of welding and heating, sometimes called the incandescent process, as distinguished from the electric arc process, consists in causing a heavy current of electricity to pass across the joint at the lowest voltage which will drive the current through the pieces to be welded, to bring the metal at the junction up to a welding heat; at the same time the pieces are pressed together to make a complete union or weld. The pieces to be welded together when clamped in a welding machine complete an electrical circuit, but are inadequate to carry the heavy current passing through them without heating; as the heat increases the resistance also increases, and the union or weld is thereby accelerated, but the volume of current is decreased; or, in other words, as the temperature increases the current volume usually decreases, a greater volume of current being used at the beginning than at the end of the heat effect. The heat is confined to the metal between the jaws, and a welding heat is reached so quickly that there is very little time for waste through radiation or conduction by adjacent cold metal; therefore practically all the heat is consumed in useful work, and the pieces, not having been heated except at the joint, are not distorted, or even discolored.

The electric resistance process of welding and heating is distinguished from all other processes by the fact that the heat is generated in the metal itself, uniformly over the section, while by all other processes the contrary is true; the heat is applied to the exterior, and is conducted into the interior. Absolute control of the heat is obtained; the pieces are heating in full view of the operator, and, if due to uneven contact of the pieces, rust, or scale at one or more points of contact, or other irregularity, the pieces heat unevenly, with a tendency to burn at one or more points, the heating effect can be instantly stopped until radiation restores the heat equilibrium, when the heating can instantly be resumed, and all danger of flaws avoided. Various degrees of temperature can be obtained and retained for any length of time. Usually no flux is required.

Applications of the Process

This process is employed principally in the following classes of welding operations: Butt welding, end to end; whole abutting surfaces, of nearly same cross-section, welded together; tee and angle welding, in the form of a letter T or L; cross welding, in the form of an X; lap welding, overlapping and squeezing or mashing together; seam welding, either by abutting, or overlapping the edges of sheet metal; spot welding, instead of riveting, practically one spot at a time; point welding, surfaces in contact only at a raised point or multiplicity of points, at which the current is confined, welding only at these points, usually in sheet metal; and ridge welding, where instead of a point, a ridge is employed, across which a weld is made.

The process is especially well adapted to duplicate work where as large an output as possible per operator is required, and the wagon, carriage, automobile and bicycle industries, with tools, wire, pipe, tubing and a large line of miscellaneous and special work, provide the field for the process. It is particularly applicable to new work rather than to repairs, although some repair work is done in iron and steel, but the process is not applicable for the repair of broken or defective castings unless of such metals as brass of simple forms. Practically all metals can be welded, also all sorts of steel and many alloys, as well as many combinations like carbon steel to mild steel, nickel and brass to platinum, cast steel to machine steel, malleable iron to steel and a great variety of other combinations. In the last few years there has been a great development in the manufacture of sheet metal articles and electric spot welding has been found a much cheaper and better method than riveting, especially with the lighter gages of sheet.

Rust is an insulator for low voltage and should be removed at those parts of the pieces which come in contact with the electrodes. In butt welding the two pieces, if of the same metal, should have practically the same cross-section at the joint, and when a larger piece is to be welded to a smaller, the end of the larger piece should be reduced to the section of the smaller for a length depending on the section or diameter. The upsetting of the ends together to make a butt weld causes the joint to be enlarged, forming a burr, fin or swelling; if objectionable, this can be removed under a press or hammer while the metal is hot, or in thin flat stock, where there is not enough heat to work, the light fin can be ground off.

Welding Machines

The electric current transformer, the clamping device and the pressure device are the three necessary elements in an electric welding machine. Although it is possible to give the transformer a different location from that of the two mechanical elements, it is rarely done, the commercial welding machine employing all three elements in the same structure. There are, of course, many special departures from this general form. The mechanical and electrical controls may be operated by hand, by foot, or may be automatic and operated by power. For small work, like welding wire, spring pressure in forming the weld is usually employed, and clamping is done either by hand or by power; for metals like copper and brass a weight pressure is usually best; for rounds and like sections up to ¾ inch, hand pressures are usually employed; for larger sections, hydraulic pressure or pressure obtained through self-contained oil jacks is used.

Electric welding machines are necessarily more or less special in the construction of their clamps and electrodes, no one machine being suitable for a great variety of sizes or forms of work, and some are entirely special and suitable only for the work for which they are built. Some are called semi-automatic, as when the operator's duty is only the putting in and taking out of the pieces, while other machines are entirely automatic, as regards clamping, exerting pressure for welding, and controlling the current.

Power machines for spot welding are built with heating time-adjustments and regulation so that the machine can be set for the right speed and the correct time of heating required for varying thicknesses and conditions of stock. They can be operated continuously or intermittently as necessary, so that the greatest amount of work which the operator can handle will be taken care of by the machine.

Time and Current Required

There is no process by which heat can be delivered to metal so quickly as by the electric resistance method. In small wire a fraction of a second only is required for welding, while with larger pieces proportionately more time is required. Welds can be made either quickly or slowly, depending upon the amount of power available. It is always desirable to have ample power so as to make the weld in the quickest possible time, as better results are usually obtained, and time and power are saved. A ¾-inch round can be welded with 15 KW. in 15 seconds or with 23 KW. in 6 seconds. Endless pieces like rings take more power, as the diameter decreases; copper and brass require more power and less time than steel or iron of like section.

The expense for current is small, as it is used only while the pieces are heating in the welding machine, which is from one-quarter to perhaps one-half of the time of the day's run. The welding machine is always ready if the current is available, by simply closing a switch, and when the weld is made the expense of consumption of energy instantly stops. The output per day for any welder depends, of course, upon the size of the stock to be welded, the shape of the pieces, and the facilities for handling. In wire hoops, under the best conditions, 1000 welds can be made per hour, while in very heavy tires, 100 per hour would be a very good output.

Large volumes of current at low pressures are required, approximately from 2000 to 50,000 amperes, at from 1 to 7 volts, being used for welding from ¼ inch to 3 inch round, or equivalent section. The pieces to be welded, when mounted on the terminals of the transformer, complete an electric circuit, all parts of which, except the pieces to be welded, are adequate to carry this heavy current without heating excessively or without much loss of energy. The current depends on the section of the pieces and the speed of welding.

An alternating current wired from a single phase, or from one phase of a multi-phase system is the most convenient and is universally used. A current of any usual frequency can be employed, the welding tranformer being adapted for the conditions, 60 cycles generally being used, although welding machines are employed on circuits of 25 cycles and even on circuits as low as 11½ and 15 cycles. The pressure also may be any commercial voltage, 220 volts being commonly available, although welding machines are operated on circuits ranging from 104 volts to 550 volts.

This current is usually obtained from the local lighting and power company rather than from individual generating plants, although in cases of large electric welding installations individual generator equipments are used. In installations of single welding machines, the current being used intermittently, the actual kilowatt-hours consumed in a day's run are small and the expense of current so light that an individual generator is not desirable.

The welding machine being a machine with self-induction, the power factor is low, sometimes 50 per cent, varying according to conditions, but rarely higher than 70 per cent. The nature of the load on the generator supplying the current is different from that of almost any other current consumer, except those using some forms of alternating-current motors, on account of the fact that when the circuit is closed through the breakswitch, the full amount of power required to make the weld is instantly thrown on the generator; and instead of building up from a minimum to a maximum, the maximum is first demanded of the generator. This necessarily creates some disturbance on the line.

Strength of Welds

When the visible surface of a piece (outside) reaches a welding heat the interior is necessarily also at a welding heat; for this reason, a more uniform result and a greater percentage of good welds can be obtained, and at least as strong, if not a stronger weld can be made than by any other method. In general it may be said that in good open-hearth mild steel, almost, and in some cases, fully, the strength of the metal section is obtained. Bessemer steel, being frequently higher in sulphur and phosphorus, cannot always be welded with such good results.

In high carbon steel the heat is so distinctly localized and its dissipation is so fast when the current is withdrawn, that just at either side of the weld the metal is chilled and may be more or less brittle. To overcome this, it is the practice to reclamp with the electrodes wider apart, letting the current flow through the brittle parts until they come to an annealing temperature. Reheating may be repeated when needed. A spot weld frequently is much stronger than a rivet. In very thin sheets the metal pulls away leaving a hole in one sheet with the metal of the weld adhering to the other sheet.

There is an infinite variety of welding work which can be done by the electric resistance process, an interesting example of which is the welding of rails for street railways, taking the direct current from the overhead trolley, transforming it to alternating current, and welding plates across the joint, making a practically continuous rail.

This work is being very extensively done in the large cities. An unusual method of making agricultural wheels consists in assembling the spokes in the two halves of the hub and mashing them all together at one operation in a welding machine. The welding of wire fabric used in wire fencing and for concrete reinforcing, for which has been developed the only fully automatic electric welding machine in existence, should also be mentioned; the strand wires and the stay wire are fed into the machine and welded automatically at all intersections.

A more detailed review of the conditions relating to electric resistance welding was presented by Mr. A. E. Buchenberg in MACHINERY. In contemplating the practicability of using electric welding machines, says this writer, the principal questions that should be given serious consideration and be definitely determined by the manufacturer, are as follows: 1. The efficiency and reliability of electric welds. 2. The output of machines in welds per hour. 3. Adaptability of electric welding machines to his work and shop requirements. 4. The cost of operation. 5. The initial cost of machines and such auxiliary apparatus as may be required.

The following pages will be devoted to a general discussion of electric butt welding as opposed to brazing and the ordinary forge method of lap welding, with particular reference to shop requirements.

Efficiency and Reliability of Welds

The manufacturer is not so much concerned with the fact that perfect welds can be made electrically, but more vitally interested in the efficiency, uniformity, and cost of the welds, that he may reasonably expect on his product and under his shop conditions. In some classes of work there can be no allowance made for even a very small per cent of breakage from imperfect work, and every weld must be a perfect molecular union over the entire area of the welding surfaces. As an example, we may take the case of the steering mechanism of an automobile, where it is found economical in machine work and stock to electrically weld the threaded steering head to the tubular stem. Under service conditions, this weld may at any instant be called upon to withstand severe longitudinal and torsional stresses which can very nearly reach the ultimate safe strength of the tube's cross-section. The safety of the occupants of the car may depend upon the efficiency of this weld, and before adopting the electric process, the manufacturer must be convinced that the welds can be made under commercial conditions so that each and every one can be absolutely depended upon.

There are many instances where the electric weld, if reliable and practical, will reduce production costs very materially in eliminating expensive machine work and the present unavoidable waste of stock. This is especially true where a great reduction in diameter is required over a considerable length of a bar or rod. It then becomes convenient to weld a rod of one diameter to another of greater diameter which results in a saving both of stock and the expensive machine work which would otherwise be necessary to remove it. Where a clevis or an eye is required on one or both ends of a rod, drop forgings might be welded to a length of cold-rolled steel. A machine bolt in place of being turned from hexagon stock might be made of two pieces, the head—an automatic screw machine product—welded to round stock of the proper bolt diameter. Where large or complicated drop forgings are required and the initial cost and upkeep of the dies would be high, the part might be made in two or more small drop forgings welded together, and allow the use of simple and comparatively inexpensive dies. From the few examples given, it will be plain that the question of reliability of electric welds may determine to a very great extent the shop production costs, assuming of course that the expense of making the welds is low.

The quality of any weld, whether made by the blow torch method, the ordinary forge method—usually called a "fire weld"—or electrically, depends entirely upon the efficiency of the molecular union between the welding surfaces. With either the electric or the fire weld, the molecular attraction, or cohesion, is brought about by first heating the stock to a plastic semi-fluid condition and then forcing an intimate surface contact between the two pieces by a succession of blows, as in the ordinary fire weld, or by the application of a heavy mechanical pressure as in the electric process. The "scarf" or lap of the fire weld is a convenience for the application of the blows of the hammer while making the weld and in many cases is a requirement, as when welding surfaces equivalent in area to at least the cross-section of the stock. With the electric process, no scarf or other preparation of the stock is required, the two pieces to be welded being simply clamped in suitable jaws or dies with their ends abutting, the welding pressure then being applied axially.

The Electric Welding Machine

The electric butt-welding machine which in some of its highly-developed special and automatic forms may be a very complicated piece of mechanical and electrical apparatus, is a structure for first heating stock by means of an electric current and then exerting mechanical pressure to force the welding surfaces together.

The component parts of an electric butt-welding machine in its simplest form are as follows:

1. A special type of transformer whose primary coils are connected to an alternating current-supply circuit and whose secondary winding delivers an output of very low voltage but heavy current. The transformer may be operated from any alternating current single-phase circuit of standard voltage and commercial frequency. The usual lighting and power voltages are 110, 220, and 440 volts, while the frequency may be either 25 or 60 cycles. If necessary, the welding machine may be operated from a 133 cycle circuit. Where polyphase alternating current is used, the welding transformer can be connected across one phase of a two- or three-phase circuit. Fig. 1 shows in detail the construction of a typical welding transformer with the

connecting leads to the clamping dies attached to the secondary winding. On account of the low voltage required, the secondary winding in this instance takes the form of a solid copper casting extending through the laminated iron core. It will be noted that the secondary leads are each made up of a large number of thin copper strips to afford the necessary flexibility for motion of the clamping dies.

2. Two copper clamping dies and supports in which the stock to be welded is securely held to afford good electrical contact and to prevent shifting and displacement of the work under end pressure.

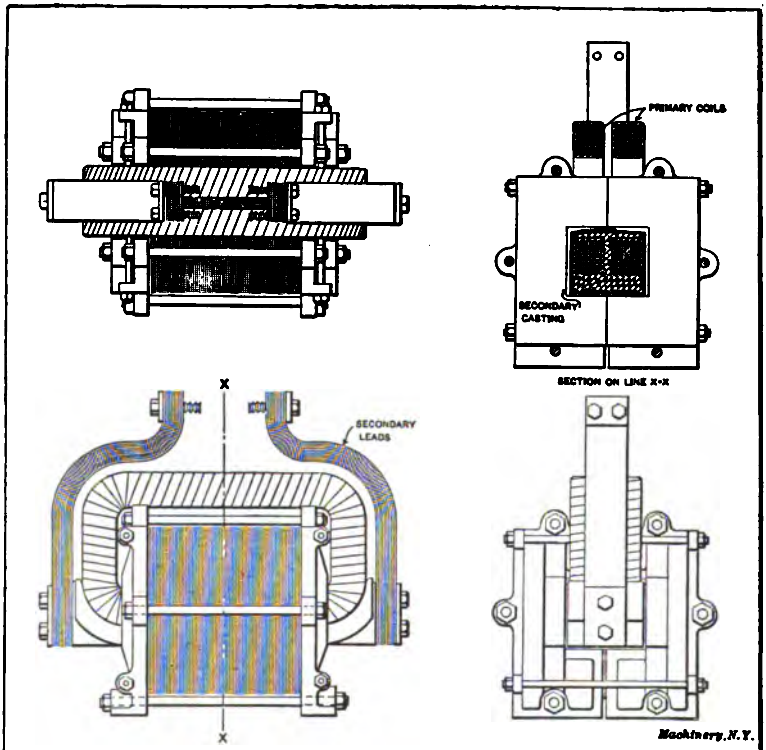

Fig. 1. Typical Transformer for Welding Machines

The dies and supports are capable of a limited movement toward and away from each other in suitable guides. In the machine as ordinarily constructed, the left-hand die is stationary but capable of adjustment, while the right-hand support is movable and connected to the compression mechanism. Each die and support is connected to one of the flexible secondary leads of the welding transformer.

3. To afford the heavy mechanical pressure necessary to be exerted at the proper time to force the heated abutting ends of the stock together to form the weld, a number of different arrangements are made use of. The compression mechanism used on a particular ma-

chine will depend to a great extent upon the size of the stock to be welded. For the smaller work, a spring or simple toggle lever is used, and for heavier stock, gears operated by a pilot wheel or a hand-operated double-acting hydraulic jack.

Machines for heavy work are seldom made automatic in their operation, since the question of large output per hour is not so important, and it is not always possible to supplant human judgment and skill with mechanical automatic devices.

Fig. 2 shows a simple form of the Toledo Electric Welding Co.'s machines for welding straight rods or tubes. The clamping dies *A* are fitted to the work they are to hold, and are mounted on the sliding supports *B* and B_1. The supports are mounted on guides shown at *C*. The clamping dies are operated to grip the stock *D* by means of the clamping levers *E*. The left-hand head *B* is stationary while welds are being made, but it can be adjusted for position by means of the shoulder-screw *F*. The compression toggle lever *G* is connected to the right-hand head B_1, by links as shown at *H*. The welding transformer *J* can be seen through the opening in the side plate of the machine. The foot switch for closing and opening the current through the primary coils of the transformer is shown at *K*.

Operation of an Electric Welding Machine

The several steps in the operation of the machine when making a butt weld are as follows. Two pieces of stock are clamped in the dies with the surfaces to be welded opposed and abutting, the dies being separated from each other a short distance to allow a converging motion for compressing the stock at the proper time. A switch connecting the primary coils of the welding transformer to the supply circuit, and which may be hand- or foot-operated, as convenience may dictate, is closed. The induced secondary current of the transformer now flows through the heavy flexible connecting leads, through the clamping supports and dies into the stock to be welded, and across the abutting surfaces. The junction of the welding stock is the point of highest electrical resistance in the entire transformer secondary circuit, which is made up of the secondary winding, connecting leads, clamping supports and dies, and the small projection of stock over each clamping die. The design of the transformer, secondary leads, clamping supports, dies, etc., makes their combined resistance very small as compared to the contact resistance at the point of weld. In conformity to the laws governing the heating of conductors carrying electric currents, practically all the heating will be confined to this point. In other words, nearly all the electrical energy taken from the supply circuit will be concentrated in this one location in the form of heat.

The secondary voltage of the transformer is so designed that the volume of secondary current forced through the junction of the two pieces of stock will produce a welding temperature at this point in a certain predetermined time. The actual secondary voltage required will depend upon the cross-section of the material to be welded, and whether the stock is iron, steel, brass, copper, or aluminum. The voltage varies between one and seven volts.

A voltage regulator of the inductive or "choking" type is usually supplied with each welding machine. This regulator is an auxiliary piece of apparatus connected in circuit with the transformer primary coils, and by means of which the secondary voltage can be readily adjusted through a wide range to afford the best operating conditions on varying kinds and sizes of stock.

At the instant a welding temperature has been reached, the switch is opened and the stock quickly compressed under heavy pressure to form the weld. A small amount of semi-fluid material is displaced under the pressure and thrown out all around the stock at the point

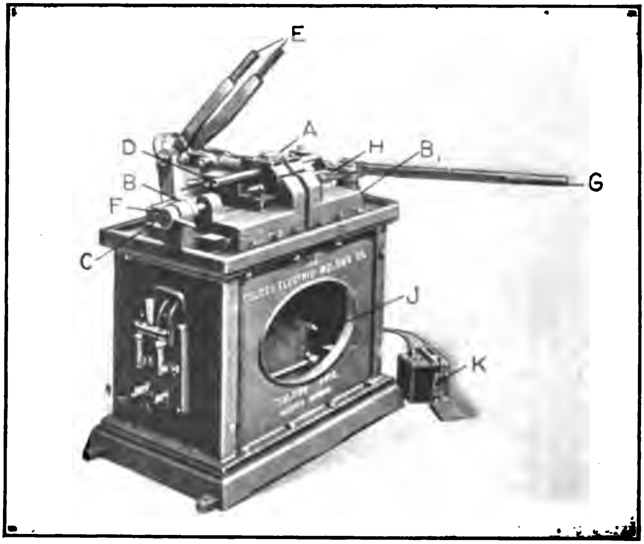

Fig. 2. Simple Form of Machine for Welding Straight Rods or Tubes

of weld in the form of a fin or burr. When necessary, this surplus metal can be removed by grinding or chipping, or it can be reduced under a power press to the stock dimensions.

Conditions Necessary for Perfect Weld

The primary conditions necessary to make a perfect weld between similar or dissimilar weldable metals are as follows:

1. The welding surfaces must be clean.
2. Each of the two pieces to be united must be at its particular welding temperature. The entire surfaces to be welded must be at this temperature, or in other words, the heat distribution must be uniform.
3. Repeated blows or a heavy continuous pressure must be applied while the welding surfaces are each at the proper heat, in order to form an intimate union between the two pieces of stock.

In the following are taken up in detail some of the more important conditions as they exist in the operation of an electric welding machine and in the fire method of lap welding:

Conditions of Welding Surfaces

The primary requisite, that the welding surfaces of the stock must be clean, is fully met in the electric process. Furthermore, the abutting welding surfaces are practically excluded from the air while being heated, and with the short time required to bring up the temperature, little or no oxidation can take place; for this reason, no flux of any description is required even on brass, copper, and aluminum. With the fire process, the welding surfaces are exposed to the action of impurities, particularly surphur in the coal, or the products of combustion in an oil or gas flame. Under these conditions and the length of time required to heat the stock, the use of a flux as a protective covering against oxidation over the welding surfaces, becomes an absolute necessity.

Heating

In the case of the electric weld, the heating begins in the interior of the stock and travels out toward the surfaces so that every particle of metal at the point of weld is at a uniform temperature. This condition is automatically attained, since the flow of current will always be greatest through the path of least resistance. If, on account of varying surface contact resistance, one part of the stock should heat up more rapidly than another, the increased resistance due to the higher temperature would automatically shunt a greater portion of the total current through the cooler part of the stock which is of lower resistance. This action, in combination with heat conduction, would result in an even temperature throughout the stock at the point of weld.

The heating action is concentrated at the junction of the two pieces to be welded, as the time of current flow is so short that the heat travels back but a short distance each side of the weld by conduction. There is no scaling or pitting due to surface oxidation, and the heat discoloration of the material in the case of round stock is seldom visible on each side of the weld for a distance greater than the diameter of the stock. All the heat is concentrated where needed, and there is no waste of energy or fuel in the useless heating of a considerable length of stock on each side of the weld.

The work is always in plain view of the operator who is able to judge to a nicety the instant at which the proper welding temperature for any particular grade of stock is reached. This is an important factor in obtaining perfect welds between materials of widely varying chemical and physical properties, where the proper welding temperature for each material may be at wide variance. Specific instances are the welding of cold-rolled steel rods to drop forgings or the welding of steel stems to brass bolt heads.

With the fire weld the heat is, of course, applied to the surface of the stock and the interior is heated by conduction only. With an intense fire and under conditions of rapid shop production, the outer surface, and especially the thinner edges of irregular sections, may easily be at a higher temperature than the heavier section. This condition may, and unfortunately often does, result in imperfect welds. It is particularly noticeable on lap welds.

With a fire weld using oil, gas or coal as fuel, a considerable length of the stock is brought to a high temperature. There is always more or less scaling and pitting of the stock owing to the length of time required for heating, during which time the surface of the stock is exposed to the oxidizing action of the air. It is a practical impossibility to forge-weld brass and other alloys of copper as the component metals of low fusing point will volatilize before the copper has reached a welding temperature. The stock is buried under a cover of coal or partly hidden in the flames of a gas or oil fire so that it is difficult to judge the temperature without uncovering the stock or removing it from the fire. The result is that the stock is, in many cases, underheated or overheated, the consequence in either case being an imperfect weld. When the output of welds per day is large, a very considerable saving of stock is effected by using electric welding machines, since the amount of stock wasted in the upset or fin is much less than the stock required for the overlap and scarf for a fire weld.

There is no danger from an electric shock to the operator of the machine since the primary coils of the transformer are heavily insulated, and the possible voltage to which the operator is subjected is no more than that of the ordinary door bell battery, and so slight that it cannot be felt under any conditions.

Output of Machines

The output, say in welds per hour, of any machine, will be determined by both the electrical and mechanical design. With automatic machines designed for a particular piece of work on light stock, the output is large. As an example, a machine for welding wire barrel hoops will take the wire from the reel, cut it into the proper lengths, and deliver the welded hoops at a rate of approximately 650 per hour. In the case of a hand-operated machine, the output will be determined by the mechanical design of the clamping dies and compression mechanism, the time required to heat the stock, and the facility with which the stock can be inserted in and removed from the machine as determined by its general shape and welding cross-section. Fig. 3 illustrates a hand-operated machine whose output on straight stock with a welding area equivalent to the cross-section of ¾-inch round stock, will be approximately 250 welds per hour. As a general rule, the larger the stock, the smaller will be the machine output, both on account of the longer time required for heating and the greater length of time required to handle the heavier stock.

Adaptability of Electric Welding Machines

Except in the case of a welder especially designed for one particular piece of work, quite a range in the shape and size of stock can be handled by one machine. A welder equipped with a voltage regulator can be adjusted to weld stock much smaller in sectional area than the rated capacity. As an example, a welder whose maximum capacity is one inch round stock, or an equivalent cross-sectional area in an irregular section, will, with a proper adjustment of the regulator, weld one-quarter inch round stock. However, as a commercial proposition, it is not good practice to weld very small stock on a large machine, as all the working parts are necessarily heavy and cumbersome on

Fig. 3. Hand-operated Machine with Output of 250 Welds on Straight Stock with Welding Area Equivalent to ¾-inch Round Cross-section

light work. For this reason the output would naturally be less than with a smaller, lighter, and more easily operated machine. Usually a change in the size of stock to be welded occupies only a few moments' time to change the clamping dies to conform to the new stock, and make the proper adjustment of the voltage regulator.

From the standpoint of maximum output, an important consideration in the selection of a welding machine is the facility with which the stock can be placed in the clamping dies, and the proper arrangement of jigs for accurate alignment of the work. Welders are now designed in standard forms for different general classes of work, and a machine whose welding capacity is ample for a particular piece of work, might be entirely unsuitable for economical production on account of the mechanical design. For instance, a machine designed for welding straight bars or rods would be impractical for taking care of such work as vehicle dash frames; these require a special machine designed so that the frame may be swung into several positions.

Cost of Operation

The operating cost will depend upon the size and material of the stock to be welded, upon the cost of the current, and the number of welds made. No current is used while the stock is being inserted into the clamping dies of the machine, or while being removed after the weld is completed. The amount of electrical energy required will depend upon the kind and shape of the material, and its cross-sectional area. The actual cost of operation is very low as is indicated in the following table, which gives the time and kilowatts per weld required for a number of sizes of iron or steel stock. The tabulated cost per 1000 welds is based upon a unit current cost of one cent per kilowatt hour. The actual cost in any particular instance can be determined by multiplying the cost per 1000 welds as given in the last column of the table by the price of current per kilowatt hour at that locality. The costs given do not include the time of the operator.

Initial Cost of Machines

The first cost of a welding machine will depend to a great extent upon the sectional area of the stock to be handled, and whether the material is iron, steel, brass, aluminum, or copper. The higher the electrical conductivity of the metal, the greater the amount of current required to raise it to a welding temperature in a given time, and the larger the welding transformer required. The cost of the machine will also be governed to some extent by the shape of the section of the stock quite independently of the actual sectional area. Heavier and more expensive clamping dies will be required to weld stock 1/8 × 6 inches than would be required for the same area of metal in the form of round stock. In the case just given, special mechanism must be used in connection with the clamping jaws in order to obtain an equal distribution of current along the abutting edges of the stock. Where a great output in the number of welds per hour is demanded, automatic or semi-automatic features become necessary and the cost of the machine is materially increased. Machines built for special work or to meet extraordinary conditions are, of course, much more expensive than standard stock machines. Up to sectional areas equivalent to 3/4-inch round stock, machines are usually operated by means of a simple hand toggle lever. From 3/4-inch to 1-inch round, a hand-wheel operating through gears may be used. For larger stock it becomes necessary to resort to a special double-acting hydraulic jack.

From the foregoing it will be seen that the first cost will be governed by size and kind of stock, shape of the parts to be welded, and the capacity of the machine in welds per hour.

While a welding machine, especially the smaller sizes, can be connected directly to the circuit supplying light or power to the shop, it is usually better, on account of the line disturbances set up by the intermittent inductive load, to install a separate transformer to supply the welder only. This transformer is usually furnished by the local power and lighting company. Where alternating current is not available, a small alternator driven from the line shafting can be installed to operate the welder.

Welding of Dissimilar Metals

A valuable feature of the resistance process of electric welding is that dissimilar metals can be perfectly joined. This possibility permits combination of metals best suited to the conditions of use to be made, as well as very substantial economies in the use of high-priced materials.

As examples of what can be done in the welding of dissimilar metals may be mentioned a number of products regularly made for the

TABLE GIVING TIME AND COST OF WELDING VARIOUS SECTIONS IN IRON OR STEEL

Diameter, inches	Area in square inches	Kilowatts, Transformer	Seconds to make Weld	Cost per 1000 Welds, Current one cent per Kilowatt hour
1/4	0.05	5	5	$ 0.07
3/8	0.11	7 1/2	6	0.13
1/2	0.20	8	10	0.22
5/8	0.31	10	12	0.33
3/4	0.44	12	15	0.50
7/8	0.60	15	20	0.83
1	0.79	18	30	1.50
1 1/8	0.99	20	30	1.66
1 1/4	1.23	26	40	2.89
1 1/2	1.77	40	60	6.67
1 3/4	2.41	45	70	8.75
2	3.14	56	80	12.44

market. Poppet exhaust valves for high-speed gas engines are made with a carbon-steel stem electrically welded to a nickel-steel head. By making the head of nickel steel, or some other alloy steel suited for the purpose, the very best metal is put into the head of the valve, which part is subjected to the hardest usage. Nickel steel is peculiarly suited to the trying conditions surrounding gas engine exhaust valves, because it does not pit, warp or corrode as does common steel in such a situation. It is also much tougher and is not apt to break because of the hammering it receives. On the other hand, the stem made of carbon steel stands the wear in the guide better than would a nickel-steel stem. It is also stiffer and can be hardened on the end. This latter condition is of considerable importance, because a high-nickel steel cannot be properly hardened to withstand the hard blows of the valve mechanism. Another important advantage of the combination is the saving of the high-priced metal and the obvious saving of labor over that required for making and machining a forging.

Cap-screws are made with brass heads and steel bodies. Such screws are fifty per cent stronger than would be screws made entirely from brass. This combination is made for use in places where an ornamental finish is required, but where the head only shows and a brass body is of no advantage.

Other valuable combinations of dissimilar metals could be mentioned, but the foregoing will serve to illustrate the advantage of electric welding in this line. One claim made for electric welded all-steel bolts and screws is that they are stronger than when made by the ordinary methods. The reason is that the die-drawn surface of the stock is retained on the body, this portion of the body being much stronger than the center which is left when the bar is turned down to the body size from the head size. This fact is indicated by tests made of electric welded cap-screws and cap-screws made by twelve makers, from ordinary stock. The tests show that the average tensile strength of ½ to 1¼ inch electric welded cap-screws was 97,862 pounds per square inch, while the average of the ordinary stock screws was only 56,570 pounds per square inch. The difference in favor of the electrically welded screw is thus 73 per cent.

Electric Welding of Copper, Brass and Aluminum

The welding of brass, bronze and other alloys of copper is almost impossible as a forging operation. The fusing points of the several alloy metals are considerably below that of copper, and it becomes a very difficult matter to prevent the oxidation of these metals before the copper component has reached a welding temperature. While it is possible to weld copper and aluminum in the same manner as iron or steel by the forging method, the work is more or less difficult and requires a careful and skilled operator. Some of the difficulties in welding are as follows: While the metal is at or near the welding heat and exposed to the air, a very rapid surface oxidation takes place, and the oxide or scale formed is extremely difficult to treat with any flux. The range of temperature between the heated plastic or welding condition and the fusing point of the material is very small. To add to the difficulties the metal becomes brittle as the temperature approaches the welding heat.

While aluminum reaches a welding heat at a temperature considerably below that of copper, it is also subject to a serious surface oxidation when exposed to the air at high temperatures. The range of temperature between the welding and fusing points of aluminum is only about 180 degrees F. If overheated it will simply spatter away under the hammer when attempt to make a weld is made.

The principle for the electric welding of copper, brass and aluminum is the same as for iron or steel, as already explained, *viz.*, forcing the two welding surfaces into intimate contact while each is in a heated plastic condition.

The time required to electrically weld copper, aluminum and copper alloys depends to a very great extent upon the cross-section of the stock, and varies from one second or less on very small stock to a minute or more on the larger sizes. The time limits between which stock of any given cross-section can be successfully welded are comparatively wide and governed in both directions by the volume of the heating current through the point of weld. If the current is low, the temperature rises more slowly at the point of the weld, and the heat travels back a considerable distance on each piece by conduction before the surfaces to be welded reach the required temperature. Under these conditions the fin or upset becomes quite large and entails too much expense in grinding to remove it. In the extreme case of insufficient current the heat is carried away from the point of the weld by conduction to the copper dies and by direct radiation to the air so rapidly that a welding temperature cannot be attained. If the volume of current is too great a very rapid heating of the stock takes place and trouble is experienced due to the fusing and oxidation at the point of weld which occurs more rapidly than the pressure can follow up the softening of the metal, and the excessively heated stock "spatters." Although the heating current is automatically cut off at the instant the forward motion of the die begins, the oxide coating on the end surfaces prevents a molecular union and a perfect weld. In other words, the stock is burned.

The heating current must be adjusted between the two extremes given above to a point where it is intense enough to bring the stock to a welding temperature, yet not so great as to cause an excessive heating and a "blowing out" of the weld. The correct adjustment is not a difficult matter, and is attained by varying the voltage impressed upon the primary coils of the transformer in one of two ways.

If the electric welder is operated by an alternator carrying this machine only, the voltage of the alternator (which in this case is the same as the primary voltage of the transformer) can be varied by a manipulation of the alternator rheostats.

Again, when the electric welder is operated from a circuit the voltage of which must be maintained at a constant value, such as a power circuit from which other welders or motors are being operated, an inductive regulator is used as an auxiliary apparatus to the welding machine. The action of such a regulator is simply that of a variable choke coil, and any desired voltage can be obtained across the primary terminals of each welding transformer by a proper adjustment of the regulator.

A skilled or experienced man is not required for operating an electric welding machine, as the only duties of the operator consist in clamping the work in the dies of the machine and closing the switch. For this reason it is customary to use boys on this work. Many machines for light work are now made automatic in their operation, requiring no attention beyond feeding in the stock to be welded.

Uniform and perfect molecular union is obtained with this process, since the heating of the stock is from within outward and the entire areas of the welding surfaces are at the same temperature. The strength of the weld is practically equivalent to the strength of any other section of the stock of equal area and will withstand any subsequent bending, rolling, hammering, or drawing process to which it may be subjected.

The difficulties encountered in the forging process due to the oxide surface films formed at high temperatures are not present in the electric process. During the extremely short heating period the welding surfaces are in contact and practically excluded from the air. Furthermore, the heating action ceases the instant the welding

TIME, CURRENT CONSUMPTION AND UNIT PRICE FOR ELECTRIC WELDING OF COPPER

Area in square inch	Approximate Equivalent diameter, inch	Kilowatts	Time in Seconds to make Weld	Cost per 1000 Welds at 1 cent per KW. hour, Dollars
0.05	1/4	5	4	0.055
0.10	3/8	7	5	0.097
0.20	1/2	14	7	0.272
0.30	5/8	19.5	9	0.487
0.40	11/16	26	12	0.866
0.50	13/16	32	14	1.240
0.75	1	46	17	2.170
1.00	1 1/8	62	21	3.610

temperature has been reached, and the heat extends to but a very small distance on each side of the weld. It is obvious that with a continuously applied pressure which instantly compresses the stock to form a weld when the proper temperature has been reached, the difficulty experienced in other processes due to the small range of temperature from the plastic to the fused state of the metals is overcome.

The electric welding of copper, brass and aluminum is a very rapid operation and entirely free from noise, dirt and smoke. The machine can be located in any convenient position in the shop and is free from danger of electrical shocks to the operator. The motion of the movable die can be adjusted for both the forward and backward travel so that all welds are to gage. This is an important consideration when, for example, many thousands of rings must each be welded to an exact diameter.

The cost of electric welding is low as compared to other methods. Herewith is given a table for copper showing the kilowatts and time required to make a weld from the time of closing the switch. Also the cost per 1,000 welds at a unit basis of current cost of one cent per kilowatt-hour. To arrive at the actual cost of the current per 1,000 welds it is only necessary to multiply the cost given in the table by the price for current per kilowatt-hour in any given locality.

CHAPTER III

POINT AND RIDGE METHOD OF ELECTRIC WELDING

The electric welding process, which from a commercial standpoint is comparatively new, has revolutionized many manufacturing methods, owing to its efficiency, particularly on that class of work which must be produced in large quantities and at a minimum cost. The extent, however, to which this method of welding metals is now employed, is no doubt very limited, in comparison with the number of manufacturing operations which could advantageously be performed by the electric process of welding. This is largely due to the fact that the art is little understood, particularly as regards the variety or range of work which can be efficiently welded electrically.

Various types of electric welding machines have been placed on the market by the Universal Electric Welding Co. One of the ma-

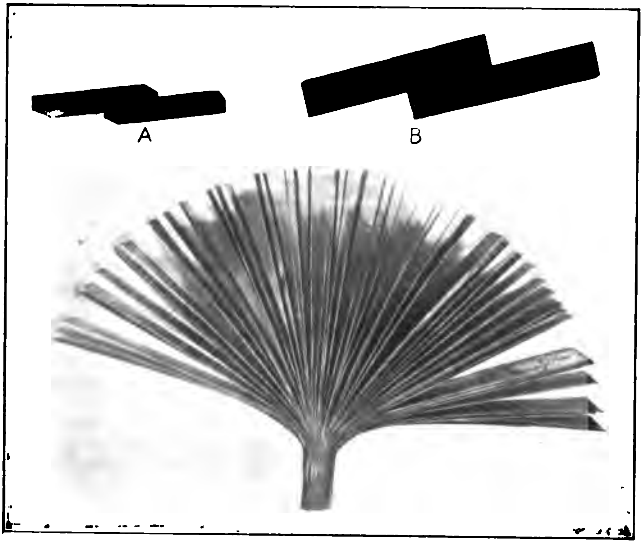

Fig. 1. Examples showing Possibilities of Welding Thick Materials

chines handled by this company is made to be fastened on a bench and operated by a hand lever. This same machine can be fitted to a stand and operated either by hand or by foot power, and can also be belt-driven and made to work automatically. It is particularly adapted for "electrode" welding, commonly called "spot welding." It is constructed with long projecting horns made as deep as three feet and with varying capacities to weld from the lightest gages up to ¼-inch sheets. The generally accepted idea that spot welding is practical to only as high as ⅛-inch thickness of sheet is fully disproved in the case of this machine. Pipe from 6 inches in diameter and up to 6 feet long can also be welded in machines of this type.

Methods of Welding

For a number of years electric welding was confined to the butt welding of rods, tubes, etc., and later the "spot" welding of flat stock by means of isolated welds of a limited area was developed. The spot method opened up an entirely new field, which, as the result of still later improvements, has been extended until, at the present time, the electric welding method of uniting metals is adapted to a great

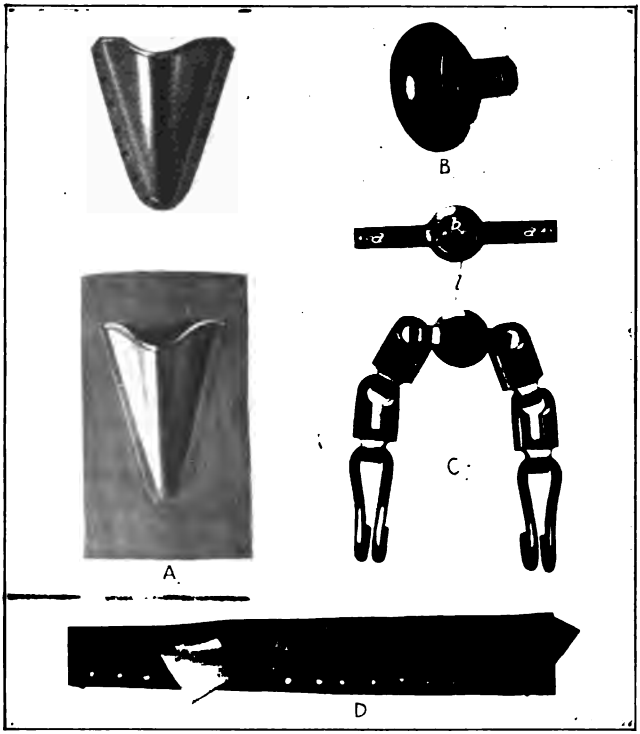

Fig. 2. Illustration of the Application of the Point Method of Electric Welding

variety of manufacturing operations. One method of making a "spot" weld is to use pointed copper dies or electrodes, which are brought into contact with the work which is welded by the passage of a large volume of low-voltage current. Another method is to raise projections above the plane surface of the parts to be welded, which serve to concentrate or localize the current in order to heat the metal to the welding point; and a still further development consists in raising ridges above the plane surfaces, which, when crossed by corresponding ridges, give the same practical results as the raised points, with the additional advantage of ease in assembling the parts prior to welding. This idea of using points or ridges in connection with electric welding has made it possible to weld, commercially, an almost unlimited variety of work, as is indicated by the accompanying illustrations. In the spot electrode welding of light-gage metals, a slight indentation is usually left in the surface at the weld, but by a method recently developed, this condition is overcome, and the sheet can be left the full thickness and finished off. By using this method there is practically no limit to the thickness which can be spot welded. This is indicated in Fig. 1, where two bars each ⅞ inch thick have been spot welded together. The operation took about one minute.

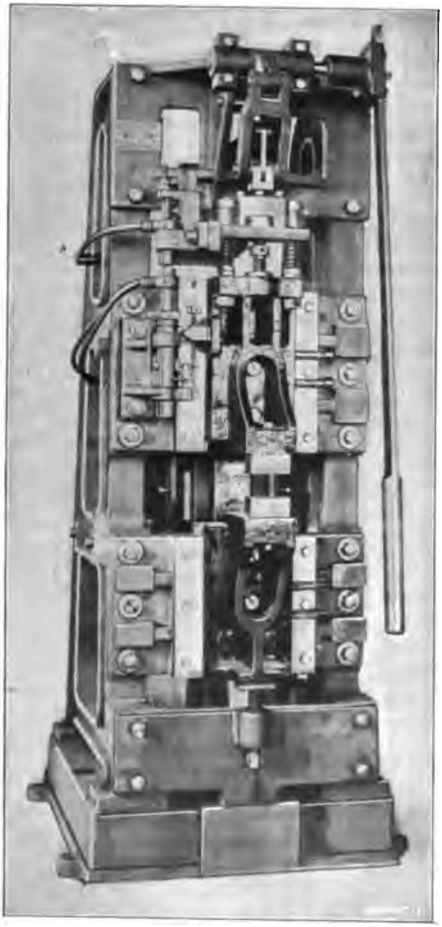

Fig. 3. Type of Electric Welding Machine for Heavy Work

Point or Projection Welding

As mentioned, the welding of sheet metal is not restricted to one spot at a time, for any reasonable number of welds can be made at one operation by the method known as "point" or "projection" welding. In such welding, used, for example, for cooking utensils, sash pulleys, etc., the parts when stamped have small projections raised above the plane surface of the metal, the height of the projection varying according to the gage of the material. This is done during the operation of stamping. When welding such parts, properly shaped copper electrodes are fitted to them. Each point acts as a resistance to the passage of the welding current. The current divides itself among these points and by their resistance to its passage, each becomes a heated welding point. Pressure applied to the softening metal completes all the welds simultaneously. Fig. 2 shows a spout welded to a coffee pot at twenty-three distinct points.

A marked distinction exists between the two methods of "spot" and "point" welding, as many cases occur when the spot method cannot be used, but the point method proves perfectly successful and commercial. Fig. 2 illustrates an anti-skid chain which is an excellent example. In making this chain the electrode method was first tried by the manufacturer. The point method was then applied, raising points on both the body and the strap, and resulting

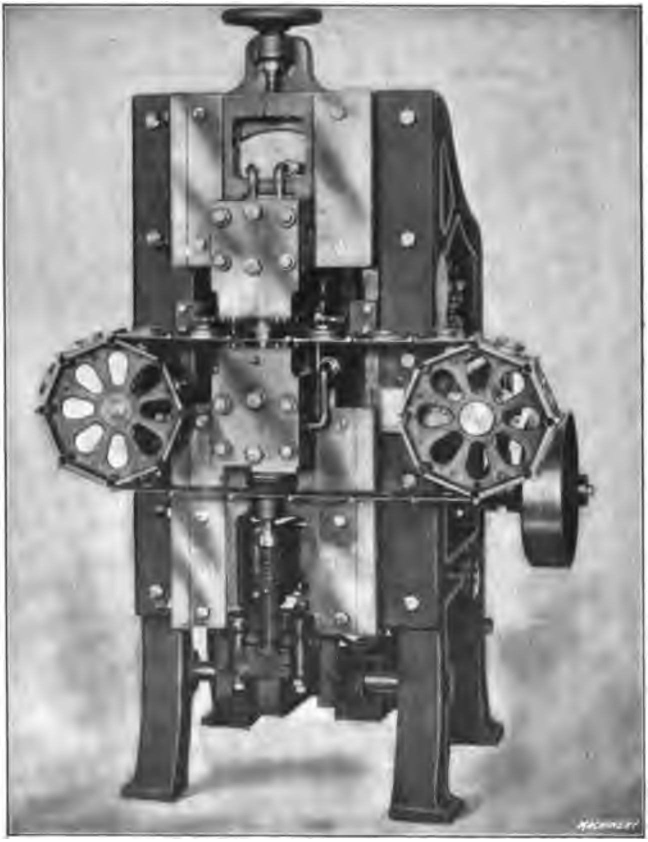

Fig. 4. Automatic Electric Sheave Welder

in a perfect weld. The output by the spot method was 600 per day of unsatisfactory welds; by the point method, 3000 good welds.

Another excellent example is that of the door knob shown in Fig. 2. The shank is welded to the hollow knob by six distinct points. It is impossible to weld this except by the point method.

Ridge Welding

To facilitate the assembling of parts, a further improvement was made by the introduction of so-called "ridge" welding. The result of two ridges crossing is the same as of two points, and the operation of making the weld is identically the same. Both point and ridge welding permit the use of large flat blocks of copper for electrodes, the heat being localized by the points or ridges forming the welding spot. In both these methods the electrodes require very little attention except an occasional touch with a file over the surface, as against continual shaping of small pointed electrodes.

