

GUN MANUFACTURE

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Compiled by the Editors of AMERICAN MACHINIST

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FOREWORD

IN SEPTEMBER, 1940, the editors of American Machinist began publication in every issue of a special section devoted to the production of armament. Each section was actually a summarized production handbook giving details of tool equipment, feeds and speeds and other essential data.

With tremendously increased demands for the production of armaments and armament components, requests for reprints of this material have outdistanced our available supplies. In the effort to combine some of the more needed data in a more conveniently usable form, we have placed in this one volume all the information thus far published dealing with the manufacture of guns.

Included are sections explaining how to tool up for everything from the Garand rifle to medium-calibre guns. Among the weapons whose manufacture is described in detail are the 75-mm. pack howitzer, the British 25-pounder, the 40-mm. Oerlikon anti-aircraft gun, 30- and 50-calibre and Bren machine guns, and the 81-mm. trench mortar. Dozens of companies and individuals have been unsparing of their time and materials in assisting us in preparation of this manual. We are particularly indebted to officers of Watervliet Arsenal, Rock Island Arsenal, and Springfield Armory; to executives of the Erie Works; General Electric Company; Kropp Forge Co.; Sorel Industries, Ltd.; Pontiac Division of General Motors; Bartlett-Hayward Co.; Service Machine Co.; General Motors Co.; A. B. Farquhar; and various Canadian companies.

It is hoped that this compendium of information will considerably speed war production and overcome many of the delays and difficulties incidental to conversion of existing facilities by men, many of which are unfamiliar with the procedures required in making these special products. It is our effort here to show both "ideal" production lines, and proper utilization of present equipment.

Several short articles pertinent to gun manufacture have also been incorporated in it, including the forging of the slipper for the 40-mm. gun, an arsenal X-ray installation for inspection of gun parts, and a specialized type of gage.

THE EDITORS

HOW G. E. MAKES PACK HOWITZERS

The Erie Works uses modern methods to turn out an old weapon which has been redesigned to meet the needs of today's defense plans

A PORTION OF the motor department of the Erie Works of the General Electric Company has been turned over to the manufacture of 75-mm. pack howitzers with marked success. For this purpose both old and new equipment are being used. Those machines which were adaptable to gun manufacture were tooled up for the howitzer operations; on the other hand some 50 per cent of the equipment employed is new. The result is current production at the rate of 35 howitzers a month.

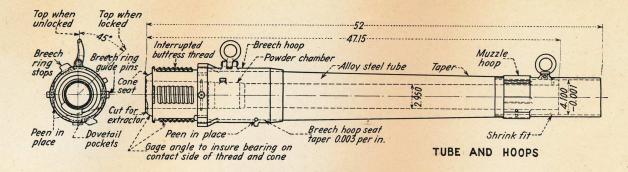
Gun manufacture by the Erie Works marked a drastic departure from its peacetime production. Through the combined efforts of the plant management and the shop personnel the changeover was accomplished quickly while the exacting quality demands were met. The design of the 75-mm. pack howitzer is such that extremely careful workmanship is called for.

This weapon combines high striking power with a maximum degree of portability. Originally the howitzer was designed so that its major components could be carried on mule back which made it necessary to disassemble and reassemble the guns with ease and to have the parts fully interchangeable. These rigid requirements are still retained today. While the Army

mule has yielded to mechanized units, it is not hard to visualize the value of this portable weapon when aerial transportation must be employed.

One of the final tests is to disassemble five guns and then reassemble them with the parts chosen at random. All this must be done without the use of tools of any kind. Assembled with its muzzle and breech hoops the gun tube weighs only 221 lb. The breech ring and breech block including the breech mechanism weigh 121 lb., bringing the total weight up to 342 lb. The 75-mm. pack howitzer has a range of approximately 9,500 yd. and throws a projectile weighing over 14 lb. It is said to have the highest striking power for its weight of any Army gun. The gun mount and the recuperator mechanism which make up the complete weapon are not manufactured at the Erie Works.

One of the major requirements in making the 75-mm. pack howitzer is to manufacture the parts so that they not only fit each other interchangeably but that they fit in a definite relation to each other. These fits are mutually dependent. For example, the breech hoop is a drive fit on the tube in a definite angular and longitudinal position. In turn the breech hoop determines the position of the breech ring by means of a



The Erie Works has adapted standard turret lathes to the boring operations on the 75-mm. howitzer. Here is shown the set-up for finish reaming the bore, and roughing and finishing the powder chamber



pair of stops. When the breech ring is screwed onto the tube it must contact a conical surface at the identical point that the stops meet. Then the breech block with its mechanism is fitted into the breech ring. Correct functioning demands that its relationship with the breech ring and with the other components be held precisely.

Smaller parts such as the firing pin body and the sear also involve exact machining and assembly operations. However, for the sake of simplicity the operations described in this article will be confined to four major parts: the tube, the breech hoop, the breech ring and the breech block.

The tube forging, of carbon steel, is received already rough bored and turned. Fortunately, the 75-mm. howitzer is comparatively short (only 47 in. long) in comparison to its bore, so the boring operation can be done in Gisholt turret lathes already installed at the Erie works.

The first step is to insert the tube in a pot chuck in one of the turret lathes and to true up the end extending out of the chuck. Then a rough cut is taken through the bore to bring it to approximately $2\frac{3}{8}$ in.

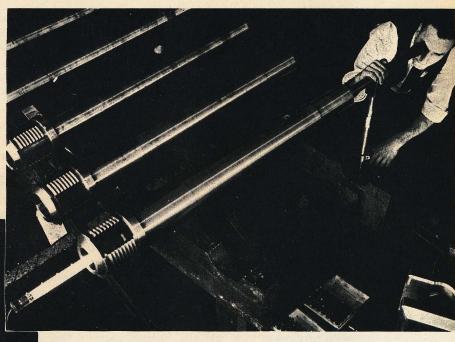
inside diameter and to remove the step which is left when the forging is rough drilled from both ends. The end is more accurately bored to 2.880 in. for a 4-in. depth to fit a plug on which the tube is supported during the turning operation, the outside diameter is spotted and the end is faced.

The tube is then reversed in the chuck while the other end is similarly bored and turned. In the turning operations the muzzle end is left oversize for a distance of about $\frac{3}{4}$ in. in order to leave a collar which is later used for indicating and chucking purposes. The chuck jaws are made to fit over the collar, thus holding the work securely axially as well as radially.

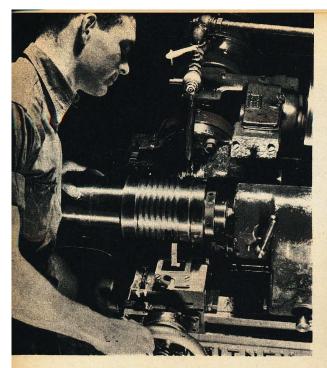
The tube is then mounted on center plugs and turned on the outside diameters leaving grinding allowance on the taper and on the breech hoop seat. These steps are done on an American engine lathe.