Types of Welding Machines

The machine used for point and ridge welding is equipped with large copper electrodes instead of the pointed type, and the current is

Fig. 5. Sash Pulley and Housing welded by the Point Method

concentrated at the points to be welded by the small raised projections, as mentioned, instead of by reducing the area of the electrodes. With the large electrodes, sufficient current for welding heavy stock can be conducted without excessive heating and deterioration. A welding machine having these large electrodes is illustrated in Fig. 3, which shows a standard type intended for general work. This machine may be either hand-operated, as shown, or may be made semi-automatic, belt-driven. When a great quantity of similar articles is to be made, special machines are usually built. The automatic sheave welder shown in Fig. 4 is used by the American Pulley Co.; it welds 15,000 pulleys in ten hours.

Examples of Electric Welding

Fig. 5 shows a sash pulley and housing which is an example of point welding. The pulley is made in halves, one half having an annular ridge and the other, six projections or raised points *A*. When the points of one half are brought into contact with the ridge on the other, the electric current, being concentrated, fuses the metal instantly, and six homogeneous point or spot welds are produced. These pulleys are welded on the automatic machine shown in Fig. 4. The housing *B* is also made in two parts, each of which is joined to the base-plate by four point welds as shown.

Another example of point welding is shown at *A* in Fig. 2, indicating how a spout is welded to a coffee pot, as already referred to. The "anti-skid" chain for automobiles shown at *C*, and also previously mentioned, has the central link *l* welded as indicated. The link is drop-forged with raised points at *a* and *b* which form the welds after the wings are bent over onto the central part. The strength of the point

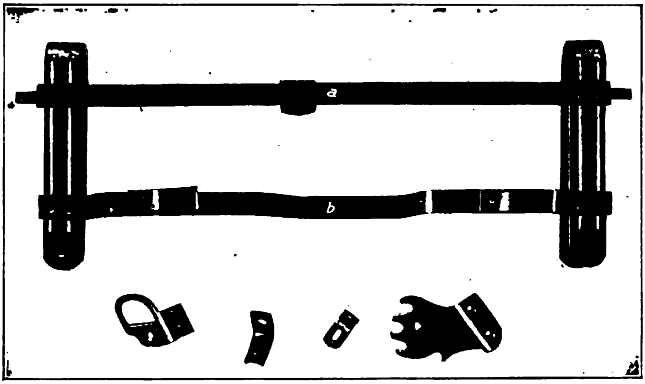

Fig. 6. Examples of Ridge Welding

weld is indicated by the sample shown at *D*. An attempt to tear the small pieces from the steel strip, resulted in shearing the metal around the weld, but in no case did the weld prove defective.

Fig. 6 shows an example of ridge welding. This is part of a go-cart frame. The stock from which the end pieces are made has ridges rolled in it as shown. The cross-bar *a* is provided with two raised points at each end that come directly over the ridges, and the bar *b* has concave ends thus giving contact points where the curved edges rest on the ridges. Beneath this frame a number of small parts are shown that are prepared with projections ready for welding. The ridge method of welding is also used for welding reinforced concrete frames, the ridges which form the points of contact being originally rolled in the stock. Generally speaking, the ridge method is preferable, owing to the greater facility in assembling parts prior to welding; the ridges also stiffen and strengthen the material. The results obtained by the ridge method are, as far as the quality of the weld is concerned, practically the same as when projections or points are used.

CHAPTER IV

ELECTRIC ARC WELDING

Electric arc welding as a means of uniting metals—particularly iron and steel—has been rapidly developed in the past few years, and apparatus for doing this work is now a standard product with a number of manufacturing concerns. This process of welding is particularly applicable to certain classes of work encountered in foundries, railroad shops, tank and boiler shops, steel mills, locomotive shops, and shipyards; and the demand for welding apparatus from these sources is well established. In addition to the field covered by these industries, where the use of this process has become more or less standardized, there are countless other lines of manufacture, each representing a great variety of work to which arc welding is adapted.

Various methods of using the arc for welding have been devised from time to time, the majority of which have met with indifferent success. At the present day practically all welding, in this country at least, is confined to the method in which an electrode and the object to be welded are connected in a simple electric circuit, and an arc of limited size is drawn between the two by bringing the electrode in contact with the work at the point at which the weld is to be made. The size of the arc is capable of adjustment to suit various classes and conditions of work.

The Carbon Arc

In practice there are two methods of applying this process to the making of welds and the cutting of metals. In the first, which makes use of the carbon arc, a rod of graphite forms the electrode; and the arc drawn between this rod and the work heats the latter to the point of fusion. This method is used for cutting or burning off metal, and is the simplest application of the arc. Its principal use is for reducing scrap material to sizes capable of being easily handled, and in foundries for cutting risers and fins from large castings. By extending this process of fusion and introducing pieces of metal within the influence of the arc, actual welding or building up of the work is accomplished. The metal supplied, which may be either in the form of small pieces of scrap material or a rod held in the operator's hand, is fused and unites with that part of the work already raised to a molten state by the heat of the arc, forming a solid mass of even structure upon cooling.

The principal field for the use of the carbon arc is in foundries and steel mills, for the repair of broken and imperfect castings of large size. The loss from this source, which is always high, can be reduced to a very small percentage, as castings containing blow-holes, cracks, shorts, etc., can readily be repaired with a small expenditure for material and labor. For all work of this nature in which the carbon arc is used, comparatively heavy currents are required, ranging from 300 to 600 amperes. Owing to the ability to use these heavy currents, and to apply the heat quickly and concentrate it at the required point, the heat generated at any particular point is very intense and the process of cutting or welding becomes a very rapid one.

The Metallic Arc

The second method in this process of welding makes use of a metallic electrode—usually of a soft grade of iron or steel—which during the operation of welding is fused by the heat of the arc and carried over in the form of small globules that are deposited at the point on the work from which the arc rises. The work itself is raised to a state of incandescence at this point, and the fused metal unites with it as it flows from the electrode. The operation of welding by this method is very rapid, as the fusing of the electrode is continuous after the arc is started, the drops of molten metal following each other in close succession. This method is extensively used in all classes of repair and reclamation work, such as filling in cracks of broken castings, building up the worn parts of rolls and rails, repairing cracks in boilers, patching locomotive fireboxes, and in many industries as a manufacturing means in the process of getting out the finished product. Examples of this latter use are the welding of heads and branches to tanks, joining the seams of tanks and boilers, welding fireboxes, flue sheets, boiler tubes, etc., and all classes of pipe and sheet metal work.

The current required for the metallic arc is small compared with that used in connection with the carbon arc, rarely exceeding 175 amperes for the heavier classes of work just described, and ranging from this down to as low as from 12 to 15 amperes for thin sheet metal work. The size of the electrode used also varies with the nature of the work and current required, the average being from 3/32 to 1/8 inch in diameter. That it is necessary in every case to have a proper relation between the current strength and the size of the electrode can be seen, when it is considered that the heat of the arc must be sufficient to raise a spot on the work to the point of fusion, in order that there may be actual union of the metal from the electrode with the work. If this condition of right temperature does not obtain, there will be an imperfect union of the oncoming metal with the work, and a poor weld will be the result. On the other hand, if the metal is overheated there is danger of burning it. Oxidation also takes place more rapidly, thus impairing the weld, and heavier heating and cooling strains are set up in the metal. The current must, therefore, be regulated to bring about the condition of a proper temperature rise in the work, and the size of the electrode should be selected to carry this current without danger of its being overheated and oxidized. On the other hand, the size of the electrode must not be too large for the current used, as this will result in slow and imperfect fusion, and equally slow and unsatisfactory welds.

Combined Use of Arc

In many cases, and more particularly in repair work, it frequently becomes necessary to remove parts of the metal at the place where the weld is to be made. For example, to widen out a crack in order that the metal from the electrode may be more readily deposited in it; or to cut out a burned, broken or worn spot for the insertion of new material. This operation of cutting is most readily performed by means of the carbon arc. In such work, therefore, the alternate use of the carbon and metallic arcs becomes desirable and to meet this requirement, as well as to make the outfit as general in its application as possible, means are usually provided whereby both classes of welding can be done from the same outfit. This feature also makes preheating possible, by which means work of large section is raised in temperature by use of the carbon arc, before the welding is actually done. The operation of welding on the hot metal results in the strains being more evenly distributed, both during the process of welding and when the work is cooling off. Welds of greater strength are thus obtained, and the structure of the metal in the weld is more homogeneous with that of the surrounding parts.

Description of Apparatus

The simplest possible outfit for welding would consist of a source of direct-current supply, an adjustable resistance for regulating the current, and an electrode holder. In practice, for reasons which will be explained later, the current is usually furnished by a low voltage generator which may be driven by a motor, engine or belt. In addition, the outfit usually includes a switchboard having on it the starting apparatus for the motor end of the outfit, if motor driven; the control and indicating apparatus for the generator, consisting of a field regulator, voltmeter, and ammeter; and the regulating apparatus for the arc circuit, consisting of a set of current regulating switches with resistance, and usually some form of automatic switch or contactor.

The generator should be compound wound in order that the voltage may be maintained constant under varying load. The need for close voltage regulation will be found to be greatest in connection with the metallic arc, and to increase as the size of the arc and the amount of current used decreases. The smaller arcs will be found to be very sensitive to even the slightest voltage variation, the direct result being an uneven deposit of metal, and burnt welds in the case of very light work. With the carbon arc, where the current used is generally large and where a certain amount of current regulation can be had by lengthening or shortening the arc, the need for close voltage regulation is not so great.

Of the resistance, a certain part is in circuit with the arc at all times when working, this resistance causing the difference between the voltage drop in the arc and the terminal voltage of the machine. It will vary with the amount of current required for welding, and is adjusted by the current regulating switch. When no contactor is employed in the arc circuit, the current at the time the arc is started is limited only by the resistance in that circuit, which is the amount required for welding. This may be of low value, particularly when using a heavy current. There is, therefore, danger of short-circuiting the generator until the arc is established and its resistance introduced into the circuit. The function of the contactor in the arc circuit is to cut out resistance after the arc is established, leaving in the circuit for welding that amount previously determined from the current to be used. By this means the chance for short-circuit is removed, and the apparatus made more automatic in its operation.

After the current is adjusted to give the size of arc needed, no further adjustment is necessary and the arc may be drawn and broken at will, the automatic character of the apparatus always insuring a return to normal conditions. By this means the operator is relieved of all concern as to current regulation, and his whole attention may be given to directing the arc over the work. The cperation of welding by either of the methods described makes necessary the renewal of the electrode, though the rate at which the metallic electrode is consumed—owing to the fact that it constitutes the filling material—is much more rapid than that of the graphite rod. To facilitate the act of renewal or of feeding down as it is consumed, the rod forming the electrode is secured to a holder by some form of clamp that readily permits of its being released. The holder is designed to carry the current to the electrode with the least amount of heating of the operator's hand.

Owing to the intense nature of the light and heat rays from the arc, the necessity for careful protection of the operator's hands, face and eyes is very important. This is particularly so in the case of the carbon arc, where the volume of light and heat is very great. Heavy gloves serve to protect the hands, while for the face, some form of shield held in the hand or supported from the head is generally used. This is provided with an opening filled with several thicknesses of ruby or blue glass, which afford protection to the eyes and still permit of the welding operation being closely followed.

Potential Required for Welding

The potential which has been found to give the most satisfactory results for welding varies from 65 to 75 volts. A higher potential can, of course, be used, but as the drop in the arc rarely exceeds 65 volts, a potential in excess of this would have to be reduced by means of resistance in series with the arc. The wasteful effect of using a higher voltage, or of welding directly from shop or commercial circuits by means of resistance banks or water rheostats can be seen. The higher the voltage of the circuit from which welding is done, the greater the amount of resistance needed and the greater the energy loss due to this resistance. Assuming that 75 volts is the maximum required for all cases of ordinary welding, if a 220 volt circuit is used for this purpose, the efficiency is seen to be approximately 33 per cent, while at 500 volts it is as low as 15 per cent. It will also be found that when heavy currents—such as are required for welding—are taken directly from the line, serious voltage fluctuations will result, with corresponding ill effects on the apparatus connected to the line.

Flexibility of the System

Any number of operators may weld from the same outfit, each working independently of the other and taking the amount of current required for his own particular work, the self-regulating feature of the generator insuring a constant voltage. All of the arc circuits may be taken from the one welding panel or they may be divided among several smaller panels, which may be located at various centers at which it may be desired to do welding, these panels being connected by leads through the shop to the main panel. The latter, in this case, would contain only the motor and generator control apparatus. This arrangement is particularly desirable in locomotive and railroad shops, where the majority of the work is of such a nature that it cannot be moved around conveniently for welding. For doing work of this nature, the electrode holder is often fitted with leads of sufficient length to allow the work to be reached.

Welding can thus be done up to any distance from the outfit, the only limit being the allowable voltage drop in the lines to the work and the electrode. This, in turn, can be regulated to a certain extent by increasing the size of the cable as the distance increases. Beyond 500 or 600 feet, however, this method is hardly practicable for any work other than that which can be done with the metallic electrode, as the size of the cable required for carbon work with its large currents would increase to such an extent that its cost would be prohibitive and the handling of the cable exceedingly difficult. To meet conditions of this character a complete portable outfit consisting of generating and regulating apparatus, mounted on a truck that can be moved from place to place, is most appropriate. For land use the generator end of such an outfit is usually motor driven, while for marine work steam-driven outfits mounted on barges afford the most convenient arrangement.

Special Features

In connecting the work and the electrode in the welding circuit, the former should be connected to the positive side of the source of supply. There are two reasons for this, the first being that the positive side of the arc is by far the hotter of the two. The point on the work under the action of the arc is thus brought to the required fusing temperature in less time than if it were connected to the negative side of the circuit. A better distribution of heat between the electrode and the work is also secured by this means, as the electrode which is usually of small mass compared with the work should naturally be subjected to the less amount of heat. But a more important reason for this arrangement is that when the electrode is made positive the resulting arc is found to be very erratic and unstable, and its control becomes practically impossible.

It is not necessary that the operation of welding always take place in a downward direction. While work with the carbon arc has to be done in this position, due to the flowing of the metal in the weld, the metallic arc can be used as readily on vertical or overhead welds as on downward ones, the only difference being in the rate at which the metal is applied. Owing to the fact that in any position other than downward, the metal is applied against the force of gravity, its rate of flow from the electrode is necessarily slower. This feature of being able to weld with the work in any position occasions a great saving in the amount of handling which would have to be done were it neces-

Fig. 1. Head, Flange and Branches welded in a 42-inch Tank with the Metallic Arc

Fig. 2. A Built-up Fit on an Armature Shaft done with the Metallic Arc

sary that all welding take place in a downward direction. The arc process of welding is thus seen to be exceedingly flexible in its application, covering work of practically all classes and degrees of accessibility, and this feature greatly facilitates the operation of welding. Handling of the work is reduced to a minimum, and welds are made with an ease and despatch not approached by any other method.

Character of Welds

A large measure of the success attained by this process is accounted for by the satisfactory character of the welds from the standpoint of efficiency. By a proper selection of the grade of filling metal, and the exercise of care in making the weld, it is possible to obtain a tensile strength in the weld of from 95 to 97 per cent of that of the original section. Welds made under the average conditions of everyday work show a tensile strength of from 80 to 90 per cent of the metal. It is possible by slightly reinforcing the welded section to make the strength of the weld even greater than that of the original section. This may be very desirable in many cases where a part has broken through having an undue strain put upon it. By a proper increase of section at this point, a repetition of the break may be avoided. Welds made by this process present a neat and finished appearance. With the metallic

Fig. 3. Fractured Mud-ring of Locomotive Firebox prepared for making the Welds

Fig. 4. The Completed Weld with Sections of the Throat Sheet replaced

arc, the filling metal added from the electrode can be deposited exactly where it is wanted; and with the carbon arc, where the added material is reduced to a molten state in the weld, it may be run at pleasure, extra material being added where needed and the surplus metal being fused down to the desired level.

Examples of Work Done by the Electric Arc

The illustrations in this chapter show examples of electric arc welding. While these are of a varied character and show work done with both the carbon and metallic arcs—with a considerable range of current—they do not in any way represent the complete possibilities of the process of arc welding and cutting. Fig. 1 shows an example of tank welding, in which the head, flange and branches of a tank 42 inches in diameter were welded with the metallic arc. The current required was approximately 165 amperes at 70 volts. The finished appearance of the welds and the necessity for little subsequent trimming will be evident from this illustration.

An armature shaft that had been turned too small at the spider fit is shown in Fig. 2; to remedy this error metal was added by means of the metallic arc, thus increasing the diameter sufficiently to provide

Fig. 5. Broken Casting from a Wood-working Machine

Fig. 6. Same Casting repaired with the Carbon Arc

for refinishing the fit to the required size. This was done with the metallic arc, using current of approximately 160 amperes. Figs. 3 and 4 show the repair of a fractured mud ring of a locomotive fire-box. It will be seen that part of the throat sheet has been cut away in Fig. 3 in order to give access to the mud ring. The fractures in the corners are first opened up with the carbon arc preparatory to welding, and after the weld is completed the sections of the throat sheet are replaced and welded as shown in Fig. 4. In this illustration, it will be noticed that the weld on the right-hand side has been dressed, while that on the left has not. The latter shows the appearance of the weld immediately after making a repair with the metallic arc. Figs. 5 and 6 show a broken casting of a wood planer before and after being repaired with the carbon arc. In cases of this kind the broken part is in use again in a short time, as the delay occasioned by having to replace it with a new casting is avoided.

Cost of Welding

The cost of making welds by this process can best be illustrated by examples covering operations of a common or familiar nature. The work capable of being done by arc welding is of such a varied character that it is not possible to give specific costs for each and every case that may present itself. The cost of generating current, the price paid for labor and the time required for doing any particular job will vary, and this will influence the cost of the weld. Of these three factors the first will be found to vary between the widest limits, the price of labor for the various classes of welding being fairly well standardized, and the time required for making welds not varying greatly when expert welders are employed. The cost of producing the following welds is figured on the basis of labor at 30 cents per hour, and current at 2 cents per kilowatt hour, the voltage in each case being approximately seventy.

A broken shaft 2 inches in diameter was welded and ready for refinishing in one hour; the current used was 350 amperes and the total cost 79 cents. A crack in the back sheet of a locomotive boiler 12 inches long was welded in nine hours, the current used was 175 amperes and the total cost $4.90. The risers on steel casting, 4 by 4 inches in size, were cut off in four minutes; the current used was 350 amperes and the total cost 5.2 cents. A cast-steel tender frame broken in three places was welded in twenty-seven hours; the current used was 300 amperes and the total cost $19.44. The journals of a worn 2-inch armature shaft were built up in three hours; the current used was 165 amperes and the cost $1.59. As an example of straight welding on sheet-metal work, seams on ⅛-inch steel can be welded at the rate of from 15 to 16 feet per hour, and on ¼-inch steel at the rate of from 12 to 13 feet per hour.

Any number of operators may work from the same outfit up to its capacity. They may be doing different classes of work, and at any distance from the outfit up to limits fixed by the allowable voltage drop in the lines. This feature is particularly effective in those cases where the job is large enough to permit of several operators working at one time. The low voltage used for welding precludes all chance of accident to the operator from contact with current-carrying parts of the apparatus. Welds made by the electric arc possess a degree of strength only slightly below that of the original section, and by reinforcing this can be increased to any desired amount. They present a neat and finished appearance, are homogeneous in structure and may be easily machined. From every standpoint they are of a highly satisfactory character.

CHAPTER V

ELECTRIC SOLDERING

The application of electricity in welding has been explained in the preceding chapters. As stated, there are two fundamental methods of welding in which the electric current is employed, *i. e.*, the arc and resistance methods. The arc is used to a limited extent for welding large broken parts and its application is considered more economical than any other process, but the danger of handling current at the high voltages that are necessary makes its scope limited. The other welding process, as invented and developed by Dr. Elihu Thomson, consists of causing a heavy current of electricity at a low voltage to flow through the abutting ends of the pieces of metal to be welded. This heats the metal at the joint to a welding temperature.

What is true of welding is also true of the electrical soldering process about to be described, as in both processes heat is developed by the same action, *i. e.*, the passage of a large current of electricity through the joint. This soldering process is a mechanical one and in operation the apparatus used is not likely to give any more trouble than any simple machine will. The wear on the clamping jaws makes it necessary to replace them periodically, but as they are comparatively inexpensive and constitute the only replacement necessary, the operating expense is very low. The amount of the current used in optical framework averages 1 KW. hour per 1500 joints. This current can be purchased from the local lighting company or a generator can be installed which would probably reduce the current expense.

How the Process is Conducted

The general method of soldering consists of holding the pieces to be joined by clamping jaws with the ends of the work in firm contact. A heavy current of electricity, regulated to heat the joint sufficiently to melt the solder, is next passed through the work. The solder, in the form of tape or wire, is then applied to the joint. It flows in and around all parts heated to the proper temperature, as when using a gas flame, but an important difference is noted: the "life" or temper is retained in pieces that have been electrically soldered, instead of their being left in an annealed condition as when heated with a flame. One theoretical reason for this is based on the fact that alternating current electricity travels on the surface of a conductor, and so the core of the work does not heat to a temperature sufficient to become annealed. This condition is illustrated in Fig. 1. The heat varies from a maximum at the joint to the normal temperature of the machine at the jaws, and the heated section would take some such form as shown. As the length of the work that is heated is relatively short, the distance between the clamps usually being twice the diameter of the work, the heat has not had time to run into the work before the joint is made and the current shut off. This is shown by the fact that two highly tempered wires soldered together by the electrical process offer the same resistance to being bent at any other point as at the joint. The yield point or bending strength of the metal is practically as high as before heating.

Range of Electrical Soldering

Practically all of the metals such as brass, copper, steel, German silver, gold, and silver can be soldered successfully in this way, and it is without doubt the most economical method for a continuous run of work. There are no noxious fumes or smoke produced in making an electrically soldered joint, and windows can be opened in warm

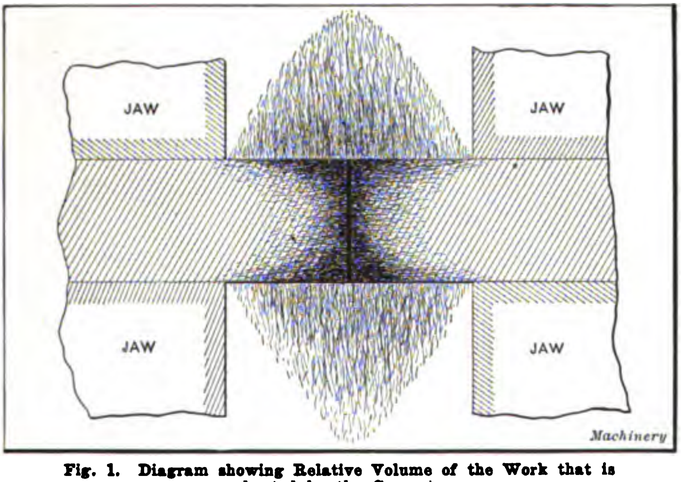

Fig. 1. Diagram showing Relative Volume of the Work that is heated by the Current

weather without affecting the process in the least. The operator is thus able to do a full day's work every day, instead of experiencing the fatigue that is caused by breathing the carbonic acid gas caused by the gas flames. The joint is made almost instantly, the time required to heat the joint, apply the solder, and shut off the current being approximately from three to five seconds, depending on the cross-sectional area of the joint. As the gripping jaws of the holders are made as large as possible, the heat is drawn from the work almost the instant that the current is shut off, allowing the work to be removed immediately.

Examples of Electrically Soldered Optical Frames

A few samples of parts of eyeglass frames joined by this process are illustrated in Fig. 2. At the extreme right is shown a "cable-temple" before and after the joint is made. These cable ends are wound in a special machine and consist of two coils, right- and left-hand, one inside the other. The inner coil is made of brass wire wound on a steel wire arbor and then swaged to a specified diameter. The outer coil is made of German silver, gold filled, or any other stock that is desired, and it is pushed over the inner coil. After the assembled cable is soldered to the "temple," which is a solid wire with the center reduced, it is swaged to the final finished diameter. This leaves a very smooth and flexible ear-piece, and at the same time a stiff connection to the lens-holders. The soldering of the brass-German-silver cables caused some trouble through the brass fusing before the German silver would heat enough to flow the solder, but this was stopped by using a larger wire in making the secondary coil of the transformer.

Two specimens of "nose-pieces" soldered to "eyes" are shown to the left of the cable-temples. These eyes are formed by rolling a round

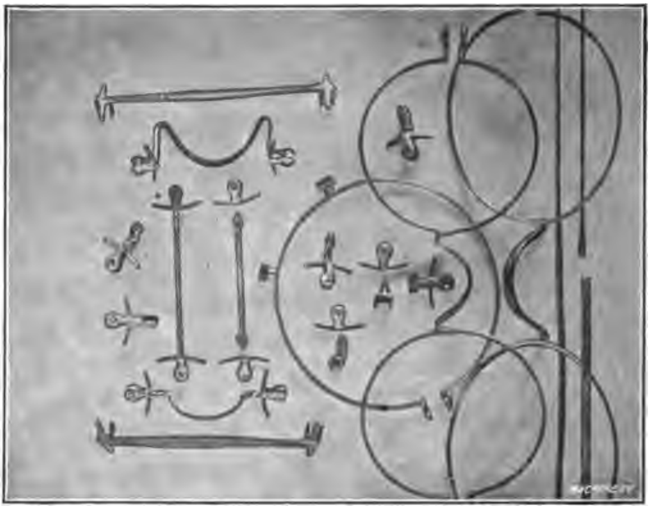

Fig. 2. Examples of Eyeglass Parts joined by Electrical Soldering

wire to form a groove in it; they are then wound on an arbor and sawed apart. The end-pieces are sawed, assembled and peened in one machine, and they were formerly soldered by gas. Previous to soldering the "bridges" on by electricity, a long space was annealed on the eyes. This made a joint that could be easily bent, and various methods of striking in dies were resorted to in order to get back some of the temper. In all cases of soldering by electricity, the eye wire is left with nearly all of the original temper. Another eye with studs attached is shown encircling samples of "straps," "studs" and "end pieces" before and after assembling and soldering, and to the left of this eye are shown different forms of bridges and nose-pieces with straps, before and after soldering. Such parts that have about the same cross-sectional area at the joint, are very easily handled.

The Utilization of High Voltage Alternating Current

In the process of electrical soldering, alternating current is invariably used, although there is no fundamental reason why direct current can not be employed. For mechanical and economical reasons, however, direct current is not to be considered. To make this clear, suppose a joint having a cross-sectional area of 0.125 square inch requires a current of 130 amperes at 3 volts to heat it properly, and that an ordinary plating dynamo rated at these figures is used to furnish the current. It will be noticed that the work heats practically solid from jaw to jaw. Then suppose a joint having a cross-sectional area of one-half the first one, or 0.063 square inch, is to be heated by the same dynamo. A suitable resistance must be interposed in order to reduce the current to a point where the joint will heat properly without melting. This resistance will use current as though it were doing useful work and the small joint will cost practically the same as the large one, as regards the amount of power consumed. On the other hand, it is claimed that the heating action of alternating current is more uniform, as it flows more on the surface; the heat is thus more intense on the surface and is evenly conducted to the core of the pieces, offsetting the effect of radiation and conductance.

The current used for electrical soldering should be a single phase alternating current of any frequency between 40 and 60. A higher frequency could be used, but it is not good practice for various reasons. A step-down transformer of the shell-core type is preferably used to reduce the 110 or 220 volt feed pressure down to the 1⅛ to 5 volts required at the machine jaws. It has been found that a pressure of from 1⅛ to 5 volts is sufficient for all optical frame work, and from 75 to 500 amperes of current is consumed. The use of a large transformer for small work is wasteful, as, although the current can be regulated as desired without much loss of energy, the work heats much more slowly than when a transformer of the proper capacity is used. The machine transformer is usually connected in series with a single phase generator, but it may also be connected to one phase of a polyphase circuit or to either phase of a two phase generator.

The Transformer

The transformer is made by winding a coil of very large insulated copper wire around a core built up of iron sheets cut to shape by dies, each sheet being insulated from the other by shellac or some other medium. This coil, known as the secondary coil, is carefully insulated from the primary coil, which consists of a large number of turns of smaller wire wound around the secondary coil and its core. The number of turns of fine wire depends upon the number of turns of heavy wire and the current to be taken in and given out; also on the rules governing transformer design. The type of transformer illustrated in Fig. 3 is particularly well adapted for use in electrical soldering, as it can be used without changes with other work holders; and this would not be the case if it were built into the machine. As shown, it has the coils protected by an iron cover which not only acts as a case, but also as part of the magnetic field. Transformers of this type are very efficient—from 95 to 97 per cent of the current taken in being given out—and they are particularly suited for constant work.

Unit System of Electrical Soldering

The writer has developed a "unit system" of soldering and applied it very successfully in the manufacture of optical frames. This system consists in mounting all the working parts of the machine for each particular operation on a base-board or stand. Figs. 3 and 4 illustrate this idea; the transformer is mounted at the center, with a fuse box at the rear and the work holder at the front of the board. Under the base-board is located the adjustable rheostat operated by a sliding plate shown at the side. To set up this machine at any position in the shop, it is only necessary to run two wires from the feed circuit and attach a foot treadle to operate the clamp jaws and switch. This system allows the same transformer and other parts to be used with another machine in case of a change or the discarding of the original machine.

There are two practical methods of controlling the heat obtained at the joint; one is by introducing an adjustable rheostat into the

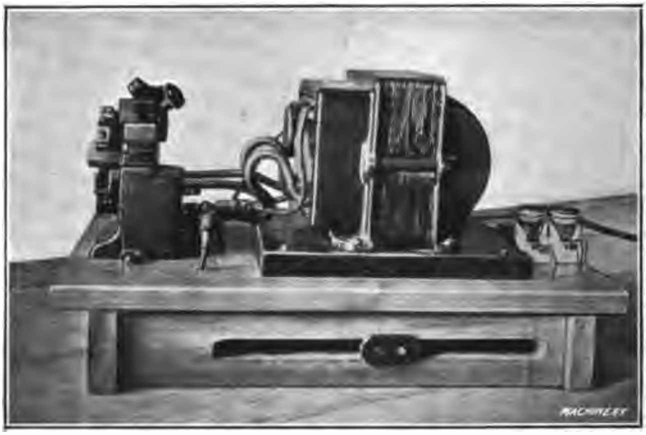

Fig. 3. Example of Unit Equipment for soldering Optical Frames

primary circuit, as illustrated; and the other method is to introduce a reactive or "choke" coil into the same circuit. Of the two, the reactive coil is undoubtedly the better, as there is practically no loss of power and an infinite number of adjustments may be made, whereas the rheostat is limited to the number of contact points used. The difference in loss of current is an inappreciable amount more with the rheostat, but it can be made for little expense and for that reason has been used more than the choke coil. The writer uses the rheostat control on nearly all of his equipments on account of its simplicity, the ease with which it may be built and the simplicity of operation.

A machine for soldering straps to eye-pieces and bridges is shown in Fig. 5. This machine or holder consists of a base *A* with a vertical slide *B* working in a slot at the rear. A second slide *C* also works in another slot at the rear, the slot being inclined at 45 degrees to the base. This slide *C* is operated through a lever *D* which receives its movement from the slide *B;* the lever *D* is pivoted in the base. The slide *B* is provided with a spring tension which allows the lever *D* to keep a constant pressure on the slide *C* while the slide *B* continues to move. The lever *D* works in a slot cut through the slide *C*, this slide carrying a cam-operated swinging arm at its upper end to which the clamping jaws *G* are attached. This upper jaw is designed to swing away from the work and leave it clear to facilitate handling.

At the rear of the machine and attached to the base there is a switch which is operated by a pin in the slide *B*. At the front of the base and insulated from it is the casting *I* which is milled to receive an arm *L* that is free to move on a pivot, but the motion of the arm is limited by the adjusting screws *J* and *K*. The arm is held against the screw *J* by means of an adjustable spring tension *N*. There is a jaw *O* at the upper end of the arm, which, in this case, holds the strap in the proper relation to the other part to which it is to be soldered. The contact of the jaw *O* with this strap is made by the pressure of the spring *N* against the arm *L*, and the strap is held against the part to which it is to be soldered, which is carried between the jaws *P* and *G*. The jaws are made interchangeable for different classes of work.

Fig. 4. Closer View of Work-holding Jaws shown in Fig. 3

At the lower end of the casting *I*, one end of the secondary or low pressure circuit is connected by means of the terminal *T*, and a spring brush *R* is used to insure a low resistance contact between the casting *I* and the rocker arm *L*. The lower clamping jaw *P* is attached to the base *A* and the jaw is provided with a gage for aligning the part held in it. The slide *B* is held at the top of its movement by means of the spring *S*. Two points of the switch control the primary or high pressure circuit, and the other two points operate on the secondary which is in the circuit with the jaws of the machine. A chain connects the lower part of the slide *B* with a foot treadle which is placed under the bench in a convenient position for the operator.

The operation of this holder is as follows: Two pieces to be joined, previously covered with a non-scaling or protective mixture, have the

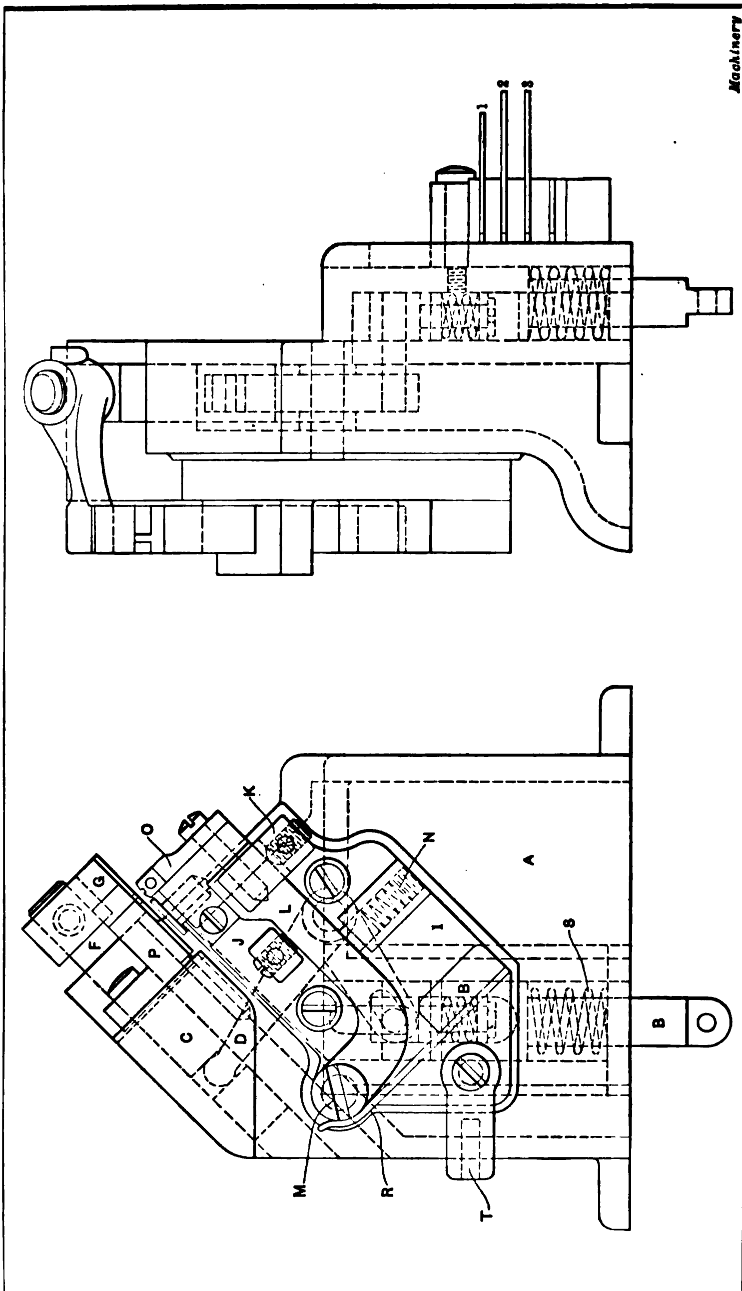

Fig. 5. Machine for Soldering Straps to Eye-pieces and Bridges

joint end of one piece dipped into the flux. They are then assembled in the proper relation to each other in the jaws of the holder, which are so arranged that the rocking arm is away from its stop when the work is in place. The foot treadle next is depressed until the upper clamp jaw grips the work; in this case only one part is held rigid. The other piece—which is a strap—is guided by its form and a teat on the piece held in the rigid jaws. The solder, in the form of wire, is then placed on the junction and the foot lever depressed further until the current is connected. Almost instantly the solder flows and runs around the joint, when the foot treadle is released entirely, and the work, which is left free, is taken out with a pair of tweezers. On work which is very small and difficult to handle with the fingers, tweezers are used; but such work as soldering temples together, bridges to eyes, bridges to straps, or eyes to studs, is handled with the fingers. The heat is held at the joint instead of spreading as it does when heated with the flame, so it causes the

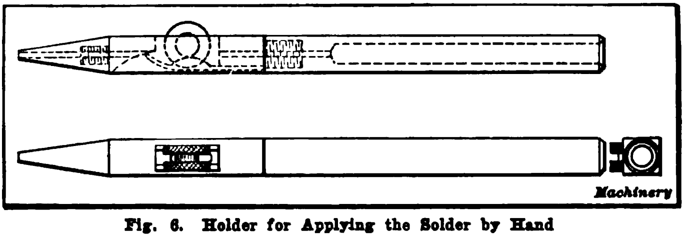

Fig. 6. Holder for Applying the Solder by Hand

operator no discomfort to take the joined pieces out as soon as the jaws are opened. The jaws are brushed clean at intervals, using a short hair stiff bristle brush for this purpose.

The idea of using a spring tension jaw was developed by the writer after having had considerable trouble caused by particles of dirt or burrs getting into the junction, also by not having the two ends fit together properly to form a contact of low resistance. By the movable jaw, all of this trouble was eliminated as the constant spring pressure holds the ends in firm contact, automatically keeps the ends together in the case of burrs or other points fusing, and prevents any break in the contact while the current is being applied. In the welding process, the ends are forced together while at a welding temperature, but this changes the form of the ends and shortens the pieces; consequently it could not be applied to optical work, as there must be no change in the size or form of the pieces to be joined. The spring behind the rocking arm *L* in Fig. 5 is adjusted to provide just sufficient tension to keep a constant pressure on the junction without deforming or upsetting the ends, thus forming the joint when the ends become hot. The jaws of the holder are made as large and heavy as possible to allow of their working continuously without heating. These jaws are made of copper, which has been found best for this purpose on account of the low resistance of the contact made between them and the metal to be operated on.

Preparing the Work to Prevent Scaling

To prevent gold-filled metal from scaling or "burning" at the joint, it is customary to cover the work with some preparation to prevent oxidation. Probably the best, and at the same time the simplest, method of preparing the work is to place it in an ordinary flour sieve, cover it with commercial boracic acid, and then shake all loose powder out. This leaves the parts covered with a thin coating of dust which becomes liquid at a low red heat and prevents the air from coming into contact with the surface of the gold. Another method is to make a solution of the boracic acid and water, dip the pieces into this solution, drain off the surplus and allow them to dry. In no case, however, should any solution be used that will leave a hard film over the parts, as this would prevent a clean contact with the clamping jaw, create a resistance that would cause an arc to develop, and spoil the surface of the work. The flux generally used is borax and it is prepared in the following manner: A piece of genuine slate, the green colored variety, which is the hardest, being the best, is thoroughly cleaned; a few drops of water are placed in the center and a thick, creamy mixture of borax is made by rubbing a piece of crystalline borax in the water on the slate until the desired consistency is obtained. The proper mixture is best determined by actual trial; a mixture that is too thin or too thick will either cause the solder to remain in one spot, instead of flowing through the joint, or create an unclean contact and interfere with the heating.

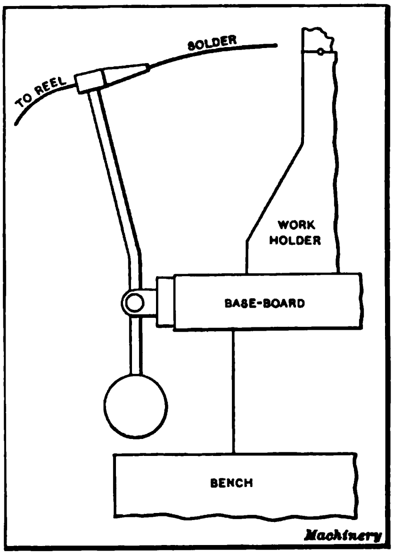

Fig. 7. Bracket for supporting Solder Holder on the Machine

The solder in the form of wire may be held in the hand in a holder, as shown in Fig. 6, or some such arrangement as the one shown in Fig. 7 may be employed. This consists of a chuck at the top of a wire, bent about as shown, and having a metal ball at the lower end heavy enough to balance the wire and chuck in an upright position. This wire is held by a screw in one member of a universal joint which allows the chuck to be moved freely to any position in front of the clamping jaws and take a convenient position to allow the solder to be grasped by the operator. When a holder of this type is used, both hands are free to place and adjust the work and apply the solder quickly.

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BORING, RECESSING AND MULTIPLE TURNING TOOLS

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CHAPTER I

DESIGN AND CONSTRUCTION OF BORING TOOLS

A boring tool or boring-bar is, in itself, a very simple tool and yet, in its various applications, it may require considerable forethought in order to obtain a tool which will be exactly the right one for the job. In order to properly design any kind of a cutting tool, an intimate knowledge of the actual working conditions which are met with in using the tool is a valuable asset. There are a number of factors which influence the design of boring tools and there are also many types of machinery to which boring tools may be applied. In some cases the bar revolves with the spindle of the machine, while in others it is held rigidly and the work revolves around it. These things affect the design and must be considered. The work naturally controls the size of the bar and also its shape, while the material which is to be cut makes a difference in the shape of the tool and determines the amount of "chip clearance" necessary.

The tools described and illustrated in this chapter must be considered as representative types of the many varieties to be met with in the general course of manufacturing. Points in design and construction will be noted and faulty tools will be discussed and criticised.

General Points in Boring Tool Design

Some of the important points in the design and construction of tools for single-point boring are here given, and while some of these may seem obvious, they may be of assistance in calling attention to matters which would otherwise be overlooked.

1. Chip clearance must be very carefully looked after when the tool is to be used for cutting steel, as an accumulation of chips caused by insufficient clearance is very annoying to the operator and also injures the work by tearing or scratching it, and finally ruins the bar itself unless it is hardened. The amount of clearance between the bar and the work should be as great as possible without sacrificing strength, and in this connection it should be noted that in addition to the necessary chip clearance at the point where the cutting action takes place, provision must also be made to get rid of the chips themselves. For this reason the portion of the bar beyond the cutting tool should be so proportioned that chips will not wedge. In cutting materials other than steel the clearance is not so important, as the chips are short and do not curl up or cling to the bar, so that they practically take care of themselves.

2. The method of holding or clamping the tool in position should be such that the thrust of the cut comes against the solid body of the bar and not against the set-screws or clamps. It is advisable to use square-head set-screws instead of the headless type whenever possible.

3. Boring-bars should be provided with some means of adjusting the tools for diameters, by the use of "backing-up" screws or wedges. The so-called "sledge hammer adjustment" type of bar should never be used when there is room enough to put in adjusting screws.

4. Boring-bar tools should be made as large as the diameter of the bar will permit without sacrificing strength, in order to assist in carrying away the heat generated by the cutting action, and to permit the use of heavier feeds without burning the tool. The rake of the tool should be such that it will turn the chips to the best advantage.

5. The bar should be so designed that micrometers can be used over the bar and tool in order that the operator may be able to set his diameters closely without resorting to the usual "cut-and-try" method used by our forefathers.

6. In the design of multiple boring-bars which are to be used to bore up to a shoulder, it is not good practice to set the tools in the bar at an angle. They should be located in a plane perpendicular to the axis of the bar. If set at an angle it will be found a very difficult matter to grind the tools so that diameters and shoulder distances will remain constant.

7. Bars designed for use on turret lathes should have the tools set in a plane perpendicular to the rotation of the turret. By this means variations in the indexing of the turret are minimized in their relation to the cutting tools, so that diameters can be held much closer to size than if the tools are arranged in a plane parallel to the turret rotation.

8. When the work is of such a nature that a cutting lubricant is required, provision should be made so that an ample supply of the fluid can be carried directly onto the face of the cutting tool. This result can be accomplished either by means of a hole in the bar with outlets at the proper places, or oil grooves covered with a strip of sheet brass. In either case a good connection must be made with the cutting lubricant system on the machine. This may be arranged by a distributing collar on the turret or by means of a special oiling device through the spindle.

Boring Tools for the Engine Lathe

Boring tools which are designed for use in the engine lathe are generally of a very simple kind, adapted only to light cutting and seldom used for more than one or two pieces of work of the same size at the same time. Several varieties are to be found in the average tool-room, although forged tools will be noted in greater numbers than any of the others. Tools of this kind of almost every conceivable shape and size, from a small round "hook tool" for cutting an inside recess, to a large bar of tool steel bent over at the end for boring some long pieces of work, will be found in abundance. There are square bars and round bars with inserted tools, and, in addition to these, each toolmaker has a special boring tool of his own make which he uses for jig work. These special tools occasionally show considerable ingenuity in their construction, and are usually made in such a way that very fine adjustments can be attained.

The upper part of Fig. 1 shows a piece of work *A* held by the outside in chuck jaws, the machine on which the work is to be done being an engine lathe. A plain forged tool *B* is held in the toolpost *C* on the cross-slide of the lathe. This type of tool is the simplest of all tools used for boring and consists of a rectangular piece of tool steel of suitable size to fit the toolpost. The tool is drawn out and bent

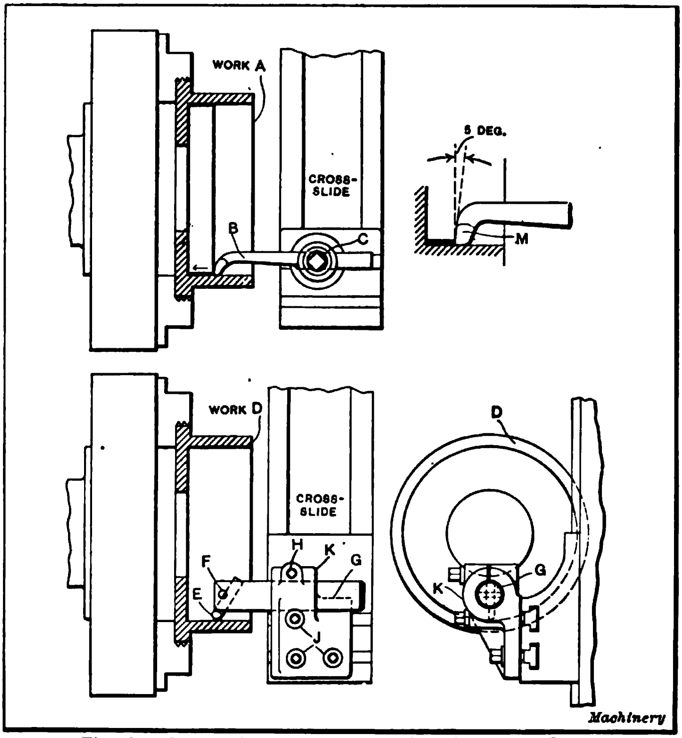

Fig. 1. (Upper View) Forged Type of Boring Tool; (Lower View) Boring Tool with Inserted Cutter

over at the cutting end by the blacksmith and is then ground to a cutting edge by the workman using it. Hundreds of tools of this variety can be found in every machine shop and factory in this country. They are suitable only for light cutting and there is a tendency toward "chatter" even when the cut is light; this is due partly to the shape of the cutting end and partly to the overhang of the entire tool. It will be found that less chatter will result if a slight land or flat is stoned on the tool immediately below the cutting edge. The tool should also be set slightly above the center. For casting work where scale is encountered, there is a decided tendency for the tool to ride up on the scale and ruin very rapidly if it is ground as shown at *B*. The enlarged view *M* shows another method of grinding which is useful in cases of this sort. It will be noted that there is a slight back taper to the end of the tool and this assists in preventing any riding up on the scale, as its tendency is to make the cutting point draw in slightly and thus keep under the scale. Care must be taken not to make the angle too great—5 degrees is ample, and much less than this can be used if desired.

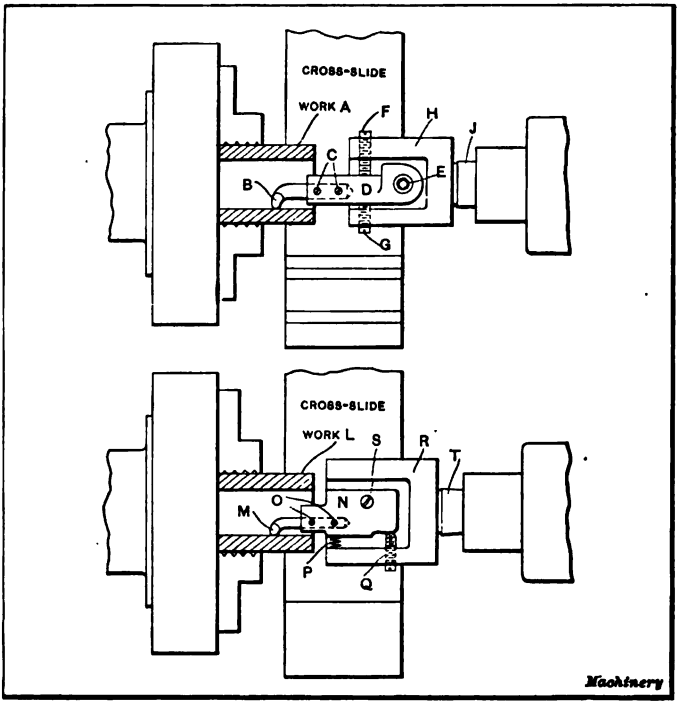

Fig. 2. Two Types of Adjustable Boring Tools for Tool-room Work

The lower part of Fig. 1 shows the same piece of work *D* with another type of boring tool in action. A cast-iron body *K* is held down on the cross-slide of the lathe by means of the three bolts *J*. A steel bar *G* is longitudinally adjustable in the cylindrical portion of the holder and is clamped in position by means of the binder screw *H*. A round cutting tool *E* is held in place by the taper pin *F*, in a manner familiar to all. A holder of this type will be found a very useful adjunct to any toolroom, and is adaptable to a variety of conditions. A series of bushings can be made to take different diameters of round stock, and tools may be quickly made to suit almost any case. Obviously, adjustment for diameters is made by the cross-slide. Rigidity and adaptability are points in favor of this device.

Adjustable Boring Tools for Jig Work

Fig. 2 represents two styles of adjustable boring tools used mostly for boring small shallow holes or jig bushings. These tools are capable of fine adjustments but are not suited for any kind of heavy cutting. The upper part of the illustration shows how tool *B* is used for boring a part of the bushing *A*, which is held in chuck jaws. The body of the tool-holder *H* is made of steel and is turned down and tapered at *J* to fit the tailstock spindle. The adjustable swivel *D* is pivoted on the shouldered screw *E*, and is adjusted by the two headless set-screws *F* and *G*. The tool *B* is of round section and fits the end of the swivel, where it is held in place by the two screws *C*. The end of the tool is bent over for the purpose of clearance. A tool of this kind is very convenient and is easily adjusted for diameters within its capacity. It is not adapted to deep holes, but can be made up in several sizes so that it will handle fairly large work.

The lower part of the illustration shows another tool of somewhat similar construction, which is designed for the same purpose as the other. The body is of steel and the shank *T* is turned taper to fit the tailstock spindle. The forward portion of the body *R* is cut out to receive the swivel *N*, which pivots on the screw *S*. The tool *M* is of round section, bent over at the end, and it is held in place by the two screws *O*. One adjusting screw *Q* is all that is required in this tool, as the coil spring *P* takes up lost motion and prevents drawing in. This tool is not as rigid as the one previously referred to, but the spring makes adjusting much quicker, as only one screw is needed. A number of tools of this type, and of various sizes, were made for tool-room use in a large automobile factory and were used on the greater part of the jig work.

Boring Tools for the Horizontal Turret Lathe

Boring tools which are required for use on the horizontal turret lathe are of many forms and their design is somewhat dependent on the type of machine to which they are to be attached. On machines having no transverse movement to the turret slide, the tools are nearly always designed for straight boring, while on the other types of machines, *i. e.*, those having transverse movement, the design is frequently made in such a way that the tools can also be used for facing operations. The form of the turret itself also influences the design to a certain extent, for it is evident that a flat turret would require a different type of tool-holder than one of the vertical face variety.

Single-point Starting Tool for Taper Holes

The work *A* shown in Fig. 3 is a malleable iron automobile hub with a cored taper hole which runs out of truth very badly. Therefore it was necessary to design a starting tool of the single-point variety in order to generate a true running hole, so that the subsequent tool would start properly without being influenced by the wobble of the core. This tool and tool-holder are very simple, the tool itself being a piece of round high-speed steel bent over on the end and ground to cut a diameter a trifle smaller than the large end of the tapered hole. The holder *E* is a piece of machine steel of cylindrical shape, which is ground on the outside to fit the turret hole and on the inside to fit the shank of the tool *B*. Two set-screws *D* are used to hold the tool in position. It will be noted that the end of the cutting point is ground very nearly square so that it will not ride up on the scale. The tool is not made for continuous boring but is merely used

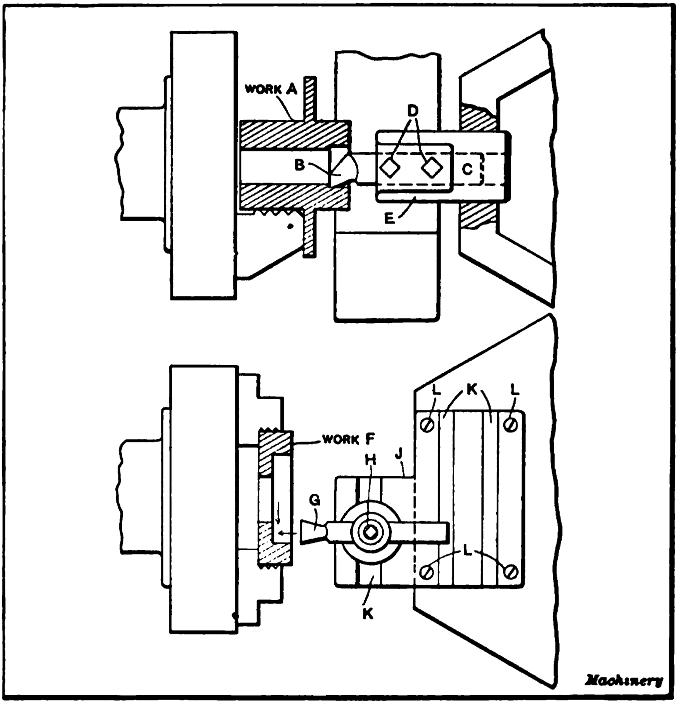

Fig. 3. (Upper View) Single-point Starting Tool; (Lower View) Boring and Facing Tool

to generate a true hole for a short distance into the cored portion of the hub.

Boring and Facing Tool for a Flat Turret

An example of a boring tool which is also used for facing out a pocket on a turret lathe having a flat turret is shown in the lower part of Fig. 3. This tool is of the "shovel nose" type and its cutting action is rather hard on account of the bluntness of the nose and the amount of stock which is removes. The work *F* is a machine steel forging and the shoulder is not recessed at all in the blank. The tool *G* is of rectangular section and it is forged and ground on the cutting end to the shape shown. The tool-holder *H* is supported by the steel bracket *J* which is fastened down on the turret face by screws *L*. The slots

K are T-shaped and permit various settings and combinations of tools to be made.

Fig. 4 shows a very simple type of single-point adjustable boring-bar for machining the bushing *A* (see upper part of the illustration). Although this bar is simple in its construction, there are several important points in design which should be carefully noted. The bar *E* is of a low grade of tool steel and is hardened and ground to fit the turret hole. The reason for making the bar of tool steel is simply to

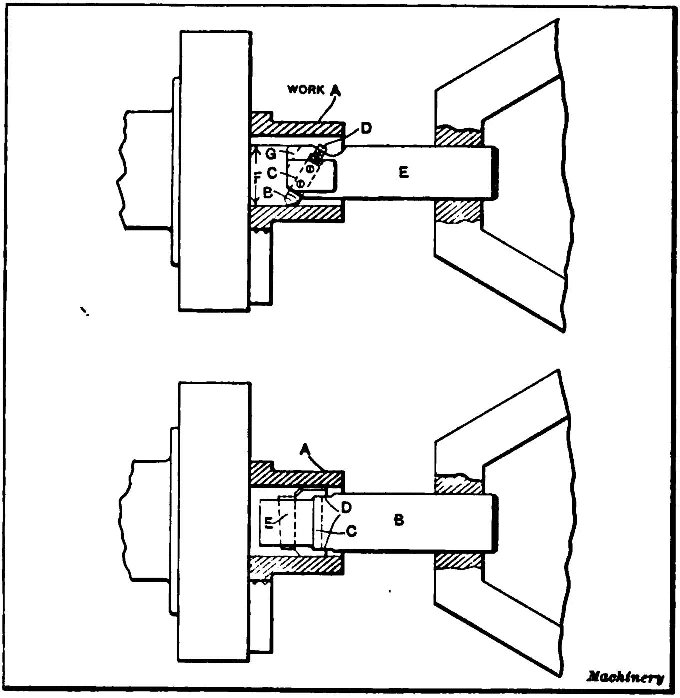

Fig. 4. (Upper View) Boring-bar with Adjustable Cutter; (Lower View) Boring-bar with Double-ended Cutter

obtain all the rigidity possible and thereby obviate chatter. The tool *B* is of round section and is put through the bar at a slight angle, being held in position by the two screws *C*. A backing-up screw *D* permits careful adjustment to be made. The bar is cut away where the tool comes through to provide chip clearance, but it is cylindrical on the end except in this one place. By making it this way, it is found an easy matter to use micrometer calipers across the bar and tool as indicated at *F*, so that accurate settings may be readily made without resorting to "cut-and-try" methods. It is very bad practice to bevel the end of the bar at *G* and put the holding screws through at this point, because a calipering point is sacrificed by so doing. A simple formula is here given for setting tools of this type for turning a given diameter:

Let F = required calipering distance for a given size hole;
X = diameter of the bar at the end where the tool is;
Y = diameter of the hole to be bored.

Then

$$F = \frac{X + Y}{2}$$

This formula will be found useful for setting tools very close to the desired diameter, although the spring of the bar will cause slight variations and the amount of stock which is to be removed also makes some difference.

The lower part of Fig. 4 shows a boring tool of an entirely different type. The cutter is double-ended, and a bar of this sort is often used for removing stock rapidly. Although it is a faster cutting tool than a bar having only a single tool or cutting point, it cannot be depended upon to produce a hole which is absolutely concentric with other surfaces machined at the same setting. The work *A* is the same as in the upper part of the illustration, and the bar *B* fits the turret hole. It is flattened slightly on two sides at points *D*, and a rectangular slot contains the cutter *C* and the wedge *E*. It will be noted that the cutter is shouldered so that it is a close fit at the points *D*. Tools of this type cannot be ground radially without changing their diameters, but this is seldom necessary as the cutting edge is at the forward end. A land of about 1/8 inch is usually left just back of the bevel, and the cutter can be ground back to this point without changing the diameter. Beyond this, however, there is a slight back taper for the sake of clearance, so that the life of the cutter does not extend beyond it.

Boring-bar with Provision for Cutting Lubricant

On certain classes of work it is very difficult to supply the cutting points of the tools with sufficient lubrication to make them thorouhgly efficient, when the regular supply system is used. Some method must be devised, therefore, to direct the flow to the point or points where the cutting action takes place. An example of a bar arranged to carry the lubricant to inaccessible tools is shown in the upper part of Fig. 5. The work *A* in the chuck jaws is an automobile hub of malleable iron. It will be noted that the portion bored by the forward tool *C* is in such a position that it cannot be reached for lubricating purposes in the ordinary way, but the rear tool *D* can easily be taken care of. The boring-bar *B* is of a low grade of tool steel and fits the turret hole at the rear end; the forward end *J* is a running fit in the chuck bushing *L*. A telescoping oil supply tube *K* enters this end of the bar and is supplied with lubricant from the rear end of the spindle. The hole in the bar at *H* leads the fluid directly onto the face of the cutting tool *C*, thus insuring constant lubrication at this point. The two tools are held in place by the screws *E* and *F*, and they are provided with means of adjustment in the backing-up screws *G*. The writer has used bars of this type in a number of cases with very gratifying results.

Fig. 5 (lower illustration) shows a very different condition, in a multi-cutting boring-bar for generating a series of true holes in the bronze artillery hub *A*. The finished hole is tapered but a starting bar was used in order to prepare the hole properly for the taper tools

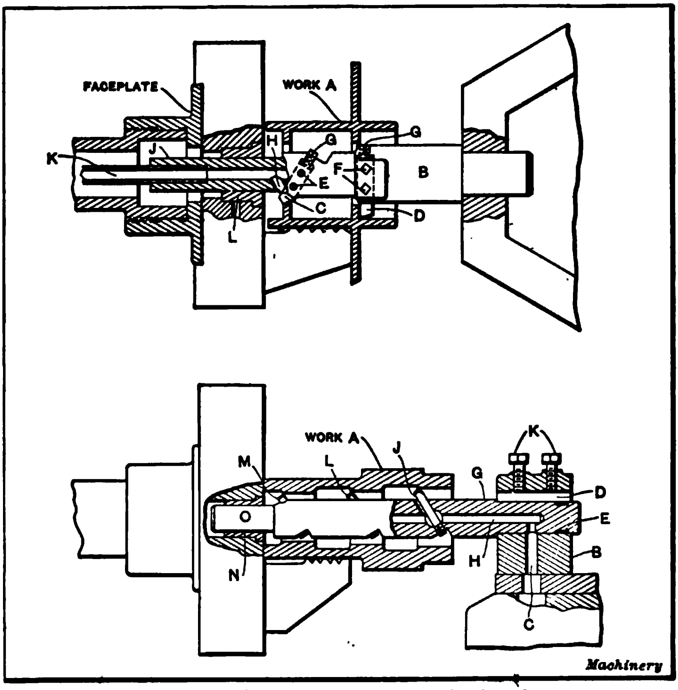

Fig. 5. Boring-bars arranged for lubricating Cutters

which followed it, so that they would not be influenced by the irregularities of the cored hole. In this case the turret lathe was one of the flat-turret variety, and provision was made for lubrication through the hole *C* in the turret face. As the turret indexed to the proper position, this hole came directly over another in the slide, which, in turn, was connected with the lubricant pressure supply system, thus allowing the liquid to pass up into the body of the tool-holder. The boring-bar *G* is turned down at the rear end to fit the tool-holder *B*, and has an annular groove *E* which is packed with felt to prevent the escape of lubricant. A shoe *D* is forced down on the bar by the two screws *K* and prevents the bar from turning. The hole *H* in the bar is drilled from the forward end and is tightly plugged so that this end remains closed to prevent the lubricant from passing through. A groove is cut in front of the tools *J*, *M* and *L*, as shown at *J*, and this allows the fluid to flow directly onto the faces of the tools. The end of the bar is piloted at *O* in the bushing *N* which is fixed in the chuck body. An arrangement of this sort has also proved successful in a number of instances.

Bar for Undercutting, Facing and Boring in the Vertical Turret Lathe

A very difficult condition for which to design tools is shown in Fig. 6, as the work itself requires rapidity of handling and is a steel casting weighing about 300 pounds. Only a part of the piece is shown at *A*, but it will readily be seen that it is necessary to make the bar in such a way that the tools can be used to do all the cutting indicated by the arrows; *i. e.*, undercut the upper flange, double-bore the interior, and face the lower shoulder. As the fixture on which the work was held was of the indexing variety and was very much off center, it was not expedient to run at high speed. Therefore, the double boring was of assistance in increasing the production. It will be noted that the hole through which the tools pass is of small diameter, which makes the problem still more difficult. The shank of the bar *B* fits the turret hole at its upper end and is slotted so that the pin *F* in the turret will act as a driver. (This feature is patented by the Bullard Machine Tool Co.) The lower part of the bar is eccentric to the shank in order to obtain the necessary clearance when the tools are in action. Even the tools themselves are considerably out of the ordinary in that they will cut in two directions. The upper tool *D* is used for undercutting the flange and also for boring, while the lower tool *E* is used for facing the lower shoulder and partially boring the interior. Both these tools have backing-up screws *G* and are held in place by the headless set-screws.

As it was necessary to set these two tools so that they would cut approximately the same diameter, the gage shown at the right of the figure was made to assist in the setting. The V-block *K* was slotted to receive the steel strip *J* so that distance *L* would measure the correct distance from the bar shown in section at *M*. It is obvious that the gage could be placed against the bar so that tools could be set out the right amount by means of the backing-up screws. This bar gave fairly satisfactory results although some trouble was experienced with chips, as there was considerable stock to remove. There was likewise a slight tendency to chatter when using a heavy feed, but this was remedied by careful grinding to make the cut as easy as possible. It must be remembered that the conditions were about as awkward as they could be, and the lack of room made it necessary to cut down the bar to such an extent that it was hardly heavy enough for the work. Taken as a whole, however, the action was satisfactory for a roughing tool. It was not used for finishing cuts.

Slip-cutter Bar for the Vertical Turret Lathe

The steel hub shown at *A* in Fig. 7 is held on a special fixture, located by the previously bored and reamed hole which fits the stud

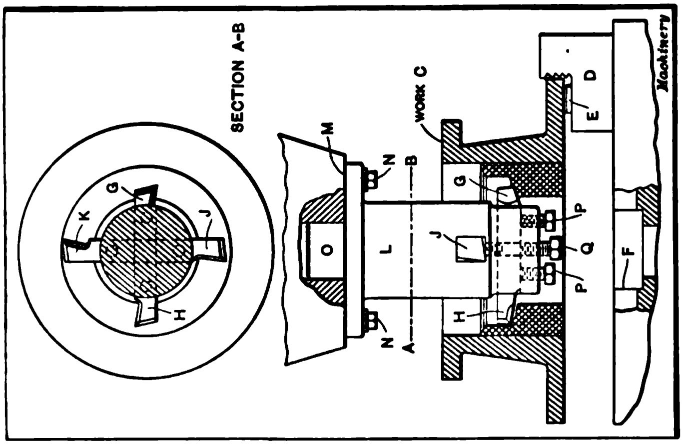

Fig. 8. Bar with Four Cutters set at Different Radii for removing Considerable Stock in One Cut

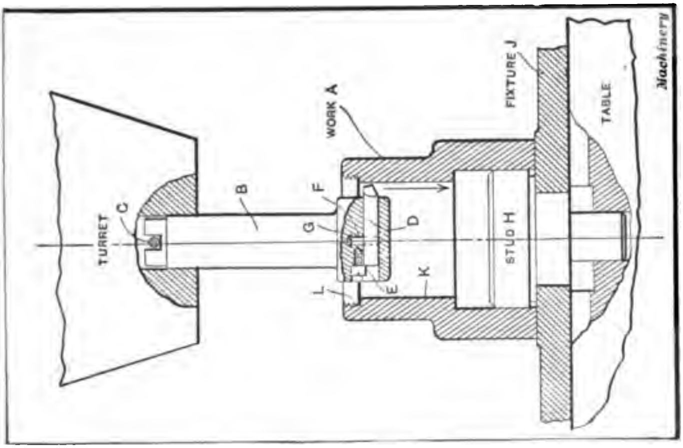

Fig. 7. Bar equipped with a Set of Interchangeable Cutters for Boring and Reaming

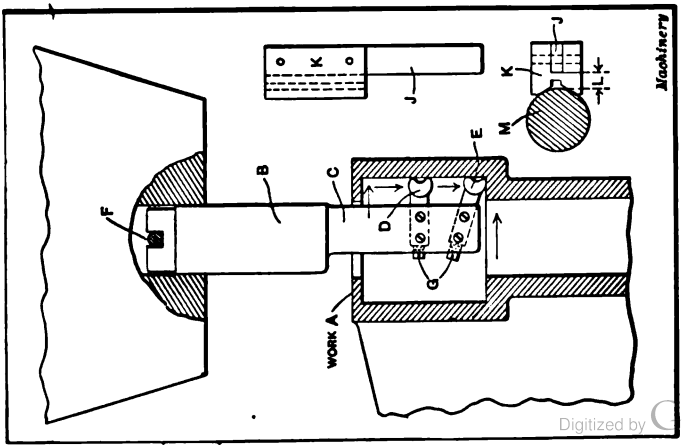

Fig. 6. Bar for Undercutting, Facing and Boring in the Vertical Turret Lathe and Gage used in setting Tools

H. The hole *K* has been rough-bored in the first operation, but enough stock has been left for the final finishing so that it may be finish-bored and reamed and part *L* threaded at the same setting. This type of bar is the product of the Bullard Machine Tool Co., and is designed especially for use in their machines. It is a combination boring- and reaming-bar, and the cutters are of the "slip" variety. One bar can be furnished with a set of cutters for the various sizes of holes within its capacity. A full set of cutters for any one size of hole consists of chamfering, rough-boring, finish-boring, rough-reaming and finish-reaming tools. The first three of these are of square section, carefully ground to fit the broached hole *D*. The rear ends of these tools bring up against the shoulder of the screw *E*, which acts as a stop. The fit in the hole is such that tools can easily be put in and taken out with the fingers.

The two reaming cutters are used in the rectangular hole *F* which is at right angles to the other hole; these tools are allowed to float so that they follow the hole generated by the boring tools. The action against the reaming cutters is in an upward direction, and comes against the hardened steel plug *G* which is inserted in the bar. The bar *B* is of special steel and is slotted at the upper end to fit the driving pin *C* which is located in the turret. Bars of this type have a number of advantages, one of which is that only one turret hole is occupied; other advantages are the cost of maintenance, and the adaptability of the bar with its series of cutters to handle a number of different sized holes. The cost of large sizes of reamers of the fluted type is considerable, while a flat reamer such as that used in this bar is inexpensive. It may be noted that the pressure or thrust of the cut is all that holds the boring tools in place, so that trouble would be experienced if a cored pocket were to be encountered. This is provided for by a detent screw in the end of the bar, which prevents the tools from coming out. This screw can be put in any time if it is found necessary.

Multi-cutting Bar for the Vertical Turret Lathe

An example of a bar designed to remove a large amount of stock in a very short time is given in Fig. 8. The work shown at *C* is a steel boiler nozzle which is forged, and a 5-inch hole punch in it before it is machined by the vertical turret lathe. The finished hole is 8 inches in diameter and it was desired to remove the surplus stock as rapidly as possible. Accuracy in the diameter of the hole was not essential. The bar *L* is a steel forging which fits the turret face at *M* and is held to it by the screws *N*. The stem *O* is used to center the bar in the turret. Two rectangular holes are broached through the body of the bar, at right angles to each other, and these receive the high-speed steel cutters shown. It will be noted that these cutters are so proportioned that they remove the stock in a series of steps, each tool extending beyond the preceding one and also above it about ⅛ inch.

The section taken at *A—B* shows the manner in which the tools extend beyond each other, and the lower view illustrates the cutting action of the tools. One end of the first tool *G* makes the first step, while the other end *H* makes the second. In like manner one end of the upper tool *J* makes the third step while the other end *K* takes out the remainder. The two screws *P* hold the first tool in place, while the other is secured by the screws *Q*. It will be noted that the work is held in jaws *D* and is supported on buttons at *E*; the height above the table is great enough to allow the end of the bar and the set-screws to go through far enough to finish the cut. Regarding the upkeep of these tools, attention is called to the fact that they may be pushed backward or forward to compensate for wear and distribute the cut. For roughing purposes requiring rapid removal of stock and rapid cutting, a bar of this sort has proved very successful, but it is not recommended for work requiring great accuracy.

Other Types of Boring-bars

There are several bars on the market which are adjustable for various diameters by means of micrometer screws and taper wedges. These are useful for many purposes but space will not permit a detailed description nor has it been the writer's purpose to deal with the many varieties but rather with representative types. Special bars for many purposes, porcupine bars and cutter heads of various kinds, have not been described, because these are not single-point boring tools. Neither has mention been made of boring tools such as are used in fixture work on the horizontal boring machine, for these are found in every tool-room, in all shapes and sizes.

In several of the illustrations it may be noted that the tools are shown in a plane parallel with the rotation of the turret. This has been done simply because the details are more clearly apparent when shown in this way. Greater accuracy is obtained by setting the tools in a plane perpendicular to the turret rotation, as previously stated.

CHAPTER II

RECESSING TOOLS

Many varieties of cylindrical work call for the machining of an annular recess or groove in a place which may be inaccessible to the cutting tools. The form of recess varies greatly and the accuracy required is likewise variable. The form may be either narrow or wide, deep or shallow, while the accuracy called for may be either within narrow or liberal limits, as for instance, when the recess is for clearance only. In fact, in the majority of cases the purpose of the relief or recess is merely to obtain clearance for some moving part or for tools when machining an adjacent surface. Very frequently a groove is cut to serve as an oil-pocket or to provide a space which can be filled with packing to act as a gland. It is evident that great accuracy is not essential when the work is of this nature. There are occasionally conditions which require more accurate work, as for instance when another piece is to be sprung into place, such as a spring ring or something of a similar nature, but even in a case of this kind a certain amount of inaccuracy is permissible. The machines to which recessing tools are most frequently fitted are the engine lathe, the horizontal turret lathe, the vertical turret lathe, the vertical drilling machine and the horizontal boring mill. Other machines are occasionally equipped with tools for the same purpose, but those mentioned are most frequently used.

In many cases the position of the relief or groove is such that it cannot be readily seen by the operator, nor can it be easily calipered. The workman, therefore, must tell how the tool is cutting by the "feeling" of it and by the character of the chips. He is really "working in the dark," and for that very reason every precaution must be taken in regard to position of tools, diameter and shoulder stops, etc., so that the machining can be done without withdrawing the tool to note the progress of the work. In this connection it is well to bear in mind that the action of any kind of grooving tool is much the same as a cutting-off tool. It must be kept very sharp and set so that the cutting edge is slightly above center, when it is used for internal work. It will be seen that if the tool is slightly above center the springing down of the cutting edge (due to the pressure of the cut) will have a tendency to keep it from "digging in", and will therefore assist in the prevention of chatter. Some of the important points in the design of recessing tools are given herewith.

Points in Design of Recessing Tools

1. Rigidity is of the greatest importance and every precaution should be taken to insure as substantial a holder as possible. The

tool itself should be of as great a section as the conditions and the space will permit. Some method of supporting the overhanging end should be provided, either by means of a pilot or in some other way which may suggest itself. Moving parts should have a means of adjustment for wear, and gibs should be set up as snugly as possible and still allow free movement.

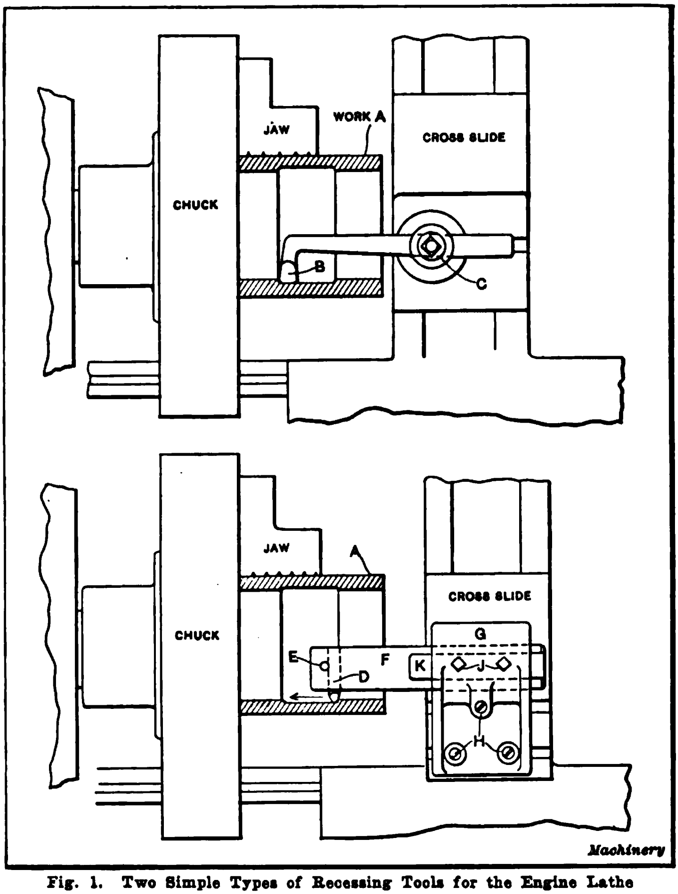

Fig. 1. Two Simple Types of Recessing Tools for the Engine Lathe

2. The feed motion should be carefully considered. Screw feed is best, and may be contained in the tool itself or may be operated by the cut-off slide. Lever feed is uncertain and produces uneven cutting unless the work upon which it is used runs at high speed. When this is the case and if the cut is not too heavy, it can be used with satisfactory results. The work to be done is a factor in determining the method most satisfactory for the feed motion.

3. Means are needed for determining the depth of the cut. There are several ways in which the depth of the cut can be positively de-

termined; a positive stop can be provided; the dial on the cut-off slide can be used when the feed motion of the slide is the operating force; an indicator or a graduated dial on the tool-holder itself may be provided.

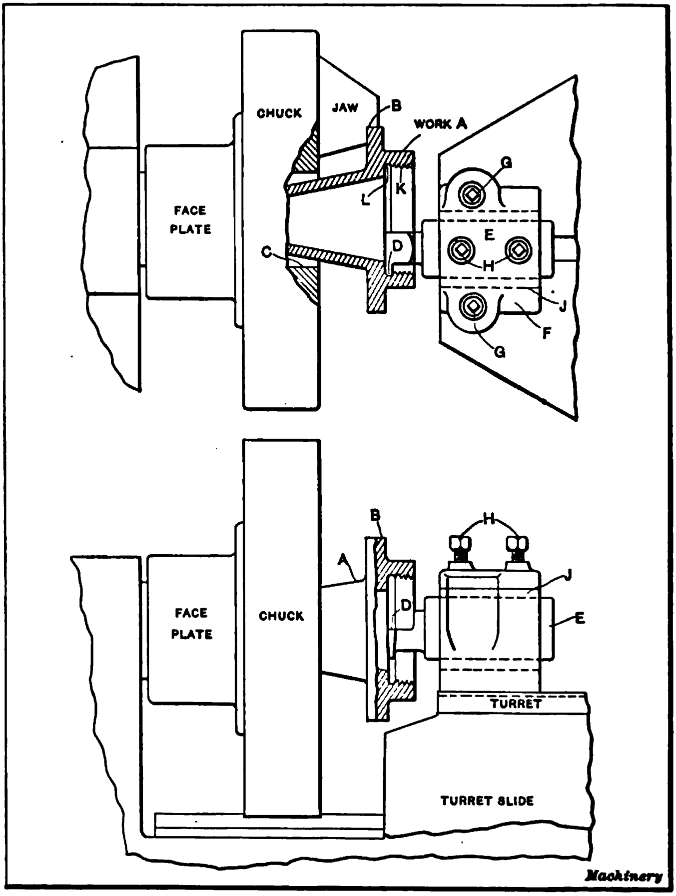

Fig. 2. Recessing Tool used in a Turret Lathe

4. Rapidity of operation is essential.

5. Adjustment for the cutting tool should be provided. This adjustment may be made either by manipulating the tool by hand or by means of a backing-up screw. The latter method is the better one and should be used whenever practicable. The upkeep of the tool is important, and for that reason inserted tools are preferable to those which form a part of the mechanism itself. In confined situations it is occasionally necessary to make the tool of special shape. This should be done only as a last resort, when necessitated by the conditions

governing the work. In cases of this kind several tools should be made to provide for emergencies.

Recessing Tools for the Engine Lathe

The upper illustration in Fig. 1 shows a bushing *A* which is held by the outside in regular chuck jaws. This work is to be done on the engine lathe, and the recess is to be cut at the same setting. A forged tool *B* is held in the regular tool-post *C* on the cross-slide of the lathe, and is forced into the required depth by hand. After this the longitudinal feed is started and the remainder of the recess cut. This type of tool is much used for lathe work when only one or two pieces are to be machined. Its advantages are that it can be easily made and quickly adjusted. Its disadvantage is that it has a tendency to chatter, and is, therefore, suitable only for very light cutting.

The device shown in the lower portion of the same illustration is much more rigid, but is not nearly as adaptable to various conditions. In this arrangement the tool *D* is of round section and is held in place by taper pin *E*. The bar *F* is of steel and is secured in the holder *G* by the two screws *J* which bear against a flat *K* on the bar. Three screws *H* enter shoes in the cross slide T-slots and secure the holder firmly to the slide.

Recessing Tool for a Horizontal Turret Lathe

The work *A* shown in Fig. 2 is a steel forging of an automobile hub which is held in a three-jawed chuck by the flange *B*, the tapered portion entering the hole *C* in the chuck body. The inside of the hub is to be threaded at *K* with a collapsing tap. A recess is therefore needed at *L* in order to obtain a clean thread. The machine selected for the work is a Pratt & Whitney turret lathe having a cross-sliding turret of the flat type. The recessing tool is of high-speed steel, with the shank turned and ground cylindrical at *E*. The front end is also turned to form the flange *D*, and is afterward cut away and finished to the shape required, as clearly shown in the lower part of the illustration. The tool-holder *F* is of cast iron and contains a steel split bushing *J* which is compressed by two screws *H* in the top of the holder. The action of this tool was satisfactory, but the upkeep is obviously rather expensive.

Eccentric Recessing Tool for a Horizontal Turret Lathe

The work *A* shown in Fig. 3 is a steel flange which is to be recessed at *B* in order to provide the necessary clearance for the threaded portion *C*. In this instance the cut-off slide was used during the progress of the work, so that a considerable overhang from the turret was required. Strictly speaking this is not an eccentric tool, for the various parts of the body are concentric, but by a reference to the upper part of the illustration it will be seen that the center-line *VW* of the recessing tool does not coincide with the center-line *TU* of the spindle. Now as the tool-holder *F* revolves on the center line *VW*, it is evident that the path of the tool *D*, as it swings, will be eccentric to the center line of the spindle. The body *L* is of cast iron and is mounted on the dovetailed turret face, being securely held in position by the gib *M* and the screws *N*. The tool-holder *F* is of tool steel and is turned down at *K* to a running fit in the body. The end *Q* with the

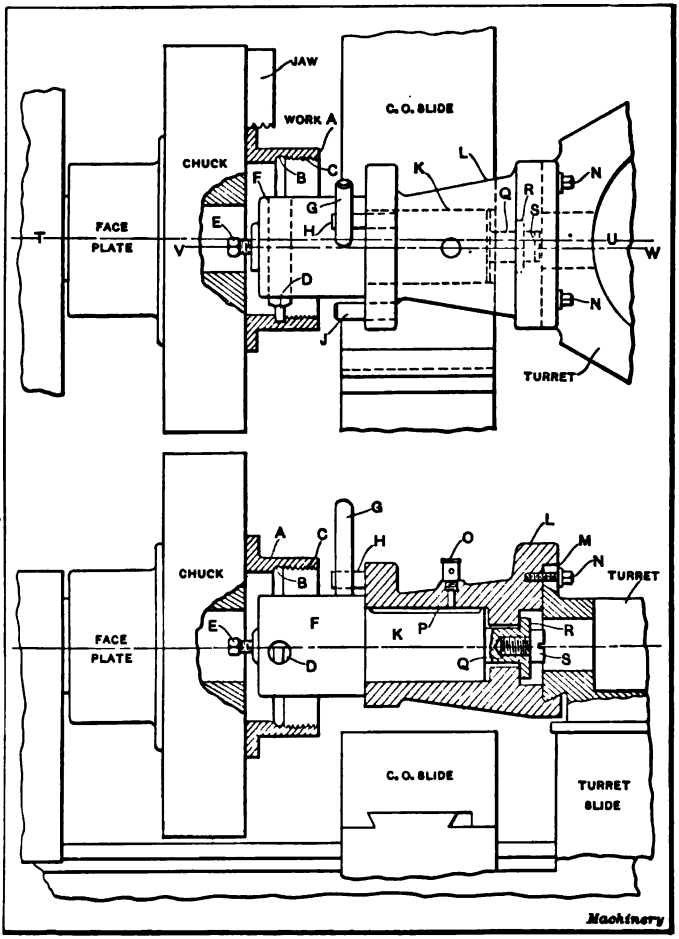

Fig. 8. An Eccentric Recessing Tool for the Turret Lathe

screw and washer *S* and *R* acts as a retainer to keep the tool-holder in position. The tool *D* is of round section with the cutting end so shaped that it will cut the recess properly. A set-screw *E* holds it in position. An oiler *O* is located in the body and distributes the oil to the bearing through the oil groove *P*. An operating handle *G* is driven into the holder, and is located between the pins *H* and *J* which act as stops. As the lever *G* is operated, the tool *D*, starting with slight clearance at the bottom of the hole, moves gradually upward and outward until the full depth of cut has been reached. At the completion of the cut the tool stands in the position shown in the

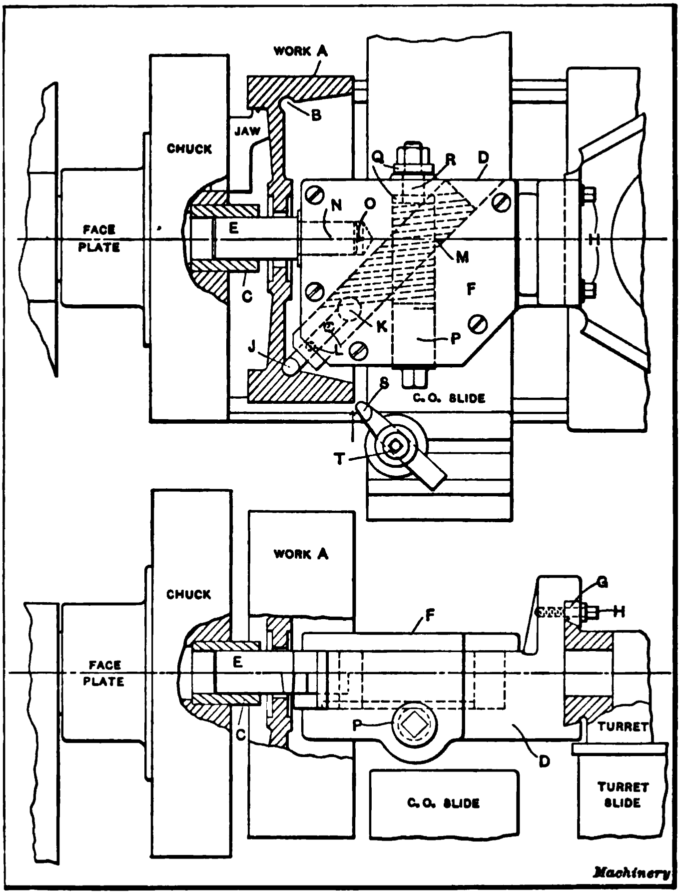

Fig. 4. A Recessing Tool used in machining an Automobile Flywheel

illustration. The action of this tool was perfectly satisfactory, and as it is comparatively simple in construction, the cost of building was not excessive.

Piloted Recessing Tool for an Automobile Flywheel

A rather peculiar condition is shown in Fig. 4, the work *A* being an automobile flywheel having a semi-circular recess at *B*. Attention is called to the fact that this recess is put in at an angle of 45 degrees with the center line. It is evidently only a clearance groove for the male clutch member and it is not known to the writer why some other style of groove would not have answered the purpose just as well.

The work *A* is held by the inside of the rim in special jaws. The body of tool *D* is made of cast steel and is fitted to the dovetailed face of the turret, the gib *G* securing it firmly by means of the collar-head screws *H*. A tool-steel pilot *E* enters the bushing *C* in the chuck and assists in supporting the body against the pressure of the cut. This pilot *E* is shouldered and forced into the body at *N*. A small hole *O* is drilled to avoid air compression when forcing in the pilot. If this is not done the fitter may be deceived into thinking that he has secured a good fit at this point when in reality it is the air compression which causes the stem to fit tightly. A cover plate *F* tends to strengthen the body and overcome the weakening effect caused by the cutting of the angular slot, and also assists in preventing the entrance of dirt and chips. Tool *J* is of square section and is held in the sliding block *M* by two screws *L*. Hole *K* is for machining purposes only. The operating screw *P* is squared up on one end to receive a wrench, while the other end is shouldered at *R* and threaded to receive a hexagon nut. There are two thrust washers shown at *Q*. The screw has four Acme threads per inch, right-hand, and meshes with the angular rack cut on the under side of the tool-carrying slide *M*. It is evident that the rotary motion of screw *P* will cause movement of the block, in its longitudinal direction, thus feeding the tool into the work at the desired angle. The forged tool *S*, held in the tool-holder *T* on the cut-off slide, is slowly fed across the rim while the recessing operation is taking place.

Double Recessing Bar for a Rear Axle Housing

The work *A* shown in Fig. 5 is a bronze rear axle housing for an automobile, and the recessing bar is only one of a group of tools used at the same setting of the work. Previous to this setting the finished annular rings at the two ends *D* and *E* of the casting were machined so that they might be used as locating points in this setting. The ring *D* slips into the split bushing in the holding device *B*. The other end *E* revolves in a roller back-rest *F* which is placed on the ways of the turret lathe. This back-rest is not shown in detail, as its construction is not essential in connection with the recessing tool. The two grooves in the work at *S* were to be spaced an exact distance part and it was partly to insure accurate spacing that this bar was designed, although rapidity of operation was also a factor. A cast-iron bracket *K* is fastened to the dovetailed face of the turret by means of gib *Y* shown in the lower view. The handwheel *W* is connected to a shaft which drives the pinion *M*. A steel pointer *X* is fastened to the bracket and acts as an indicator on the graduated rim of the wheel. It will be seen that this arrangement makes it very easy to determine the depth of the cut.

The pinion *M* meshes with a rack cut upon the enlarged end *N* of the operating rod *L*. This rod is considerably below the center of the bar and is flatted at *O* and *P*. The tongues *Q* and *R* are angularly cut on these surfaces, and they engage with grooves on the under side of the tool-carrying blocks *T*, so that any longitudinal movement of the rod *L* is transformed into a radial movement of the blocks. The

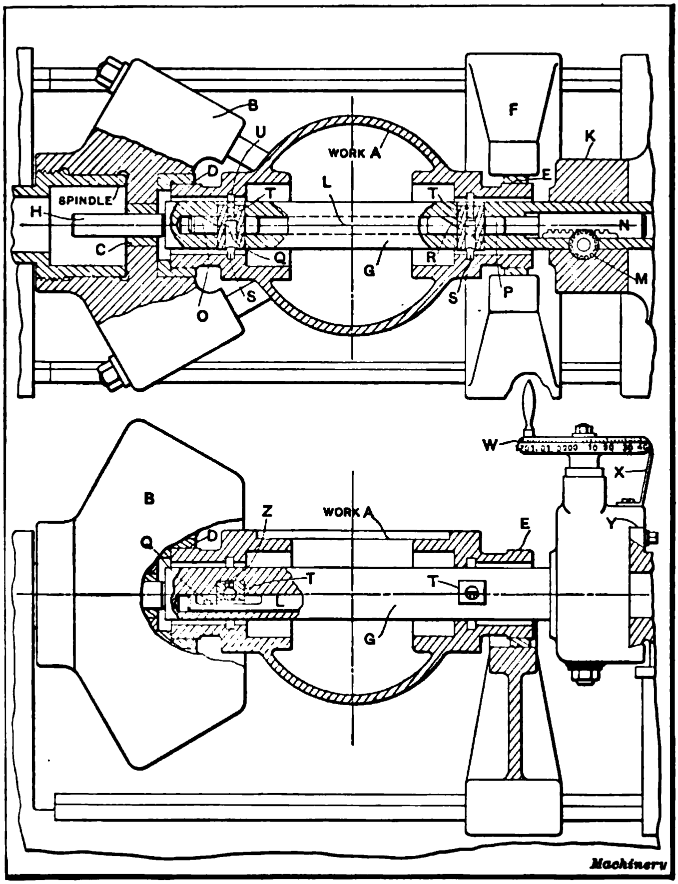

Fig. 5. A Double Recessing Tool Arrangement for a Rear Axle Housing

grooving tools *S* are of round section and are held in position by the headless screws *Z*. The backing-up screws *U* permit accurate adjustments to be made with ease. The pilot *H* enters the steel bushing *C* in the body of the holding device and assists in preventing chatter. An added refinement to this tool was an oil-groove from which oil was lead directly to the cutting tools. This was supplied with oil through a special piping system and a distributing collar on the turret. In order to avoid confusion in the drawing, this has not been shown. This device gave very satisfactory results.