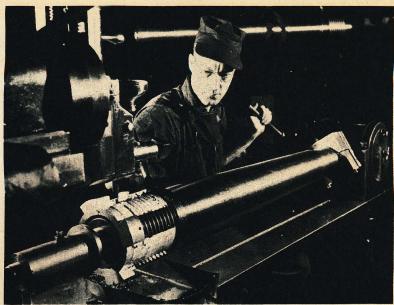
With the plugs still in the tube a Norton grinding machine grinds both ends to provide indicating surfaces for the boring and honing operations. At this point the tube goes back to one of the Gisholt turret lathes where the bore is rough and finish reamed. Rough reaming brings the bore to 2.90 in. and finish

The bore is honed in a special machine before and after rifling. Cutting lubricant is fed both through the tube and over the outside surface to keep the forging cool



Visual examination of the surface finish by means of a borescope is used on the honed bore and on the rifling grooves





Breech ring threads are milled with the tube mounted on center plugs. The size is checked with a thread snap gage. After the thread sectors have been cut, the tube is returned to remove the partial thread

Thread sectors are cut out on a shaper; a dividing head provided with a clamp which fits over the muzzle end of the tube has been adapted for indexing. For this work a gooseneck tool has been found best

reaming to 2.945 in. Wood-packed reamers are used with hard maple inserts impregnated with oil as described in a previous article. These reamers must be redressed after each use. For these operations, as for most steps on the howitzer parts, the cutting lubricant used is a two-to-one mixture of kerosene and white lard oil. After the straight bore has been finish reamed the powder chamber is machined in the same set-up. The chamber consists of a bore with a slight taper, a short beveled surface, a straight bore and another beveled surface which meets the gun bore proper. These surfaces are first roughed out with a single point tool and then rough and finish reamed with two woodpacked reamers. The reamers are piloted by means of bronze bushings which fit in the tube bore. A number of bushings are kept at the machine so the operator may select one which gives an exact fit. The finishing powder chamber reamer removes only about 0.002 in. of metal on a side. This work is done with the tube chucked in jaws on the lathe faceplate while the outer end is supported in a steadyrest. Powder chamber dimensions are checked with "go" and "not go" gages.

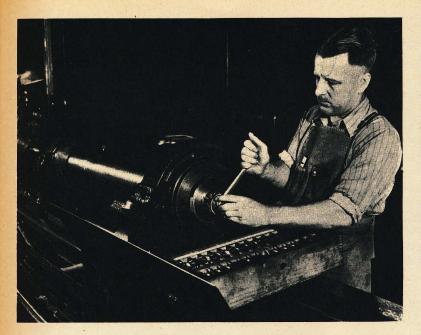
Next the tube goes to a W. F. & John Barnes honing machine which has been installed especially for work on the howitzers. The tube is carefully set up from spots previously ground on the outside diameter. It is honed to 2.9515 in. using roughing and finishing stones. Cutting lubricant is applied to the inside of the bore through the end opposite the tool and to the outside of the tube in order to prevent an excessive rise in temperature during the honing operation.

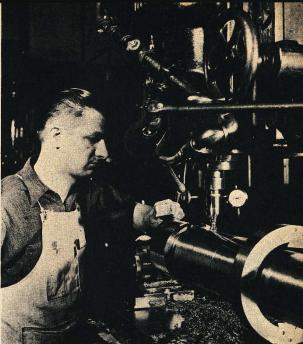
Before and after honing the bore is visually inspected with a bore search or borescope. This instrument consists of a tube which extends into the bore and carries a mirror at the far end which reflects an image of the surface into a microscope. The surface is illuminated by an electric lamp fastened near the mirror and is magnified twenty times in order that any defects in the surface may be evident.

Star Gage Used on Bore

After the honing operation a star gage inspection is also made. The star gage has three points which can be adjusted to come in contact with the inside surface of the bore; two points are fixed while one is moved by means of a vernier micrometer at the outer end of the gage. A large magnifying glass is provided so that the vernier reading can be read clearly. With two points of the star gage up and one point down, readings are taken every inch of the bore starting at the muzzle end; then the star points are reversed and a reading is taken every five inches moving the instrument in the opposite direction. The outer end of the star gage is supported on a roller rest to keep it in a horizontal position.

After inspection the tube goes back to the machining department and is again mounted on center plugs for turning in an American engine lathe. All shoulders





Twenty-six broaching disks are used for rifling. Here the operator is shown removing a disk after it has been pushed through the bore. The broach box is not kept in this position as it would fill with cutting oil

Exact location of the dovetail is maintained in relation to the thread sectors. The cut taken by the formed end mill is checked with a gage block, while the ring gage at the right is used as a final test

are cut and the outside diameters are turned for grinding. However, some stock is left on the shoulders and on the end of the tube so it is possible to make an adjustment if any of the surfaces are found to be incorrect.

Straight surfaces are then rough and finish ground in a Cincinnati grinder leaving 0.010 in. on the muzzle hoop surface and 0.002 in. on the opposite end. These surfaces are used in setting up the tube in the rifling machine. Other surfaces ground in a Cincinnati machine are the taper surface and the breech hoop surface.

The thread for the breech ring is then rough and finish milled in a Pratt & Whitney thread milling machine. The thread has a special buttress shape into which the breech ring fits in such a way as to give maximum resistance to the force of the propelling charge of the shell when the gun is fired.

Thread Determines Center Line

Up until this point no attention has been paid to the angular position of the tube; since the tube is entirely symmetrical, the thread can be cut beginning at any point on its circumference. However, once the thread is cut it is essential to locate a center line for setting up the tube in subsequent operations. This is done by means of a thread location gage which is fitted to the tube from a centerline layout on a blue vitrioled surface to make sure of a good fit. With the gage on the tube, center lines are scribed on the side of the breech end and muzzle hoop surface. Right and left sides are indicated so that the tube will not be accidentally inverted.

Since the design of the tube calls for an interrupted thread it is necessary to cut out sectors of the thread. This work is done in an Ohio shaper using a gooseneck tool. The breech end is mounted on a plug, while the muzzle end if held by a welded clamp secured to the face of a dividing head. The shaper tool cuts away the unwanted portions of the thread while the tube is indexed by hand. Then the work is returned to the Pratt & Whitney thread miller for removing the part thread left in the shaping operation.

The cone seat is then rough and finish turned in an American engine lathe. This surface determines the point of contact when the tube is assembled with the breech ring. Hence it is gaged accurately with an angle ring gage and a ring thread location gage.

The rifling operation comes next. This is done in a LeBlond hydraulic machine which uses the broaching process. Before the tube is mounted in this machine it is demagnetized as a precaution against the lodging of chips where they may cause damage. The broaching disks are pushed through the tube, beginning at the muzzle end and are removed at the breech end before the bar is returned to the starting position. Twenty-six broaching tools are used each of which is mounted in sequence on a special head through which cutting lubricant is forced under 150-lb. pressure in order to

drive the chips ahead of the tool and prevent scoring the rifling grooves. These disks cut alternate grooves, that is, 14 of the 28 called for in this design. After the first 14 rifling grooves are cut the tube is indexed so intermediate grooves may be cut by the same process. The purpose of cutting only half the grooves at one time is to operate the machine well below its rated capacity in order to insure ample power to obtain freedom from vibration and chatter marks. Broaching disks are good for about 25 gun tubes between grinds.