Recessing Tool for an Automobile Bearing Retainer

The work shown at *A* in Fig. 6 is a malleable iron bearing retainer for an automobile. The casting is held by the outside in a

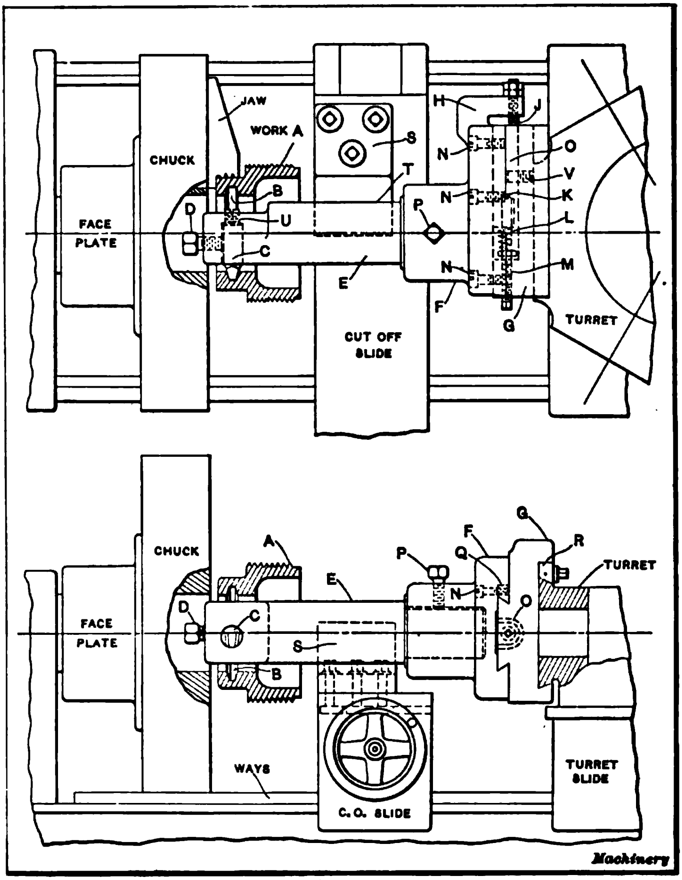

Fig. 6. A Recessing Tool for an Automobile Bearing Retainer

three-jawed chuck; the machine on which the operations are performed is a horizontal turret lathe. The piece is completely finished in one setting. As the cut-off slide front tool carrier was used during the progress of the work, it was found necessary to design the recessing tool so that it extended out over the slide. It is evident that an overhang as great as this would cause trouble unless some means of intermediate support were provided. The bracket *S* was therefore used on the rear of the cut-off slide, the portion *T* being cut out to the radius of the bar so as to act as a support and at the same time provide the feed motion necessary (through the reverse feed of the slide) to force the tool into the work. The cutting tool *C* is of round section properly shaped at the end to form the required groove *B*. It is secured in place in the bar *E* by the set-screw *D;* radial adjustment is

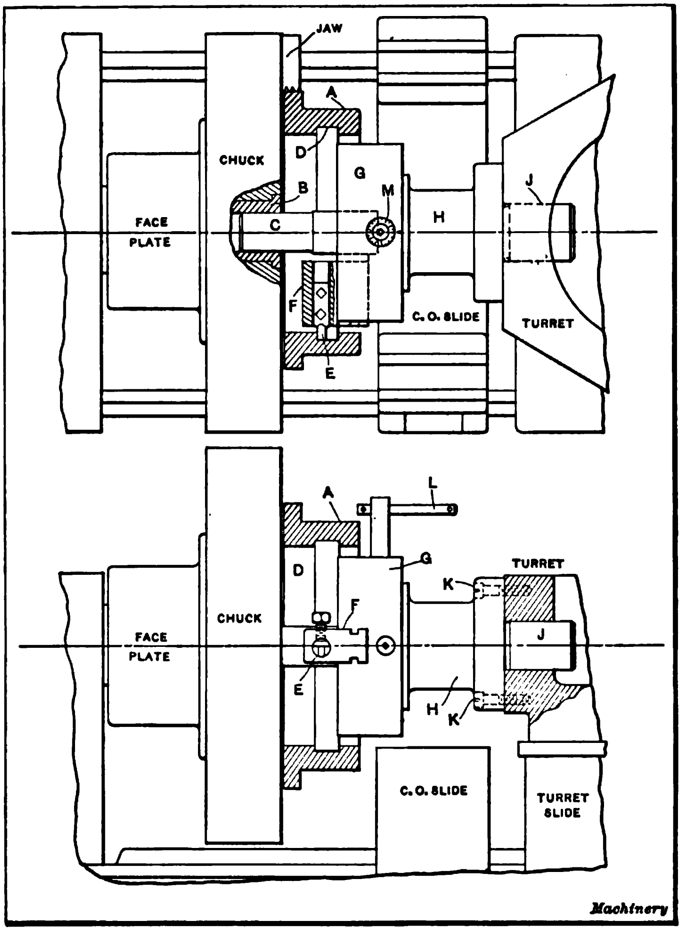

Fig. 7. A Recessing Tool for a Large Collar, used in a Turret Lathe

secured through screw *U*. The rear end of the bar is shouldered and fitted to the sliding bracket *F;* the set-screw *P* holds it in place. The slide *F* is dovetailed and is gibbed to the fixed bracket *G* by the gib *Q* which is adjusted for wear by the screws *N*. The lug *H* at the end of the slide is provided with a stop-screw *J* which permits close adjustments to be made for the depth of cut. This lug is not shown in the lower view but it is set slightly to one side of the cored groove *O* so that the screw will bear against the solid portion. The bracket *G* is mounted on the dovetail of the turret and is held in place by the gib *R*. The special screw *M* is shouldered to receive the coil spring *L* which thrusts against it and against lug *K* on the slide. The strength of the spring may be easily adjusted by the screw to the desired compression. The screw *V* is simply used to limit the reverse movement of the slide, so that it will not move back too far before or after the work has been done. This device was used for three different pieces by simply changing the tool and regulating the stop-screw. Its performance was thoroughly satisfactory.

Recessing Tool for a Large Collar

The large collar *A* in Fig. 7 was held by the outside of the flange in a three-jawed chuck on a horizontal turret lathe. The internal groove *D* was to be cut during this setting of the work, and as a small geared scroll chuck was conveniently available, it was arranged as a recessing device for this casting. The cast-iron bracket *H* was fitted to the faceplate recess at the rear of the chuck body. The stem *J* was turned down to fit the hole in the turret face, and the four screws *K* secured it thereto. One of the standard chuck jaws *F* was annealed and shaped up as shown. It was then drilled to receive the tool *E*, and tapped out so that two set screws could be used to hold the tool. The jaw was then re-hardened and a small amount of fitting done so that it worked smoothly. A graduated collar was applied at *M*, and a special wrench *L*, having a slip handle, served to operate the scroll and thereby caused the tool to move radially as required. A tool-steel pilot *C* was forced into the center hole in the chuck body *G*, and a bushing *B* in the spindle chuck body served as a guide and support for it, thereby greatly increasing the efficiency of the tool and doing away with the chance for chatter.

Recessing Bar for a Triple Groove

In all of the examples which have so far been given, the work has been done in a horizontal plane, but we shall describe a few cases which are handled in a vertical plane on the vertical turret lathe. As this machine has a turret slide which can be traversed horizontally, it is evident that no special attachments are required for plain recessing or grooving, but there are conditions which may be decidedly out of the ordinary, under which a special arrangement for recessing may be used to advantage, for example, any sort of groove which is deep down in a hole, multiple grooving at a considerable depth, or any other condition of a similar nature. When the groove is very deep, there is naturally a considerable overhang of any tool which may be used for the work. If the overhang is excessive, it follows that there is apt to be more or less vibration, and vibration means chatter. If, however, a tool or bar having an excessive overhang from the turret is supported at its lower end, the tendency to chatter is at once overcome; but, if support is provided at this point, the horizontal movement of the turret slide cannot be used. Therefore, some method which will give a radial movement to the grooving tool must be used when the bar is to be supported at its lower end.

Fig. 8 shows a piece of work at *A* which is set up so that it can be machined complete in one setting. The casting is held by the in-

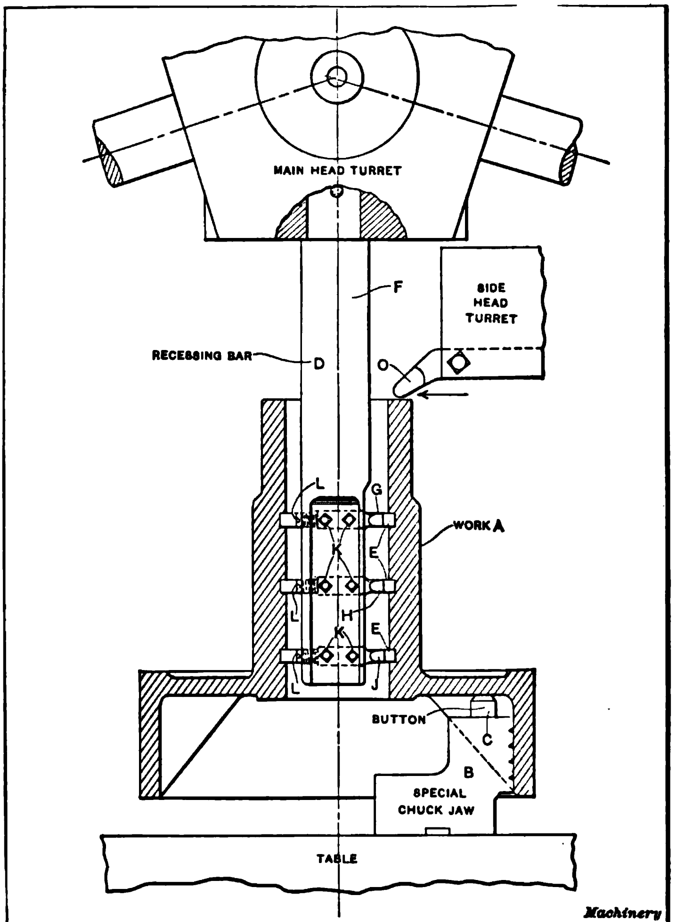

Fig. 8. A Multiple Recessing Tool used in a Vertical Turret Lathe

side of the rim in special chuck jaws *B*, and is supported at three points on the steel buttons *C* which rest in pockets in the jaws. The inner ribs of the casting act as drivers against the sides of the jaws. The three grooves *E* are to be machined and the tools *G*, *H*, and *J* are correctly spaced to perform the work. These are secured in the bar *D* by means of the set-screws *K*, and accurate adjustment is provided by screws *L*. The bar *D* is shouldered at the turret face and is driven by a pin in the turret in the usual manner. The tool *O* in the side head turret is used for facing while the inside work is being

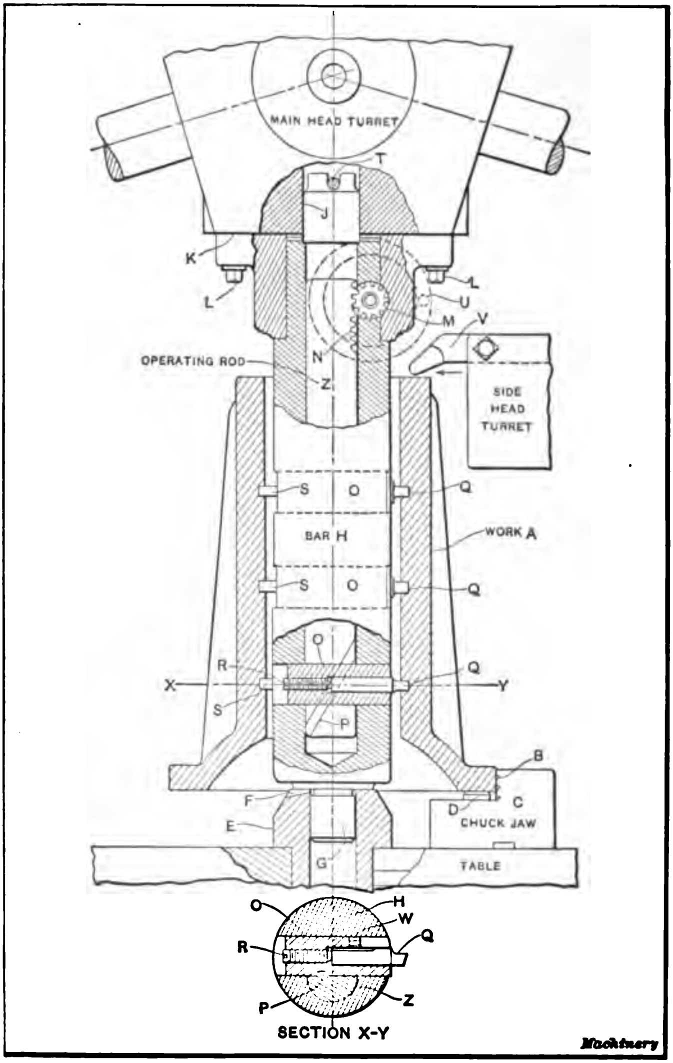

Fig. 9. Another Multiple Recessing Tool used in a Vertical Turret Lathe

done, as this brings the cutting action of the outside and inside tools in opposition and therefore tends to overcome vibration. If very fine feed is used on the turret traverse, good results may be obtained with this method, although there is a tendency to chatter due to the excessive overhang. Slight variations in the depth of the grooves may also be found on account of the spring of the bar.

Piloted Recessing Bar for a Triple Internal Groove

The cast-iron valve cap shown in Fig. 9 is another example of a piece of work having three grooves equally spaced, and in which the lower groove is at a considerable distance from the turret. This piece is finished complete in one setting and is held by the outside of the flange in the standard chuck jaws *C*, being supported at three points by the buttons *D*. This tool is somewhat similar in its operation to that shown in Fig. 5, except that it is arranged in a vertical instead of in a horizontal plane. A heavy cast-iron bracket is bolted against the turret face *K* by screws *L*, and a locating plug *J* centers the device in the turret. The bar *H* is of steel and has a pilot *G* at its lower end. This pilot is hardened and ground to fit the bushing *E* which is inserted in the center of the table. The top of the bushing is milled out to leave three projecting pads *F*. These pads form a positive stop to insure the correct height; it will be noted that the tendency when in action would be to keep these pads clean and free from chips or dirt. The upper end of the bar is shouldered and is fastened to the bracket. As in the former instance the operating rod *Z* is flatted at certain places and angular tongues *P* are provided. These tongues mesh with corresponding grooves in the tool carrying blocks *O*. The section *X-Y* gives a good idea of the construction.

The tools *Q* are held in place by the short set-screws *W* in the square steel blocks *O*. The backing-up screws *R* permit of rapid and easy adjustment. At the upper end of the operating rod the rack *N* is cut and the pinion *M* meshes with it and operates the rod. The handwheel through which the pinion is operated is indicated at *U* by the dotted lines. This portion of the mechanism is identical with that described in Fig. 5. The tool *V* in the side-head turret is used for facing the end of the casting during the progress of the recessing operation.

Recessing Tool operated by Bevel Gears

A somewhat unusual condition is shown in Fig. 10, this arrangement having been suggested for the work *A* in order to rapidly perform the grooving operation deep down in the interior of the casting at *V*. It was desired to machine this casting complete at one setting. The chuck jaws *B* were of special form, having a slight angle on the inside of the jaw which drew the casting down onto the three points *C*. A cast-iron pot *E* was fastened to the table by screws *K*, and cored openings *J* were left at the points where the jaws gripped the work. Midway between the jaws, the pot casting took the form as shown at *D* and the dogs *F* were sunk into the edges of the flange by means of the hollow set-screws *G*. The bar *M* is a steel casting which bolts against the turret face at its upper end; it is located by the plug *L*. The operating sleeve *T* is of tool steel, hardened and ground, and having an angular slot *X* at its lower end, which bears against the tool *V*. It is well to make up several of these tools, so that replacements can be quickly made in case of breakage. A steel plate *W* is let into the casting at this point to form a cover plate for

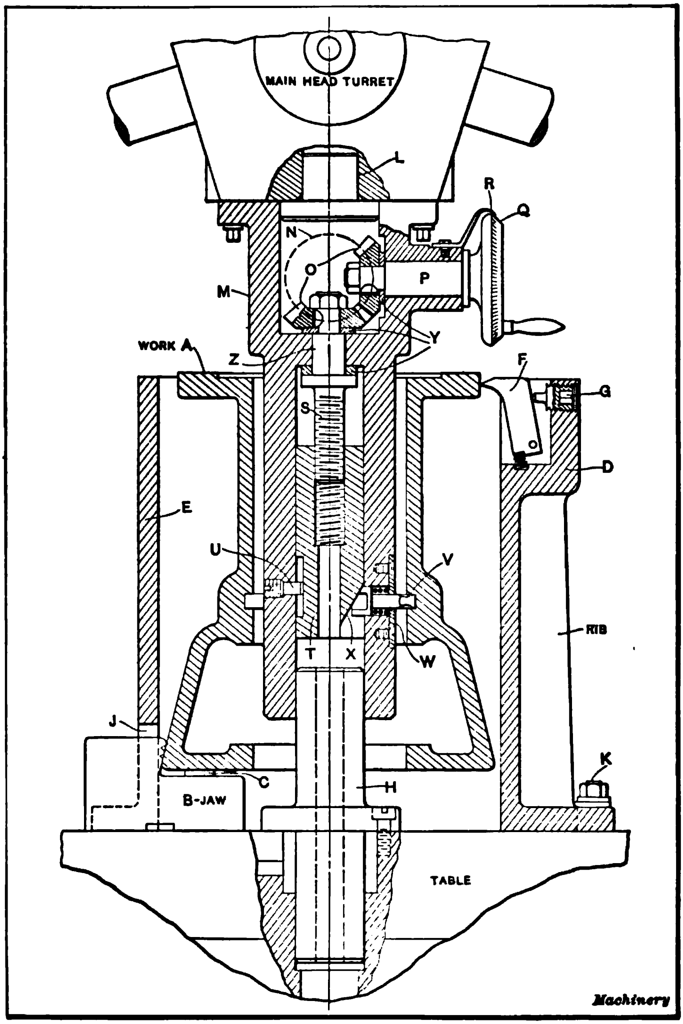

Fig. 10. A Tool for recessing in a Difficult Position, in Use in a Vertical Turret Lathe

the tool and spring pocket. A teat-screw *U* fits a slot in the operating sleeve and prevents it from turning.

The left-hand threaded shaft *S* is journaled at its upper end *Z* and the miter gear *O* is keyed in place. The shaft *P* carries another gear which meshes with the former, and the entire mechanism is operated by the handwheel *Q*. (This handwheel in reality is located 45 degrees toward the front of the machine from the position shown). A pointer *R* assists in making accurate readings from the graduated bevel on the handwheel. Steel thrust collars *Y* are provided for wear. The tool-steel pintle *H* is fitted to the center of the table and is held down by the screws shown. This pintle acts as a guide upon

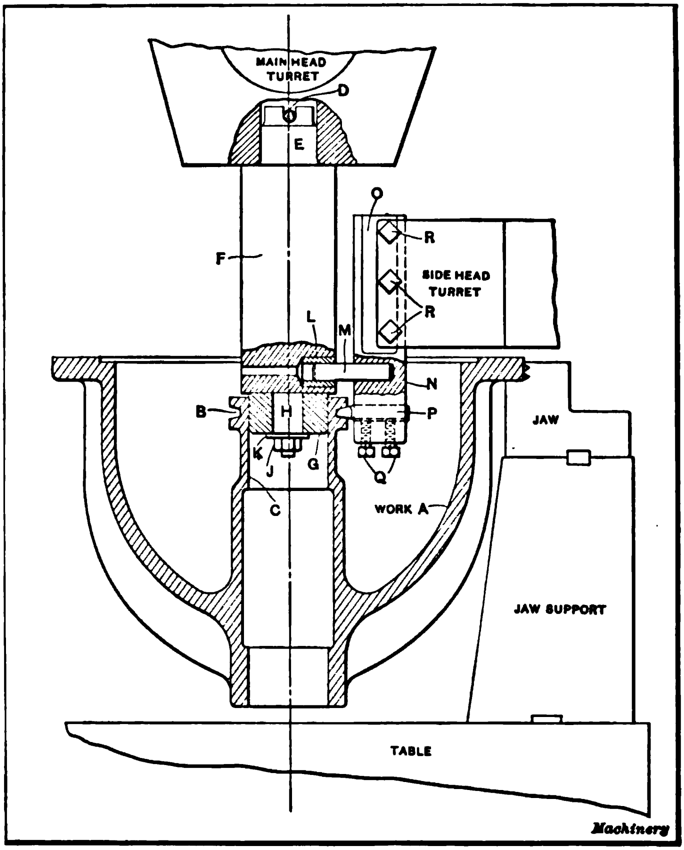

Fig. 11. An Arrangement for cutting a Groove on the Outside of a Sleeve

which the mechanism is located and greatly assists in making it rigid.

Arrangement for External Grooving

A thin piece of work for electrical machinery, shown at *A* in Fig. 11, has been completely machined with the exception of the groove *B*. At the time when the operation of grooving takes place, a revolving steel pilot *G* fits the previously reamed hole *C* and is held in its position on *H* by the nut and washer *J* and *K*. The upper portion of the bar *F* is shouldered at *E* and fits the turret hole, being kept from turning by pin *D*. A round bar *N* is flatted on two sides at *O* and is held in the side-head turret by the three screws *R*. The lower portion of the bar carries the grooving tool *P* which is held in place by the two screws *Q*. A tool-steel pin *M* is forced into the bar *N* and forms a sliding tie between the pilot bar *F* and the side-head bar *N*. The bushing *L* is inserted in the pilot bar to receive the pin. It will be readily seen that this method overcomes the vibration which would naturally be caused by the grooving tool acting on the thin and unsupported hub.

CHAPTER III

ADJUSTABLE AND MULTI-CUTTING TURNING TOOLS

The cost of tool equipment for the manufacture of interchangeable work is an item which should be proportionate to the number of pieces to be machined. The saving in time which can be made by the use of special tools should also be carefully considered, as there are many cases where special equipments are designed for work which could be handled to advantage by the judicious use of standard tools. In order to obtain the greatest possible production from their machines, there have been instances where machine tool builders have sold tool equipments of expensive design, when a standard equipment would have done the work very nearly as well. Undoubtedly there was some gain in production, but it is doubtful whether the saving in time would pay for the special tools. The upkeep of special tools is also a factor which must be taken into consideration. It is interesting to note that the present aim of machine tool builders is to so design standard tool equipments that they can be adapted readily to a great variety of working conditions. A great deal of time is spent by manufacturers in devising and experimenting with various tools in order to perfect them to such an extent that they will conform to these conditions.

The rapid growth of the automobile industry in the past ten years is largely responsible for the broader development of our machine tools. The enormous quantities of interchangeable parts which are required in this industry and the manufacturers' desire for increased production have brought into existence a great variety of multi-cutting tools. Tools of this kind may be designed for a variety of uses, and tool-holders capable of containing several tools can also be designed to handle a considerable range of work.

Adjustable tools and those having cutters for turning several diameters are sometimes combined with boring-bars, drills, or cutter heads, these being applied to some one of the various types of turret lathes. They are also occasionally designed for use on a vertical boring mill.

When used on the turret lathe, the cut-off slide is frequently equipped with a gang of tools so that the operations of turning, boring and facing can be carried on at the same time. Quite frequently the tools are so arranged that from nine to twelve are working at the same time, with the result that there is a considerable gain in production. There are a great many varieties of so-called "box-tools" on the market, and these are principally used for bar work on turret lathes or screw machines having a collet mechanism. Tools of this type are usually a part of the standard equipment furnished with screw machines adapted to bar work, and they will not be discussed in the present chapter.

The design of multi-cutting turning tools for castings and forgings which have several diameters to be machined is a subject well worth considering, for it is safe to say that nearly an manufacturer who uses horizontal or vertical turret lathes can greatly increase the productive efficiency of his machines by the judicious use of multi-cutting tools. The several designs of turning tools illustrated in this chapter have been built for various purposes, and a careful study of the types shown may be of assistance in suggesting methods which can be used to perform some piece of work requiring tools of a similar kind. Some of the important points in the design of tools of this nature are given herewith.

General Points in Design

1. Rigidity: Avoid overhang as much as possible unless some sort of outboard support can be used. Pilot the tool if practicable.

2. Arrangement of tools: They should be perpendicular to the plane in which the turret rotates when indexing, because variations in diameters are less likely to take place when tools are arranged in this way. Unequal indexing of the turret has very little effect on the radial position of the tools under these conditions, so that sizes can be held much closer than if they are placed in a plane parallel to the turret rotation. Use standard rectangular stock for the cutting tools so that the upkeep will be inexpensive and reforging be avoided.

3. Try to make the block containing the tools removable so that it can be replaced easily by another block with tools arranged differently to handle other work.

4. Make the tool-block adjustable if possible.

5. Back up the tools with adjusting screws.

6. See that provision is made so that cutting lubricant can be directed on the faces of the tools when forgings or steel castings are to be machined.

7. Arrange the tool-block in such a way that the thrust of the cut does not come against it; it is much better to have the thrust come on the body of the tool.

Multi-turning Tool for Electric Motor Shafts

One example shown in Fig. 1 is given of a multi-turning tool for bar work. This tool was designed for use on the electric motor shaft shown at *A* in the illustration. The work was handled in short lengths although the stock is a regular commercial product. Roughing and finishing operations were performed with the same type of tools. The work was held in collet jaws. Something like twenty

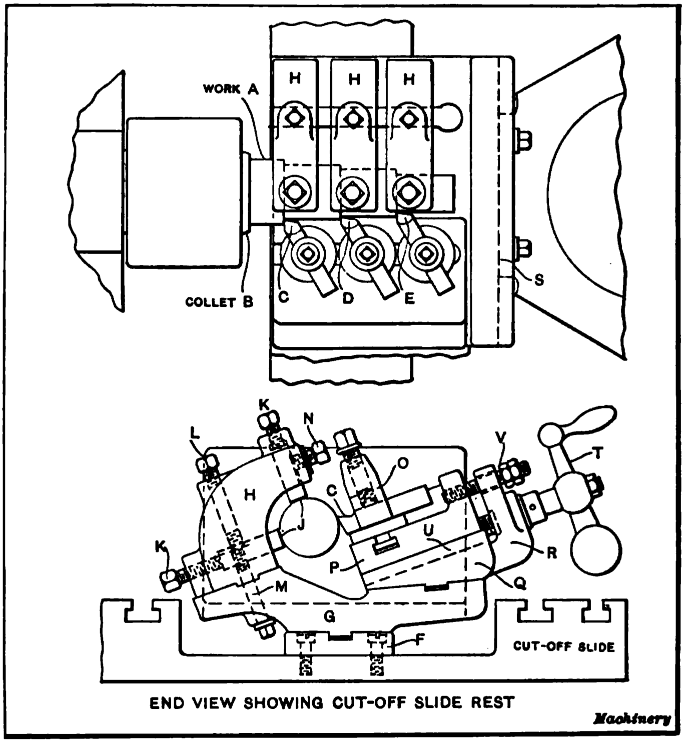

Fig. 1. Special Multi-turning Tool for Bar Work

varieties of shafts having different diameters and shoulder lengths were handled by these tools.

A Pratt & Whitney turret lathe with collet mechanism was used for this work; as this type of machine has a turret with dovetail faces, the body of the tool *G* was arranged to fit the dovetail and the gib *S* held it in place. The cut-off slide was planed off at the center and the hardened steel block *F* was secured to it. It will be noted that this block acts as a support for the tool, and the tongue assists in preventing lateral movement. The cast-iron block *Q* is fastened to the body of the tool and it is dovetailed at *U* to receive the tool-slide *P*. This is of steel and it is T-slotted so that standard toolposts *O* can be used. It will be seen that the tools *C*, *D*, and *E* are held in such a way that they can be adjusted readily both for different diameters and for shoulders of varying lengths. The slide is screw controlled and is operated by the handle *T*. A positive adjustable stop is provided by the check-nuts *V*. The back-rests *J* are of tool steel and are contained in the brackets *H*. The screws *K*, *L*, and *N* are used for binding and adjusting, while those at *M* pass down through slots in the body of the

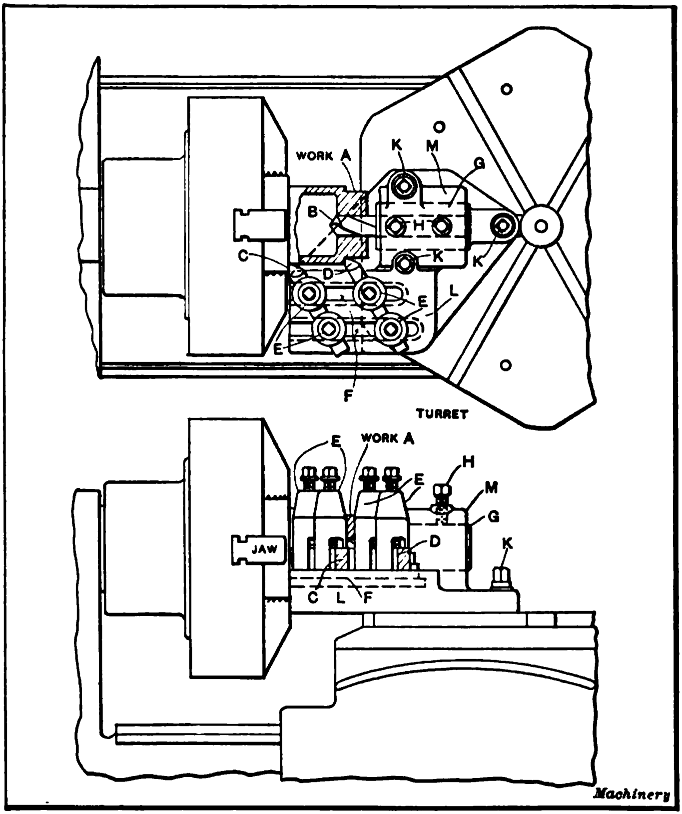

Fig. 2. Multiple Tool-holder for the Turntable Type of Lathe

tool and permit adjustment of the back-rests in a longitudinal direction.

Points worthy of notice in this tool are the method of supporting the body by means of the block on the cut-off slide, the flexibility of the tool adjustments, and the ease with which any tool may be replaced if broken or used up. The tools are of standard section and therefore require no machining except cutting off and grinding.

Multiple Tool-holder for the Turntable-type of Lathe

The bronze nut shown at *A* in Fig. 2 is an example of a piece of work which is to be drilled and turned on two diameters at the same time. There were six pieces of this kind varying slightly in size, which had to be machined in lots of twenty-five. Two tool-holders were used to do the work, one tool being arranged as shown in the illustration, while the other contained a boring tool in place of the drill *B*. The holder *L* was made of cast steel and was T-slotted in two places at *F*, so that tool-holders *E* of the standard type could be used. These carry the tools *C* and *D*, and attention is called to the

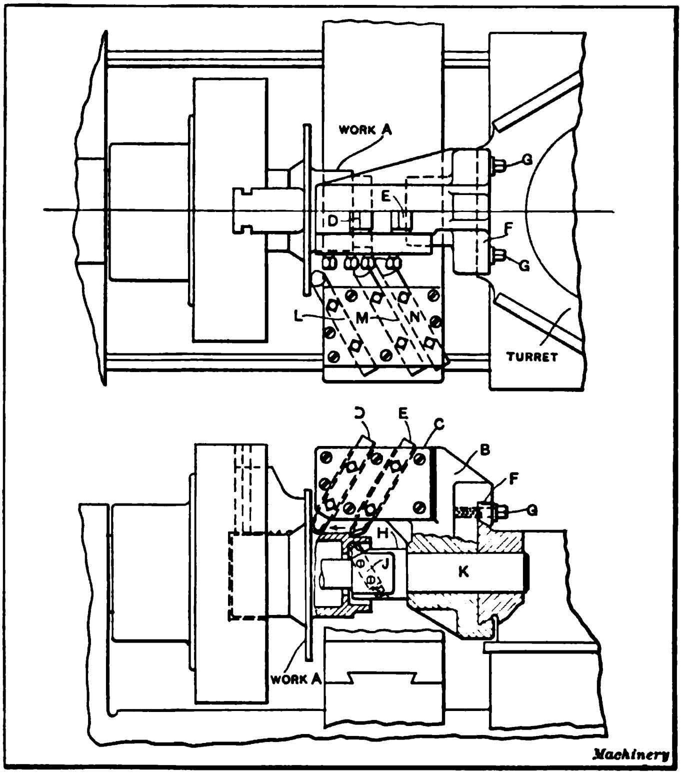

Fig. 8. Multiple Tool-holder for machining Automobile Hubs

way in which two posts are used for each tool to insure the maximum rigidity. The body of the holder is fastened to the turret face by the screws *K*, and is tongued on its under side to fit the slot. A semi-cylindrical boss *M* contains the split bushing *G* which holds the drill *B*. Two screws *H* are employed to clamp the bushing. This holder is simple, easily made and quite adaptable for work within its capacity. There are likely to be slight variations in the diameters turned due to imperfect indexing of the turret, but for general commercial work these usually are not great enough to cause any serious trouble.

Multiple Tool-holder for an Automobile Hub

The piece of work shown at *A* in Fig. 3 is an automobile hub, and the tool-holder is arranged so that the operations of turning and boring can be carried on simultaneously with the facing. The tools *L*, *M* and *N* are secured in a special block on the cut-off slide. The tool-holder *B* is of cast iron and well ribbed; it fits the dovetailed face of the turret, being secured in position by the screws *G* and the gib *F*. The turning tools *D* and *E* are mounted vertically, and the steel cap-plate *C* contains the necessary holding screws. The boring-bar *H* is

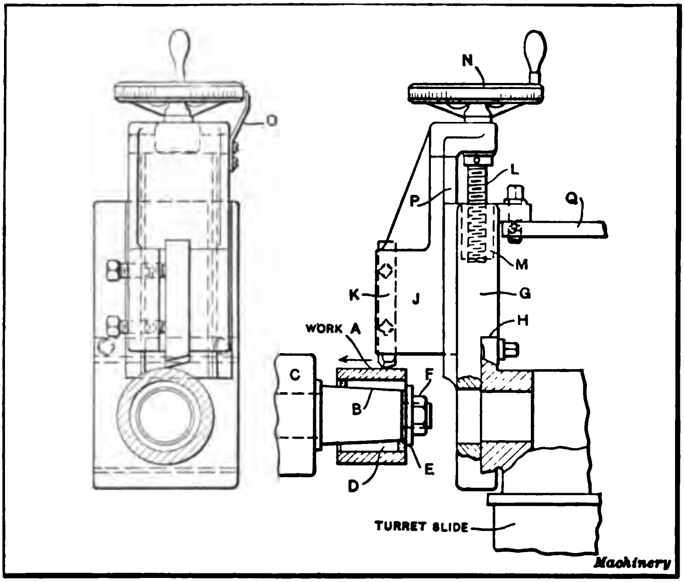

Fig. 4. Adjustable Turning Tool for finishing the Outside of Short Bushings

piloted in a chuck bushing at its forward end and contains the tool *J*, which stands in a vertical plane like the turning tools. The shank of the bar *K* is secured by the turret binding screw and an additional set-screw in the holder itself. A tool of this type will produce more accurate work than the type shown in the preceding illustration, on account of the position of the cutting tools with reference to the turret indexing. A feature of some importance is the piloting of the boring-bar, as this assists in the prevention of vibration. Care should be taken in the design of tool-holders of this type, that the overhang from the turret face is not too great, for if this is excessive, a certain amount of chatter is inevitable.

Adjustable Turning Tool for Short Bushings

A number of short bushings such as that shown at *A* in Fig. 4 were to be refinished on the outside. The bushings were of various diameters ranging from 2¼ to 4 inches, while the lengths varied from 1½ to 3 inches. The pieces were held on arbors *B*, in collet jaws *C*. A split sleeve *D* was expanded inside the work by the action of collar *E* and nut *F*. The body of the tool *G* was secured to the dovetailed face of the turret by gib *H*. The tool-slide *J* is a steel casting dovetailed at *P* and fitted with an adjustable taper gib to take up the

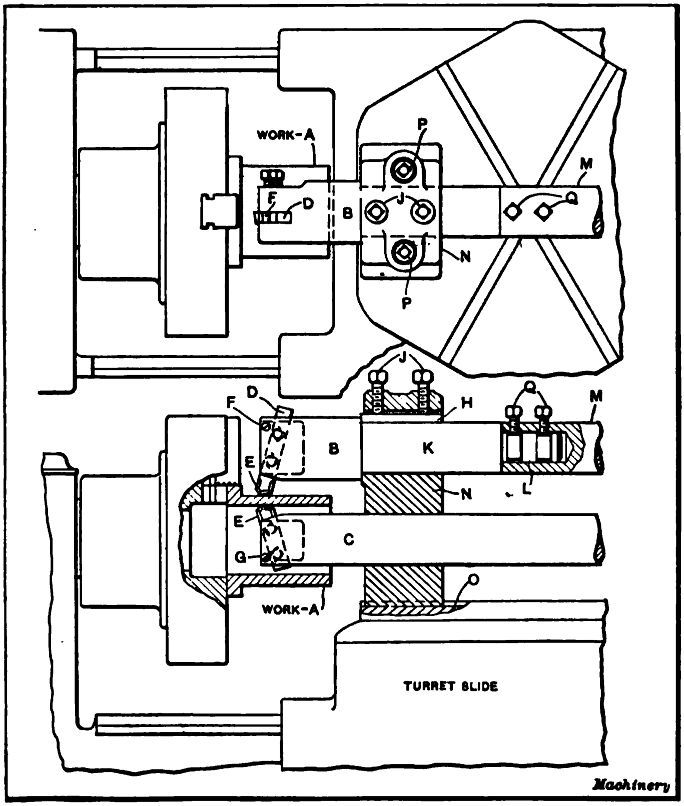

Fig. 5. Boring-bars for turning Concentric Packing Rings

wear. The cutting tool *K* is placed in a slot in the slide and is secured by the screws shown. The screw *L* is journaled in a lug at the upper end of the slide and enters a steel nut *M* in the body of the tool. Radial adjustment is obtained through this screw by means of the handwheel *N*. The rim of the wheel is graduated and the pointer *O* permits accurate readings to be made. This tool is very good indeed for light work, and accurate results can be obtained by its use. When two tools are used, a tie-rod *Q* assists in making the combination more rigid.

Holder for Adjustable Boring- and Turning-bars

The work shown at *A* in Fig. 5 is a cast-iron pot from which concentric packing rings are to be cut, and the boring and turning are done at the same time. Two cast-iron holders *N* are tongued at *O* and secured to opposite sides of the turret by the screws *P*. The turning- and boring-bars *B* and *C* pass through the holders and extend entirely across the turret. The boring-bar *C* is of the same diameter

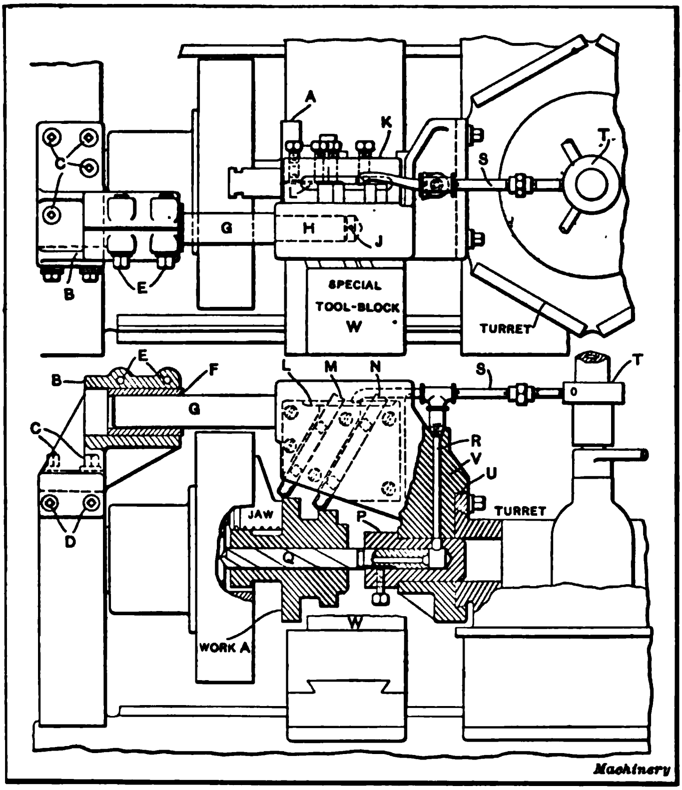

Fig. 6. Piloted Multiple Turning Tool for Gear Blanks

along its entire length, and it is secured in the holders by shoe binders similar to that shown at *H* but located in the sides of the holders. The boring tools *E* are of rectangular section and secured by setscrews in the slots at the ends of the bar. The screws *F* and *G* help to stiffen the ends of the bars where they are slotted. The upper or turning-bar is made in two sections *K* and *M* so that the tools may be swung radially to bring them into their proper position when the turret is set off center for turning larger diameters. The end of one bar is turned down at *L* to fit the hole in the other bar and the screws *Q* make a firm joint. A set of bars and holders of this kind is a very useful adjunct to a turret lathe equipment, and it may be adapted to a variety of uses. The double tie feature across the turret gives exceptional rigidity.

Piloted Multiple Turning Tool for Steel Gear Blanks

The automobile jack-shaft gear blank shown at *A* in Fig. 6 is of alloy steel and it is held in special chuck jaws so that it can be

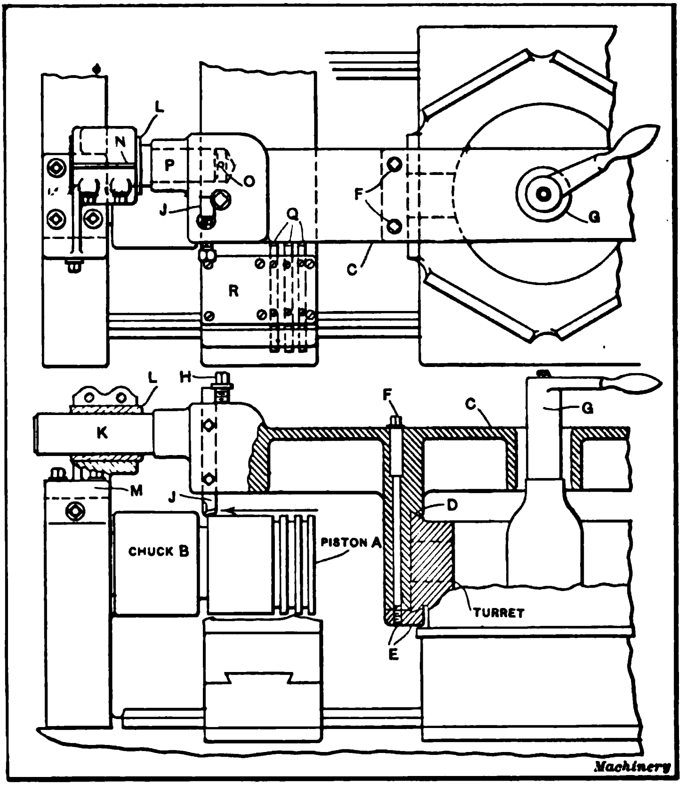

Fig. 7. Double-end Piloted Turning Tool for Pistons

drilled, turned and faced simultaneously. A special tool-block on the cut-off slide performs the latter operation, while the turning and drilling tools are carried by the turret. The body of the turning tool *V* is made of cast iron and is fastened to the dovetail turret face by the gib shown at *U*. The tool-block *K* is of steel and is slotted to receive tools *M* and *N*. An oil groove is cut at *L* along the top of the block and it is supplied with oil from the special piping system shown. The pipe *S* leads to the distributing collar *T* which, in turn, is connected with the cutting lubricant piping system on the machine. The slots in the tool-block are of sufficient width to permit an ample supply of fluid to run down and reach the cutting ends of the tools, thus assisting greatly in prolonging the life of the tools and also allowing higher cutting speeds. The oil-drill *Q* is held in a steel supporting bushing *P* which fits the body of the tool-holder. It is supplied with lubricant through the hole *R* which is connected to the piping system. The steel pilot *G* is shouldered at *H* and is forced into the body of the holder. The small hole *J* is put in so that air pressure will not be generated when the pilot is pressed into place, as this would tend to

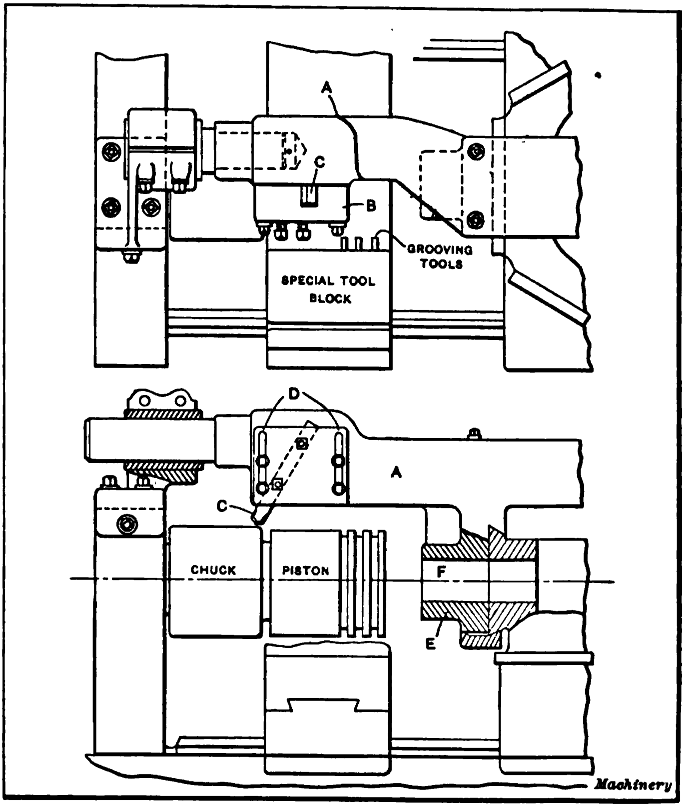

Fig. 8. Piston Turning Tool having Adjustable Tool-block

deceive the fitter by making him think he had a good fit when, in reality, it was compressed air that made the pilot hard to force in. Pilots are sometimes fitted so that they were apparently all right at the time when the work was done, and yet when the time came for the tools to be used, it was found that they were loose enough to cause trouble. The air hole will prevent trouble of this kind.

A special bracket is shown at *B* and it is screwed to the spindle cap by the screws *C* and *D*. The bronze bushing *F* receives the end of pilot *G*. and it is clamped by the binding screws *E*. This method of supporting a turning tool is very successful and assits greatly in permitting heavy cutting without chatter. Another feature of this tool is the manner in which oil is conveyed to the cutting tools. Attention is also called to the position of the tool-block, this being at the rear of the body so that the thrust of the cut is brought directly against the heavier part of the casting. The method of mounting the tools is also a little out of the ordinary, in that the block and tools form a

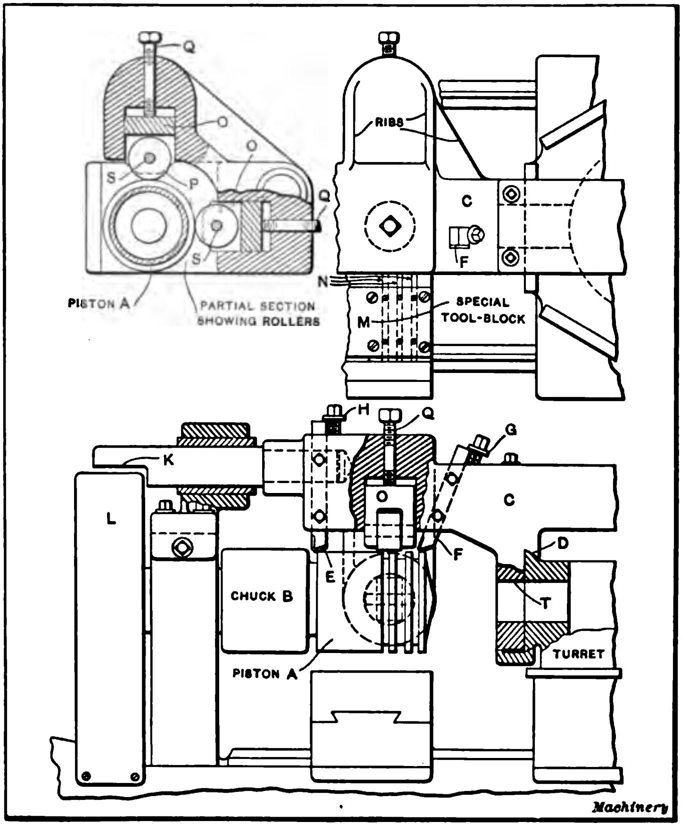

Fig. 9. Multiple Turning Tool equipped with Pilot and Roller Back-rest

unit which can readily be removed, permitting the substitution of another block with tools arranged differently, to handle other work requiring different spacing. Two turning tools on opposite sides of the turret were used for this particular piece, one being used for roughing and the other for finishing.

Double-end Piloted Turning Tool for Pistons

The piston *A* shown in Fig. 7 is held by the inside on a special expanding pin chuck *B*. The arrangement of tools is that recommended by the Pratt & Whitney Co., for turning automobile pistons on their horizontal turret lathe. The turning tool-holder *C* is of cast iron and is double ended, reaching entirely across the turret, and the two ends are exactly the same. The body or arm is of U-section and it is cored out at the center so that the turret binder-lever can pass through it, as shown at *G*. A careful fit is made on the dovetail at *D*, and two special bolts *F* pass down through the body of the tool and pull up the gib *E* against the lower dovetail, thus clamping the tool securely. The tool *J* is backed up by the collar-head screw *H* and is secured by means of two screws. The steel pilot *K* fits the bushing *L* in the spindle cap bracket *M*, as in a previous instance. It will be noted that an air hole *O* is provided where the shank *P* enters the end of the tool body. In connection with the turning tools a special block on the cut-off slide is used to cut the ring groove in the piston. This block and tools are shown at *R* and *Q* in the upper view. This style of equipment is very well known and has given universal satisfaction.

Piston Turning Tool having Adjustable Tool-block

A development of the preceding tool is shown in Fig. 8. It will be noted that although the general construction is about the same, in this instance the tool-block is made separate so that other blocks may be substituted having more than one tool. Considerable adjustment is also permissible by means of slots shown at *D*. It is obvious that this method of construction requires the tool-block *B* to be of steel and somewhat heavy, so that it will properly resist the thrust of the cut. The screws which hold the block in position must also be of ample size. As this particular tool was designed for use in turning and boring ring pots, in addition to piston work, the boss *E* was supplied and bored at *F* to receive a boring-bar.

Special Multiple Turning Tool with Roller Back-rest

In a great many instances the design of an automobile piston is such that it is permissible to center the solid end, and this gives a chance to support the end by a conical rest. While the ring grooves are being cut some support is essential, and in the case of the piston shown in Fig. 9 the use of roller supports in place of a center rest was found necessary for the reason that centering was not permitted. The piston *A* is held on the special chuck *B* and the two tools *E* and *F* are held in a double-end tool-holder. Adjustment is obtained by means of the collar-head screws *H* and *G*. The turning tool body *C* fits the turret dovetail at *D* and it is clamped, as previously stated. The end of the pilot *K* is cut away on its under side in order to clear the gear guard *L*. The steel supports *O* are backed up by the screws *Q*, which are also used for adjusting purposes. The hardened and ground steel rollers *P* are hung on the pins *S*. (See detail view.) A special tool-block *M* contains the grooving tools *N*. This equipment also was very successful.

Adjustable Piloted Turning Tool for Large Diameters

A somewhat different type of tool is shown in Fig. 10, this being adjustable for various diameters from the 12-inch casting *A* down to a diameter of 6 inches or a trifle under that size if necessary. This tool was rather heavy and cumbersome and not entirely successful on heavy cuts. On the lighter variety of work, however, it proved satisfactory and adaptable. Two tools were used on opposite sides of the turret; the flat steel tie-bar *L* helped to prevent sagging.

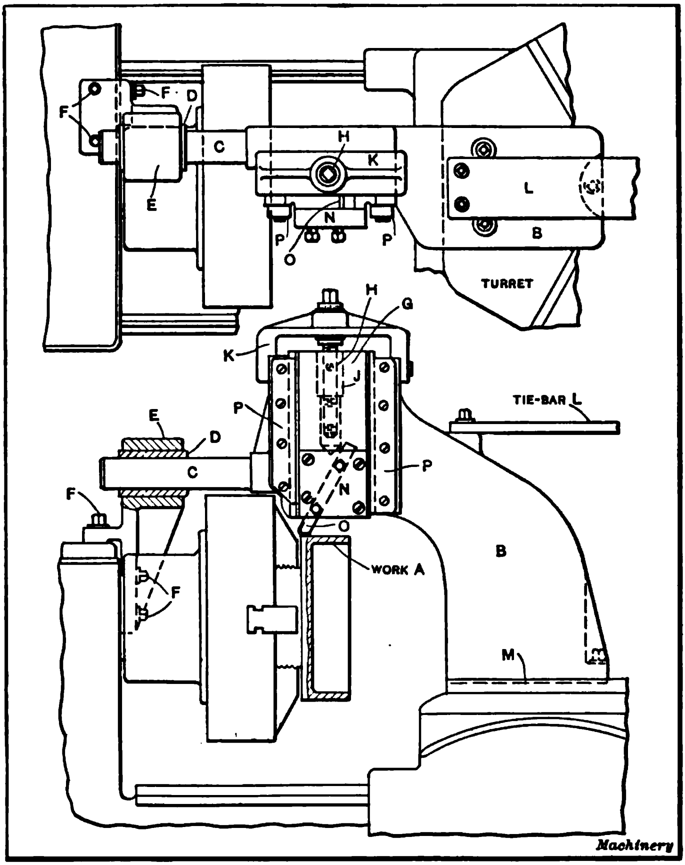

Fig. 10. Adjustable Piloted Turning Tool for Large Work

The body of the holder *B* is of cast iron cored out so that the walls are ½ inch section, and it is tongued along its lower face to fit the turret at *M*. The forward end holds the steel pilot *C*, which is supported and guided by the bushing *D*. The bracket *E* is fastened to the head of the machine by the screws *F*, thus insuring a rigid support for the end of the pilot. The tool-slide *N* contains the tool *O* and it is securely gibbed by the two steel straps *P*. A taper gib (not shown) provides adjustment for wear on the sides. The bracket *K* is screwed to the top of the tool body and journals the operating screw *H*. A graduated collar permits accurate settings to be made without trouble. A bronze nut in the body of the slide at *J* receives the operating screw.

Multiple Turning Tool for the Vertical Turret Lathe

The vertical turret lathe is less frequently supplied with multiple tools than the horizontal type of machine, for the reason that the regular equipment supplied by the manufacturers is adapted to a wide range of conditions without very much special tooling, and, in addition, the class of work for which this machine is more likely to be used is of such a nature that multiple turning tools are less likely to be re-

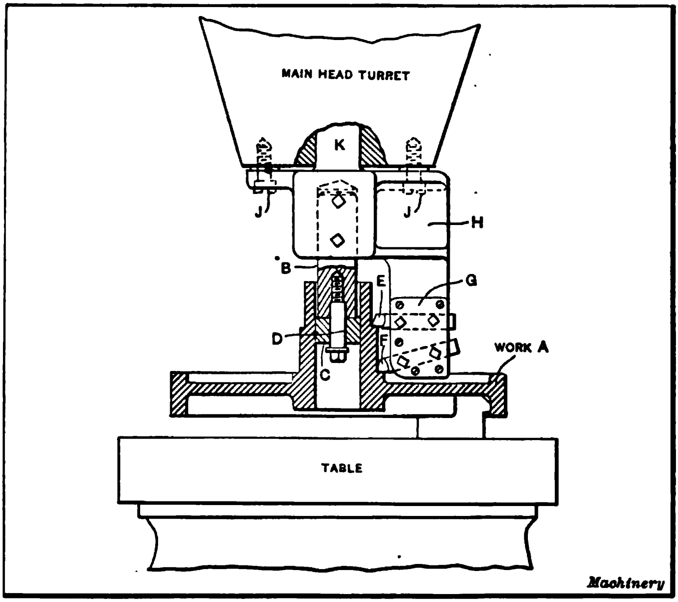

Fig. 11. Multiple Turning Tool for Vertical Turret Lathe

quired. There are instances, however, when a considerable increase in production may be made by the use of the multiple type of tools. Take for example the special gear shown at *A* in Fig. 11. This piece of work is held by the inside of the rim in special jaws, and the tools in the side-head turret are used to face and turn the gear portion while the special multiple tools are at work on the hub. Before the operation illustrated takes place, the work has been bored, reamed and faced on the other side.

The body of the tool *H* is of cast iron and it is fastened to the turret face by the screws *J*, while the plug *K* centers it in the turret hole. The turning tools *E* and *F* are secured in the slots and a steel cover-plate *G* gives support for the set-screws which hold the tools in place. A steel shank *B* has a revolving roll *C* fastened to its lower end by the shouldered screw *D;* this roll acts as a pilot in the finished hole.

The construction of this device is simple and the results obtained by its use are excellent.

Piloted Multiple Turning Tool for Triple Gear Blank

A radical departure from regular methods is shown in Fig. 12. The work *A* for which the equipment was designed is a cast-iron triple gear blank. Attention is called to the fact that in this illustration the side-head is shown in a false position in order to show the cutting action more clearly. The body *H* of the multiple turning tool is fitted

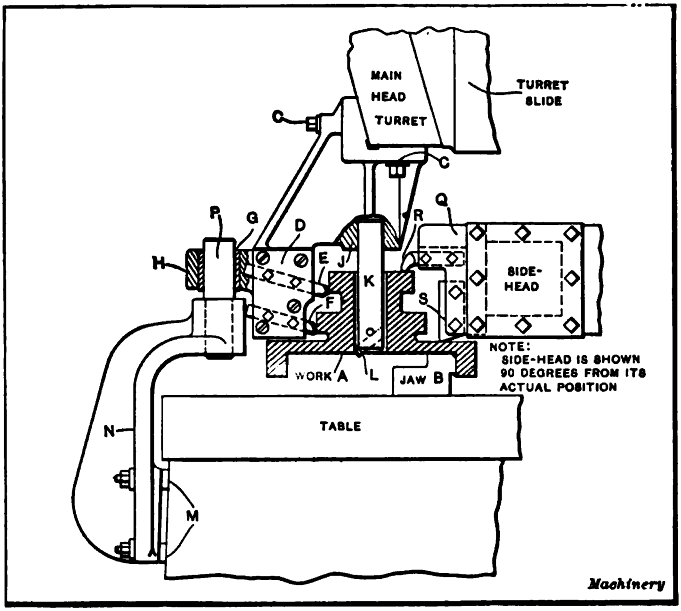

Fig. 12. Piloted Multiple Turning Tool for Triple Gear Blank

to the turret and held in position by the screws *C*. A steel bushing *G* acts as an outboard support for the tool, and it is a sliding fit on the pilot *P* which is shouldered in the supporting bracket *N*. This bracket is heavily ribbed and is fastened to the bed of the machine. The adjustable washers at *M* are used to align the bracket properly. A tool-block *D* contains the two turning tools *E* and *F*, and the boring-bar *K* is held in the hub *J*. The arrangement of the side-head, in this instance, is a little out of the ordinary. A special tool-block *Q* contains the two facing tools *R* and *S*, and these work simultaneously with the turning tools, thereby making production very rapid.

Multiple Toolpost Turret for the Side-head

The cone pulley shown at *A* in Fig. 13 was machined in one setting. The casting was held by the inside of the lower or largest step of the cone and a driver (not shown) was placed against the interior ribbing, as the jaws were not sufficient to hold the work securely against the cutting action of the four turning tools. A special side-head turret tool-holder was designed for this piece of work, and the facing and turning tools *D*, *E*, *F* and *G* were held in it as shown in the illustration. One set of tools was used for roughing and a duplicate set on the other side of the turret post was used for finishing. The entire group of tools pivoted on the stud *H*. While these cutters were operating on the outside of the pulley, the boring-bar *B* (held in the main head turret and driven by the pin *C*) was slowly boring out the hole. A forming plate was used to give the desired crown to the steps. The production could have been improved if a special turning tool had been used in the main head for turning the four steps of the cone, and the side-

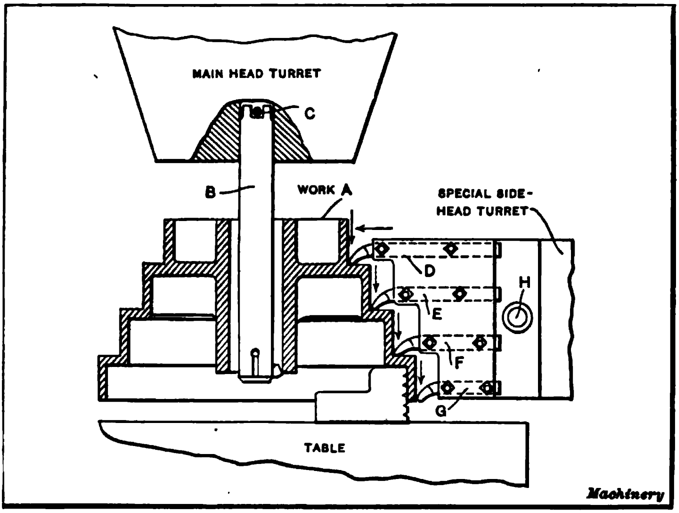

Fig. 13. Multiple Toolpost Turret for the Side-head

head used for facing only. These operations could have taken place at the same time, and the speeds would have been more nearly correct. The boring could have been done at a higher rate of speed. However, the results obtained with the arrangement shown in the illustration were satisfactory.

Multiple Turning Tool for the Vertical Boring Mill

The vertical boring mill is seldom equipped with multiple turning tools, but there are cases where production can be increased considerably by their use. One example only is given of the use of an equipment of this kind. Fig. 14 shows a large pulley at *A*, and this is held by the inside of the larger step in the special jaws *B*. The buttons *C* give a three-point support to the work. A special tool-holder *D* is slotted out to receive the tools *E*, *F* and *G* which are used for the turning and boring. The plate *H* is fastened over one end of the tool-holder in order to tie it together, and the filler-block *J* gives additional strength while its upper end engages the right-hand ram and acts as a driver. Another block *K* ties the lower end of the tool-holder together. The left-hand head contains the toolpost *L* which supports the tool *M*. This tool is used for facing while the other tools are turning.

Other instances of multiple turning might be given, and illustrations

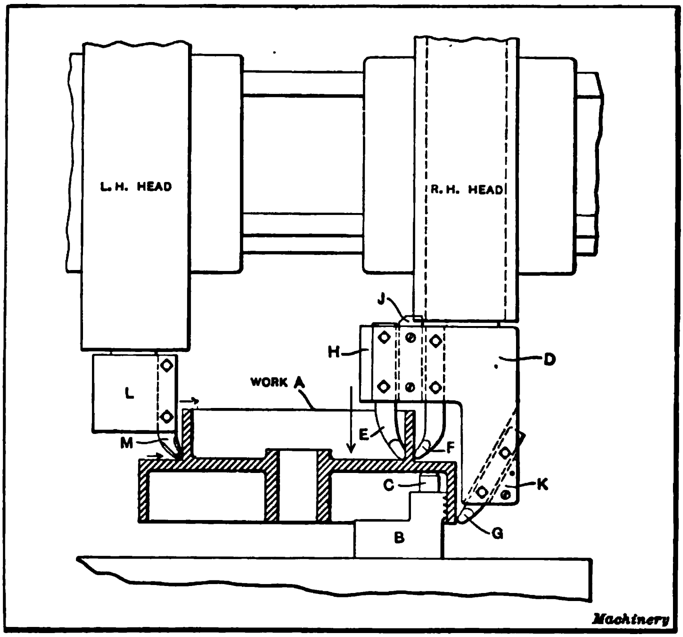

Fig. 14. Application of Multiple Turning Tool to Vertical Boring Mill

shown, but these would be much on the same order as those which have been mentioned and would be of no particular value as representative types. Tools have been selected for this chapter which seem to best illustrate the principles of design required in the various types.

No. 67. Boilers.
No. 68. Boiler Furnaces and Chimneys.
No. 69. Feed Water Appliances.
No. 70. Steam Engines.
No. 71. Steam Turbines.
No. 72. Pumps, Condensers, Steam and Water Piping.
No. 129. Care and Repair of Gas Engines.

LOCOMOTIVE DESIGN AND RAILWAY SHOP PRACTICE

No. 27. Locomotive Design, Part I.
No. 28. Locomotive Design, Part II.
No. 29. Locomotive Design, Part III.
No. 30. Locomotive Design, Part IV.
No. 79. Locomotive Building.—Main and Side Rods.
No. 80. Locomotive Building.—Wheels; Axles; Driving Boxes.
No. 81. Locomotive Building.—Cylinders and Frames.
No. 82. Locomotive Building.—Valve Motion.
No. 83. Locomotive Building.—Boiler Shop Practice.
No. 84. Locomotive Building.—Erecting.
No. 90. Railway Repair Shop Practice.

ELECTRICITY—DYNAMOS AND MOTORS

No. 34. Care and Repair of Dynamos and Motors.
No. 73. Principles and Applications of Electricity.—Static Electricity; Electrical Measurements; Batteries.
No. 74. Principles and Applications of Electricity.—Magnetism; Electro-Magnetism; Electro-Plating.
No. 75. Principles and Applications of Electricity.—Dynamos; Motors; Electric Railways.
No. 76. Principles and Applications of Electricity.—Telegraph and Telephone.
No. 77. Principles and Applications of Electricity.—Electric Lighting.
No. 78. Principles and Applications of Electricity.—Transmission of Power.
No. 115. Electric Motor Drive for Machine Tools.

HEATING AND VENTILATION

No. 39. Fans, Ventilation and Heating.
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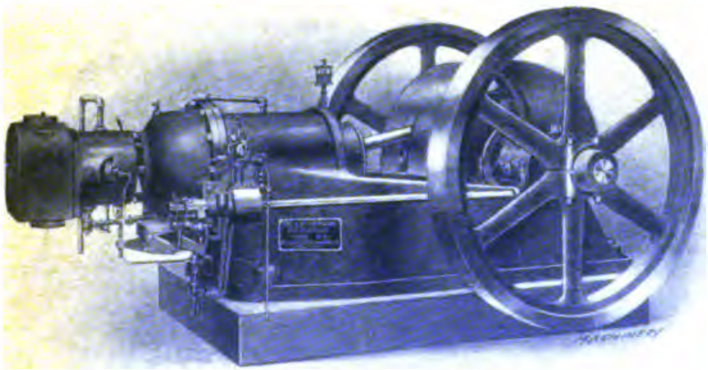
CARE AND REPAIR OF GAS AND OIL ENGINES



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NUMBER 129

CARE AND REPAIR OF GAS AND OIL ENGINES

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PREFACE

This Reference Book has been prepared mainly from a series of notes compiled by J. L. Hobbs, who has had a long and varied experience with the care and repair of gas and oil engines. Much valuable information has also been abstracted from the publications of various manufacturers of gas and oil engines, especially from material obtained through the courtesy of the International Harvester Company of America, the De La Vergne Machine Company, and the Westinghouse Machine Company.

INTRODUCTION

INTERNAL COMBUSTION ENGINES

While there are a great many books dealing with the theory and design of gas engines, as well as their operation, there has been a great lack of information relating to the care and repair of gas engines. Those that have devoted themselves to the work of gas engine repair have largely obtained their knowledge of the subject by practical experience. The author of this treatise on gas engine repairs has been forced to obtain his knowledge in this way, which, after all, is the best, although it is often a slow, expensive and difficult one. In order to make it easier for others who are engaged in this work or who intend to enter into this field, the most important points relative to the care and repair of gas engines have been put down in the following chapters, thereby providing a means by which others may find it easier to become familiar with this subject.

There has always been an air of mystery surrounding the gas engine. Often everything seems to be in the best condition and yet the engine may refuse to start or may not develop its rated power. The fact is, however, that, as a rule, the troubles likely to arise are easily detected, providing one has the knowledge to look for the causes of the difficulties at such points where they may arise. Under the four heads of "Compression," "Carburetion," "Ignition" and "Lubrication," practically all of the ordinary difficulties that arise in gas engine operation are dealt with; special chapters on cooling systems and on installation have been added, the latter giving information to owners and others to whom the installation of a gas engine plant may be entrusted.

It may be said, in a general way, that any gas engine which has proper compression and receives the proper mixture of fuel and air from its carburetor, and, in addition, ignites this mixture at the proper time, and the moving parts of which, including the inside of the cylinder and the outside of the piston, are properly lubricated, will run and will develop the power it is intended to develop. When anything goes wrong with any of these conditions, the engine will give trouble, and it is the purpose of the following chapters to explain how these troubles may be avoided or remedied.

Principles of the Internal Combustion Engine

The gas engine and oil engine are practically identical as far as the principles of their power producing qualities are concerned, both being internal combustion engines, that is, engines which derive their power from an expansion of gases caused by burning a mixture of gas, or a gasified liquid fuel, and air in their cylinders. Of the various fuels that can be used to produce the explosive mixture, gas, gasoline, kerosene and alcohol are the most commonly used.

It may be well at the outset to explain the difference between the so-called two-cycle and the four-cycle engine. In the four-cycle engine, which is most commonly used, there are four distinct movements or cycles necessary for one power impulse to the crankshaft. The first of these strokes is the intake stroke, which is made with the piston moving towards the crankshaft and with the intake valve open; the cylinder is now being filled with the explosive mixture. The second or the compression stroke is made when the piston is forced back against the mixture which has just been drawn in during the intake stroke. During the second stroke all the valves are closed and the proper compression of the mixture secured. Then, just as the piston starts back towards the crankshaft on its third stroke, all the valves still being closed, the charge is ignited, the explosion occurs and the power of the explosion is conducted to the crankshaft. As the piston now reaches the end of this stroke the exhaust valve is opened and remains open while the piston returns for the fourth stroke, thus expelling the exhaust gases in the cylinder. This completes the four cycles and requires two full revolutions of the crankshaft. The flywheel is depended upon to store enough energy to keep the engine moving at a fairly uniform rate of speed during the complete cycle. A camshaft is provided to operate the valves in such a manner that they will open and close at the proper moments during the forward and backward strokes of the piston.

In the two-cycle engine a power impulse is transmitted to the crankshaft for each revolution. There are two models of this type of engine. In the one an auxiliary cylinder is used to compress the gas and force it into the main cylinder at the proper time. In the other type an air-tight crankcase is used for this purpose. When an auxiliary cylinder is used, it is operated in the reverse order from the power cylinder, so that a charge is entered into the main cylinder just when the exhaust port in this cylinder is closed, and in this way the intake and exhaust strokes are eliminated, giving a power stroke for every revolution. The incoming charge is necessarily mixed to some extent with the exhaust gases not yet thoroughly driven out, and for this reason it is generally conceded that the two-stroke engine is neither as economical nor as reliable as the four-stroke or four-cycle engine. Its advantages, however, are light weight and a more uniform application of the power, and because of these features it is extensively used, especially for marine engines.

Principal Parts of Gas and Oil Engines

The principal parts of an internal combustion engine are the cylinder, piston, connecting-rod, crankshaft, flywheel, valve gearing, inlet and exhaust valves, mixer or carbureter, igniter, and governor, with a base on which the various parts are mounted. The cylinder, with its head, is either provided with a water jacket through which the cooling water is circulated for keeping down the temperature of

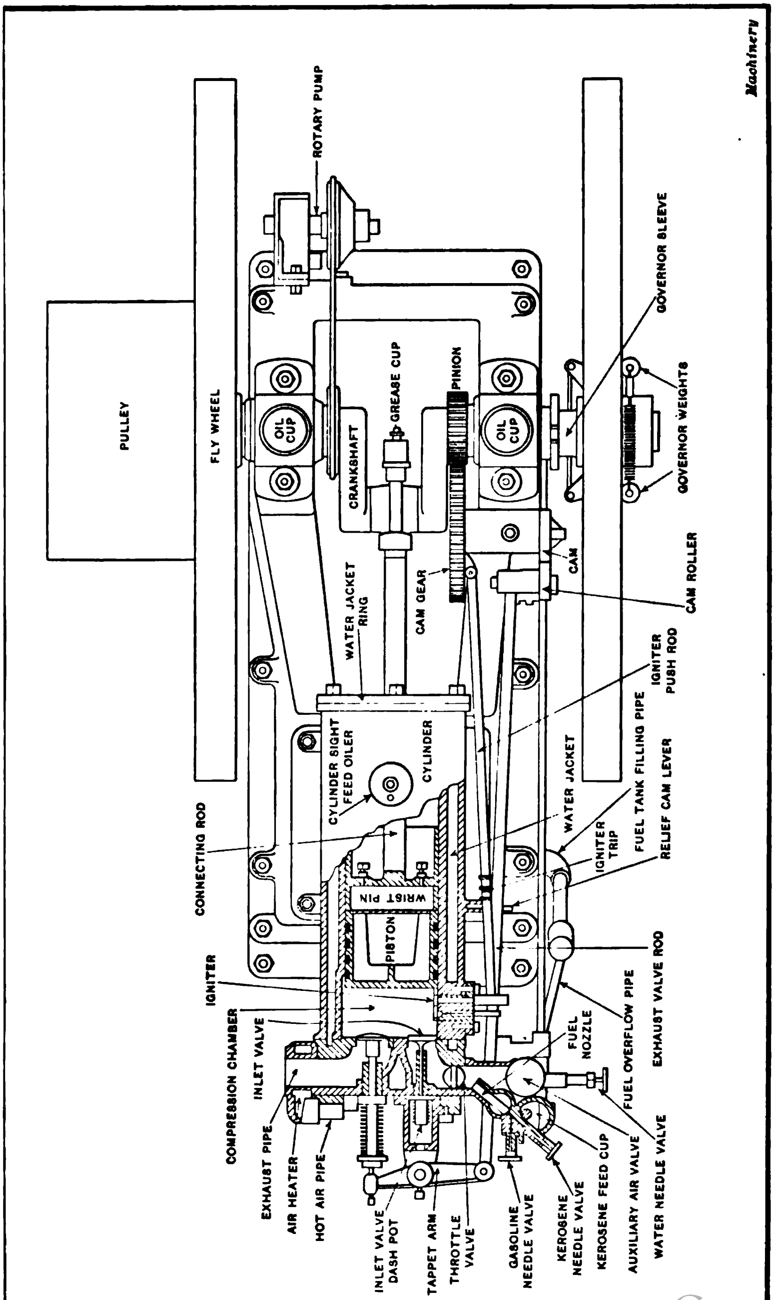

Fig. 1. Section and Plan View of International Harvester Co. Horizontal Oil Engine

the cylinder walls, or it may consist of a single shell with projecting ribs for radiating the heat to the air. The piston is provided with packing rings to prevent the combustion gases from leaking past it. The inlet and exhaust valves serve the purpose of admitting and discharging the combustible gases at the proper moments, the valve gearing governing and timing their action. The mixer or carbureter is used for vaporizing or gasifying liquid fuels and mixing them with the proper amount of air to obtain the explosive mixture of right proportions. The igniter is timed to ignite the compressed explosive charge at the given moment, and the governor is designed to make the speed of the engine uniform within certain predetermined limits. It may regulate the speed either by regulating the amount of mixture for each charge, as in the case of the throttling governor, or by preventing ignition and explosion of power charges in cases when the speed is above normal, as in the case of the "hit-and-miss" type of governor.

The governor of a gas engine must be in perfect working order. The type generally used is some form of fly-ball governor, the same as is almost universally employed on steam engines. This governor is operated by the action of the centrifugal force pulling against springs which tend to hold the fly-balls near each other. On the "hit-and-miss" type of engine, when the governor runs above a certain speed, it forcibly prevents the exhaust valve from closing, thus allowing the engine to run without an explosion or to miss an explosion or two until the speed decreases enough for the governor to release the exhaust valve, when the explosions begin again. In some engines, the governor also controls the sparking device and eliminates the spark, except when it is needed to ignite a charge. This saves the batteries materially. Some engines are provided with a device which locks the intake valve when the exhaust valve is held open by the governor. This is a valuable feature as it saves fuel.

When the throttling governor is used, a device is provided in the intake pipe to regulate the amount of gas passing to the cylinder, only enough being allowed to enter the cylinder to retain the speed. The instant the load is put onto the engine it will slow up slightly, and then the throttle will open just enough to maintain the speed. This governor is superior to the one of the "hit-and-miss" type as far as steadiness of power and speed is concerned, but it is claimed that the "hit-and-miss" governor is more economical, providing the intake valve is closed when the exhaust valve is held open by the governor, and for burning gasoline, the "hit-and-miss" type is probably the best. When using other fuels, the throttling governor seems to be preferable, because the less volatile fuels require the increase of heat made possible by the operation of this type of governor, where combustion takes place for every cycle.

The exhaust valve is operated mechanically by some form of eccentric or cam on the camshaft, the valve being opened at the end of the power stroke by means of this cam. A spring is used for closing the valve, but some positive means must be provided to open it.

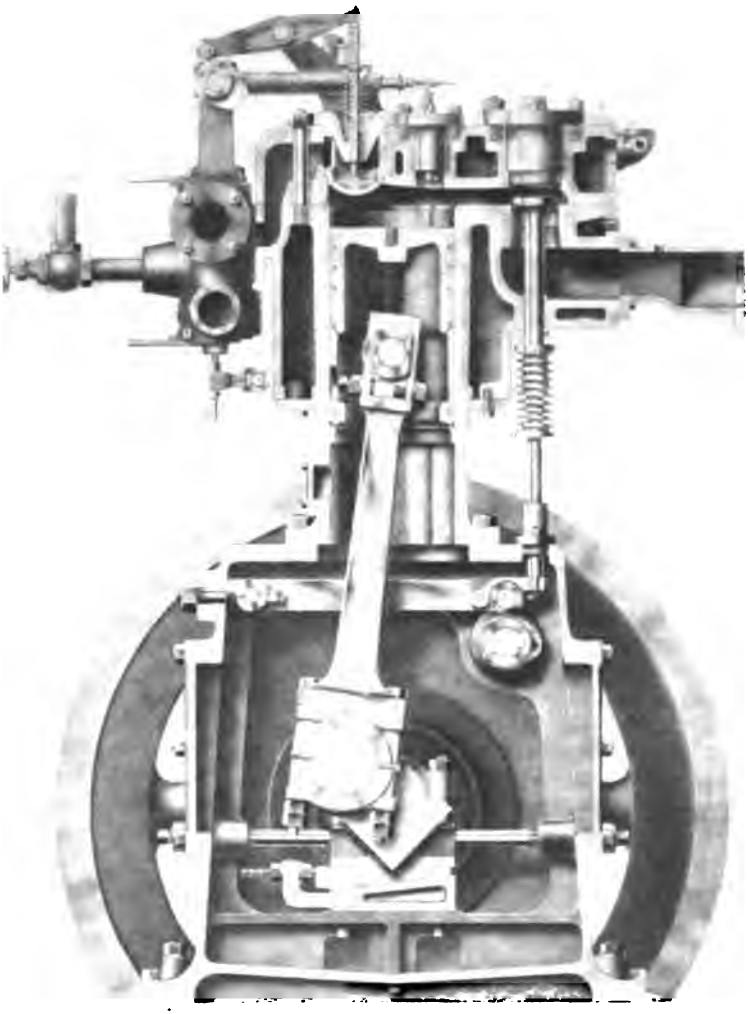

Fig. 2. Section through a Westinghouse Vertical Gas Engine

On some engines the intake valve is operated in a similar manner, except that it opens at the beginning of the suction stroke and closes at the beginning of the compression stroke. When this valve is not mechanically operated, it is allowed to open automatically and is closed by the spring which is provided for that purpose. When the intake valve is opened automatically, a spring just strong enough to keep the valve closed is used so that the suction of the piston on the suction stroke will open the valve to admit the charge. As long as this valve spring holds the proper tension, the arrangement will work to good satisfaction, but if the spring is too weak or too strong it will cause trouble. On new engines it is frequently found that the intake valve is stuck fast with paint. In that case, a little kerosene on the stem and a few movements of the valve by hand will loosen it.

On some engines a compression relief is provided to assist in starting the engine. This opens the exhaust valve slightly during the compression stroke and allows the spring to close it again, giving compression enough to start the engine, but not enough to interfere with the turning of the engine over the dead center.

In most engines all the principal bearings are made in halves and separated by thin shims which may be removed as the bearings wear, so as to always insure a snug fit for the parts to fit in them. All bearings should be kept as tight as is permissible and yet let the engine run freely. A knocking noise which is caused by a loose bearing should never be permitted, as it will soon destroy the bearing.

Starting an Engine

It is always best to have some regular way in which to start an engine. The following method is recommended by The International Harvester Company:

1. See that the fuel supply is ample.
2. Oil the engine thoroughly with gas-engine oil, filling every oil cup and noting carefully its adjustment.
3. See that all nuts are tight and that all parts are secure.
4. Close the battery switch and see that the ignition system is in good order. It is best to remove the wire from the stationary electrode and try for a spark by brushing this wire against the circuit breaker on the engine, or test as follows: If batteries are used, test the battery current by closing the switch, disconnecting the end of one of the wires and brushing it against the binding post to which the other wire is attached. If a bright spark does not show every time the wire is snapped or slipped off the binding post, there is something wrong with the current or the conductors. It may be a disconnected switch, loose wires, or exhausted batteries. If there is a good spark on the end of the wires, and a weak one or none at all at the point of contact of the electrodes, there is something wrong in the sparking mechanism of the engine—the mechanism is either corroded, gummed up, short circuited, or out of adjustment.
5. Try the valves to see if they operate freely.
6. Turn on the cooling water, if a water-cooled engine.

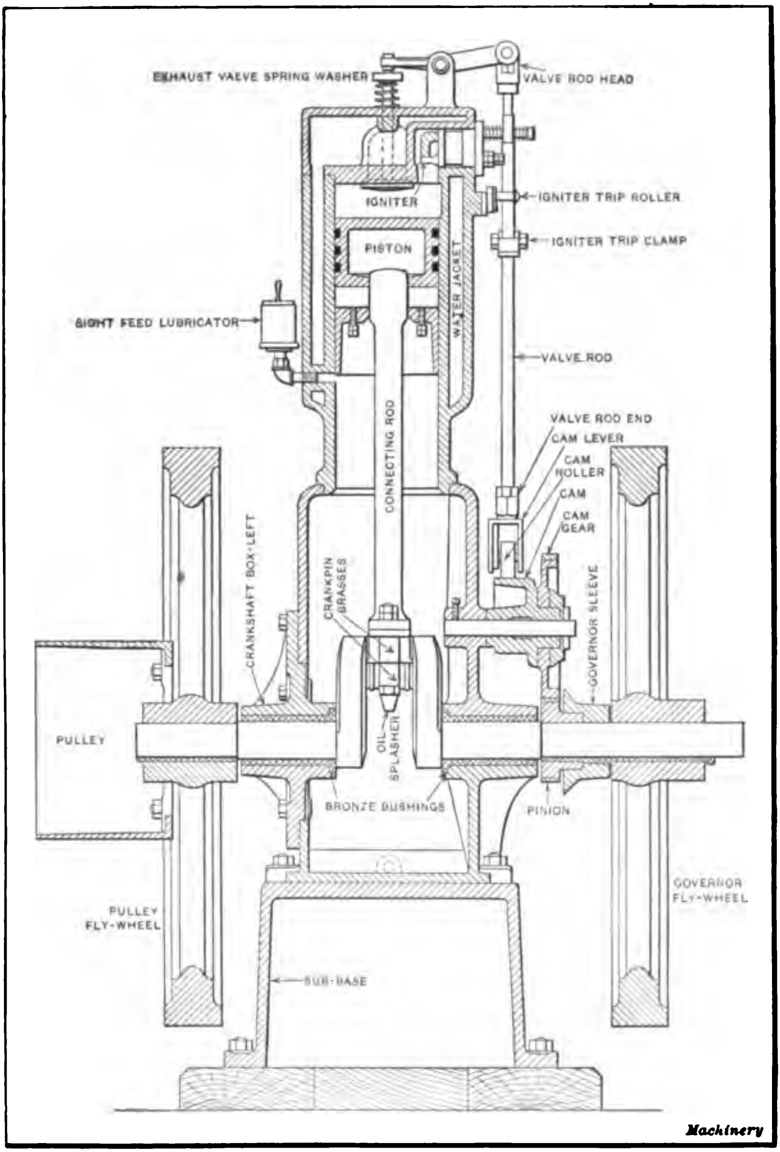

Fig. 8. Section through an International Harvester Co. Vertical Engine

When properly set, the engine should start with two or three turns of the flywheel. It is not necessary to turn the engine for a long time. If it does not start readily, it is time to begin to examine the parts systematically in an effort to find what is wrong.

Troubles that Prevent Starting

The troubles which may prevent starting an engine may be due either to lost compression, faulty ignition, slow vaporization of the fuel in cold weather, not enough fuel, too much fuel, or water in the cylinder. These various difficulties will be referred to in the following chapters under the headings of "Compression," "Carburetion" and "Ignition."

Stopping an Engine

After stopping the engine, close all oil cups and all needle valves, and drain the water from the cylinder jacket and from the cooling tank. If the engine is to be shut down for a short time only, and there is no danger from freezing, the cooling tank need not be emptied each time. See that the exhaust valves are left closed to prevent corroding of the valve seats and injury to the inside of the cylinders, and be sure that the battery switch is left open. If an oil engine, the kerosene and water should be shut off before stopping, and the engine run on gasoline for a minute to clean the water and oil from the cylinder and valves.

Every time the engine is stopped the operator should take a wrench or a set of wrenches and go over every nut on the engine to make sure it is tight. A few minutes spent this way each day will greatly increase the life of the engine. Any part that shows wear should be taken care of at once, for if it is allowed to wear on it will cause some other parts to begin to wear also, and the life of the engine, as a whole, will be shortened. There is no reason why an engine properly taken care of should not look as good as new after having been running for five years, and it probably does not require, under ordinary conditions, more than about ten minutes a day to give an engine enough attention to preserve it in good condition. At the same time as the nuts are tightened, all parts of the engine are wiped dry and cleaned, as in doing so the engine is also given an inspection that all parts are in good condition. The cost for repairs will be greatly minimized if this care is given to gas engines.

Care of the Engine

It is advised that as far as possible one man only should be held responsible for the care of an engine. Two advantages are gained in this way: the operator will get a thorough knowledge of the engine, and failure of the engine to operate will not be due to errors on the part of others who are incompetent or not familiar with the working of the mechanism.

It is very important that the engine be kept clean. When an engine is run regularly every day, the piston and valves should be removed from the cylinder and these parts and the cylinder itself should be washed with kerosene or gasoline at frequent intervals. When the engine is used only intermittently, the number of times it is necessary to clean the engine will depend upon the conditions, but in order that it may work properly it should in no case be allowed to stand

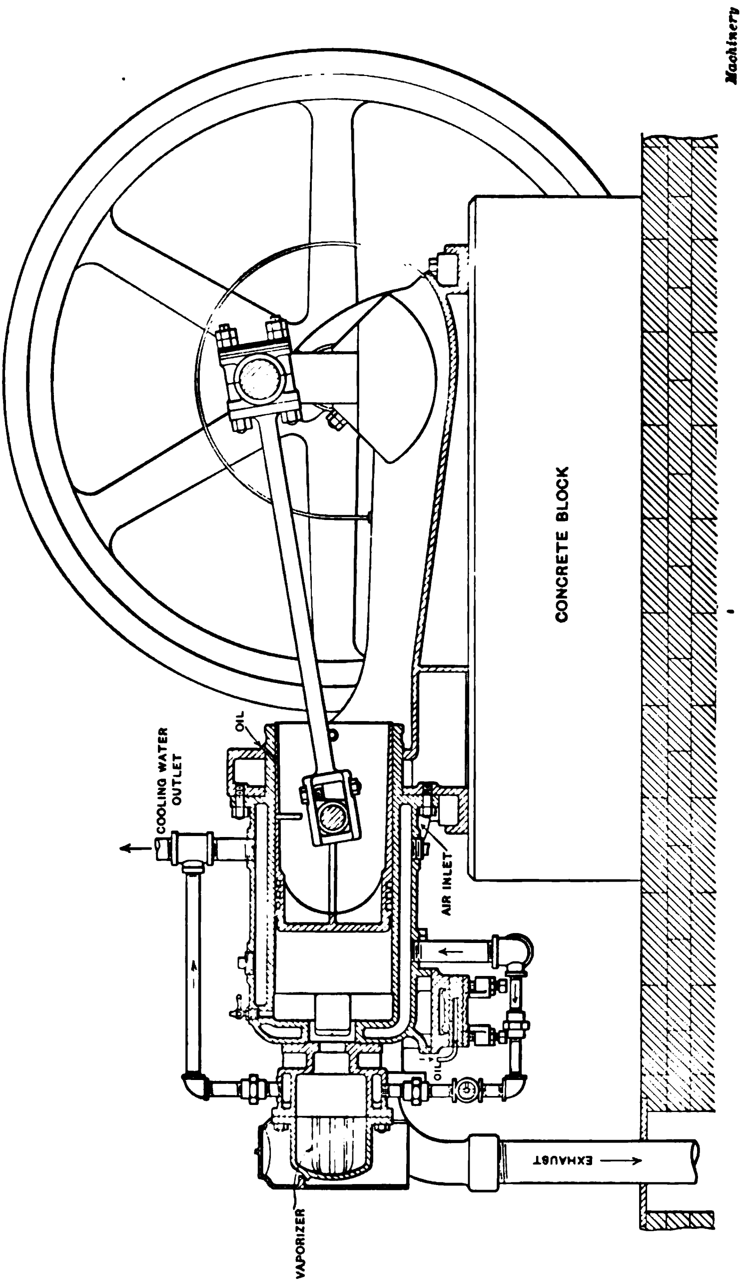

Fig. 4. Longitudinal Section of De La Vergne Machine Co. Oil Engine

more than six months without being dismantled and thoroughly cleaned. The igniter should be removed about once a week and the points of the electrodes cleaned with sand paper or with a fine file. The elements of a wet battery should be removed about every six months.

Replacing a Worn Babbitt Bearing

A worn babbitt bearing can be replaced by anybody, even if he has had no previous experience with this work. To babbitt a one-piece bearing, cover the shaft with ordinary laundry soap and place it in the bearing in the position it will have when it is to run, and fasten it securely. Pour in the babbitt at the highest point of the bearing. The shaft and box must be heated previously, so that the hands cannot touch it and the babbitt must be hot enough to burn a stick of wood when inserted into it. Both ends of the bearing must be stopped off, except for a small hole into which the babbitt is poured. A piece of wood should be driven into the oil hole until it touches the shaft. After having poured the babbitt into the bearing, allow it to cool thoroughly before making any attempt to turn the shaft. The shaft may turn a trifle hard at first, and, in some cases, it may even be necessary to drive out the shaft and to ream the babbitt to get a good fit.

A two-piece bearing is handled in practically the same way, except that only one-half of it is babbitted at a time. The outer half of the bearing is first removed and laid to one side, the shaft is fastened in exactly the same position it will have when running, the bearing should be perfectly level while pouring, the end of the bearing is stopped off with any heat-resisting material, and enough babbitt is poured to run around the shaft and fill the box halfway around it. The babbitt is then dressed down smoothly after it cools, even with the top of the lower half of the bearing box. Cardboard is now fitted entirely over the lower half of the bearing, tightly up against the shaft. The top half of the bearing is now placed in position, fastened securely and the ends stopped off with heat-resisting material, and the babbitt poured into the oil hole until the bearing is full. The oil hole is drilled out after the top half is removed, and the bearing is complete and ready to run after cooling.

CHAPTER I

COMPRESSION

The power developed by an engine is largely determined by the compression in the cylinder. "If the engine is not developing its power," says Leslie in the *Engine Operator's Guide*, "look for loss of compression."