After rifling another inspection follows, using the borescope and the star gage. The borescope visual inspection is similar to that used prior to rifling, but for this inspection the star gage has four points, two of which are adjustable and touch the bottoms of the grooves while the other two are fixed and ride through the grooves at 45-deg. angles to the adjustable points. Each pair of grooves is inspected for size every five inches along the length of the tube.

The tube is then faced to length by taking a cut on the muzzle end and on the shoulders as required. This extra stock makes it possible to adjust any error that may be discovered without spoiling the forging. Center plugs are again used for this operation.

The design of the howitzer calls for drilling and reaming stud holes through the cylindrical surface of the tube at an angle. In order to do this work it is necessary to take some precaution to avoid the danger of drill run-out. A sacrifice plug is used to keep these holes straight. In the drill jig bushing, a steel plug, square at one end and curved at the other, is placed to fit the outside surface of the tube against which it is pressed tightly by means of a setscrew. The drill cuts through this plug and when it meets the surface of the tube it is cutting metal on all sides. The plug is wasted

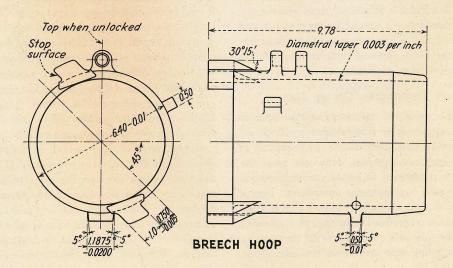
as each hole is drilled, but good alignment is assured. Reaming is done with a hog-nose tool, that is, one having a straight end somewhat like an end mill with only one lip.

Next dovetail pockets are cut in the breech end of the tube to provide location for the breech hoop. The work is done in a Cincinnati vertical milling machine with the tube mounted on center plugs supported by a dividing head at one end. A special formed end mill is used, and the tube is positioned angularly from the interrupted thread. Accuracy is assured by the use of special gages. In the same set-up a small groove known as the extractor pocket is machined.

As an added precaution before the tube is sent to assembly, it is again put in the honing machine and a small amount of stock removed from the lands between the rifling grooves. This operation has been found well worth the time it takes because in addition to straightening and sizing the bore it removes any feather edges that may be formed in rifling. Tubes are also given a hand honing operation on the assembly floor if it is deemed desirable.

In all machining steps on the howitzer components, it is necessary to transfer heat numbers from time to time. As these numbers are used to identify the part from the rough forging to final assembly, it is a rule that an Army inspector must be present when a number is transferred. All parts are carefully hand finished to remove burrs and smooth sharp corners before assembly. Portable tools are extensively used to expedite this work.

The tube assembly consists of the machined forging just described together with two hoops known respectively as the muzzle hoop and the breech hoop. The muzzle hoop is shrunk on. In order to make this fit

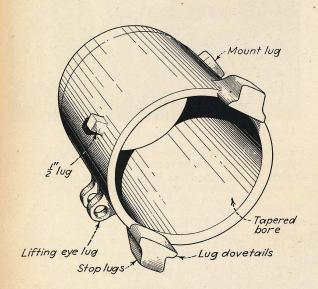


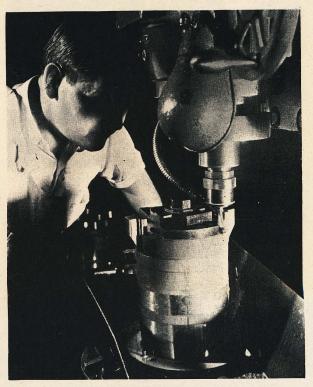


Since all lugs on the breech hoop are integral with the forging, they are first turned as rings; then the extra metal is removed in a series of slotting operations. In the foreground is a hoop before slotting

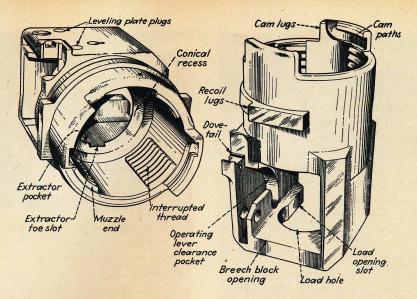


Faces of the stop lugs are machined in a horizontal milling machine with the breech hoop mounted on an arbor positioned with an indexing plate and pin. The work is offset to give the proper angle on the lug

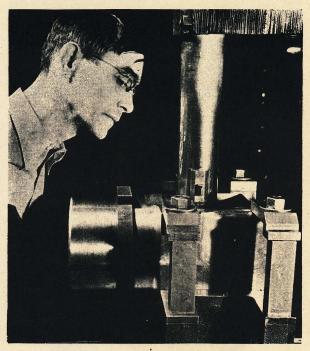




Dovetails position the breech hoops in relation to the tube. A set gage is used to fix the position of the work in relation to an end mill to obtain accuracy



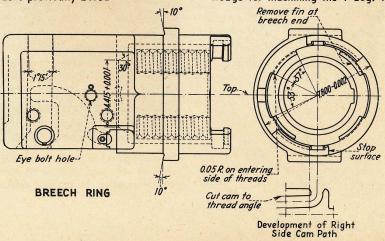




The exterior outline, all radii, and the load opening slot are milled in a horizontal boring, milling and drilling machine. The work is located on a plug from surfaces previously bored

8

The breech block opening is cut in the breech ring by means of a slotter. After roughing and finishing the straight surfaces, the block is tilted by means of a wedge for machining the 1 deg. 15 min. angle



the muzzle hoop is made 0.0025 in. smaller in the bore than the mating ground surface on the tube. The hoop is placed in an electric furnace and heated to 500 F. for one hour. Then it is slipped over the tube and cooled with water while it shrinks in place.

The breech hoop is a drive fit on the tube. It is made from a carbon steel forging rough turned and bored. There are a number of lugs on the outside of the breech hoop which according to Army specifications must be integral with the hoop forging making it necessary to machine them out of the solid. In order to do this the forging is turned with a number of rings left at points along the axis where the lugs are located.

The first operation is to chuck the breech end of the forging in a Warner & Swasey turret lathe while it is turned, faced and bored. Then the workpiece is reversed, end for end, and corresponding operations are performed on the breech end previously held in the chuck. A third turret lathe operation does the finish turning on the rings from which the lugs are formed. In order to establish angular location for this piece, which up to now has been symmetrical, a 18-in. slot is milled central with the top of the 12-in. lug using a Cincinnati horizontal milling machine. Other operations in the same machine mill the mount lug to height and then straddle mill to form the sides and radii.

Lugs Formed by Slotting

Then follow a series of slotting operations, using Pratt & Whitney machines, in which the rings are entirely removed except for the lugs. These slotting operations are interspersed with straddle milling cuts to form the sides of the lug and eventually get the hoop down to its proper diameter. The hoop then goes to an Acme turret lathe to turn the stop lugs to angles of 30 deg. 15 min. including the radius that blends into the outside diameter of the hoop. Then the work is chucked on the table of a Bullard vertical turret lathe where it is bored and taper ground using a portable grinding head on the tool ram. It is this surface that matches the tube when the hoop is assembled with a drive fit, and hence it must be accurate as to size and taper.