The compression space is usually about one-fourth of the entire cylinder space, the compression space being that part of the cylinder space between the piston and the cylinder-head when the piston is at its extreme inner end of the stroke, and the cylinder space the complete space behind the piston when the latter is at the extreme outer end of its stroke. In a four-cycle engine the cylinder space is entirely filled with a mixture of air and combustible gas on the intake stroke. Then on the compression stroke this amount of combustible mixture is compressed so that it occupies about one-fourth of the space formerly occupied. It is the degree of the compression that determines the power the engine will produce when the compressed charge is ignited.

Importance of Good Compression

The object of compression in an internal combustion engine cylinder is to insure rapid ignition of the gases to be consumed, thus insuring the highest degree of heat and the greatest expansion of the gases, thereby giving more powerful impulse to the piston. The slower the process of burning in the cylinder is, the less vigorous is the expansion. Hence, if the compression is good, the particles of the combustible mixture are closely crowded and will burn quickly, and a higher degree of heat and a more powerful impulse to the crankshaft is insured.

The compression of a gas engine thus takes place in the air-tight chamber at the closed end of the cylinder, in which the mixture from the carbureter is compressed to from 60 to 75 pounds per square inch. There are a number of difficulties met with which prevent good compression. We will suppose that we have to do with an engine where the compression is found to be defective. The first thing to do in a case of this kind is to take hold of the flywheel and move the engine forward, listening for any hissing sound which might aid in finding where the leak is that prevents the proper compression from being obtained.

Carbon Deposits on the Piston

If the leak is not located directly by this means, release the connecting-rod from the crankshaft. As a rule, the connecting-rod is attached to the crankshaft by means of two bolts. Then remove the piston from the cylinder by pulling the piston out towards the crankshaft. After having pulled out the piston, examine its head carefully. It will be found that the end of the piston head is covered with a black coating of carbon; this coating will vary in thickness from a thin film to as much as one-half inch. If carbon has accumulated to a depth above one-eighth inch, it will, in a properly designed compression chamber, raise the number of pounds pressure of the compression to such a point that the vapor will be fired before the proper time, which interferes with the running of the engine. This firing ahead of time, or "pre-ignition," will be explained in Chapter III, under the head of "Ignition."

The carbon on the piston head must all be scraped off until a clean surface is obtained, and the carbon in the compression chamber of the cylinder must also be removed in order that the engine may be restored to its original condition. The square end of a flat file can generally be used for this work, although if the carbon deposit is baked on in the form of a hard crust, it is sometimes necessary to use a cold-chisel and hammer. When the latter method is used, care must be taken not to pound hard enough to break the parts from which the carbon deposit is removed. After the removal of all the carbon, the piston must be further inspected to find the cause of the leak.

Cracks or Sand-holes in Piston

Examine the head of the piston for a crack or a sand-hole. A very small hole will cause a serious leak at this point. If a crack is found which cannot be sealed with some good iron cement or welded by the oxy-acetylene process, it will be necessary to replace the piston with a new one. If a sand-hole should be found, the trouble can be easily remedied by drilling out the hole with an ordinary drill and countersinking the hole a little on each side, and then putting a piece of iron into the hole, this piece being about one-eighth inch longer than the length of the hole. Then, with a light hammer, rivet one end of the piece of iron, the other end, meanwhile, resting upon some solid support; then turn around and rivet the other end, and the leak will be stopped up permanently.

Influence of Poor Lubrication

Poor lubrication of the cylinder will cause a loss of compression. This difficulty is indicated by a peculiar blowing noise in the cylinder at each impulse, being due to the fact that the lack of lubrication permits part of the compressed gases to pass by the rings. The trouble is overcome by adjusting the lubricator means in such a way that a freer flow of oil is allowed. If the cylinder has been running dry for some time, the piston should be taken out and the rings, piston and inside of the cylinder walls cleaned and inspected.

Removing the Piston Rings

For a thorough examination of the piston, remove the rings by using thin pieces of metal under them to prevent them from slipping back into the grooves. The rings can then be slid over these pieces in order to take them off the piston. After the rings are out of the way, attention must first be directed to the grooves in which the rings fit. First examine these for carbon deposits. If any foreign matter is found there, remove it, leaving the bottom and sides of the grooves smooth and bright. Then take one of the rings and, without putting it onto the piston, fit it into the groove to which it belongs and see that it fits closely, but at the same time works freely all the way around the piston; continue this test with all the rings, fitting them into their respective grooves. If a ring fits loosely, it must be replaced with a new one which fills the space.

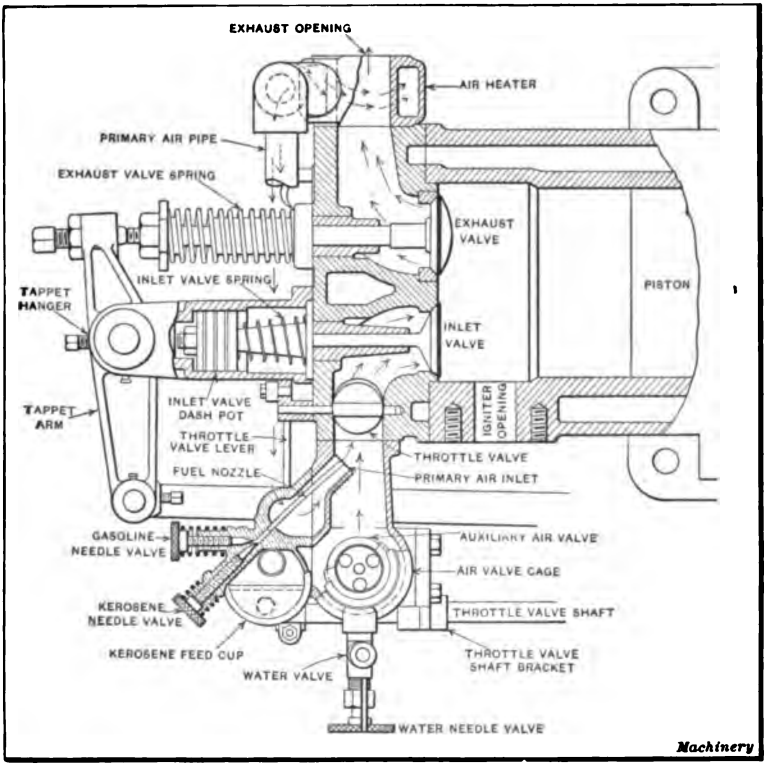

Fig. 5. Sectional View of Oil Engine Cylinder-head

Before replacing the rings, slip the piston back into the cylinder and move it from side to side and up and down, watching all the time for defects in the fit between the piston and cylinder. There should be just room enough for the piston to work freely and there should be the same space on all sides. With a horizontal engine, there is a strong tendency for the piston to wear on the top and bottom. If this wear is noticed, the same defect must be looked out for on the inside walls of the cylinder. This matter will be considered later.

While continuing the examination of the piston, remove the piston pin which passes through the piston and the end of the connecting-rod. If there is any wear in this pin, it will cause a knocking sound in the cylinder when the engine is running. In some engines means are provided for taking up this wear, but when no means are provided, it may be necessary to put a new bushing into the end of the connecting-rod. If this does not remedy the trouble, a new piston pin will also have to be provided. In all engines means are provided for fastening the piston pin rigidly to the piston.

The piston is now ready for replacing the rings, which may be done in the same manner in which they were removed. Care should be taken in replacing old rings, because when they have been exposed to the intense heat on the cylinder for some time, they become very brittle and will break easily. The same care should be exercised with new rings, as there is danger of springing them out of round, which will prevent them from fitting the piston properly. Do not replace the piston before a careful examination of the inside of the cylinder has been made while the piston is out of the way. The inside of the cylinder should be perfectly smooth, round, and bright with a coat of oil. The piston should also be covered with a fine coating of oil when removed.

Defects on the Inside Walls of the Cylinder

We will assume that instead of finding the cylinder perfectly smooth and bright on the inside, we have discovered some brown streaks on the top or bottom of the bore. These brown streaks are caused by the fire from the explosion escaping past the space between the rings and the cylinder. This may have been caused by worn rings, and if we have already renewed the rings, this will probably remedy the trouble. However, it may not be caused by worn rings, but by irregularities in the diameter of the cylinder at various points. In order to make sure of this, take an ordinary caliper and fit it to any part of the inside of the cylinder. Then pass it back and forth from one end of the cylinder to the other, turning it a little each time until the entire surface of the inside of the cylinder has been tested. If this test does not reveal any irregularities, the cylinder is in good condition and the trouble must have been with the rings. If this test reveals irregularities in the inside dimensions of the cylinder, it must either be rebored and the new piston and rings fitted, or it must be replaced with a new cylinder.

Defects in the inside walls of a cylinder which was perfect when new, may be caused in two ways, either by overheating or by scratching or scoring. Overheating has the same effect in water-cooled engines as in air-cooled. It is caused by the failure of the cooling system. In the air-cooled system, it is generally caused by the fan belt being too loose or entirely off. In the water-cooled cylinder, it may be caused by a clog in the water-cooling system, which prevents the water from circulating, or it may be caused by the failure of the operator to supply the circulation system with water. The effect of this failure of the cooling system causes the metal in the cylinder to expand unduly because of overheating. As the inside of the cylinder is subjected to a considerably more severe heat than the outside, the metal on the inside must expand more than that on the outside, and this expanding metal must find a place somewhere. It generally buckles or warps back into the cooling jacket, leaving a space between the cylinder and piston. If it does not do this, it is forced in against the piston, causing a binding on the piston which generally is the reason for scratches or scores on the inside of the walls of the cylinder. In either case, there will be a loss of compression and the engine will give less favorable service than if the cylinder were perfectly round. If the cooling system is at fault, this trouble must, of course, be remedied as explained in Chapter V, on "Cooling Systems."

Having the internal parts removed, it is advisable to look into the compression end of the cylinder to see whether there are any cracks or sand-holes or any other defects which would allow the compressed gases to escape. If anything is found defective, it must be remedied before going further. The more nearly air-tight the compression chamber is the better service the engine will give.

We will now assume that we have remedied every known trouble which may affect the compression in what we might call the piston end of the cylinder. We may, therefore, replace the piston and connect the connecting-rod to the crankshaft, care being taken to leave no lost motion at either end of the connecting-rod in doing so. There are generally thin shims provided in the bearings at the crankshaft end, which may be removed when the bearing is too loose, to allow the bearing to be clamped a little tighter around the crankshaft. These bearings should be just as tight as possible (while yet running freely) so that no movement can be observed between the parts. A properly tightened bearing will run much longer without giving trouble than one having a little play.

Valve Troubles

Attention is now directed to causes for lost compression at the other end of the cylinder. The valves are a frequent cause of loss of compression, especially the exhaust valve, because all the hot gases from the cylinder must escape through this valve. The intense heat has a tendency to warp the metal of the valve out of shape, as well as to make the valve surfaces rough or pitted. A slightly pitted valve may be put into shape again by removing the valve stem, and placing a small amount of valve grinding compound, or emery flour and oil, between the valve surfaces; after this is done the valve is placed again in its seat and turned back and forth until a perfectly smooth seat is obtained. When the valve is warped it must be replaced by a new one, which should be ground into its seat in the same way as a pitted valve.

Valves are placed in the cylinder by two methods. In one case the valve is seated directly on the inside of the cylinder head, in which case sometimes a small removable ring is fitted into the head and the seat made in this ring, or the valves have seats machined directly in the head. The object of removable seats is to save the expense of a new cylinder head when the valve seat becomes worn. The other method is to seat the valve into a valve cage and then fasten this cage to the cylinder from the outside. Both of these methods have their objections. In the first case, it is necessary to remove the cylinder head when grinding-in the valve seats. In the latter case, the cage can be removed for grinding-in purposes, but an extra joint, which must be kept air-tight, enters in the design. When the cage is set in the cylinder from the outside, an air-tight, fireproof gasket is generally used to prevent a leakage of compression. When this is not provided, the cage must be mounted on the cylinder by means of a ground joint, the same as the valves.

The intake valve is continually admitting cool charges of gas to the cylinder. This keeps the valve comparatively cool and as a result there is very little trouble with the intake valves, although it is good policy when grinding-in an exhaust valve to examine the intake valve also. The same method is used for the grinding-in of all valves.

Other Defects and Troubles Likely to be Met With

Besides the defects in the gas engine, which are noticed by the eye and the sense of touch, many defects can be detected by the sense of smell and hearing. The sense of smell will tell when a bearing is running hot, and will also aid in determining when the combustible mixture is about right. An odor of gasoline in the exhaust is evidence that too much fuel is being fed into the carbureter or mixer. By the ear, a number of gas engine troubles may be determined, as any knocking sound is easily detected and located by the practiced ear. A hissing sound is an indication that some of the compressed gases are escaping. A squeaking sound indicates that a bearing needs lubrication. A coughing sound through the intake pipe indicates that the mixture is too weak. A smothered exhaust indicates that the mixture is too rich. An expert becomes trained to these different sounds so as to be able to detect quickly the seat of many gas engine troubles.

If there are any openings into the cylinder from the outside, such as pet cocks, drain cocks, priming cocks, peep holes, or any other openings, it is necessary to make sure that they are air-tight, as a very small leak will seriously interfere with the power obtained from the gas engine.

The place where the igniter is attached to the cylinder is a frequent cause of compression troubles and the igniter itself may sometimes leak. Provision is generally made for a fireproof, air-tight gasket between the igniter and the cylinder, and it is well to examine this joint. The igniter is provided with a movable electrode necessary to produce the spark at the right time. This electrode should be kept well oiled so as to prevent wear, and thus assist in retaining the full amount of compression.

The bearing through which the stem of the intake valve moves as the valve opens and closes, often becomes slightly worn. There is a strong suction in this intake pipe just as the charge passes into the cylinder, and if a small amount of air is admitted here it weakens the mixture in proportion to the size of the air space. A leak here will make it difficult to start the engine and will even cause it to fail to run.

The place where the intake valve is joined to the cylinder is also provided with a fireproof, air-tight gasket. If this gasket leaks it will have the same effect as a leak caused by a worn valve stem, as mentioned in the previous paragraph. Leaks of this character may be easily detected. Take an ordinary oil can, fill it with gasoline and squirt a small amount of the gasoline in every place to be tested. If there is a leak, there will be an immediate effect in the running of the engine. If there is no leak, no difference will be noticed.

Another important matter to be investigated is whether there is a leak in the cylinder-head gasket. Such a leak is very difficult to locate. Often, in taking off the cylinder head to grind the valve seats, the gasket is injured in such a way that it will not provide a tight joint. In such a case, some sharp instrument should be used to remove every particle of the old gasket and to clean out the small grooves generally found there. A new gasket is then put in its place, care being taken not to allow any hard substance to get onto the gasket, such as a grain of sand or a small metal chip, as this might keep the cylinder head away from the cylinder and prevent the gasket from forming a perfectly tight joint. When the new gasket has been properly put in place, replace the cylinder head and tighten each nut a little at a time until they are all properly tightened. Then start the engine and after it has run a few minutes go over the nuts again and tighten them a trifle more.

In the jump-spark system of ignition, there is a spark plug instead of an igniter which must be tested for leaks just the same as other parts of the engine. Spark plugs, as a general rule, are air-tight but sometimes one is found that is not. Some spark plugs are made to screw into the cylinder with a straight thread, a shoulder and a copper or other gasket being employed to make the joint air-tight. Some spark plugs are screwed in with a taper thread and depend upon the tightness of the threads to make them air-tight. In every case, they should be screwed in tightly.

In looking for gas engine troubles, do not overlook little things. Never take anything for granted and never take the word of anyone for any condition, for the giver of the information may be mistaken. Investigate every individual feature personally to make sure that everything is in perfect order, taking one step at a time as indicated in the preceding paragraphs.

CHAPTER II

CARBURETION

Carburetion is the process of atomizing the fuel for the engine, thus mixing the proper amount of fuel in the form of vapor with the proper amount of air. There are two general devices used for this purpose, the carbureter and the mixer.

The carbureter consists of a float, float valve, needle valve, fuel bowl, air inlet and fuel inlet. The float is made in a manner to obtain the most buoyancy or lifting power in the fuel chamber in which it is used. Floats are made either of cork covered with a coating of shellac or of some light sheet metal, forming an air-tight bulb.

The Float

Troubles are sometimes experienced with floats. If the coating of shellac of a cork float is in some way injured, it will allow the gasoline or other fuel to soak into the cork and make it too heavy to close the float valve properly. When a sheet-metal float is used, it is liable to spring a small leak, and when filling up with the liquid fuel it will lose its buoyancy and fail to work. The remedy for the cork float is to remove it from the chamber, dry it thoroughly either in the sun or in a warm oven, taking care to leave the oven door open to prevent an explosion. After it is thoroughly dry, it is given one or two coats of shellac and allowed to dry until the coatings are thoroughly hard. In the case of metal floats, the fuel must be removed from the inside and the hole soldered.

The float is used to keep the liquid fuel at the same level in the bowl of the carbureter at all times. This is accomplished by the use of the float valve and the lever connecting the two. The mechanism is so arranged that when the fuel rises to a given height, the float which remains at the top will operate automatically and close the fuel supply or float valve. When some of the fuel has been used, the float will settle down, allow the valve to open again, and cause the bowl to be filled up to the desired point.

The Float Valve

The float valve generally consists of a cone-shaped valve suspended at one end of the lever connecting the float with the float valve. This lever is hinged in the middle in such a way that it will open and close the float valve as the float moves up and down with the surface of the fuel. This valve sometimes causes trouble. Occasionally a small grain of sand or other substance will lodge between the valve and its seat, holding it open and allowing the fuel to waste when the engine is not running. If this is the trouble, it can generally be remedied by a light tap on the side of the carbureter, near the float valve, which will dislodge the foreign substance and allow the valve to work freely. Sometimes a valve or its seat may be slightly worn so as to allow the fuel to waste when an engine is not running. This does not generally interfere with the working of the engine, but should be remedied by grinding in the valve with emery flour and oil or some grinding-in compound specially prepared for the purpose.

The Fuel Bowl

The fuel bowl is, as its name implies, a bowl for holding the fuel in the carbureter preparatory to its vaporization and entrance into the mixture to be carried to the cylinder. This bowl is generally spherical and the needle valve is placed in the center of it so that tipping the carbureter in any direction will have no effect upon the action. For a stationary engine a fuel bowl of any desired shape may be used, but for a tractor or any movable engine, it should be spherical and have the needle valve in the center.

The Needle Valve

The needle valve regulates the amount of liquid fuel which passes into the mixture of vapor and air. The gasoline or other liquid passes through the needle valve in the form of a spray and is immediately taken up by the air in the form of gas; this gas passes into the cylinder and forms the explosive charge. It is important to see that there is no obstruction of any kind in the needle valve, as very little is required at this point to upset the working of the engine. A small speck of dust, too large to pass through the needle valve, may obstruct the passage of gasoline and prevent the proper running of the engine. The adjustment of the needle valve will be explained under the heading "Carbureter Adjustments."

The Fuel Tank

It is important that there is a proper connection between the carbureter and a suitable fuel tank, as a great deal depends upon this tank and its connections. If gravity is to be depended upon to feed the carbureter, the tank must be so placed that at all times it is at least eight inches above the fuel level of the fuel bowl of the carbureter. This arrangement will allow the gasoline to flow to the carbureter by its own weight. Great care should be taken to prevent water or any other foreign substance from entering the tank. When filling the tank, the gasoline should be strained through a chamois skin to prevent foreign substances entering the tank. The cap on the top of the tank must be provided with a suitable air vent to allow the air to enter as soon as the fuel is drawn out of the tank, otherwise the gasoline would not leave the tank on account of the vacuum that would be produced at the top. The bottom of the tank should be provided with some kind of a trap which will stop any foreign substance from entering the carbureter. There should also be a shut-off valve between the carbureter and the tank so that if the float valve should fail, the supply of gasoline could be shut off. When it is desired to place the tank in some particular place, without regard to the height of the carbureter, the top of the air tank may be made air-tight and an air pump used to produce sufficient pressure in the tank to cause the gasoline to feed to the carbureter. Any pressure from 5 to 50 pounds per square inch will work, as the float valve will be able to resist that pressure.

It is important to take care that the air hole in the top of the tank does not fill up with dirt, as in certain cases it has happened that, due to this cause, engines have run for a short time and then failed to run for want of fuel. In one case it was found that the hole in the top of the tank had become filled with paint used in painting parts of the engine, and this prevented the air from entering in sufficient quantity to admit a steady flow of gasoline.

Carbureter Adjustments

The carbureter adjustment is one of the most important features in connection with the running of a gas engine. It is important that every man having anything to do with gas engines should be able to make all the required adjustments, because if he is unable to do so he invites trouble. Assume, as an example, that the carbureter is to be adjusted on a new engine which has never been run. After making sure that there is plenty of gasoline in the carbureter, close the needle valve entirely, then open it again about three-fourths of a turn, which, as a rule, will permit the engine to start. After it has run a short while, turn off the gasoline very slowly by closing the needle valve until the engine commences to miss, then open it slowly again until smothered explosions are noticed, which is an indication that the engine gets too much gasoline. Now the correct position is between these two, and a little moving back and forth of the needle valve will soon indicate which is the adjustment at which the engine runs the best. When this position has been obtained, fasten the needle valve with a lock-nut so that it will not jar out of position by the vibration of the engine. If the engine is of the variable-speed type, there will probably be a compensating air valve which will require adjustment. In this case, speed up the engine to about 300 revolutions per minute and open the air valve until the engine begins to miss fire, then close it until it runs steadily and fasten this valve with a lock-nut also.

The Mixer

On heavier engines, a mixer which is more simple than the carbureter is used. The same remarks with regard to the fuel tank apply in the case of the mixer, with the exception that in most cases mixers are supplied with a pump so that the tank is generally buried in some convenient place outside of the building and suitable pipes run from the tank to the pump, and from the mixer back to the tank, as an overflow.

Some mixers on the smaller types of engines employ the suction of the piston as a means to bring the gasoline to the needle valve. In this class of engines, the tank and mixer are generally attached with very short connections at the bottom of the cylinder. There should be a trap and drain in the bottom of the tank for dispensing of any water which might accumulate in the tank.

The mixers on the heavy type of engines are supplied by some kind of pump. Generally a plunger pump with two check valves, one between the pump and tank and the other between the pump and mixer, is used. The check valves are generally of the steel-ball type. Engines using one kind of fuel are provided with a simple kind of mixer, while there are also more complicated double mixers intended for the use of two kinds of fuel, one for starting and one for running conditions.

The simple or single mixer intended for one kind of fuel at a time consists of a fuel bowl and needle valve and an overflow pipe to maintain the fuel level at the proper point. As mentioned, it is generally supplied with a plunger pump and generally gives little trouble. The piping from the pump to the tank must, however, be air-tight, and the plunger must fit snugly and have suitable packing to make it air-tight. This packing must be kept properly lubricated to prevent undue wear. The valves seldom give any trouble. Occasionally a small piece of foreign substance will enter between the valve and its seat and cause the pump to fail in its action, but this difficulty is generally removed by a light tap with a small hammer or wrench. The valves sometimes become worn and require reseating. When the ball valve is used, all that is necessary is to remove the top of the valve, place a small piece of wood on the ball and tap it gently until it will hold gasoline poured into the valve. If the valve is of such a type that it needs to be reground, emery flour and oil or some grinding-in compound is used in the well-known manner employed with all valves of this type.

Cases have been known where a plunger pump with ball check valves has given trouble on account of too large balls being used in the check valves. If the balls are too large for the seat and project up rather high, the vibration of the engine will cause them to leave their seat so that the gasoline can return to the tank. In that case, they may be replaced by smaller balls and no difficulty will be experienced afterwards.

A mixing valve which serves to properly proportion the gas and air and which also controls the quantity admitted to the cylinders, is shown in Fig. 6. The construction there shown is used on a Westinghouse gas engine employing natural or illuminating gas. A vertical and free-moving cylindrical valve *A* with suitable ports is surrounded by two independent sleeves *B* and *C*, provided with ports and arranged to be rotated or adjusted by handles *N* and *N′* through a small arc. The gas enters at *P* and the air enters through an opening at the side, not shown in this illustration. This arrangement of ports insures a thorough mixing of the air and gas before entering the combustion space. Pointers *T* and *T′* move over graduated scales and indicate the size of the openings in the ports. Hence, the ratio of these two readings gives the proportions of gas and air. By rotating the sleeves when the engine is running, the correct mixture can be easily regulated, after which the mixing valve acting under the control of the governor, admits the proper amount of gas and air into the cylinders. In producer gas engines a poppet type valve is used, because of the presence of small quantities of dirt and dust. Mixing valves of this type can only be used for gaseous fuels. When gasoline or other liquid fuels are used a carbureter is, of course, necessary to gasify the liquid fuel.

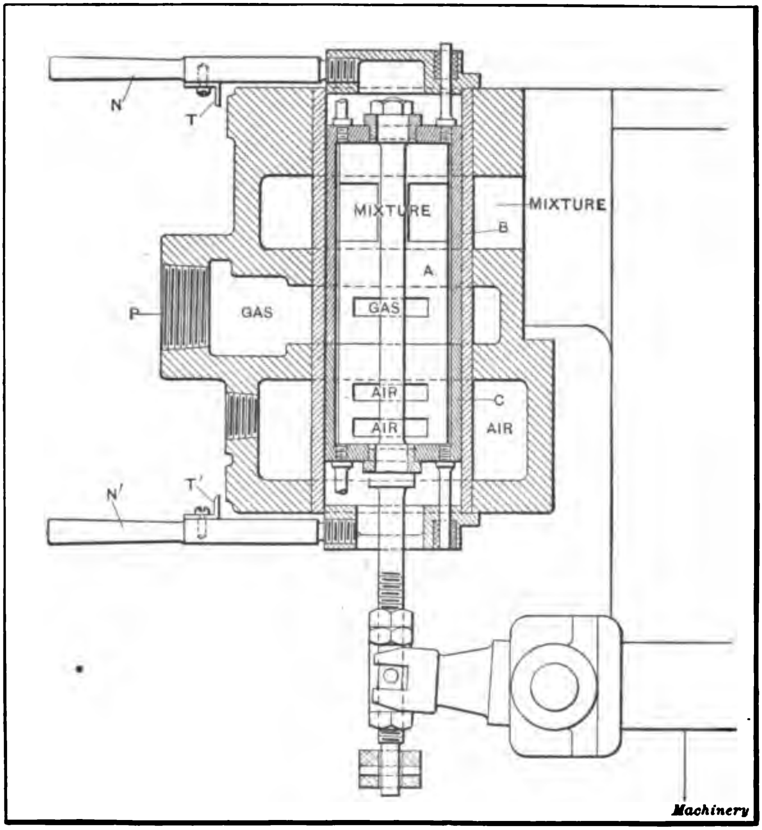

Fig. 6. Mixing Valve used on Westinghouse Gas Engine

Needle Valve Adjustment

The needle valve of gas engines using a mixer is generally provided with marks to enable the operator to get somewhat near to the position where the proper mixture will start the engine, but after the engine is running, the operator should depend upon the sound of the exhaust for the final proper adjustment of the needle valve, and should not depend upon the manufacturer to tell him the position of the needle valve for the operating condition. The best method for accomplishing this adjustment is to shut off the gasoline entirely until there are indications of absence of sufficient gas and then open the needle valve a little at a time until the exhaust is steady.

Single Mixer for Two Kinds of Fuel

A single mixer is sometimes used to burn two kinds of fuel. This is accomplished by having a pump with a three-way valve which makes it possible to first draw fuel from one tank for the starting and by a movement of the valve switch to another tank for the running fuel. This is a simpler arrangement than a complete double mixer with double piping and two pumps, and works well with a load, but does not run well without a load. Of course, it is always necessary when using this kind of a mixer to switch back to gasoline for two or three minutes before starting the engine, in order to have the gasoline ready to start with the next time. If this is neglected, however, there is a provision by which the pump can be worked by hand to produce the same results. However, few drops of gasoline in the cylinder, after having run on some other fuel, is a splendid thing in order to clean out the cylinder, mixer, intake piping and valves. This system is used on some heavy tractors with good results under load.

By using a double system of mixers, pumps, piping, etc., it is possible to have an arrangement which will handle fuels which require a higher temperature before they will vaporize. While this system is a little more complicated, it gives the best results under all circumstances.

It may be mentioned that a piece of screen wire placed in the intake pipe between the needle valve and the cylinder often aids in mixing the vaporized liquid fuel properly with the air.

Gas and Oil Engine Fuels

The following information relating to fuels is given by The International Harvester Co. The liquid fuels, with the exception of alcohol, used in the modern internal combustion engines are all products of petroleum oil or crude oil as it is usually called. This oil is a mineral liquid which is obtained usually at a great depth in the earth by drilling a well and pumping. The oil is seldom refined at the wells but is stored in large tanks or open reservoirs and pumped to the refineries, sometimes hundreds of miles distant through pipe lines as needed. The first fields found in America are in Pennsylvania. Today fields are being worked in Pennsylvania, Illinois, Indiana, Kansas, Oklahoma, Texas, California, and many other states. The oil fields in the East are gradually being exhausted, so that little Pennsylvania, Illinois, or Indiana oil is now refined.

Methods of Testing Fuels

There are two general methods of testing fuels in common use. The usual way in the field is by comparing the weight of fuels with the weight of an equal bulk of water, although this test does not always distinguish the grade on account of the difference in composition of crude oils from the different oil fields, and the practice of mixing low-grade and high-grade distillates. This test is accomplished by means of a hydrometer, and supposed to be made at a temperature of 60 degrees F.

On the Beaumé scale for comparing the density of liquids lighter than water, water is rated 10 degrees. Heavy liquids run lower and oils run higher than water. Crude oil runs from 12 up to 50 degrees, mostly averaging from 22 to 40 degrees, distillate, about 39 degrees; kerosene, from 40 to 50 degrees; and common gasoline, from 50 to 80 degrees. In the larger cities gasoline is kept in stock with gravity of from 64 to 70 degrees, or even lighter for special purposes. Owing to the small amount of gasoline which can be produced, the tendency is to make it heavier by distilling off some of the heavier oils with it in order to supply the demand.

Kerosene as sold today varies between 42 degrees and 54 degrees, Beaumé test. It is the common belief that because gasoline is more easily evaporated and ignited than kerosene, that it gives more power, but the reverse is true. Kerosene and the lower grade oils, such as distillate, solar oil, fuel oil, etc., contain more heat units than an equal bulk of gasoline and in a properly designed engine will give proportionately more power. The reason for this is that in every pound of petroleum products there are about 20,000 heat units. Therefore, it is evident that there are more heat units in the heavier liquids than there are in an equal bulk of the lighter liquids. It is this that makes hard coal worth more per ton than soft coal. It has more heat units per pound and heat is power.

It is evident that the Beaumé method of testing does not in reality give the true value of the liquid tested; in fact, liquids of the same quality distilled from crude oil from the different fields vary in weight, the Eastern oils being lighter than those obtained from the West. It has been demonstrated that Pennsylvania crude oil of 66 Beaumé gave the same results as the refined gasoline testing 58 Beaumé from Kansas crude oil. The reason for this is that both oils, although differing, in gravity have the same points. The only accurate test to determine the quality of a distilled fuel is to determine the initial (lowest) and maximum (highest) boiling points. This is the method used by the refineries and it can only be determined by actually distilling the liquid. The refiner knows and distinguishes each product, not by gravity but by boiling points. He knows it would be impossible to make his goods uniform by using the fleeting standard of gravity, but knowing the boiling points, he can depend upon the quality.

It is not difficult to understand what boiling point means, for the expression explains itself. It is the point on the Fahrenheit thermometer at which a liquid will begin to boil. But the refiner does not stop here. He distills a given quality of gasoline, and while it is in the process of distillation, ascertains at what point each 10 per cent will boil until the entire quantity is evaporated or distilled. This is called fractional distillation. In this manner is determined what is known as the initial boiling point, as well as the maximum boiling point and all intervening boiling points. The rapidity with which a liquid will evaporate is determined by its boiling points. For instance, a liquid that has a low boiling point will evaporate quicker than one with a high boiling point—it takes less heat to boil it. that is, to cause it to go off in a vapor; consequently, it requires less heat and air to vaporize it.

Water boils at 212 degrees F.; consequently it will take it longer to evaporate than gasoline that has an initial boiling point of, say, 115 degrees F. But water will evaporate quicker than kerosene oil with an initial boiling point of 325 degrees F. From this we see that the lower the boiling point the quicker the liquid will evaporate under ordinary temperature. Of course, any liquid will begin evaporating long before it boils.

The Distillation of Fuels

To understand thoroughly the action of fuels in an internal combustion engine, one must know something of the process of distillation. The crude oil is pumped into a huge steel boiler or still and gradually heated. A pipe leads from the still to a condenser, and as the gas rising from the crude oil seeks to escape, it runs through the condenser and is condensed again into a liquid. The temperature at the still is constantly watched and recorded and the liquid from the condenser is also tested with a Beaumé hydrometer and recorded. By previous experiment the oil refineries know at just what temperature the different fuels are distilled off so that as the temperature rises in the still, the fuels are run into separate tanks according to their quality. The lighter liquids testing around 80 degrees Beaumé come off first and as the crude oil becomes hotter the liquids that are distilled off gradually become heavier. This process continues until nothing is left of the crude oil but a kind of coke.

In this manner the refineries obtain gasoline carrying in quality from 80 degrees down to 50 degrees, Beaumé tests; kerosene from 50 degrees down to 40 degrees Beaumé; distillate from 40 degrees down to 29 degrees Beaumé; and below that, lubricating oils. The gasoline as sold now usually runs from 50 degrees to 62 degrees Beaumé test, but as the gasoline obtained from the crude oil varies from 50 degrees to 78 degrees or 80 degrees Beaumé, it is evident that the small proportion obtained at 56 degrees to 62 degrees Beaumé would not be enough to supply the trade. In order to get a product that will have a uniform weight, and to use up the very high and low grade gasoline, they are mixed in such a proportion as to produce the desired results. For example, if equal parts of gasoline testing at 55 degrees and 65 degrees Beaumé, were mixed, the result would be a gasoline testing at 60 degrees Beaumé.

The big oil companies now realize that the heavy fuels give trouble in starting when used in internal combustion engines, and are now putting out a winter gasoline and a summer gasoline. The winter gasoline, being a little higher grade, contains more of the lighter grades of gasoline, having a low boiling point, which are more easily evaporated in cold weather.

Motor Spirit

Within the last two years the rapid increase in the use of gasoline has shown the oil companies that the time would come and that very soon when the production of gasoline would not meet the demand. The Standard Oil Company has for some time been experimenting with substitutes and now announces that they are equipping their distilleries for the manufacture of a new product of crude oil called Motor Spirit which has all the characteristics of gasoline and which will sell for three cents a gallon lower. This product is obtained by redistilling under pressure the distillates that range from 29 degrees to 40 degrees Beaumé. This will practically double the output of oils in the gasoline class as soon as the distilleries are equipped for manufacture.

The distillation process is practically the same as with the original crude oil except that it is done under pressure which produces an entirely new product with new boiling points and gravity. The original distillate having a boiling point of about 400 degrees and a gravity of from 29 degrees to 40 degrees Beaumé is turned into motor spirit with a boiling point of 95 and a gravity of 59.2 Beaumé.

The Standard Oil Company makes many claims for this new fuel, among them are 20 per cent greater power than gasoline and easier starting. The one point which might be brought against it is its disagreeable odor.

CHAPTER III

IGNITION

There are two general systems of ignition; the "make-and-break" system and the "jump-spark" system. The make-and-break system is used extensively on stationary, portable and traction engines running below 500 revolutions per minute. The "jump-spark" system is almost entirely confined to small high-speed engines used on automobiles and motor trucks.

The "Make-and-break" Ignition System

The make-and-break system consists of an igniter, a coil, a switch and batteries, and may also use a magneto. It operates by breaking an electrical current inside of the cylinder. The igniter generally consists of a cast frame, a stationary electrode, a movable electrode, and means for making and breaking the circuit, by having its parts connected with the camshaft by a push-rod, bevel gear and shaft, or chain drive. The movable electrode is made to move through about one-tenth of the circumference of a circle. It must fit snugly into the igniter frame and must be properly oiled to prevent the compressed gases from escaping. The stationary electrode must be insulated from the igniter, this being easily done by mica washers, but porcelain or glass may also be used, if the exposure to the heat is not too great. The electrodes are each provided with a small point on the inside of the cylinder. These points are separated except when a spark is desired, when they are pushed together and allowed to separate to produce a spark.

Wiring the Batteries

The wiring for the make-and-break system and the jump-spark system is, in general, the same. Before starting to wire the batteries, it

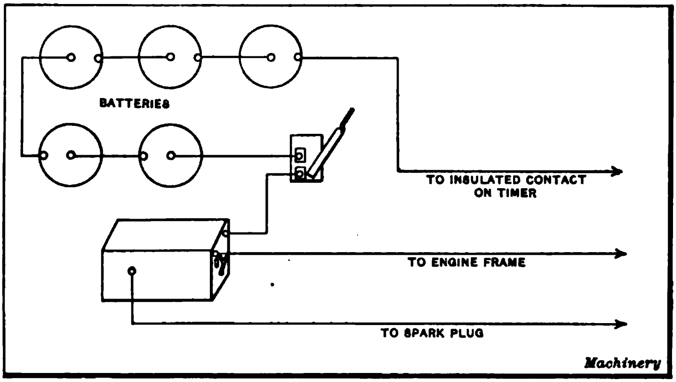

Fig. 7. Wiring for "Jump Spark" with Batteries

is necessary to choose a good place for the location of the battery box, coil and switch. The battery box should be located in a clean, dry place where it will not be affected by the vibration from the engine. If so placed it will last much longer and the absence of vibration will tend to eliminate loose connections. The switch can be placed on the outside of the battery box or at any other convenient point. The coil box may be placed inside of the battery box or it may be placed on a small shelf near the switch. The nearer the coil is to the battery box and switch, the less wiring will be required.

There is generally a so-called "ground-post" provided on the frame of the engine to receive the ground wire from the batteries, but if this is not the case, a wire can be run from any metal part of the engine frame to the zinc or outside electrode of the first battery, assuming that the engine uses the ordinary dry cells for ignition, which can be procured in almost any locality. Then from the center or carbon electrode of this battery run the wire to the zinc of the next, and so on until all are connected. When the wires are all connected together, there will be one vacant carbon electrode. Run a wire from this carbon electrode to one side of the switch, a three-point switch being used, and from the center of this switch run another wire to one terminal of the coil. Then from the other terminal of the coil run a wire to the stationary electrode of the igniter and the battery circuit is complete. Insulated wire is generally furnished with the engine for the wiring.

The Magneto

An ordinary friction-drive magneto is often used to run the engine after it has been started by the use of a battery. A suitable place for the magneto is provided so that the magneto drive pulley will be in contact with the flywheel, the pressure being great enough to drive the magneto. The place selected should be as free as possible from vibra-

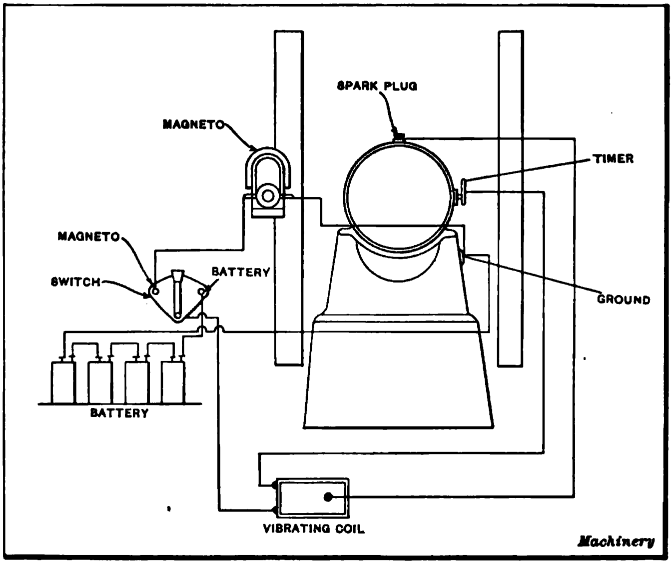

Fig. 8. Wiring for "Jump Spark" with Batteries and Magneto

tion and the magneto mounted as firmly as possible. Run a wire from one terminal of the magneto to the vacant terminal on the switch. The other terminal of the magneto may be connected by a wire to the ground wire which runs from the engine frame to the zinc of the first battery, or it may be connected directly with any metal part of the engine frame. This wiring applies to a magneto depending upon its permanent magnets for its magnetism, but if a magneto uses small coils in connection with the magnets to increase the magnetism, these field wires are connected together, and the wire is run from each end of this small circuit to each of the brushes of the magneto. In this style of magneto, it is necessary that the direction in which the magneto will run when placed on the engine is determined upon when it is manufactured, because this determines the method for attaching the field wires. If a magneto is attached in such a way that results are not obtained, all that is necessary is to change about the connections at the terminal posts.

If the magneto furnished with the engine is connected to the camshaft or crankshaft with gear wheels, and runs at the same speed as the crankshaft, it is likely that a coil is not necessary, but a small change in the wiring outlined in the previous paragraphs will be necessary with this style of magneto. The wire which runs from the carbon electrode of the battery to the switch and the wire which runs from the coil to the igniter should be interchanged. Upon examination of the wiring it will now be seen that the battery current passes through the coil but the current from the magneto passes directly to the igniter.

All friction-drive magnetos are provided with a governor of some kind, which, when the armature of the magneto attains a certain speed, usually about 1800 revolutions per minute, will release the pulley wheel from the flywheel or allow it to slip, so that the speed will not

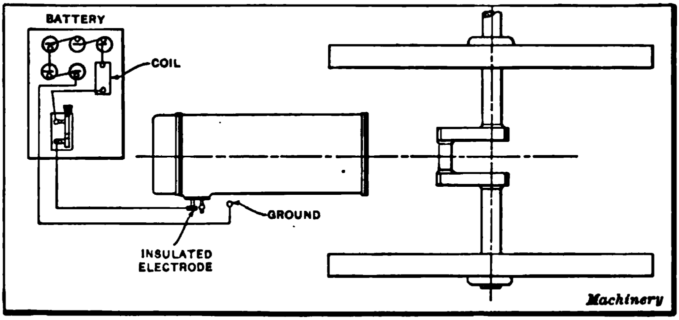

Fig. 9. Wiring for Horizontal Engine with Batteries

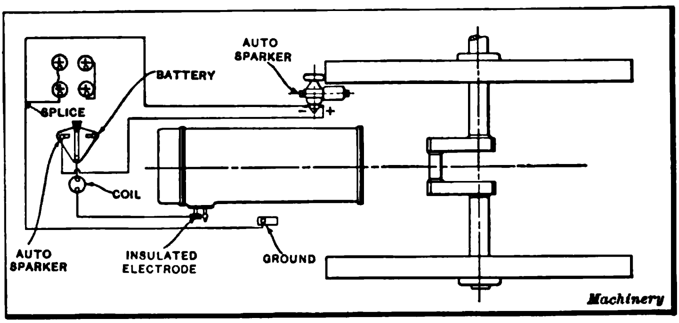

Fig. 10. Wiring for Horizontal Engine with Batteries and Auto Sparker

exceed that given. Care should be taken to adjust this governor so that it will do its work properly. With some magnetos the adjusting spring is arranged to work in two ways, one way being used when the magneto drive pulley touches the upper side of the flywheel, and the other when it is touching the bottom side of the flywheel. If the spring allows the drive-pulley to be lifted from the flywheel and returns it to its place when released, it is in the proper position, but if it refuses to leave the flywheel, the adjustment is not ccrrect and must be changed.

High-tension Magnetos

High-tension magnetos are beginning to be used on stationary and traction engines. These magnetos are self-contained and require neither coils, timer or switch. They are generally provided with a breaker box at one end of the armature, which acts as a timer and also advances or retards the spark. These magnetos are gear-driven and run at engine speed.

In all gear-driven magnetos the gears should be marked so that if it should become necessary to remove the magneto, or if it should be removed by some accident, it could be replaced without the services of an expert. If these gears are so marked, the replacing can be done by anybody. If the gears are not marked and the magneto has to be replaced, it is necessary to set the engine at the firing point, about 10 degrees ahead of the center on the compression stroke, that is, when

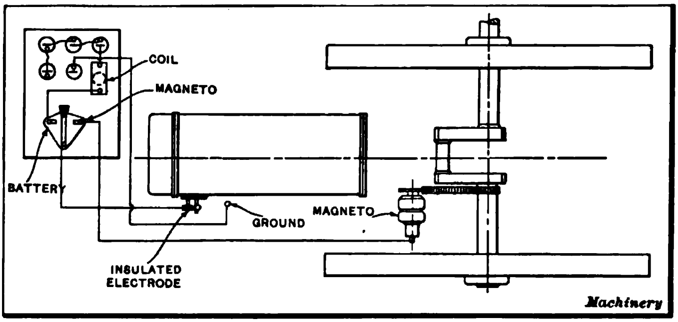

Fig. 11. Wiring for Horizontal Engine with Batteries and Gear-driven Magneto

the piston ordinarily would be within about, say, one-half inch of the end of the compression stroke. Now place the magneto in mesh with the gears so that the points in the breaker box on the end of the magneto, which are separated once and sometimes twice during each revolution, are just ready to separate. In this position the gears should mesh.

Gear-driven Magneto with Coil Box

In a gear-driven magneto, which is used with a coil box or with an igniter only, the process is a little different. Hold the magneto in the hand and take hold of the gear with the other hand and turn it in either direction. It will then be discovered that at two points in each revolution the armature turns harder than in other positions. These points are called points of resistance and are the points of the rotation at which the spark is made. Set the engine so that the igniter has just tripped, turn the magneto until one of these points of resistance is found, and place the gears in mesh at this point. Then connect up the wires as usual.

The Oscillating Magneto

There is still another type of magneto known as the oscillating magneto which only requires that the igniter push-rod should trip the magneto rotor at the proper time. The spark in this magneto is made by the rotor which is used instead of the armature in other magnetos, and which rocks back and forth between the magnetic fields. The igniter pushes the rotor in one direction and it is tripped and returned to its normal position by springs supplied for this purpose. This style of magneto has been in use for several years and has proved very satisfactory.