The dovetails are then cut in the end lugs with the work mounted on a plug on the table of a Cincinnati vertical milling machine. Since these surfaces determine the angular position of the hoop in relation to the tube they are cut using a set gage, the faces of which, having the same angles as the dovetails, are used to set the work in relation to an end mill.

The stop lugs are then milled in a Cincinnati horizontal milling machine. In order to realize the importance of these surfaces the method of assembly between the breech ring, the hoop and the tube must be remembered. The breech ring is threaded to fit the tube and

has a conical recess that fits the conical end surface of the tube. The thread and conical surfaces must fit snugly but not so tightly that they will become jammed during assembly. It must be borne in mind that these parts must be disassembled without the use of tools. In order to prevent jamming, stop lugs are placed on the breech hoop to match projections on the breech ring to limit the amount the breech ring can be rotated.

If the ring is threaded slowly on the tube during assembly and all fits are accurate, the locating points on the ring will be open about $\frac{1}{8}$ in. from the lugs on the hoop when the conical surfaces seat. If, however, the ring be given a slight spin, the inertia of its weight will close this gap without the application of any other pressure. An assembly pressure of from 8 to 10 lb. is desired, and this spin is ample to supply it. Assembled in this fashion the breech ring should fit the tube at the conical surface with an 85 per cent bearing as indicated by Prussian blue. Thus a snug fit is obtained which at the same time permits the gun crew to disassemble the ring from the tube by hand as called for in the Army specifications.

In order to position the stop lug faces properly, the hoop is mounted on a horizontal arbor with angular adjustment fixed by means of a locating hole and a stop pin. In this fixture the lug on one side is milled with a form cutter in order to supply the radius, and then the work is indexed 180 deg. to machine the opposite lug. These lugs are cut in an off-center position to supply the angle called for in the design of this part.

Additional operations on the breech hoop consist in milling and slotting radii between and around the lugs, and in drilling and reaming the holes in which the lifting eye is fastened.

Breech Ring Calls for Fine Workmanship

The breech ring involves some of the most ticklish operations on the entire howitzer. It is made of an alloy steel forging, and is received rough machined. The first operations are done conventionally enough on Gisholt lathes. The forging is chucked first on one end, then on the other while it is faced, turned and bored on the various inside and outside diameters, including the important conical recess that later determines the fit to the gun tube. As in other turning operations on howitzer parts, tungsten carbide tools are employed wherever practicable.

Since this forging is not symmetrical, it is important to locate the work properly. A pot chuck is used to hold the work while the muzzle end operations are performed. Then a boring fixture holds the piece while the load hole is bored and the breech end faced. A center line is then scribed on the piece.

Next the breech ring is clamped, muzzle end down, over a plug on the table of a Giddings & Lewis hori-

zontal boring, drilling and milling machine, while the exterior outline, all radii and the load opening slot are milled. Special form mills are required for the radii.

Four slotting operations follow. Using locating plates on the breech face, the recoil lugs are outlined and the metal between them removed. Then, using a cradle fixture, the breech block opening is rough and finish slotted.

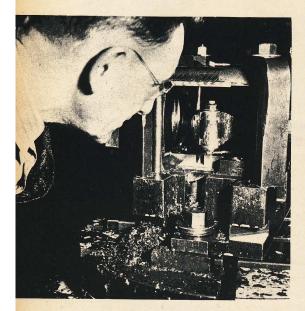
Since one face of the opening is 1 deg. 15 min. out of line with the others, it is necessary to tilt the block in order to slot this face. This is done by means of a wedge which is placed under the fixture. The 10-deg. angles and the radii on the recoil lug are then milled in two set-ups using vertical milling machines.

At this point two blind holes are drilled and reamed using hog-nose tools and then undercut. These holes provide anchors for two soft metal plugs which are peened into them. These plugs supply supporting points for the leveling plate used in sighting the howitzer when in use. They are later machined, engraved with double cross lines to insure alignment between the instrument and the gun tube, and are hand-scraped to get them exactly level with the bore.

Inside the breech block opening there are two radial slots and in order to reach them, a special milling head

is required. One of these forms the clearance pocket for the operating lever. Using Cincinnati horizontal machines and a right-angle cutter arm driven through helical gears, it is possible to reach this slot from the side of the breech block opening. The work is mounted on a circular table and swung around in an arc as the metal is cut. A number of cuts are taken with an end mill in order to form the pocket to its proper width. A similar but shorter slot, which forms the extractor pocket on the opposite inside face of the breech block opening, is similarly machined using the same milling head.

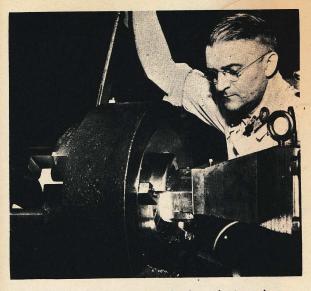
The most exacting job on the breech ring is to bore and counterbore the thread surface, cut the 30-deg. angular recess and cut the thread itself. It has already been explained that the position of the threads in relation to the recessed conical surface must be precisely machined in order to have the breech ring fit the gun tube satisfactorily. When the conical surface of the breech ring meets the mating surface of the gun tube in assembly, the angular position of the ring must be such that its spot lugs meet those on the breech hoop, with an 8- to 10-lb. pressure. The lead of the buttress thread is such that there is a ratio of 43 to 1 between the longitudinal distance along the axis and the angu-



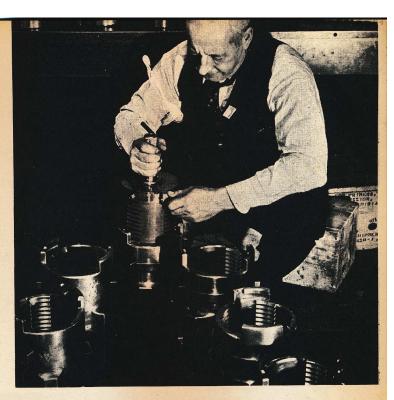
A special cutter head reaches into the square opening of the breech ring to machine the radius for the operating lever pocket. The circular table controls the path of the work in relation to the cutter

In this set-up, the breech ring is bored, counterbored, the conical recess finished and the thread cut. Note the indicators to position the work and the tool slides, the thread limit gage on top of the compound rest and the thread set gage at the lower right





Rotating cam paths guide the breech ring when assembled to the tube. They are cut by using a right angle milling head. The work is fed axially into the cutter and then rotated along a helical path through the use of a special fixture



Breech rings are inspected by using a special gage which checks the conical recess, the thread, the stops and the cam paths simultaneously

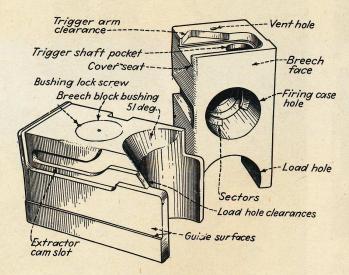
lar movement of the contact point when the breech ring is rotated. This ratio means that if the conical recess and the thread are 0.001 in. out of position with each other axially, the angular location of the lugs will be off by 0.043 in.