Care of Magnetos

Magnetos must not be oiled too freely. Generally they are provided with ball bearings which require but little oil. If more oil is used than the magneto requires, it will get onto the armature and a short circuit may be formed. In case of trouble on this account, wash off

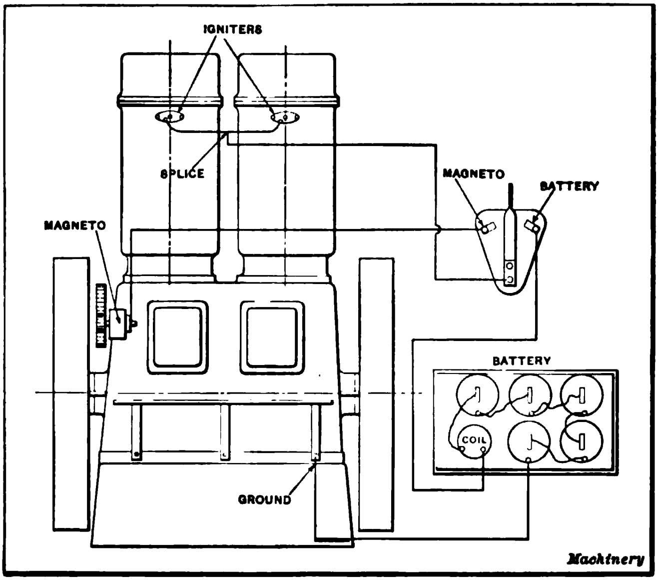

Fig. 12. Wiring for Two-cylinder Vertical Engine with Batteries and Gear-driven Magneto

the magneto with gasoline, removing every particle of dirt and grease; then let it dry out. It is then usually ready to run again without trouble. In nine times out of ten this simple remedy will take care of the difficulty.

Other Means for Obtaining Electricity

Storage batteries are used for ignition purposes and give good results when a suitable plant for re-charging them is accessible. They should be handled by a electrician, except for the wiring connections into the circuit, which may be made by anybody. Once in a while one will find a man who wants to use electricity from the regular electric light circuit, but this is dangerous and hard on the igniters on account of the voltage being excessively high for this purpose. From six to ten volts is all that is necessary for ignition purposes.

The Jump-spark System

The jump-spark system differs from the make-and-break system only in the means of igniting and in the kind of coils used. In the make-and-break system a so-called "silent" coil, or one without a vibrator is employed, but in the case of the jump-spark system a vibrating coil is necessary. The silent coil needs no adjustment or other attention as long as it works, and when it fails it must either be attended to by an

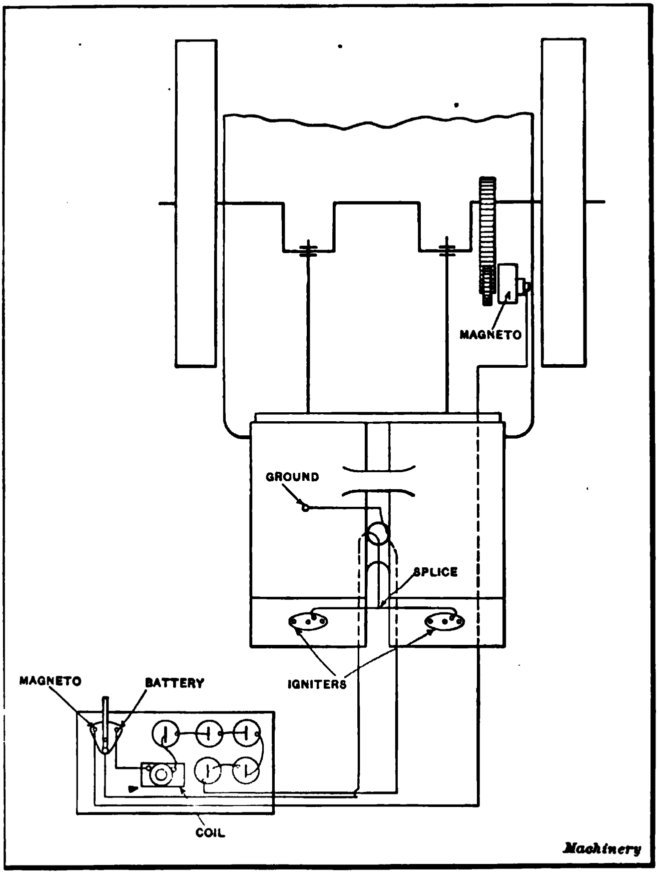

Fig. 13. Wiring for Two-cylinder Horizontal Engine with Batteries and Gear-driven Magneto

electrician or be replaced by a new coil. As a rule, it is about as cheap to replace it as to undertake to repair the old coil. An ordinary spark plug, such as is used in the regular automobile engine, will prove satisfactory.

The vibrating coil must be adjusted and the adjustment is simple, when understood. The coil should be so adjusted that the points will touch each other during the vibrations as lightly as possible, as this lengthens the life of both the coil and batteries. The best way in which to accomplish this adjustment is to turn the adjusting screw until one can see the light between the points, and then turn it back until the points just touch each other.

Ignition Troubles

The ignition trouble most frequently met with is perhaps unsuitable or run-down batteries. It seems as if the average engine operator

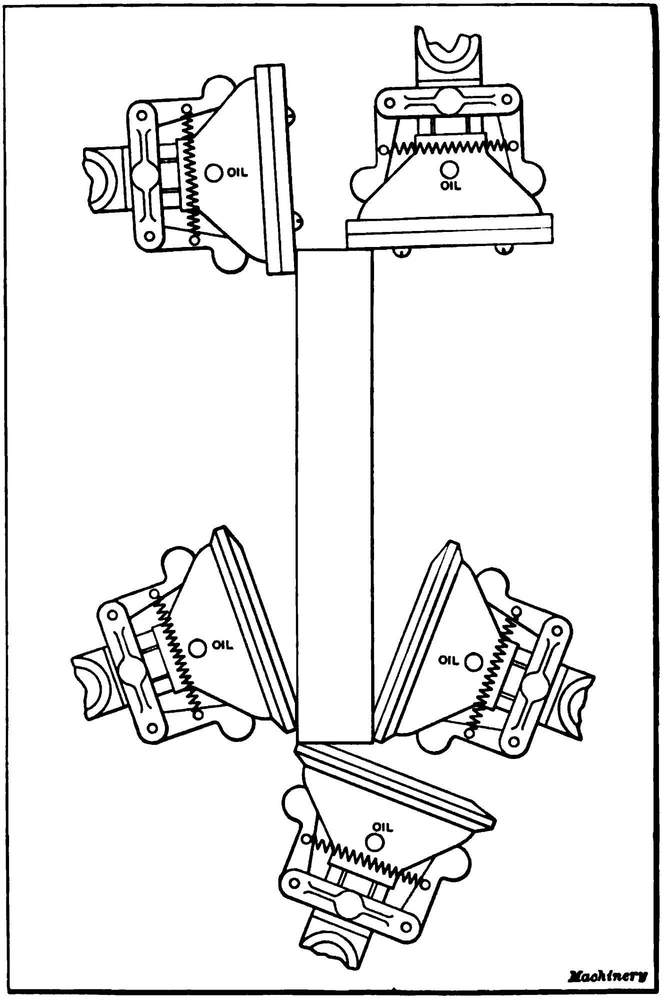

Fig. 14. Diagrammatical View showing the Different Positions that may be used for Driving a Rotary Magneto

could not realize that a set of batteries must necessarily give out some day. The average operator seems to think that because a set of batteries did its work properly the day before or last week, it should go on indefinitely performing the same task. A good battery tester is, therefore, suitable to have around where batteries are used. It will instantly indicate how much power is left in the batteries and often save a great deal of useless work in cranking a gas engine with run-down batteries.

Another common fault with batteries is the loosening of the connections. When the batteries are subjected to vibrations the connections are very apt to work loose. The only way to locate a loose connection is, as a general rule, by examining each connection in turn. All the connections should be kept as tight as possible. Broken wires are also likely to cause loss of time and must be located. Assume that an engine has been running smoothly and that it then without warning stops suddenly as if the switch had been turned off to the ignition system. If the carbureter and fuel supply system seem to be all right, it may be taken for granted that the fault is with the ignition system. First test the igniter by allowing a piece of metal to come in contact with both electrodes and then removing it quickly to see whether it causes a spark. If a wire is broken or a connection is loose, the spark will not be there. Then test the wires which run from the engine to the battery box to see if they are in good condition. Examine the switch, take out the coil of the circuit and test it by passing a current through it to see if it works properly. Then test the batteries one by one to see if they are in good condition. If no defect has been detected so far, the only thing left to do is to test the batteries as a complete circuit by placing the wire of the battery tester on the carbon at one end of the set of batteries and connecting the other terminal of the tester with the zinc at the other end. Assume that when this is done no current is indicated. It is then clear that there is a broken connection between two batteries and if these are tested in order, the broken connection will be found. Broken wires are sometimes caused by allowing the batteries to be placed so loosely in the box that the vibrations of the engine keep bending the wire constantly until it breaks. The igniters should be kept clean and free from carbon deposits.

CHAPTER IV

LUBRICATION

In the present chapter attention will be given to different types of oilers and the different kinds of oils to be used. The lubrication of a gas engine is accomplished in a great many different ways. It may be said, in general, that there are four principal methods: force-feed oilers, gravity oilers, grease cups, and lubrication by means of the ordinary squirt oil-can.

There are several different methods in use for driving force-feed oilers, the most common being by means of gears, belts, chains or the ratchet and pawl. Some manufacturers provide oilers with sight-feed attachment, while others do not. The sight-feed oiler is valuable, in many respects, but there is nothing to prevent this oiler from failing to do its work just after the operator has looked to see if it is feeding, so that it does not present an absolute guarantee against ruined bearings.

Early engines were generally provided with large oil cups in which a quantity of waste or felt was packed to prevent the oil from feeding too fast and be wasted. This method was quite satisfactory at that time because better methods were not known. It was necessary, however, with this method, to fill the oil cups several times a day in order to insure that the engine would be properly lubricated, and, as a matter of fact, on engines provided with these oil cups there were not many bearings ruined from running dry. The operator knew that he had to watch them in order to prevent trouble and they were generally attended to. This kind of oil cup was gradually improved with many modifications until the gravity-feed oiler in general use today was developed.

When grease cups are used care should be taken to provide a good grade of grease, neither too thin nor too heavy, otherwise good results cannot be expected. The oil-can used for oiling various moving parts around the engine should always be kept filled with clean oil ready for immediate use, as it is sometimes possible to save a bearing after it has been discovered that it is running warm, by giving it a generous dose of oil with the hand can. Every time before the engine is started it should be gone over with the hand oil-can in the one hand and a piece of waste or an old rag in the other. All the old grease and grit should be removed with the waste and fresh oil applied.

It is sometimes desirable to lubricate the crank bearing with lubricating oil instead of with grease, and this may be done easily and with little extra expense. To accomplish this, it is necessary to provide some method to support a gravity-feed oiler or a pipe from a force-feed oiler directly above the highest point that the crank reaches during its revolution. To the bottom of this support is attached a small piece of ordinary lamp wicking in such a position that the oil from the oiler may be dripped onto it. A small cup is provided on the top of the crank bearing which passes close enough to this wicking to wipe the oil off it without touching the wick. If it touches the wick the latter will soon be worn out, and as it wears particles from it are likely to fall into the cup and clog up the oil supply. The oiler can now be set to feed any number of drops per minute to the wick and the cup on the crank bearing will wipe off this oil, and from the cup it will flow directly into the bearing. When gravity oilers are used, it is necessary in most cases to provide an oiler for each bearing, although appliances are on the market by means of which both the main bearings and the crank bearing can be supplied with one oiler by providing a three-way feed.

Force-feed Oilers

Force-feed oilers may be divided into direct-feed and sight-feed oilers. The sight-feed oiler brings the oil into plain sight as it is fed into the bearing, while with the direct-feed oiler the lubricant generally passes from the bottom of the oiler directly into the bearing. The connecting pipe is then generally provided with small screws, generally called "bleeders," which may be loosened in order to tell whether the oil is feeding as it should or not. The force-feed oiler is provided with one or more small pumps, generally of the plunger type. These pumps are placed in the bottom of the oil tank. A pipe is run from each of the pumps to the bearing to be lubricated. The supply of oil may be increased or decreased as desired. When these oilers are kept filled with clean oil and the driving mechanism is kept in good condition, they generally work very satisfactorily, but a little dirt in the tank or a loose belt in the driving mechanism is apt to cause trouble. As an example may be mentioned a 20-horsepower traction engine fitted with a six-pump force-feed oiler. The customer assumed, and in fact had been told by the salesman from whom he had bought the engine, that this type of oiler was absolutely automatic and would never require any attention except to put oil into the tank. The engine was running nicely for six weeks when at times it began to show loss of power. A gas-engine expert was sent to investigate the trouble. This man began his work by putting in a new set of piston rings, and when putting them in used a very liberal supply of oil. The engine was started and ran nicely for a few minutes, long enough, in fact, for the gas-engine expert to get time to disappear, after which the old trouble again developed. Finally, trouble in the oiling mechanism was suspected, and it was found that the oil pumps were feeding only about half of the time on account of the wear in the driving mechanism, which did not admit the pawl and ratchet to do their work properly. This experience shows, in the first place, how necessary it is that the oiler should work properly in order to lubricate the engine, and also that unless the engine is properly lubricated it will not develop its rated power. New engines are generally adjusted to use considerably more oil than is necessary after they have been in service for some time.

Lubricants to Use

For lubricating the inside of the cylinder, the piston and the rings, which are all exposed to high temperatures, on account of the combustion of the gases, it is necessary to have an oil with a high fire test and at the same time with good lubricating qualities. If proper oil is used, the piston, upon removal from the cylinder, will be found to be oiled properly and the inside of the cylinder to be coated with an even coat of oil. The piston will also be comparatively free from carbon deposits. If the high fire-test oil used for the cylinder has good lubricating qualities in general, it can also be used for all other lubrication about the engine.

What has been said in the previous paragraph applies especially when gasoline is used as a fuel, but when kerosene or any of the other less volatile fuels are used, it is necessary to have the cylinder much hotter than with gasoline, in order to get the best results, and, hence, an oil which will work well with gasoline may be absolutely unfit for an engine using kerosene as a fuel. When kerosene is used, therefore, it is necessary to use an oil with the very highest fire test obtainable, and this oil is not of a quality which could be used for other parts of the engine, except those which are exposed to exceptionally high heat. In the case of a kerosene engine anything except a very high fire-test oil is likely to ruin the cylinder and piston in a few weeks.

Too much oil in the cylinder will be indicated by a blue smoke in the exhaust. Too much fuel in the cylinder is indicated by a black smoke coming from the exhaust. Either of these troubles should be remedied at once. The exhaust of an engine which is working to its full load should be practically free from color or odor.

The manufacturers of most engines have made extensive tests with different oils on the market and will, as a rule, give all users of their engines information as to the best brand of oil to be used for any particular make of engine. It is, therefore, well for any user of engines to write the manufacturers and ask them what brand of oil ought to be used for the lubrication.

CHAPTER V

COOLING SYSTEMS

There are two general methods for cooling the cylinder of the gas engine, either by means of water or air. Water-cooled systems may be divided into two classes; those which use some kind of a pump, and the thermo-siphon systems. The thermo-siphon system is a simple, effective method of cooling, although it requires considerably more water than when a pump is used and some screen or radiator employed as an aid in cooling the water. In the thermo-siphon system the water is moved in its circuit simply by means of the heat and the apparatus necessary consists merely of a tank and necessary piping. The tank is set with the bottom about on a level with the bottom of the water jacket of the cylinder. A pipe is run from the lower part of the tank to the bottom of the water jacket of the cylinder. Another pipe is run from the top of the cylinder to a point near the top of the water tank. The tank must be kept filled with water to a height above the opening of the pipe from the top of the cylinder. When the engine is started and the water begins to heat around the cylinder, it rises into the upper pipe and passes into the tank. As the water in the water jacket rises, cold water from the tank passes into the bottom of the cylinder jacket to take its place, and when this water is heated it rises in turn to the top of the tank, thus keeping the water constantly in circulation.

Water Cooling Systems Using Pumps

Cooling systems operated by a pump may be classified into three divisions according to the kind of pump used, the pumps being either plunger, rotary or centrifugal, and gear operated pumps. With a plunger pump, at least two check valves are necessary, one between the tank and the pump and one between the pump and the cylinder, these being either ball-check valves or of the regular valve type. The plunger of this type of pump is generally operated by a cam or crank attached to either the crankshaft or the camshaft of the engine. It is fitted with suitable packing to make it air-tight. This packing should be kept well oiled to prevent wear. The parts to be especially taken care of in this style of pump are the check valves and the connection to the propelling shaft. Undue wear in this connection will shorten the stroke of the pump and interfere with its efficiency. The valves sometimes wear and need reseating, which is done in the same manner as explained in previous chapters.

The rotary or centrifugal pump may be operated either by chain, belt or gear drive. All three have their advantages and drawbacks. With the belt drive the pulley is likely to slip and insufficient water will be circulated for proper cooling purposes; but in case the water should be frozen in the pump on a cold morning, or if something else should go wrong, tbe belt will slip and not break the inside parts of the pump. The chain and gear drives will always deliver a uniform amount of water to the cylinder when in working order, but have the disadvantage that they will not slip under any circumstances, and breakages are often due to this condition. In this style of pump the body of the pump must be below the level of the water in the tank so that the water will flow naturally to the pump. The rotary pump is probably the most satisfactory pump for the circulation of cooling water. It must be watched, however, to see that it is performing its work properly and should be drained carefully when the engine is used in cold weather.

A gear-operated pump is one in which the movement of a pair of gears causes the water to pass through with the meshing gears, between the gear teeth and the walls of the pump. This pump must also be placed below the level of the water in the tank and will, when in proper condition, work in a satisfactory manner. These pumps should also be carefully drained in cold weather.

Purpose of Cooling Water

The cooling water is not intended to keep the cylinder cold, but only to keep it cool enough to prevent the lubricating oil from burning. The hotter the cylinder walls and the parts within it can be kept without interfering with the lubrication, the better the engine will run and the more power it will develop. After the water has passed through the water jacket, its temperature should be about 180 degrees F. If water from a well or a hydrant is forced around the cylinder there will usually be a decrease of power, because the heat from the ignited charge is cooled down so quickly by the water that the expansion force is greatly reduced.

Air-cooled Systems

The air-cooled system is the simplest cooling system and works satisfactorily as long as the parts are kept in good working order. The cylinder, instead of having a water jacket, is provided with a series of ribs for the radiation of the heat. A blast of air is blown upon this cooling surface in order to dissipate the heat. This blast of air is generally produced by some kind of fan. There are different methods of driving the fan. Some manufacturers place the fan on the flywheel which gives a positive drive, and the fan runs when the engine runs. Others drive the fan with some kinds of gears or a chain. Either of these methods is positive, and when the engine is running the fan will run at the proper speed. The belt-driven fan is the one that is most likely to give trouble. If the belt is too tight, it will place unnecessary strain upon the bearings. If it is too loose, the fan will not drive fast enough and the cylinder will become injured if not entirely ruined by the excess of heat. An overheated cylinder may be detected either by the heat itself or by the sluggish action of the engine. The engine will act as if it was receiving too much fuel, and yet no black smoke will be visible at the exhaust. No gas engine should be run more than a few minutes without ascertaining if the cooling system is in working order. A cylinder can be ruined in a few minutes in this way.

Cooling Systems for Engines Using Kerosene and Other Less Volatile Fuels

What has been said in the previous paragraph refers to engines using gasoline or natural gas as a fuel. If the less volatile fuels are used, such as kerosene, distillate, or alcohol, a slight change must be made in the cooling system. A piece of pipe of the same size as the pipe connecting the pump to the bottom of the cylinder jacket must be attached to this pipe between the pump and the cylinder; this pipe should extend up until the top end of it will join the pipe coming down from the top of the cylinder just where it enters the tank or cooling system above the tank. A valve is placed in this pipe so that by opening or closing it we may admit just enough water to the cylinder to produce the degree of heat needed to cause this less volatile fluid to vaporize, in order that it may mix properly with the air to form the explosive charge.

It is sometimes necessary and always advisable to be able to admit warm air from around the exhaust pipe to the intake pipe in order to aid the mixture. It is also necessary when kerosene or distillate are used as fuels to admit a small quantity of water in vapor form with the charge to the cylinder, the reason for this being to prevent premature ignition. A water valve is generally provided on the mixer for this purpose and only enough water to prevent premature ignition should be used. Premature ignition is detected by a metallic sound inside the cylinder at the time of explosion. This sound will not be heard until the cylinder becomes very warm, and when noticed, water should be turned on in the water valve until this metallic sound stops. Water is only necessary when pulling a load. When the engine is running empty on kerosene it is rarely necessary to turn on the water valve, which should never be turned on until this signal of premature explosion begins to be heard. Water must not be used with gasoline or natural gas as in either case it is detrimental to the charge. The water should always be drained from the mixer when the engine is stopped.

Anti-freezing Mixture

The International Harvester Co. recommends the use of an anti-freezing mixture in the cooling water in the winter. Calcium-chloride is commonly used in the following proportions: one pound of calcium-chloride to one gallon of water for temperatures down to 27 degrees F.; two pounds of calcium-chloride to one gallon of water for temperatures down to 18 degrees F.; three pounds of calcium-chloride to one gallon of water for temperatures down to 1 degree F.; four pounds of calcium-chloride to one gallon of water for temperatures down to 17 degrees F. below zero; five pounds of calcium-chloride to one gallon of water for temperatures down to 39 degrees F. below zero.

Cracked Water Jackets

Freezing of the water in the water jacket of an engine cylinder and thus cracking the cylinder is a common occurrence in winter. In fact, the jacket water will often freeze, when the temperature is barely down to freezing. The reason for this is as follows: iron gives off heat very rapidly, consequently it quickly returns to the temperature of the surrounding atmosphere. Now, as the sheet of water around the cylinder in the water jacket is very thin, it is evident that if the water is not taken out of the cylinder at night, it will freeze if the temperature drops below freezing. Water in bulk retains heat much longer than a thin sheet of water, consequently the thin sheet in the water jacket will freeze on some nights when a pail of water standing near the engine will not have even a crust of ice on its surface.

When water in the cylinder jacket freezes it rarely causes the cylinder itself to crack, so that there is no damage to the interior of the cylinder, but it will frequently cause the outer wall to crack. A crack of this nature can be repaired by the operator if he is handy with tools. A small size drill for drilling a row of little holes on each side of the crack, about an inch from it, a tap to thread these holes, some screws to fit a sheet of iron plate, a screw-driver, asbestos, a cold chisel, and a little white lead are necessary to do the work. The following directions for carrying out the work are given by the International Harvester Company.

The first thing to do is to cut with the cold chisel a V-shaped crease along the crack from one end to the other, then cut the sheet iron plate so that it will cover the crack and extend one inch on each side, and the same distance beyond each end, lay it over the surface of the cylinder and shape it so that it fits closely; next drill a row of small holes around the edge of the plate, about one inch apart, large enough to admit the screws. Then place this plate directly over the crack in proper position and drill corresponding holes in the jacket, a size smaller than those in the plate and thread them with a tap. Now put some white lead paste in the V-shaped crease over the crack, saturate some of the asbestos wick with white lead and place it directly over the crease the entire length and a little beyond the ends of the crack; then cut out a sheet of asbestos about the size of the plate inside the holes which have been drilled around the edge; soak this in water, place it over the wick and crease and then fasten the plate down securely over all by means of the screws.

In making a patch of this description be sure that all the paint has been scraped off the cylinder where the patch is being made. After the patch has been put in place it can be smoothed down by a file, and then the engine should be allowed to stand for several days before using. A patch of this description will be found adequate in most cases.

CHAPTER VI

INSTALLATION OF A GAS ENGINE

There are a number of points which should be considered before purchasing a gas engine, one of which is the amount of power required for the work to be done. It is generally advisable, no matter what style of engine is to be purchased, to buy a unit somewhat larger than what at first may seem necessary. It is always well to have some power in reserve, because an engine working under an excessive load is inefficient and involves a money loss to the owner, because of the wear and tear on the engine.

The style of engine to be selected is determined by the location and the nature of the work to be performed. If the engine is used in a fixed location a stationary type should be selected, whereas the portable type and the traction engine must be selected when the engine is for use at various points and when loads are to be hauled. The selection of the right type of engine is fully as important as the selection of tne right make; also, while attractive paint and a high polish are desirable, these tell very little of the real value of the engine.

When repairs are necessary, the importance of having an engine which has been standardized is fully realized by the purchaser. Repair parts should be obtainable at convenient points within a few hours of the place where the engine is installed, because delays in waiting for repair parts usually prove expensive.

It is important to bear in mind that the rated horsepower of an engine is not always a reliable basis for comparison with the actual power that the engine will deliver. There are many gas engines on the market rated at five horsepower, for example, which will hardly have a maximum output of as much as five horsepower under regular operating conditions. Again, there are engines built by reputable manufacturers which deliver continually an overload of as much as 20 per cent above their rating. If there is any doubt in the mind of the purchaser as to the power possible to be obtained from an engine, he should insist upon proofs of the actual brake horsepower.

When the engine has been purchased, the next thing to consider is where it is to be placed. In selecting the position for the engine, note that it ought to be placed in the cleanest, driest and lightest place obtainable for it. If it is to be belted to machinery which is already in place, it is necessary to decide where the flywheel of the engine will be located and the foundation should be made with this in mind. If the machinery is to be installed later, suitable position for it must be determined at the time the engine is installed in order to insure that no difficulties will be met with in transmitting the power. If the engine is installed in a large room, a small room or space should be partitioned off around it in order to keep out dust and dirt. Under all circumstances, never allow a gas engine, or any other engine, for that matter, to run in the same room where there are emery or polishing wheels.

Assuming the engine to be of the stationary type, the purchaser should obtain a templet and anchor bolts, generally furnished with each engine. The templet is a wooden frame of the size of the bottom of the base of the engine, having holes in it to match the holes in the base of the engine frame.

The Foundation

The dimensions of the foundation at the bottom should be at least twice the length of the engine base and not less than two and one-half times the width, and the depth of the foundation should be equal to its length. The shape of the foundation is then made in the form of a frustum of a pyramid, sloping up towards the top, where it is only about three inches larger on all sides than the base of the engine. When the hole has been dug in the ground, a form for the concrete must be made and then the concrete is mixed as follows: one sack of good cement, two wheelbarrows of sand, and three wheelbarrows of crushed rock or small gravel, well mixed with plenty of water to make it easy to handle. When putting the concrete into the form it is advisable to use old scrap iron of all kinds, chains, wire, etc., to reinforce the concrete and keep it from cracking. Put in the concrete and scrap iron together, tamping it tightly into the form. Before putting in the concrete, however, place the anchor bolts in the bottom of the hole, with large heavy washers on their heads, and use the templet to locate them properly at the bottom; then run the nuts down on the anchor bolts far enough to allow the templet to rest upon them while locating the bolts at the top at about the level where the engine will be set on the foundation. Then fasten the bolts in some way so that they will not move while the concrete is being put in place. The wooden templet is left on the top of the foundation, the nuts, of course, having been removed when the foundation reaches to them, and the engine is set on the top of the templet, as it is advisable to use a thin strip of wood between the concrete and the cast iron of the base. The foundation should be left to set at least four days before the engine is placed upon it.

Removing an Engine from a Railroad Car

The foundation now being ready, we will assume that the engine has arrived in a railroad car to the station, and that it is to be removed from there by the purchaser. A few points relating to this operation will prove of value to all prospective buyers of engines. The engine has been delivered to the transportation company by the manufacturer or dealer, properly packed for shipment. The responsibility of the manufacturer or agent stops at this point, and the transportation company is supposed to deliver it to the purchaser in perfect condition. The engine, if of a heavy type, has been transported in a separate car, and is left on a side track accessible for teams. The first thing to do is to have the local station agent make an inspection of the engine in the presence of the purchaser or his representative, to see if it is in good condition and that no damage has been done to it in transportation. Should any damage be revealed at this inspection, the station agent should be required to make a notation of the damage upon the expense bill before the freight is paid. After this is done the transportation company is liable for the damage, if any, and the buyer is safe in unloading and taking charge of the engine.

If any timbers or assistance are needed in unloading the engine from the car, the transportation company, through its agent, is supposed to furnish them. If the transportation company furnishes bad timbers for this purpose and an accident is caused thereby, the mere acceptance by the purchaser of the bad timbers does not place the responsibility upon him. The engine should preferably be moved onto a flat top dray wagon without springs. In moving the engine, take care to see that it is properly supported at all times, and look out for where each step in the moving is going to leave it. If any accident happens to the engine before it is clear of the car or before it is taken off the skids conveying it from the car to the wagon, the transportation company is liable for the damage, because being a local shipment, the company is supposed to remove it from the car and the purchaser is merely acting for the company when taking the engine from the car. After the engine is placed on the wagon, the purchaser is entirely responsible for it.

As an example of what may be encountered in unloading an engine, the following experience may be mentioned. An engine arrived at its destination in good condition and the car was set on a siding near a pile of ties which were to be used in unloading. Some other timbers were also necessary which the agent of the railroad company furnished, but these were not as strong as the man unloading the engine required; however, the station agent informed him that he would have to use them. He went on with the operations, taking extra precautions to brace the weak timbers, but just as the engine was about half way between the car and the wagon, one of them gave way and the engine went into a ditch upside down. The man in charge of the unloading went to the long-distance telephone and called up the general agent of the manufacturing company, stating the circumstances and asking for instructions. He was told to inform the station agent that the engine could not be used, and that it would be left on the railroad company's hands. A new engine was loaded at the factory the same day and shipped, and in that case ample assistance was rendered in unloading the new engine. The first engine was loaded by the railroad company onto a car and returned to the factory free of charge, and the bill for repairs necessary to restore it into satisfactory working condition was rendered to the railroad company, which paid it without a damage suit.

After the engine is safely placed on the wagon it should be conveyed by the safest and easiest road to the place of installation. Avoid uneven ground and bad street crossings; take plenty of time and be sure of every move. Always release the team from the wagon while loading and unloading the engine. In unloading the matter is greatly simplified if two trenches are dug for the wheels of the wagon so that the axles almost touch the ground. In this case, the timbers on which the engine is handled will be more nearly level. If they are entirely level, rollers may be used under the skids to which the engine is fastened. If, however, the timbers slope at all, rollers should not be used. The main thing is to avoid being in a hurry, and not to permit anything else to interfere until the engine has been placed on the foundation.

Installation of Auxiliaries

The next thing is to select a suitable place for the battery box. This place should be dry and free from vibration. Then connect the wiring as has already been explained in Chapter III. If natural gas is to be used as a fuel, it is necessary to have a special mixer which will be furnished by the manufacturer of the engine. All that is necessary is a gas bag or tank, together with the necessary piping, to allow the charge to be thrown quickly into the cylinder. Some engines use gasoline for a start and then switch onto the natural gas, while others start directly on the gas. If the engine *will* start directly on the gas, there is no good reason for using gasoline.

If liquid fuel is to be used, it is advisable to place the fuel tank outside of the building and it is still better to bury it in the ground. After the tank has been buried in a suitable place, it is an easy matter to arrange the piping to the fuel pump on the engine. As far as possible, this piping should be underground, as it is out of the way. A pipe for the fuel, passing from the pump to the mixer, and a pipe for the overflow to return from the mixer bowl to the tank, must be provided as already explained in Chapter II. If the overflow pipe stops at the top of the fuel tank, it will not be necessary to have a vent hole at the top of the tank, as the air will flow into the tank from the overhead pipe which will not always be full of gasoline. The pump pipe should pass to the bottom of the tank and should be provided with a fine screen to prevent foreign substances from passing into the mixer.

Starting a New Engine

After the engine is properly installed, the first thing is to start it running. This is done by turning on the battery switch, setting the needle valve in the starting position, turning off the air damper, releasing the compression, and giving the flywheel a few turns, which will put it in motion. After the engine has made a few revolutions, open the air damper, close the needle valve to the running position, put the relief cam back into place, and let the engine run, watching for developments. It is, of course, presumed that all the oilers and grease cups have been filled, and that all movable parts have been oiled with the oil-can. Now see that water enters into the cylinder cooling jacket within five minutes, or stop the engine, as it is not safe to allow the engine to run without cooling water in the jacket. It is best to allow the engine to run an hour or so without any load, and to watch the bearings to see that they do not overheat or get warm. In case of doubt on any point, stop the engine and make an examination.

In cold weather, a gasoline engine is more difficult to start than in warm weather, the reason being that gasoline, in changing from a liquid to a vapor, reduces its temperature about 30 degrees F. If the air is cold on the outside of the cylinder and the mixer has taken in vapor 30 degrees colder, it is easy to understand that this would interfere with the proper vaporization. Hence, it will be difficult to start the engine. There are several methods to overcome this difficulty, either by warming the gasoline, warming the air, or by using one part ether and four parts gasoline for a start; this will make a liquid which will vaporize readily several degrees below zero. To warm the gasoline is a process which is dangerous and should only be attempted as a last resort. It can be done safely only by using hot water or a hot cloth. The air may be warmed by heating a piece of iron red-hot and holding it at the mouth of the intake pipe, allowing the air to pass over the hot iron as it passes into the intake pipe, after which it joins the gasoline vapor and raises its temperature.

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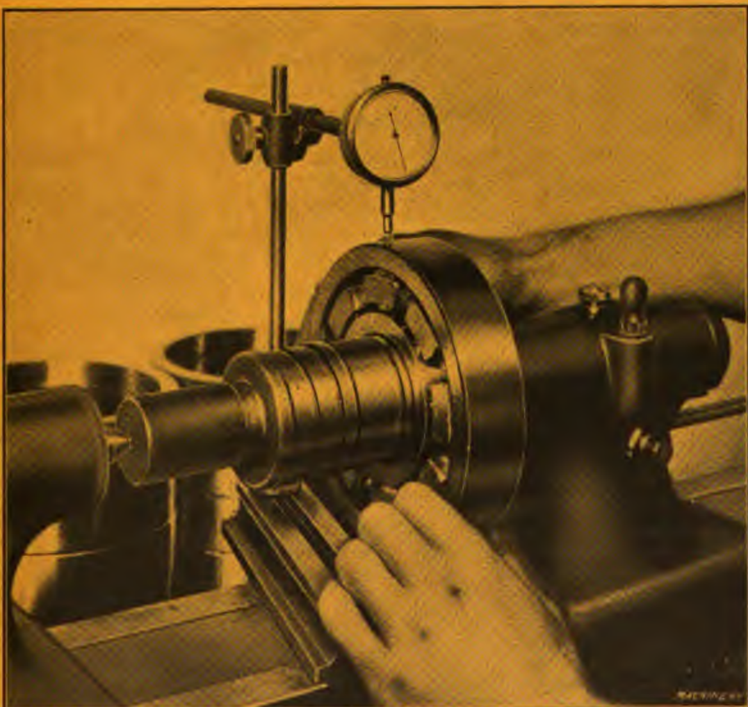

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CHAPTER I

CLASSES AND STANDARDS OF MEASUREMENT

This treatise deals with the various forms and types of gages and measuring instruments used in machine shops and tool-rooms. Practically all of the measuring tools used by machinists and toolmakers may be divided into two general classes; *viz.*, the tools for measurements of length, and those for the measurement of tapers or angles. Length measurements, in turn, may be divided into *line* measurements and *end* measurements. The former are made by direct comparison with graduations on the measuring tool, and the latter by bringing the work into actual contact with the measuring surfaces of the instrument. Examples of line measurement are those made with a machinists' rule, whereas, end measurements are those made with a micrometer or similar tool. Angular measurements are also obtained either directly by means of degree graduations on an adjustable protractor, or by testing the work with a gage which conforms to the required angle.

In the two general classes of tools for length and angular measurements, there are many different types and designs. For instance, there is the adjustable type, which is graduated and is used for taking direct measurements in inches or degrees; then, there is another type which is fixed and cannot be used for determining various sizes or angles, but simply for gaging or testing one particular size. There are also tools for taking approximate measurements and others designed for very accurate or precise measurements. Ordinarily, both classes of measurements would be required in building a machine or tool, because some parts must be accurate, whereas others can vary in size to some extent, and, in such cases, any unnecessary refinement means an increase of time and cost. Measurements which, in machine and tool construction, belong in the approximate class, are those made by means of a rule or scale, or by working to lines which have been laid out on the work and represent finished surfaces. For precise measurements, there are vernier calipers, micrometers, fixed gages, and reference gages which represent subdivisions of the standard yard within very small limits.

Standards of Measurement

Evidently, if there is to be a uniform system of measurement, it is necessary to have a fixed standard. The yard is the commonly accepted standard of length in the United States, although it is not the legal standard. In 1866 Congress passed a law making legal the meter. In 1875 representatives of various countries signed a treaty providing for the establishment and maintenance, at the common expense of the contracting nations, of a scientific and permanent bureau of weights and measures, to be located in Paris. This bureau was empowered to construct and preserve the international standards and to distribute copies to the different countries.

The international meter adopted by this Bureau is the fundamental unit of length in the United States. The primary standard is deposited at the International Bureau of Weights and Measures near Paris, France. This is a platinum-iridium bar with three fine lines at each end; the distance between the middle lines of each end, when the bar is at a temperature of 0 degrees C., is one meter by definition Two copies of this bar are in the possession of the United States and are deposited at the Bureau of Standards, in Washington.

The United States yard is defined by the relation, 1 yard $= \frac{3600}{3937}$ meter. The legal equivalent of the meter for commercial purposes was fixed as 39.37 inches by law in July, 1866, and experience having shown that this value was exact within the error of observation, the United States office of standard weights and measures was, by executive order, in 1893, authorized to derive the yard from the meter by the use of this relation. No ultimate standard of reference for angular measurements is required, inasmuch as the degree can be originated by subdivision of the circle.

The Bureau of Standards employs various methods of making comparisons of bars which are submitted by manufacturers for test, the method depending upon the kind of bar, the accuracy desired, and the adaptability of the apparatus available to the bar or test piece. Thus, there are several classes of tests, such as Class *A*, for reference standards, Class *B*, for working standards, etc. The fee charged for this work depends, of course, upon the class and nature of the test. Metric length measures tested by the bureau are standardized at 20 degrees C., and standards in the customary units of yards, feet, and inches are made to be correct at 62 degrees F.

Value of a Standard of Measurement

The standard bars at Washington are the ultimate standard of reference for the manufacturers in this country. Working standards or duplicates have been made for the use of manufacturers of gages and measuring instruments. In 1893, the Brown & Sharpe Mfg. Co. decided to make a new standard to replace the one they had at that time. The following general description of how a copy of the government standard was made is taken from a paper by Mr. W. A. Viall, presented before the Providence Association of Mechanical Engineers, and shows the great accuracy necessary in connection with work of this kind.

First steel bars about 40 inches long and 1¼ inch square were planed, and then allowed to "season" for several months. At the ends of these bars two gold plugs were inserted with centers 36 inches apart, and a little beyond these, two other plugs 1 meter apart. This bar was placed in position upon a heavy bed so arranged that a tool carrier could pass over the bar. The tool carrier consisted of a light frame-work holding the marking tool. The point of this marking tool was curved and had an angle, so that if dropped, it made an impression in the form of an ellipse. A line made with this tool was short and that portion of the line was used which passed, apparently, through the straight line in the eye-glass of the microscope. In order to make these lines as definite as possible, the point was lapped to a bright surface. A microscope at the front of the tool carrier was set to coincide with the graduation on the standard bar from which the new bar was to be graduated. After obtaining this setting, the marking tool was dropped by turning a lever, thus making a line on the plugs that was so fine it was not visible to the naked eye. After making this first line the carriage and marker was moved along to coincide with the other line on the standard, and after the correction had been made by the use of a micrometer in the microscope, the marking tool was again dropped, giving a second line which was intended to mark the distance equivalent to one yard. This same operation was repeated in marking lines representing the meter. This work was done, of course, with the greatest care, and while it may appear very simple from the description, it required a great deal of time and patience.

The standard bar thus marked was taken to Washington and compared with the government standard Bronze No. 11 and also with Low Moor iron No. 57. In comparing these standards, a method was employed very similar to that used in marking. The bar, properly supported, was placed upon a box that rested upon rolls and on this same box was placed the government standard with which the Brown & Sharpe standard was to be compared. Both the government standard and the bar to be tested were placed in position under the microscope and by the micrometer screw of the microscope the variation between the two was measured. Three comparisons or tests were made on each end before determining the reading of the microscope, and after these comparisons the value of the B. & S. standard No. 2 was found to be 36.00061 inches for the yard, and 1.0000147 meter for the meter.

After completing this work, a second standard known as No. 3 was prepared, and comparison with the government standard showed the error to be 0.00002 inch for the yard, and 0.000005 meter for the meter. After establishing a yard in this manner, the next problem was that of obtaining an inch; this was done by subdividing the yard into two equal parts, and then further subdividing these two divisions into three, and the three into six, thus giving thirty-six subdivisions or inches.

CHAPTER II

CALIPERS AND MICROMETERS

Calipers are used principally for external and internal measurements not requiring great accuracy, and are made in a variety of designs. Sketch *A*, Fig. 1, shows outside calipers and indicates how they are used for testing the size of a cylindrical part. Inside calipers for testing the diameter of a hole are shown at *B*, and sketch *C* illustrates how the outside calipers are set by comparison with the inside pair or *vice versa*. For instance, if the shaft at *A* were being fitted to the hole *B*, the calipers would be set as follows: First the inside pair would be adjusted to just touch both sides of the hole, when held as shown. The outside calipers would then be set to just touch the ends of the inside calipers so that the outside pair, practically speaking, would represent the hole and could be used for testing the size of the shaft. Obviously, if a rather heavy pressure were required to force the outside calipers over the shaft, this would indicate that the diameter was too large. If the pressure were the same as between the two pairs of calipers, the shaft would fit tightly; whereas, if the calipers passed over easily and without perceptible pressure, a close sliding fit should be obtained.

Evidently, when testing sizes by means of calipers, the degree of accuracy attained depends largely upon the skill, judgment and experience of the one who sets and uses the calipers. Some machinists can work within very close limits, whereas others lack the delicate sense of touch that is necessary. In order to eliminate this personal factor, micrometers are extensively used in order to obtain direct measurements and secure different classes of fits by a definite allowance in thousandths of an inch, instead of by judging the allowance from the pressure or side play of the calipers. Fixed gages, which are accurately made to the sizes required, are also widely used, especially for testing duplicate parts in connection with interchangeable manufacture.

Most calipers are either the firm joint or the spring type; the former, which is shown in Fig. 1, simply has a friction joint between the two "legs," whereas the spring type (illustrated in Fig. 3) is provided with an adjusting screw and nut, and the two members are forced together against the tension of the curved spring at the upper or pivot end. These are merely constructional features and have nothing to do with the use of the calipers. Spring calipers are not made in large sizes like the friction-joint type.

Hermaphrodite and Shoulder Calipers

The caliper illustrated at *A*, Fig. 2, is half caliper and half divider. This form is often used for drawing a line parallel to a finished edge (as the illustration indicates) or for locating a central point on the end of a shaft by setting the caliper to the radius of the shaft, as near as can be judged, and then scribing arcs which, at the point of intersection, indicate the center.

The special form of caliper shown at *B* is useful either for testing the distance from the end of a shaft or rod to a shoulder, or the distance from one shoulder to another. This type of caliper is also convenient for testing the diameter when boring a cylindrical surface (such as the crown-brass of a locomotive driving box) which does not extend through a half circle, thus making it impossible to measure

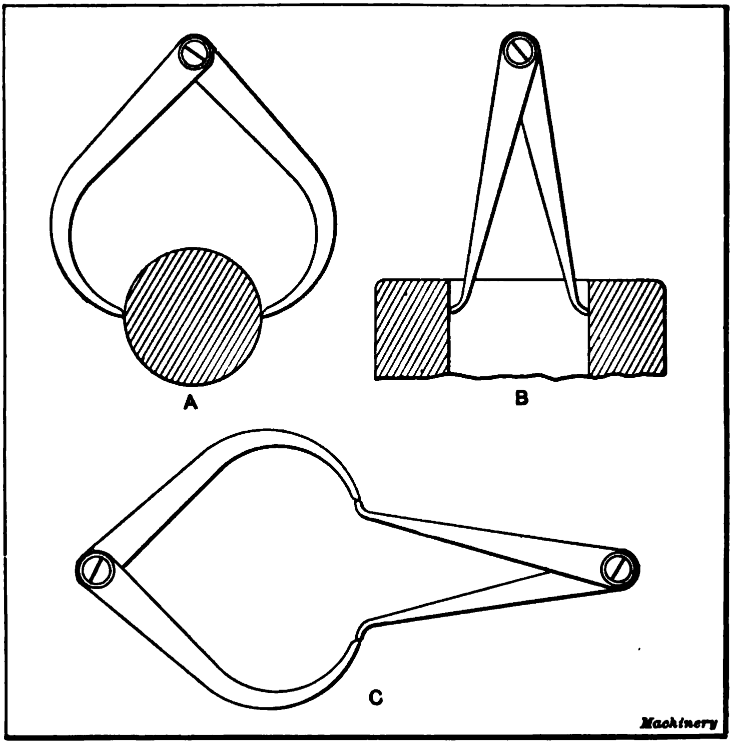

Fig. 1. Outside and Inside Calipers

the diameter of the cut directly. In the case of the driving box, the caliper points are set to the diameter of the journal and the size of the bore is tested by calipering from the point of the boring tool to the bored surface, when the box is turned around to locate the bearing brass away from the tool. Evidently, when the work is in this position, the distance from the cutting edge to the bored surface represents the diameter of the cut.

Thread Calipers

The spring type of calipers shown at *A* and *B*, Fig. 3, are used for measuring the diameters of threads. Caliper *A* is for testing the outside diameter. It has broad ends which span two or more threads so that the diameter across the tops of the threads can easily be obtained by first adjusting the calipers to just touch the threads and then measuring the distance beween the ends with a machinist's rule. Caliper *B* is for testing the diameter at the bottom or root of the thread. The ends are V-shaped so that the points will bear at the bottom of the thread groove. For accurate measurements a thread micrometer should be used. (See "Thread Micrometer.")

While the principal types of ordinary calipers have been referred to in the foregoing, other forms are often used. For some classes of work, combination calipers are very convenient. This type usually

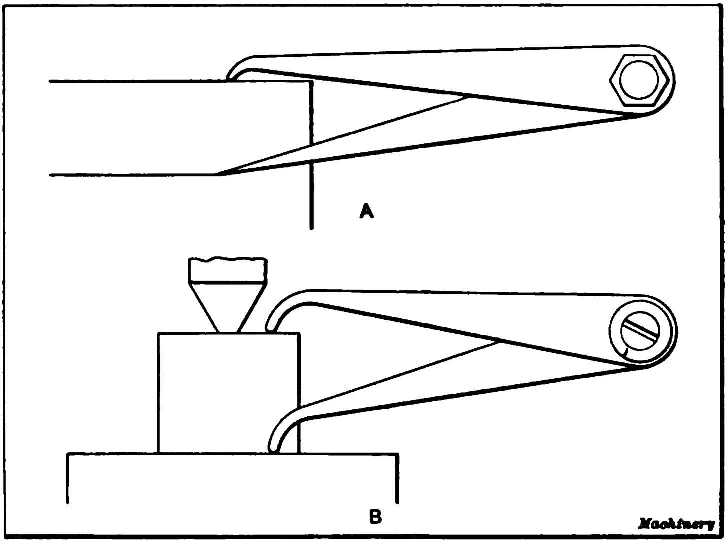

Fig. 2. (A) Hermaphrodite Calipers (B) Shoulder Calipers

combines dividers and outside and inside calipers in one tool. There are also many other special forms, many of which are made by machinists, for taking measurements under unusual conditions which make it impossible to use ordinary calipers.

Points on Setting Calipers

The accuracy of caliper measurements is governed partly by the adjustment of the calipers and also by the skill or judgment of the workmen in transferring this size to the work. Outside calipers are commonly set to a given dimension in inches, by holding one end against the end of a scale and adjusting the other end until it coincides with the graduation line representing the required size. A more accurate and positive method is to use a standard plug or disk gage of the required diameter, if one is available.

When setting inside calipers with a scale, the end of the latter should be placed squarely against some true surface; then one end of the caliper is held against this same surface, thus aligning it with the end of the scale, while the other end is adjusted to the required measurement. To insure a square end against which to place a scale and caliper, some machinists hold the scale on the blade of the square with one end resting against the beam or stock.

Standard ring gages or an outside micrometer are preferable for setting inside calipers. A ring gage of the required diameter is not always available, but an outside micrometer is a common tool, and,

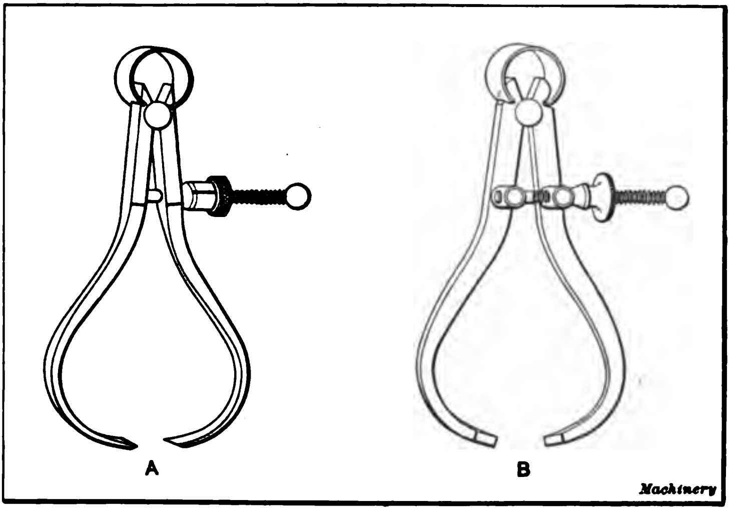

Fig. 3. Thread Calipers of Spring Type

being adjustable, affords an accurate method of setting inside calipers. The micrometer is first set to the size required; then the ends of the caliper are adjusted to just touch the parallel faces of the anvil and spindle of the micrometer. When an attempt is made to set inside calipers to a given measurement, by first setting outside calipers with a scale and then transferring the size to the inside calipers, obviously, several chances of error are introduced.

Side Play of Calipers

Judging a fit allowance by the amount of side play the calipers have in a hole, is a common method, although not very reliable, especially when considerable accuracy is necessary. To illustrate this method of fitting, suppose a pulley hub were being bored to fit a shaft. After setting the outside calipers to the size of the shaft, the inside calipers should be adjusted to the outside pair, so that the bearing or degree of contact is the same as between the outside calipers and the shaft.

The hole should then be bored to such a diameter that the inside calipers have a slight side play, in order to provide an easy sliding fit for the shaft.

The amount of this side play would depend upon the diameter and length of the hole and the accuracy required for the fit. For instance, a side play of only ⅛ inch might be sufficient for a small size hole, whereas, ½ inch or more might be necessary for a comparatively large hole, especially if quite long. The following rule may be used to determine the allowance for a given amount of side play, or, in other words, the difference between the diameter of the hole, and the

ALLOWANCES FOR DIFFERENT CLASSES OF FITS*

Diameter, Inches	Running Fits	Push Fits
Up to ½	−0.00075 to −0.0015	−0.00025 to −0.00075
½ to 1	−0.001 to −0.002	−0.0005 to −0.001
1 to 2	−0.0015 to −0.0025	−0.0005 to −0.0015
2 to 3	−0.0015 to −0.003	−0.0005 to −0.0015
3 to 4	−0.002 to −0.0035	−0.00075 to −0.002
4 to 5	−0.0025 to −0.004	−0.00075 to −0.002
5 to 6	−0.0025 to −0.0045	−0.00075 to −0.002
Diameter, Inches	**Driving Fits**	**Forced Fits**
Up to ½	+0.0004 to +0.0006	+0.0005 to +0.001
½ to 1	+0.0005 to +0.001	+0.001 to +0.003
1 to 2	+0.00075 to +0.002	+0.002 to +0.004
2 to 3	+0.0015 to +0.003	+0.003 to +0.006
3 to 4	+0.002 to +0.004	+0.005 to +0.008
4 to 5	+0.002 to +0.0045	+0.006 to +0.010
5 to 6	+0.003 to +0.005	+0.008 to +0.012

* These allowances are intended for average machine work. If the bearings are long the allowances for running fits may have to be increased.

dimensions to which the calipers are set or the length of a standard end-measuring rod.

Rule: Determine the amount of side play in sixteenths of an inch or the number of sixteenths; square this number and divide the result by twice the dimension to which the calipers are set, or by twice the length of the end-measuring rod. The quotient represents the allowance or difference in thousandths of an inch.

For example, suppose a standard end-measuring rod, 6 inches long, had a side play of ¼ inch in a bored hole. What is the difference between the length of the rod and the diameter of the hole?

In ¼ inch, there are 4 sixteenths; hence, the allowance or difference

$$= \frac{4 \times 4}{2 \times 6} = \frac{16}{12} = 1.3 \text{ thousandths or } 0.0013 \text{ inch.}$$

While this method does not give results which are absolutely accurate, the error is so small, especially when the amount of side play is small, that it can usually be disregarded. Judging an allowance for a fit in this way, however, is not to be recommended, and, in most shops, would be unnecessary, owing to the gages and micrometers for both external and internal measurements which are now in common use and give direct measurements.

A general idea of the allowances required for average machine work may be obtained from the table on page 10, which covers four different classes of fits and diameters varying from 0 to 6 inches.

The Vernier Caliper

The vernier is an auxiliary scale that is attached to vernier calipers, height gages, depth gages, protractors, etc., for obtaining the fractional parts of the subdivisions of the true scale of the instrument. When a scale is graduated in hundredths or even sixty-fourths of an inch, it is confusing to take measurements with it owing to the fineness of lines. If it were possible to graduate a scale to thousandths,

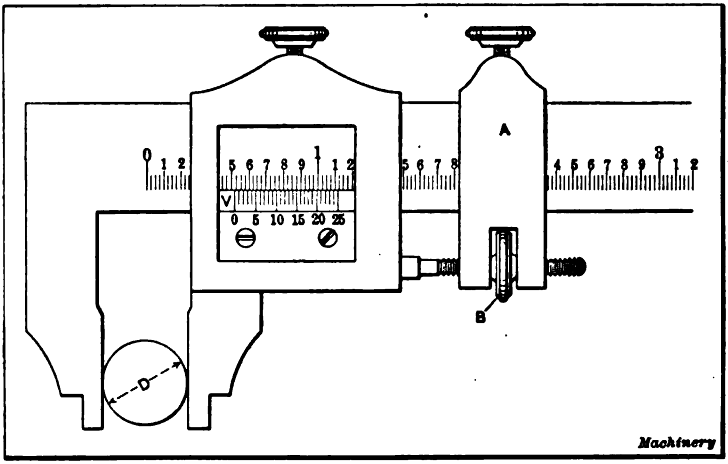

Fig. 4. Vernier Caliper

or with every inch subdivided into a thousand equal parts, such a scale would, of course, be useless, owing to the extreme fineness of the lines and the minute distances between them. Such fine divisions on a scale are not, however, necessary, for by means of the vernier scale, graduations which are comparatively large can be divided so that fine measurements may be taken.

For example, the true or regular scale of the vernier caliper shown in Fig. 4, is graduated in fortieths of an inch, but by means of the vernier scale *V*, which is attached to the sliding jaw of the instrument, measurements within one-thousandth of an inch can be taken. In other words, the vernier, in this case, makes it possible to divide each fortieth of an inch on the true scale into twenty-five parts. To measure the diameter *D* with a vernier caliper, adjust the sliding jaw until it is close to the work and then lock the slide *A* by the screw shown. With the nut *B*, which is used for making fine adjustments, move the jaw until it just touches the work. The distance that the vernier scale zero has moved to the right of the zero mark on the true scale (which equals diameter *D*) is then read directly in thousandths of an inch, by calling each tenth on the true scale that has been passed by the vernier zero, one hundred thousandths, and each fortieth twenty-five thousandths, and adding to this number as many thousandths as are indicated by the vernier. The vernier zero in the illustration is slightly beyond the five-tenths division; hence, the reading is 0.500 plus the number of thousandths indicated by that

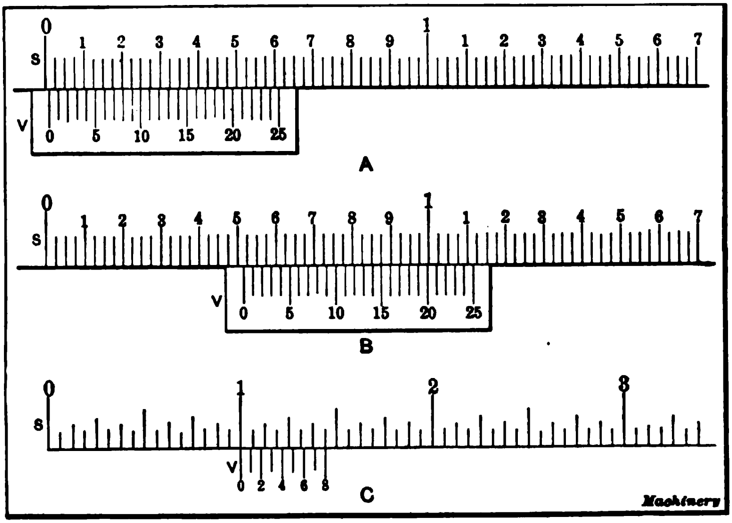

Fig. 5. Scales with Verniers set in Different Positions

line on the vernier that exactly coincides with one on the scale which, in this case, is line 15, making the reading 0.500 + 0.015 = 0.515 inch.

Principle of the Vernier Scale

By referring to the enlarged scales shown at *A* and *B*, Fig. 5, the principle of the vernier will be more apparent. When a vernier caliper reads to thousandths of an inch, each inch of the true scale *S* is divided into ten parts, and each tenth into four parts, so that the finest divisions are fortieths of an inch. The vernier scale *V* has twenty-five divisions, and its total length is equal to twenty-four divisions on the true scale, or 24/40 of an inch; therefore, each division on the vernier equals 1/25 of 24/40 or 24/1000 inch. Now, as 1/40 equals 25/1000, we see that the vernier divisions are 1/1000 inch shorter than those on the true scale. Therefore if the zero marks of both scales were exactly in line, the first two lines to the right would be 1/1000 inch apart; the next two 2/1000, etc. It is evident, then, that if the vernier were moved to the right until, say, the tenth line from the zero mark exactly coincides with one on the true scale, as shown at *A*, the movement would be equal to 0.010 inch, since this line was 0.010 inch to the left of the mark with which it now coincides, when the zero lines of both scales were together. Similarly, if the fifteenth line were exactly opposite a line on the true scale, the movement of the vernier would be equal to 0.015, etc.; so we see that the number of thousandths that the vernier zero has moved past a graduation on the true scale is determined simply by counting the number of spaces between the zero of the vernier, and that line on it which exactly coincides with one on the true scale. If the vernier were moved along to the position shown by the next sketch *B* (Fig. 5) the true scale would indicate directly that the reading was slightly over 0.500 inch, and the coincidence of the graduation line 15 on the vernier with a line on the true scale, would show the exact reading to be $0.500 + 0.015 = 0.515$ inch.

In Fig. 5 a true scale *S* is shown at *C* that is graduated into sixteenths of an inch, and the vernier *V* has eight divisions with a total length equal to seven divisions on the true scale, or 7/16 of an inch; therefore, each division on the vernier is 1/8 of 1/16, or 1/128 inch shorter than the divisions on the true scale; so we see that in this case the vernier enables readings to be taken within one hundred and twenty-eighths of an inch, instead of in thousandths as with the one previously described. The divisions then that may be obtained by a vernier depend altogether on the way the true and vernier scales are graduated.

In order to determine the fractional part of an inch that may be obtained by any vernier, multiply the denominator of the finest subdivision of an inch given on the true scale by the total number of divisions on the vernier. For example, if (as in Fig. 4) the true scale is divided into fortieths and the vernier into twenty-five parts, the vernier will read to thousandths ($40 \times 25 = 1000$). If there are sixteen divisions to the inch on the true scale and a total of eight on the vernier, the latter will enable readings within one hundred twenty-eighths of an inch to be taken ($16 \times 8 = 128$). It will be seen then that each subdivision on the true scale can be divided into as many parts as there are divisions on the vernier.

The following is a general rule for taking readings with a vernier: *Note the number of inches and whole divisions of an inch that the vernier zero has moved along the true scale, and then add to this number as many thousandths, or hundredths, or whatever fractional part of an inch the vernier reads to, as there are spaces between the vernier zero and that line on it which coincides with one on the true scale.*

The vernier caliper can be used for measuring the diameters of holes or for other inside measurements, as well as for external measurements, by using the outside surfaces of the jaws or measuring points. The width of the jaws should be added to the apparent reading as given by the scale and vernier, to obtain the correct inside dimensions. No such allowance is necessary when using the graduations on the opposite side of the beam of some vernier calipers, as two lines marked "in" and "out" indicate inside and outside maesurements.

Vernier Caliper with Metric Graduations

The application of the vernier to a caliper graduated on the metric system is illustrated in Fig. 6. In this case we have, instead of inches, centimeters which are subdivided into ten parts called millimeters. By the aid of the vernier, each millimeter is again divided into ten parts so that readings can be taken to within 1/10 of a millimeter or 1/100 of a centimeter (0.0039 of an inch). The reading with the caliper set as shown in the illustration is 2 55/100 centimeters, or, as commonly expressed, 25 5/10 millimeters. As shown more clearly by the enlarged detail view, the left-hand or zero mark of the vernier has

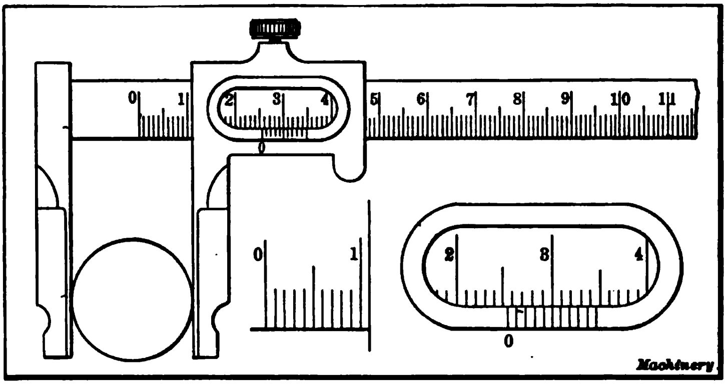

Fig. 6. Vernier Caliper Graduated on Metric System

passed the 2½ centimeter graduation, and the fifth line on the vernier coincides with one on the true scale; therefore, the reading is 25 millimeters plus 5/10 of a millimeter. This particular instrument has on the opposite side of the beam two series of inch graduations which, with the verniers, enable measurements within 1/100 and 1/128 of an inch to be taken. Therefore inches may be converted into metric measurement, and *vice versa*, by taking the reading first on one side of the beam and then on the other.

Micrometers for External and Internal Measurements

Micrometer callipers are used for taking accurate measurements. A small size for external measurements is shown at *A*, Fig. 7. The part to be measured is placed against the anvil *a* and the adjustable spindle *b* is then screwed in until it bears lightly against the work, by turning the thimble or sleeve *c;* the size is then determined by referring to the micrometer graduations. Most micrometers are graduated to read to thousandths of an inch, although some have an auxiliary vernier scale which enables readings to within 0.0001 inch to be taken. (The method of reading a micrometer will be explained later.) This particular micrometer will measure all sizes varying from 0 to 1 inch. Some outside micrometers have a lock-nut which is used to clamp the spindle in order to convert the micrometer into a fixed gage. To use a micrometer in this way is generally considered poor practice. The proper method of taking a measurement is to close the contact points against the work with a light pressure and then determine the size by the graduations as previously explained.

Many micrometers have what is called a ratchet stop *d* at the end of the barrel or thimble. If this is used when adjusting the measuring point against the work, it will slip when the point bears lightly, and thus prevent excessive pressure. The advantage of securing a

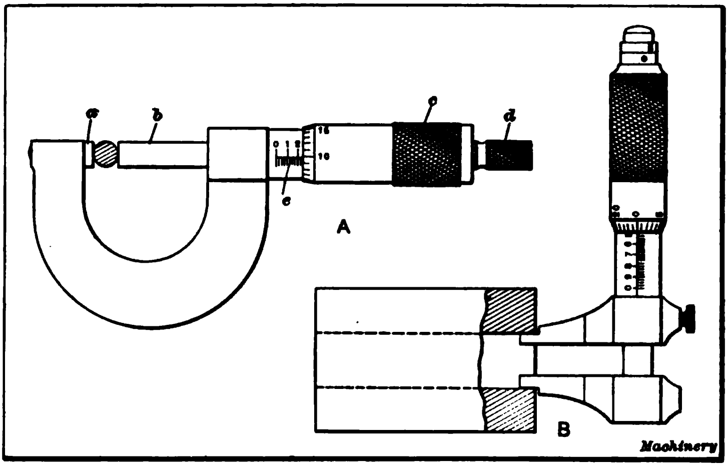

Fig. 7. Outside and Inside Micrometers

uniform contact or degree of pressure is that uniform readings are then obtained. Obviously, a difference in pressure will give a different reading and might result in a serious error. Inaccuracies from this cause might be negligible so far as one workman is concerned, but they become important where measurements are taken by many different workmen, because everyone does not have the same sense of touch.

A micrometer for measuring the diameters of holes or for taking other internal dimensions is shown at *B*, Fig. 7. The measuring surfaces are hardened and ground to a radius to secure accurate measurements and to avoid cramping when measuring the distances between parallel surfaces. The movable jaw has a clamp screw that is tightened when it is desired to retain the setting of the calipers.

Another form of inside micrometer is shown in Fig. 8. This particular size can be used for measurements varying from 2 to 12 inches. When testing the diameter of a comparatively small hole, when there is not sufficient room for the hand, an auxiliary handle *a* is screwed into the micrometer head as shown in the illustration. The micrometer screw has a movement of one-half inch and by inserting extension rods of different lengths in the head at *b*, any dimension up to 12 inches can be obtained. Two of these extension rods are shown to the right. They are provided with collars which serve to locate them accurately in the micrometer head.

An inside micrometer gage that is especially adapted for large internal measurements is shown at *A*, Fig. 9. This gage consists of a holder equipped with a micrometer screw with graduations reading to 0.001 inch, and into this holder is inserted an adjustable rod. This rod also has graduations in the form of a series of annular grooves of a form and depth that allow clamping fingers on the holder to spring into them, thus making it possible to shift the rod in or out to the required length. Gages of this type usually have a series

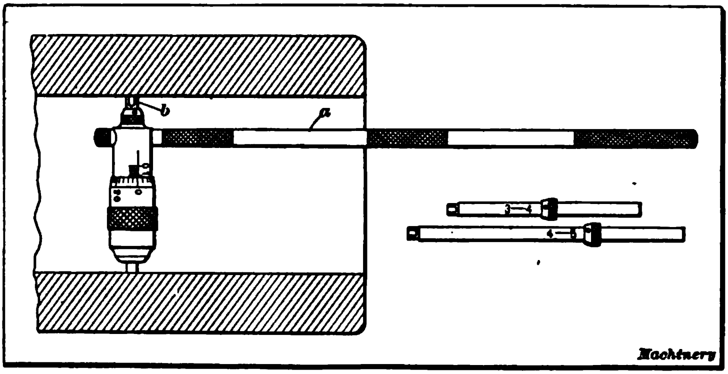

Fig. 8. Inside Micrometer equipped with Extension Rods

of rods so that a wide range of sizes can be measured. They are not only used for internal measurements but for setting calipers and for similar work.

A micrometer caliper for large external measurements is shown at *B*. The micrometer screw has an adjustment of one inch and is graduated to read to 0.001 inch. When measuring small sizes, the long anvil or spindle *s* is used, whereas, for larger sizes, one of the shorter spindles is inserted. The sides of the steel frame are covered with hard rubber to prevent inaccuracies in the measurements as the result of expansion from the heat of the hands. As will be noted, this micrometer has a ratchet stop to insure uniform pressure when measuring.

Thread Micrometers

For the accurate measurement of screws or threads, the special thread micrometer shown in Fig. 10 is often used. The fixed anvil is V-shaped so as to fit over the thread, while the movable point is cone-shaped so that it will enter the space between two threads. The contact points are on the sides of the thread, as they must be in order that the pitch diameter may be determined. The cone-shaped point of the measuring screw is slightly rounded so that it will not bear at the bottom of the thread. There is also sufficient clearance at the bottom of the V-shaped anvil to prevent it from bearing on the top of the thread. The movable point is adapted to measuring all pitches, but the fixed anvil is limited in its capacity. To cover the whole range of pitches, from the finest to the coarest, a number of fixed anvils are required.

To find the theoretical pitch diameter, which is measured by the micrometer, subtract the single depth of the thread from the standard outside diameter. The depth of a V-thread equals 0.866 ÷ number of

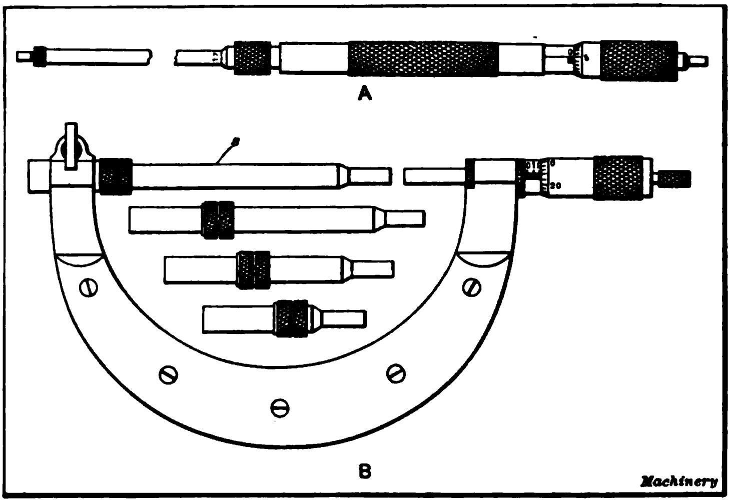

Fig. 9. (A) Inside Micrometer Gage for Large Holes
(B) Large Outside Micrometer

threads per inch, and depth of U. S. standard thread equals 0.6495 ÷ number of threads per inch.

If standard plug gages are available, it is not necessary to actually measure the pitch diameter, but merely to compare it with the standard gage. In this case, a ball-point micrometer such as is shown in Fig. 11 may be employed. Two types of ball-point micrometers are ordinarily used. One is simply a regular micrometer with ball points made to slip over both measuring points, as shown by the detail sketch *B*. This makes a combination plain and ball-point micrometer, the ball points being easily removed. These ball points, however, may not fit solidly on their seats and are apt to cause errors in the measurements. The best method is to use a regular micrometer into which ball points have been fitted as shown at *A*. Care should be taken to have the ball point in the spindle run true. A hole is provided in the spindle so that the ball point can easily be driven out when a larger or smaller size of ball point is required.

How to Read a Micrometer

The pitch of the thread on the spindle *b* (Fig. 7) of an ordinary micrometer is 1/40 of an inch. Along the frame at *e* (see also detail sketch *A*, Fig. 12), there are graduations which are 1/40 inch apart; therefore, when thimble *c* and the measuring spindle are turned one complete revolution, they move in or out, a distance equal to one of

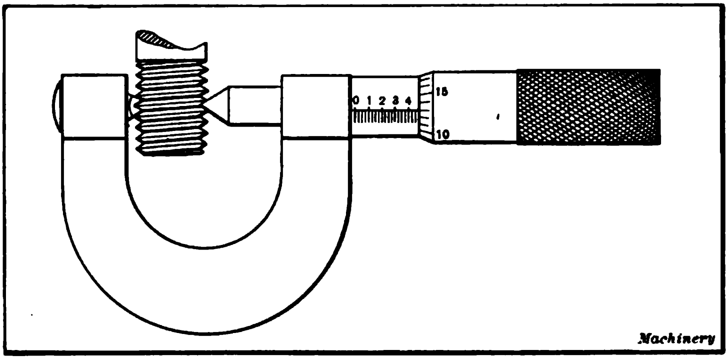

Fig. 10. Thread Micrometer

the graduations or 1/40 inch, which equals 25/1000 inch. It is evident then that if instead of turning the thimble one complete revolution, it is turned say 1/25 of a revolution, that the distance between the anvil and the end of the spindle will be increased or diminished 1/25 of 25/1000 of an inch, or one thousandth inch; therefore, the beveled edge of a micrometer spindle has twenty-five graduations, each of

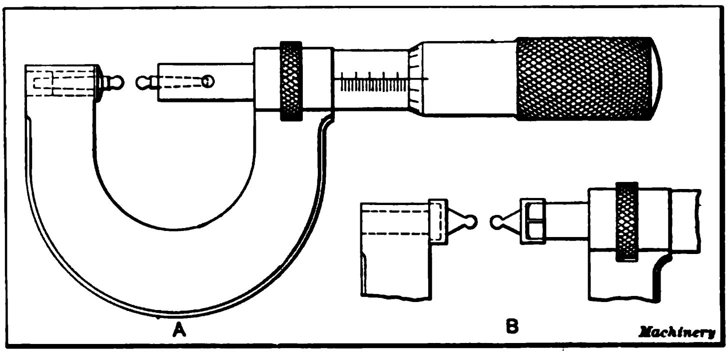

Fig. 11. Ball-point Thread Micrometer

which represents 0.001 inch. Following is a general rule for reading a micrometer:

Count the number of whole divisions that are visible on the scale of the frame, multiply this number by 25 (the number of thousandths of an inch that each division represents) and add to the product the number of that division on the thimble which coincides with the axial *zero line on the frame. The result will be the diameter expressed in thousandths of an inch.*

As the numbers 1, 2, 3, etc., opposite every fourth subdivision on the frame indicate hundreds of thousandths, the reading can easily be taken mentally. Suppose the thimble were screwed out so that graduation 2, and three additional subdivisions were visible (as shown at *A*, Fig. 12), and that graduation 10 on the thimble coincided with the axial line on the frame. The reading then would be 0.200 + 0.075 + 0.010, or 0.285 inch.

Some micrometers have a vernier scale *v* on the frame (see sketch *B*, Fig. 12) in addition to the regular graduations, so that measurements within 0.0001 inch can be taken. Micrometers of this type are read as follows:

First determine the number of thousandths, as with an ordinary micrometer, and then find a line on the vernier scale that exactly co-

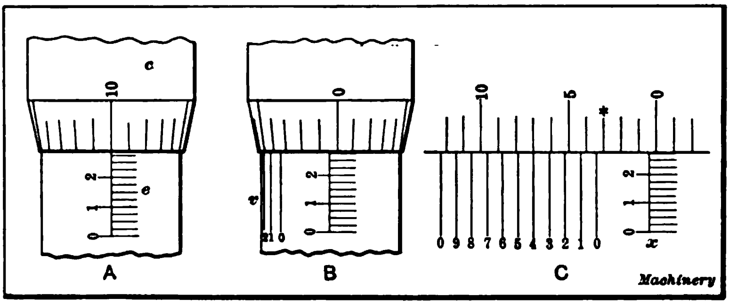

Fig. 12. Micrometer Graduations

incides with one on the thimble; the number of this line represents the number of ten-thousandths to be added to the number of thousandths obtained by the regular graduations.

The relation between the graduations of the vernier and those on the thimble is more clearly shown by diagram *C*. The vernier has ten divisions which occupy the same space as nine divisions on the thimble, and for convenience in reading are numbered as shown. The difference between the width of a vernier division and one on the thimble is equal to one-tenth of a space on the thimble. Therefore a movement of the thimble equal to this difference between the vernier and thimble graduations represents 0.0001 inch. When the thimble 0 coincides with the line *x* on the frame, the 0 of the vernier coincides with the third line to the left (marked with an asterisk). Now when the thimble 0 (or any other graduation line on the thimble) has passed line *x*, the number of ten-thousandths to add to the regular reading is equal to the number of that line on the vernier which exactly coincides with a line on the thimble. Thus the reading shown at *C* (Fig. 12) is 0.275 + 0.0004 = 0.2754 inch.

CHAPTER III

FIXED AND ADJUSTABLE GAGES

Strictly speaking, any tool or instrument used for taking measurements might properly be called a gage, but this term, as used by machinists and toolmakers, is generally understood to mean that class of tools which conform to a fixed dimension and are used for testing sizes but are not provided with graduated adjustable members for measuring various lengths or angles. There are exceptions, however, to this general classification.

Measuring instruments, such as the micrometer and vernier caliper, are indispensable because they can be used for determining actual

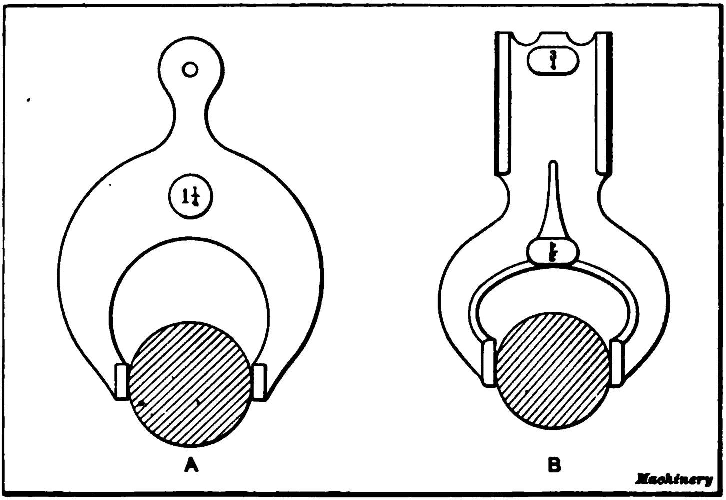

Fig. 13. (A) Snap Gage (B) Internal and External Gage

dimensions, and, being adjustable, cover quite a range of sizes. Any form of adjustable measuring tool, however, has certain disadvantages for such work as testing the sizes of duplicate parts, especially when such tests must be made repeatedly, and solid or fixed gages are commonly used. There is less chance of inaccuracy with a fixed gage and it is more convenient to use than a tool which must be adjusted, but owing to the necessity of having one gage for each variation in size, and because of the cost of a set covering a wide range of sizes, solid gages are used more particularly for testing large numbers of duplicate parts in connection with interchangeable manufacture.

Two different types of fixed gages are shown in Fig. 13. The form shown at *A* is commonly known as a "snap gage." The distance between the measuring surfaces is fixed and represents the size stamped upon the gage, within very close limits. This type of gage can be obtained in various sizes and is used for measuring duplicate parts in connection with general shop work. As a gage of this kind is repeatedly passed ovcr the work, it becomes worn, and, therefore, should be compared or tested occasionally with a standard reference plug or disk. In case of excessive wear, the gage can be closed in slightly smaller than the required size and then be reground or lapped to the original size, as shown by a reference gage.

Sketch *B* illustrates another form of snap or caliper gage. This is double-ended and is intended for both external and internal measure-

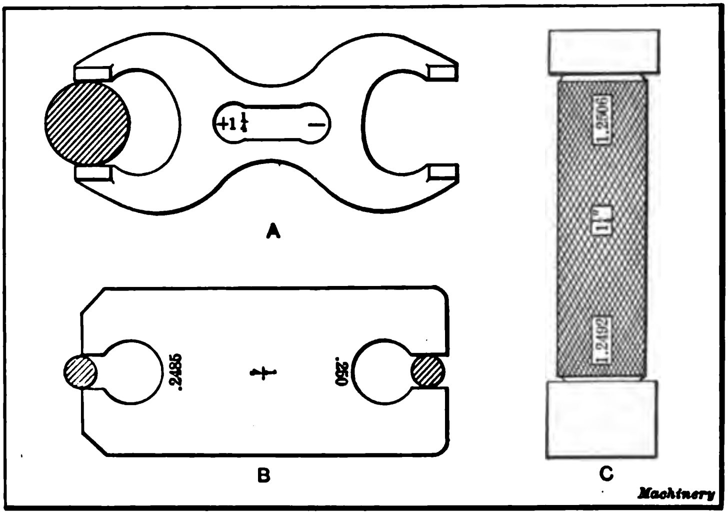

Fig. 14. External and Internal Limit Gages

ments, the width of the internal end being the same as the distance between the measuring surfaces of the external end.

Limit Gages

With the modern system of interchangeable manufacture, machine parts are made to a definite size within certain limits which are varied according to the accuracy required, which, in turn, depends upon the nature of the work. In order to insure having all parts of a given size or class, within the prescribed limit so that they can readily be assembled without extra and unnecessary fitting, what are known as "limit gages" are used. One form of limit gage for external measurement is shown at *A*, Fig. 14. It is double-ended and has a "go" end and a "not go" end; that is, when the work is reduced to the correct size, one end of the gage will pass over it but not the other end. When a single-ended snap gage *A*, Fig. 13, is used, the diameter of the work may be slightly less than it should be, but by having a gage for the minimum as well as for the maximum size, every part must come within the limits of the gage. This allowance or limit is made to conform to whatever amount experience has shown to be correct for the particular class of fit required.

Another external limit gage is shown at *B*, Fig. 14. Nominally this is a ¼ inch gage. The size of the "go" end is 0.250 inch and the size of the "not go" end is 0.2485 inch; hence the tolerance is 0.0015 inch. Therefore a part that is more than 0.0015 inch less than 0.250 inch will not pass the "not go" end of the gage.

An internal limit gage is shown at *C*. The nominal size of this particular gage is 1¼ inch. The diameter of the "go" end is 1.2492 inch, whereas the diameter of the "not go" end is 1.2506 inch; hence, in this case, the tolerance equals $1.2506 - 1.2492 = 0.0014$ inch. Incidentally, it is good practice to make all holes to standard sizes within

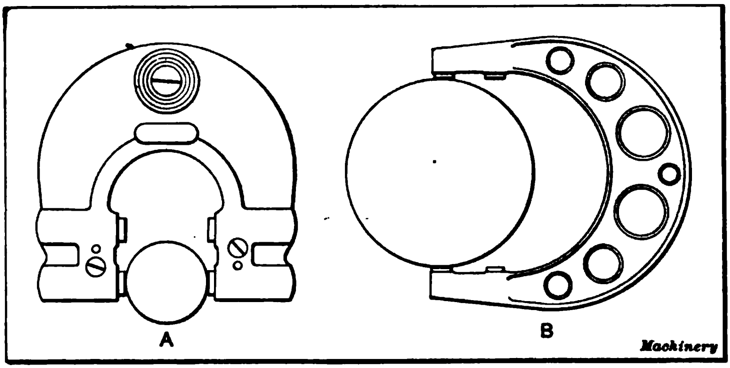

Fig. 15. (A) Adjustable Limit Gage; (B) Limit Gage with Fixed Points

whatever limits may be advisable, and vary the size of the cylindrical parts to secure either a forced fit, running fit, or whatever class of fit may be required.

It will be noted that the ends of these limit gages are of different shape so that the large and small sizes can readily be identified without referring to the dimension stamped on the gage ends. Limit gages are very generally used for the final inspection of machine parts, as well as for testing sizes during the machining process. They are superior to the micrometer for many classes of inspection work, because the adjustment and reading necessary with a micrometer often results in slight variations of measurement, especially when the readings are taken by different workmen.

Adjustable Limit Snap Gage

The snap gage shown at *A*, Fig. 15, differs from the ordinary single-ended type in two particulars: In the first place, it has two sets of measuring plugs and is a limit gage. The lower set forms the "go" end and the upper set the "not go" end. These plugs are also adjustable so that when the gage becomes inaccurate, as the result of wear, the plugs can easily be reset, a standard reference gage being used to determine the distance between them.

The plugs are plain cylinders of hardened steel and are lapped to a snug sliding fit in the hole of the gage body. The ends are square and bear against adjusting screws, the forward ends of which are also

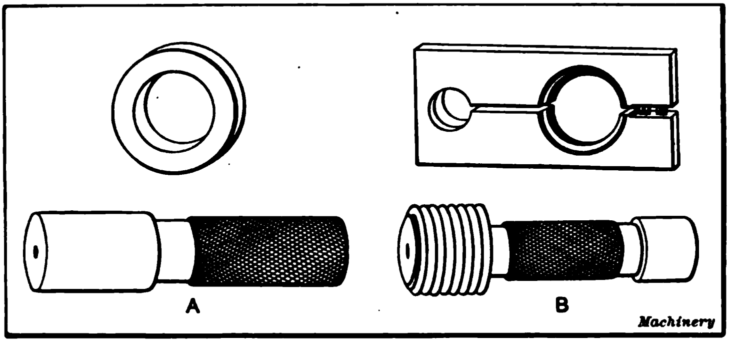

Fig. 16. (A) Plug and Ring Gages (B) Internal and External Thread Gages

lapped square. The clamping screws at the side not only clamp the plugs but tend to force them against the adjusting screws. The handle has an insulated grip.

Another snap gage of the limit type is shown at *B*. This gage has fixed points which can be renewed in case of wear.

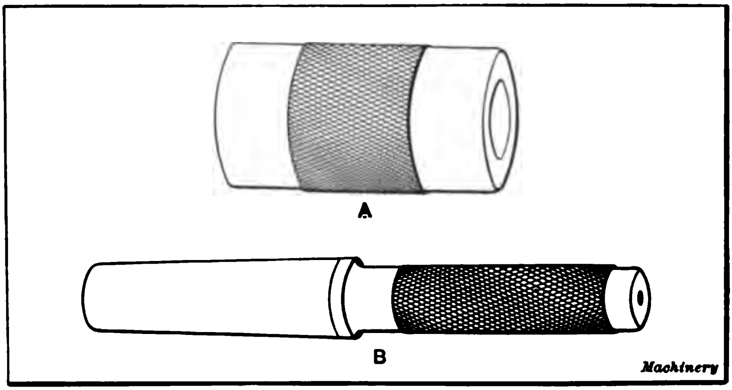

Fig. 17. Internal and External Taper Gages

Plug and Ring Gages

A standard external or ring gage and internal or plug gage is shown at *A*, Fig. 16. These gages are very accurately made and are used either as reference gages or for setting calipers, etc., or as working gages. One gage manufacturer makes solid gages of this type in diameters varying from 1/16 inch to 3 inches. For larger sizes, up to 6 inches in diameter, the plug gages are made hollow.

U. S. standard thread gages are shown at *B*, Fig. 16. These gages are intended as a practical working standard. The internal gage or plug is a standard to which the external templet is adjusted. The plain unthreaded end of the plug gage is ground and lapped to the exact diameter at the root or bottom of the thread.

Gages for testing the accuracy of tapers are shown in Fig. 17. The ring gage *A* is used for external tapers and the plug *B* for holes. The plug accurately fits the ring and when they are assembled, a line on the plug coincides with the end of the ring. This line is used for gaging the depth of holes which must conform to the standard size of the ring gage. When the plug gage is used as a working gage in the shop, the ring is usually kept as a reference gage. On the other

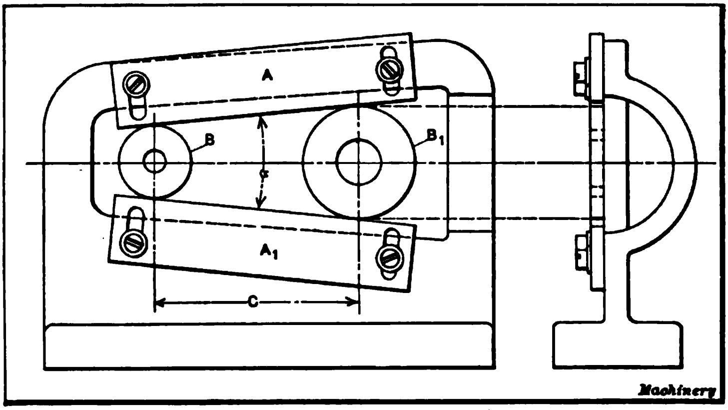

Fig. 18. Disk Gage for Originating or Accurately Measuring Tapers or Angles

hand, if a ring is used for testing external tapers, the plug is often preserved as the reference gage.

Gage for Originating and Accurately Measuring Tapers

When a certain taper or angle must be originated or accurately measured, the disk type of gage shown in Fig. 18 may be employed. The principle of the disk method of taper measurement is that if two disks of unequal diameters are placed either in contact or a certain distance apart, lines tangent to their peripheries will represent an angle or taper, the degree of which depends upon the diameters of the two disks and the distance between them. This gage consists of two adjustable straight-edges *A* and A_1, which are in contact with disks *B* and B_1. The angle a or the taper between the straight-edges depends, of course, upon the diameters of the disks and the center distance *C*, and as these three dimensions can be measured accurately, it is possible to set the gage to a given angle within very close limits. Moreover, if a record of the three dimensions is kept, the exact setting of the gage can easily be reproduced at any time. The following rules may be used for adjusting a gage of this type.

To Find Center Distance for a Given Angle.—When the straight-edges must be set to a given angle a, to determine center distance C between disks of known diameter. *Rule:* Find the sine of half the angle a in a table of sines; divide the difference between the disk diameters by double this sine.

Example:—If an angle a of 20 degrees is required, and the disks are 1 and 3 inches in diameter, respectively, find the required center distance C.

$$\frac{20}{2} = 10 \text{ degrees; } \sin 10° = 0.17365;$$

$$\frac{3 - 1}{2 \times 0.17365} = 5.759 \text{ inches} = \text{center distance } C.$$

To Find Center Distance for a Given Taper.—When the taper, in inches per foot, is given, to determine center distance C. *Rule:* Divide the taper by 24 and find the angle corresponding to the quotient in a table of tangents; then find the sine corresponding to this angle and divide the difference between the disk diameters by twice the sine.

Example:—Gage is to be set to ¾ inch per foot, and disk diameters are 1.25 and 1.5 inch, respectively. Find the required center distance for the disks.

$\frac{0.75}{24} = 0.03125$. The angle whose tangent is 0.03125 equals 1 degree 47.4 minutes; $\sin 1° \ 47.4' = 0.03123$; $1.50 - 1.25 = 0.25$ inch;

$$\frac{0.25}{2 \times 0.03123} = 4.002 \text{ inches} = \text{center distance } C.$$

To Find Angle for Given Disk Dimensions.—When the diameters of the large and small disks and the center distance are given, to determine the angle a. *Rule:* Divide the difference between the disk diameters by twice the center distance; find the angle corresponding to the quotient, in a table of sines, and double the angle.

Example:—If the disk diameters are 1 and 1.5 inch respectively, and the center distance is 5 inches, find the included angle a.

$\frac{1.5 - 1}{2 \times 5} = 0.05$. The angle whose sine is 0.05 equals 2 degrees 52 minutes; then, 2 deg. 52 min. × 2 = 5 deg. 44 min. = angle a.

To Find the Taper per Foot.—When the diameters of the large and small disks and the center distance C are given, to determine the taper per foot (measured at right angles to a line through disk centers). *Rule:* Divide the difference between the disk diameters by twice the center distance; find the angle corresponding to the quotient, in a table of sines; then find the tangent corresponding to this angle, and multiply the tangent by 24.

Example:—If disk diameters are 1 and 1.5 inch, respectively, and center distance is 5 inches, find the taper per foot.

$\frac{1.5 - 1}{2 \times 5} = 0.05$. The angle whose sine is 0 05 equals 2 degrees 52 minutes; tan 2° 52′ = 0.05007; 0.05007 × 24 = 1.2017 inch taper per foot.

Reference Gages

Reference gages are intended for testing the accuracy of working gages such as are used in the shop and toolroom, and for setting other forms of measuring instruments. Reference gages are made in different forms varying from plain blocks or disks to special shapes designed for some particular class of work. The standard set of reference disks made by Brown & Sharpe contains 45 disks varying by sixteenths of an inch, from ¼ to 3 inches in diameter. Handles are provided so that these disks can be used in place of standard cylindrical gages, but they are generally used without the handles for setting calipers, testing measuring instruments and for reference purposes.

Fig. 19. Johansson Reference Gages

Plug and ring gages similar to the type illustrated at *A*, Fig. 16, are also used to some extent for reference purposes, as well as for working gages. In some shops it is the practice to use the plug as a working gage and the ring for testing it, or, in case the ring is required as a working gage, the plug is kept as a standard or reference gage, as previously mentioned.

End-measuring rods and blocks are often used for testing snap gages, etc. Ordinarily, the solid measuring rods are cylindrical in form and may be obtained in sets covering a considerable range of lengths. These rods are used for testing the parallelism and width of two finished surfaces, as well as for setting calipers and testing gages. The ends of some rods are made flat and parallel, whereas others have ends which are sections of spheres, the diameters of which equal the lengths of the rods. The spherical-ended form is very convenient for testing the diameters of rings, cylinders, etc. Some end-