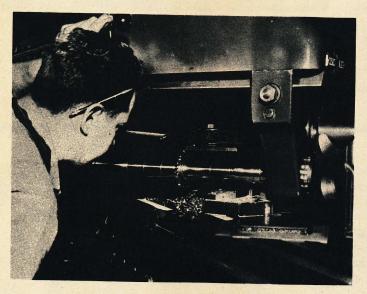
The machining operations ares performed in an American engine lathe with the breech ring carefully positioned in a fixture that is open between clamping points to permit gaging through the breech block opening. The workpiece is trued up by using an indicator on the outside diameter. Then it is bored, counterbored and the 30-deg. conical recess is machined and located from the adjacent surface of the breech block opening by means of a plug gage which fits the cone to a depth which brings it flush with the surface. A positioning gage is used to locate the threading tool. It locates from the same breech block opening surface and extends through the bore. The tool is set into a V notched into this gage. In addition to the other difficulties of this job, the thread must be cut in a blind hole; to stop the tool accurately, a dial indicator is mounted on the carriage in such a way that it strikes a stop when the proper depth has been reached.

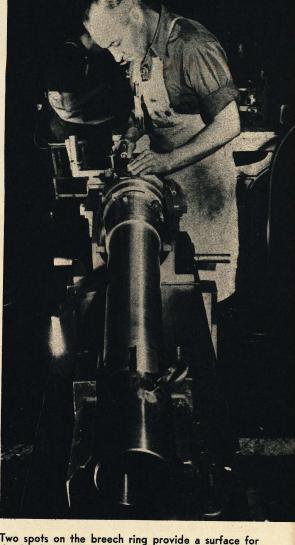
As the thread is chased out in a series of cuts, it is checked by means of a special roller thread gage. This gage fits the thread by the contact of two multiple V-rollers which are forced apart by means of springs. Each half of the gage has a locating point so positioned that a gage block can be placed between them. The block has a step in it, making one end larger than the other, and when placed between the locating points gives the "go" and "not go" positions of the thread sections. The locating gage which has been used to set up the threading tool also has a male V which fits between the threads to check their position when the breech ring centerline is set horizontally. From time to time, during the threading operation the thread position is checked until only a few thousandths remain for the final cut. Then the whole job is rechecked with a special plug gage which carries a threaded section and a cone to simulate the correct dimensions of the gun tube itself.

A small slot is then machined inside the breech block opening as clearance for the extractor toe, using a Norton keyseater. The extractor is a pivoted arm that removes the shell case after firing, and this slot allows the toe to remain flush with the inside face of the breech ring so the shell will fit squarely until the extractor is operated.

The cam lugs on the muzzle end are then form milled. It should be explained that in order to make sure that the assembly between the breech ring and the

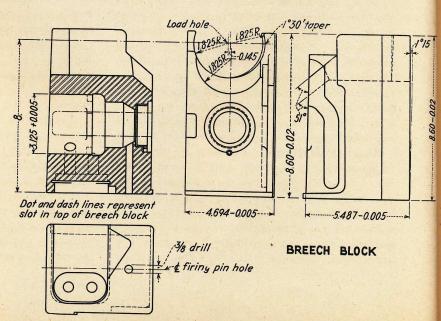






Two spots on the breech ring provide a surface for the leveling plate used in sighting the gun. They are carefully scraped with the breech ring assembled to the tube and supported by a fixture which simulates a gun carriage

Clearance is milled in the breech block load hole in a horizontal milling machine. After the right - angle cut has been taken the block is fed at an angle of 51 deg. Note that the axis of the cutter in relation to the block is not changed



tube is foolproof and that the threaded segments cannot possibly be started in a wrong position, the breech ring is guided by lugs in which are cut cam paths that fit over locating pins on the tube. These paths start out axially and then turn to follow the same lead as the threads of the breech ring. To make sure that the position of the lug cannot be reversed in fitting the ring to the tube, the pin that enters one path is larger than that which enters the other. When the ring is assembled to the tube, the cam paths follow the pins and guide the threads into engagement with those on the gun tube. This arrangement insures that the thread sectors will match and also avoids the possibility of butting the ends of the threads against each other during assembly which would be likely to create burrs that would destroy a good fit.

Fixture Controls Shape of Cam Paths

To mill the rotating cam paths, a special fixture is used on a Cincinnati horizontal milling machine. The paths are cut by means of end mills. The fixture is moved on a sliding base so that the ring travels axially into the cut. Then a handle is turned manually so that the work-holding section of the fixture is rotated. This section is fitted to the outer frame by means of threads which have the desired lead. As the breech block held within the fixture is rotated, a lead is formed in the cam path which corresponds to that built into the fixture which, in turn, is identical to that of the threaded portion of the breech ring.

Next a series of operations is performed on horizontal milling machines which chamfer angles on the side corners, the breech face and the load opening. Still another series of steps are taken on Pratt & Whitney slotters. These consist of slotting the sectors, clearances for the operating lever, the catch seat and the dovetail.

The slotting operations are followed by a number of other set-ups in vertical milling machines which have for their general purpose the removal of excess metal and the forming of radii to give the desired rounded corners to the part. The most extensive of these steps are those which remove the metal between lugs, put radii between the lugs and bevel the sectors.

Breech rings then go to the assembly department where they are finished by hand and portable tools to remove all burrs and rough edges.

Breech blocks are cut from forged steel bars $5\frac{1}{16}$ x 6 in. in cross section and about 8 ft. long. These bars are set up on a Cincinnati planer and planed on four sides leaving 0.025 in. for grinding. They are then cut to 8.7 in. lengths in a Wagner cold saw. One end of the block is ground square with the plane surfaces by mounting it on an angle plate on the table of a Blanchard grinding machine.

The blocks are then put into a drill jig on an American radial drilling machine, to cut and counterbore a number of holes including the firing case hold and the load hole.

At this point the blocks are normalized by heating them to 1,500 F. for two hours and quenching them in oil. They are then reheated to 1,300 F. for two hours and cooled in the furnace. This normalizing process refines the grain and at the same time removes any strain resulting from forging or the rough machining operations.

The blocks go back to the Blanchard grinder to be finished on the sides and the ends. Then come two turret lathe set-ups. The first is on a Gisholt machine which does the finish boring of the firing case seat, the recess and the boring and reaming of a number of angular surfaces in this portion of the block. The second set-up is in a Libby turret lathe in which the recess is counterbored and threaded.

Excess stock which has been left on the muzzle face is then removed in a Cincinnati vertical machine leaving an allowance for grinding.

This face is then ground on a Norton surface grinder. In two set-ups on a Cincinnati horizontal milling machine, the load hole is rough and finish bored, first parallel to the firing case seat and then cut at an angle of 1 deg. 30 min. to give it the taper on one side as specified in this design.

The sectors in the firing case seat are then slotted in a Pratt & Whitney machine. After this the breech block is set up in an American radial drilling machine to drill and ream the \(^3_8\)-in. vent hole, to drill the \(^5_{10}\)-in. radius which forms the corner of the trigger arm clearance, to drill and ream the trigger shaft hole and the hole parallel to it and to counterbore the trigger shaft pocket.

Irregular Contours Formed by Profiling

A Gorton profiler is then used to form the recess clearance for the trigger. Another American drill set-up drills, counterbores and taps the 10-32 hole for the bushing lockscrew.

After the cover seat has been milled and undercut, by using end mills in a vertical milling machine, another set-up on a Gorton profiler is used to finish the trigger clearance.

The 1 deg. 15 min. angle on the breech face is then ground on a Blanchard surface grinder. A series of nine operations follow using vertical milling machines and profiling machines to mill a number of slots and seats in the block including the extractor cam slot. Following this the guide surfaces are ground on a Norton machine. Then the 1.825-in. bore at the muzzle end of the load hole is milled to a 51-deg. angle. It will be noted that this radius is taken in the

direction of the bore of the gun and not parallel to the direction of the cut.

This is done by setting up the block on the milling machine table parallel to the cutter arbor, but with the table itself swivelled to an angle of 51 deg. By using a milling cutter of the proper diameter, the work can be fed across at this angle, generating an eliptical surface that blends into the load hole opening. This work is done on a Kearny & Trecker milling machine. Two other set-ups using the same make of machine, mill the load hole clearances, both the right-angle clearance on one side and the 61-deg. angle clearance on the other.

A series of milling operations follow which have for their purpose the rounding of the various radii on the corners of the block and the many slots and recesses as called for in the design. Here again Gorton profilers and Cincinnati vertical milling machines are used.

A block is then pack-hardened in a General Electric furnace and tested in the presence of a government inspector by means of a scleroscope. It is cleaned by mud blasting, reground on the outside surfaces in a Norton machine and hand-polished before assembly.

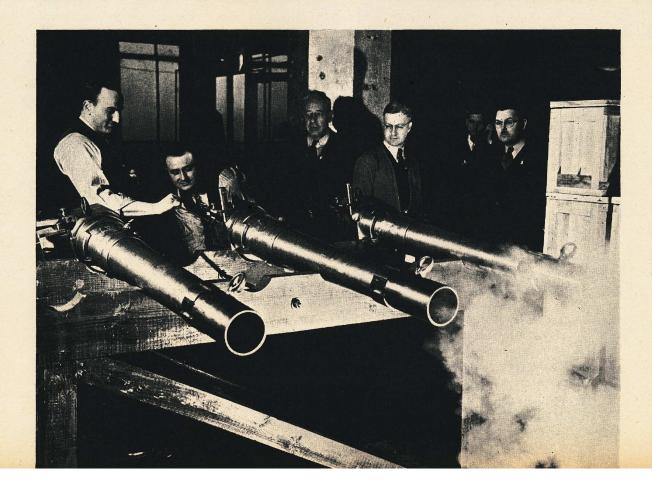
In addition to the main units described above, the breech mechanism of the 75-mm. howitzer includes a large number of small components which call for extreme accuracy in machining and assembly. All parts are carefully gone over by hand to burr and polish

them in order that no surface roughness remains.

Each part is checked 100 per cent by Army inspectors before assembling. For this purpose a large number of inspection gages are used. A popular type of gage for this purpose is the flush pin gage by means of which a number of dimensions can be checked simultaneously when the part is seated in the fixture. The pins are pushed into contact with the work and if the dimensions are accurate, the outer end of each pin should come between two surfaces that form a step in the gage. These two surfaces represent the "go" and "not go" limits and are usually only a thousandth or two apart. In spite of the fineness of this measurement, it can be quickly determined whether the end of the pin extends above one surface and below the other. In this way rapid and precise checks may be made with a minimum possibility of error.

The Army inspector's booth is adjacent to the assembly floor. In addition to inspection of the parts themselves, they are scrutinized as they go together.

As a final test, three primers are fired in each assembled howitzer. These primers are inserted into the primer seat of empty shell cases and are then loaded into the breech just as if the gun were being used in service. Firing the primer gives an additional check on the functioning of the breech block. On removal from the gun, the primer is inspected in order to note the striking position of the firing pin.





Howitzer components are carefully hand finished, fitted and assembled under the watchful eyes of the army inspectors

Small parts that make up the breech mechanism are carefully controlled as to size and quality by an exacting set of gages in the hands of an army inspector

After assembly three primers are fired in each breech. The functioning of the mechanism and the location of the firing pin impression on the primer are noted





BORE OPERATIONS ON MEDIUM CALIBER GUNS

BY MEDIUM CALIBER guns is meant the range of weapons larger in size than the rifle and the machine gun, but smaller than 8 in. in bore, commonly considered the minimum size of major caliber guns used for coast defense and for naval armament. For the purpose of this article guns used by the United States Army will be considered, although similar sizes of many classifications are used in the Navy.

The importance of this class of weapon may be realized by the fact that the French 75's were given credit for turning the tide in the World War. Today, even with the trend toward heavier, more powerful armament, medium caliber guns, ranging from 37 to 155 mm., are vital for our national defense. Big guns with a 20-mile range are spectacular in newspaper headlines, but in the last analysis military objectives are won and lost through the strategic use of smaller weapons.

The 37-mm. gun, for example, which may be rated as the smallest in the medium caliber category, is made in four types: tank, anti-tank, aircraft and anti-aircraft. There are variations in the length of the barrel and in the breech mechanism, but the basic design is

the same. For ground uses this weapon can be towed at high speed behind a truck; in an emergency it can be operated by one man through the medium of a simple telescopic sight. It throws a projectile weighing almost 2 lb., and is effective against the average armored target. It will pierce $1\frac{1}{2}$ in. of armor plate at 1,000 vd.

When used for anti-aircraft or aircraft service, a semi-automatic breech is provided, making its operation similar to, though not as fast as, a machine gun. In the air it is popularly known as the "cannon," carried by fighter or pursuit planes to distinguish it from the machine guns which formerly constituted aircraft's only armament.

For heavier tank service, the 75-mm. gun has been modernized through the application of a new breech mechanism. This gun is capable of stopping the largest tanks that have been introduced in the current European war.

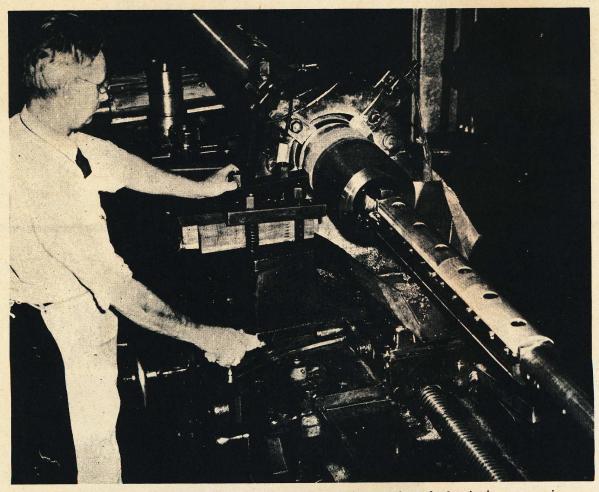
In addition to the 37-mm. gun, anti-aircraft classifications are represented by the 3-in. gun and the new 90-mm. gun considered to be the most effective weapon for this service. The 3-in. A. A. gun is capable of firing from 25 to 30 accurately aimed shots per minute; the projectile weighs 12.7 lb., and can be fired to a height of about six miles. The 90-mm. A.A. gun was designed to fill the need for an even more powerful weapon. It has greater range, a larger projectile, and fires faster.

The 105-mm howitzer is the high trajectory weapon that will be needed in largest numbers. It typifies the heavier division field pieces that are needed in modern warfare. The new 155-mm. field gun is another example of the powerful weapon required in large numbers today.

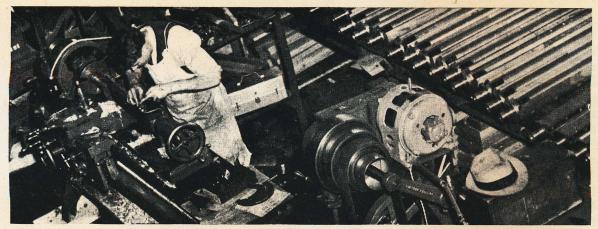
These weapons do not represent all the guns in the medium caliber class used by the United States Army, but they cover the range of sizes and will be used as examples in the following discussion on reaming, honing and rifling bores.

The most important part of a gun is the barrel or tube, for upon its precision depends the accuracy of fire. The most important steps in the manufacture of the gun tube are those on its bore. These operations are time-consuming and consequently determine the rate of output of this class of weapon; but because of the necessity for high precision, the quality of workmanship cannot be sacrificed for increased production. Vital, therefore, are those considerations that will permit greater output without impairing the quality of the final product. Methods to this end have been developed, and their wider use will remove another barrier to speedy rearmament.

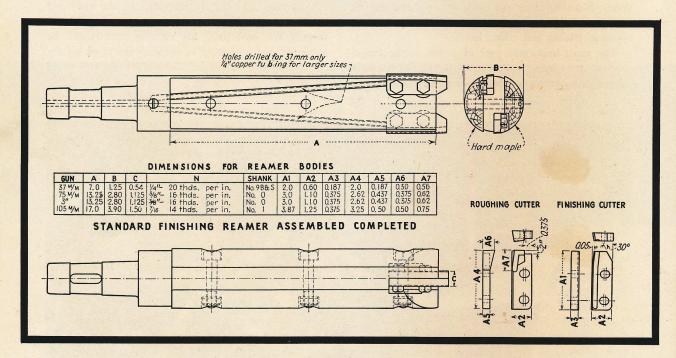
Gun tubes are usually rough drilled by the forge shop supplying them. On the 37-mm. size, however, Watervliet Arsenal prefers to do its own drilling. In this case the alloy steel forging (U. S. Army Specification 57-103) is first faced on the ends and then centered in an engine lathe. In setting up the forging for centering, the tube is "tell-taled" by means of dial indicators to equalize the stock on the outside in order to make certain that it will clean up to the finished tube. After drilling, a rough cut



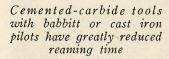
Bore reaming by means of traditional wood-packed tools gives good results but is time consuming

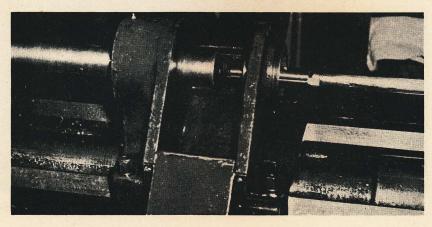


Since wood packing is good for only one bore the cost of maintaining this type of reamer runs high



Standard wood-packed reamer bodies for both roughing and finishing are shown for four sizes of gun tubes





is taken off the outside diameter in a Lo-swing formturning lathe to leave about 0.2 in. of stock for finishing.

Drilling is done on a two-spindle Pratt & Whitney machine. A $1\frac{1}{1}\frac{5}{6}$ -in. hole is put through the 37-mm. tube, using a single-fluted gun drill carrying a brass tube through which cutting oil is forced to flush out the chips. In drilling, a speed of 300 r.p.m. is used with 0.003-in. feed, to give a total time per tube of about $3\frac{1}{2}$ hours. The cutting tips of the gun drill are pieces of high-speed steel about 8 in. long, brazed to the shank. They can be sharpened until only about 3 in. of high-speed steel remains.

For the drilling operation, and for boring and reaming all sizes of medium caliber gun tubes, Watervliet Arsenal uses a 2:1 kerosene-mineral lard

Physical Requirements Gun Tube Steel
U. S. Army Specification Alloy Steel 57-103

	Transverse Specimen	Longitudinal Specimen
Tensile Strength, lbs. per		
sq.in		95,000
Yield Point, lbs. per sq.in.	The state of the s	65,000
Elongation, percent in 2 in.		21
Reduction of Area, percent		40

oil mixture. Oil pressures range from 60 to 500 lb. per sq.in., depending on the size of the tube and the size of the chip taken.

When gun tubes are furnished already drilled, the bore and outside diameter are carefully tell-taled with indicators along the entire length. The objective is to set up the tube so that the roughing reamer will have about an equal amount of stock to remove on each side, and at the same time leave sufficient stock for finishing the outside diameter.

The traditional method of reaming gun tubes for both roughing and finishing operations is by means of wood-packed reamers. The tube is first counterbored for a short distance in order to make certain that the reamer is started straight. The wood-packed tools consist essentially of a cutting head followed by two semi-cylindrical wood inserts which form the support for the bar. The inserts are made of selected hard (or rock) maple, which is first kept under a vacuum for 24 hours to extract all moisture, and is then soaked in an impregnating oil for an equal period of time. The ends are waxed to keep the wood from checking. The woods are turned when ready to use in their place on the bar to 0.005 in. over the reamer cutter size, which insures rigid support for the bar. High-speed steel cutter blades are used for roughing and carbon steel for finishing.

For many years this method was considered the

OPERATION LIST FOR THE 37-MM. GUN TUBE

Oper.	Operation	Machine	Oper. No.	Operation	Machine
1	Face ends and center	Lodge & Shipley engine lathe	13	Rifle	Rifling machine
2	Rough turn, leave 0.2 stock for finish	Lo-Swing automatic lathe	14	Semi-finish turn, leave 0.02 stock on diam. finish grind	Engine lathe
3	Drill bore	Two-spindle P. & W. drilling machine	15	Finish grind exterior, all surfaces except	20-in. Cylindrical grinder
4	Spot for roughing reamer, turn breech	Engine lathe		muzzle end and rear slope	
	end to 4.812 diam., muzzle end to 2.312		16	Finish shoulders and slope on rear exterior	Engine lathe
	diam. to fit rifling	Dealers laste	17	Cut thread	12x48 in. Thread mill- ing machine
5	Rough ream bore from muzzle end	Boring lathe, 10-in.x24-ft.	18	Mill breech ring	Hobbing machine
6	Straighten if necessary	50-ton press		thread	
7	Spot for finish reamer	Engine lathe Boring lathe	19	Mill extractor pockets and keyways	No. 5 Vertical milling machine
8	Finish ream bore from breech end		20	Mill keyway	No. 4 Horizontal mill- ing machine
9	Hone bore	Honing machine			
10	Star gage bore	Star gage	21	Cut to length and bevel rifling in	Engine lathe
11	Face breech end and bore powder	No. 3A Turret lathe	22	muzzle end	Ponch
12	chamber Grind bore	Bryant grinder	22	Mark top of tube and muzzle	Dencii

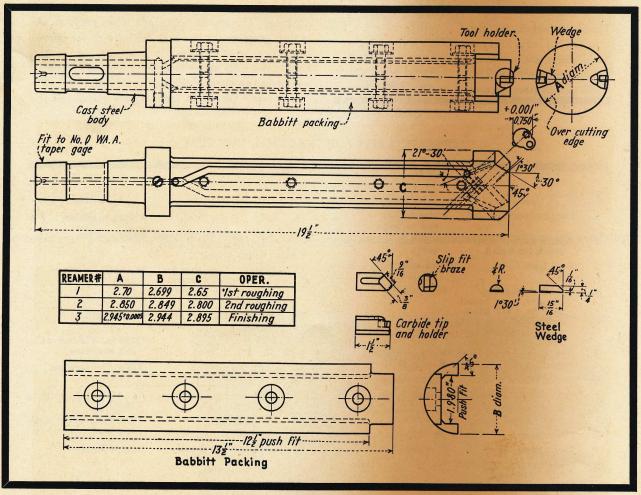
only way by which gun tubes of required size and straightness could be reamed. The process involves several disadvantages. The wood packing must be replaced after each hole is reamed, which makes the initial preparation and the maintenance of the reamers expensive. The process is slow; on the 3-in. A.A. gun tubes, and up, it is necessary to start the roughing reamer from each end of the tube and then pass the finishing reamer throughout the length. Each of the three steps on the 3-in. A.A. gun takes about eight hours, making 24 hours in all; the time for the 90-mm. gun runs about the same. The 105-mm. howitzer being shorter (about 7 ft. as compared to 13 ft. for the 3 in. and the 90-mm. guns) takes twelve hours to rough and finish ream by the wood-packed reamer method.

About $\frac{1}{4}$ in. of metal is removed on each side in rough reaming, with a feed of 0.010 to 0.012 in., and a speed of 4 to 5 r.p.m. Finish reaming removes

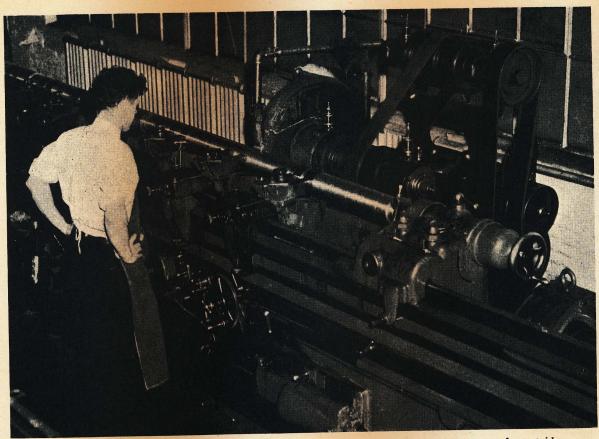
0.025 to 0.030 in. on a side, with a feed of 0.030 in. and a speed of 9 r.p.m. These cuts are for the 3-in. and the 90-mm. A.A. gun tubes. On the 155-mm. gun, with the wood-packed reamer, roughing takes about 24 hours and finishing twelve hours. This time is exclusive of the powder chamber and gas seal reaming on the 155-mm. gun, which also employs wood-packed tools.

The introduction of two modern tools, cemented carbide and honing, has greatly facilitated gun reaming. It must be remembered that the speed of the older method is limited by the necessity of keeping tool wear at a minimum throughout the length of the cut. Any wear meant taper in the gun gore. Cemented-carbide tipped cutters resist wear, even when used at high speeds while the final honing process further smooths and straightens the bore.

For instance, rough reaming the 37-mm. gun is now performed successfully with carbide-tipped tools in

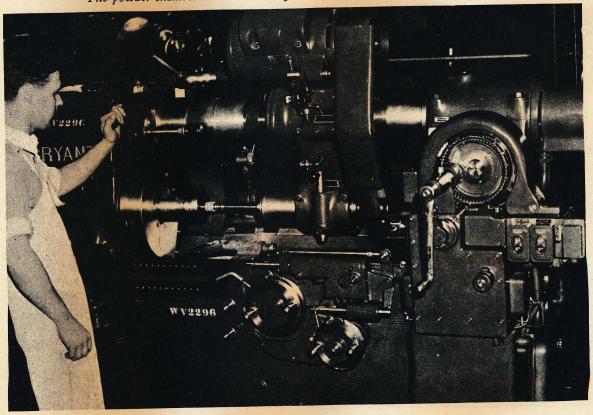


The new babbitt-packed reamers use carbide cutters. A set of three gets the 75-mm. tube ready for the honing operation



The 3-in. A.A. gun has a loose replaceable liner that must be taper ground on the outside

The powder chamber on the 37-mm. gun is now finished on a grinding machine





Honing is done on surface speeds ranging from 80 to 120 surface ft. per min. using a 60:40 mixture of sulphur base oil and kerosene

The White head is still used on some sizes for the rifling operation. Only part of the grooves are machined at a time



20 min., an operation that consumed 3½ hours by the older method. Wood-packed reamers are still used for finishing this size. But for the 75-mm. gun, reaming is done in three steps, all using carbide cutters at 260 r.p.m., and 0.015 in. feed. The reaming operations are entirely completed in one hour.

For carbide tipped reamers, the wood packing is replaced by babbitt with about 0.001-in. clearance in the bore. In using these tools, as with the wood-packed reamers, it is essential to keep the supply of cutting oil at a pressure that will flush out all the chips ahead of the cutter. However, with the carbide reamers the chips are formed at a much faster rate, and for this reason a cutting oil pressure of 500 lb. per sq.in. is maintained. Because of this flushing away of the chips the babbitt-packed reamers have the further advantage of being usable on six to eight tubes instead of one, as in the case of wood packing.

Bronze supporting collars are used on the bar after it has entered the hole a sufficient distance to receive them. During the reaming operation, dial indicators are placed against the bar near the mouth of the hole to indicate any runout. If the hole is not straight, the indicator needle will swing through an arc to show eccentric motion of the bar. Final reaming is always done from the breech end of the tube.

The 3-in. A.A. gun involves a special problem. Because the design calls for a loose liner that can be replaced in the field, the tube is tapered in the bore 0.005 in. per inch of length; to fit this taper the outside of the liner is ground to the same taper. The bore of the gun tube is reamed with wood-packed tools, and because of the taper, fourteen stepped reamers are required for roughing; these are straight, but differ in diameter. The finish reaming operation uses two sets of tapered reamers, six in each set. These reamers, together, make up the taper of the tube and overlap in the bore about 1 in. so the cuts will be properly blended. They are fed to a scribed line on the boring bar, and the feed must be stopped accurately to insure a good bore. Rough step reaming takes about 48 hours and finish taper reaming 44 hours.

Powder chambers are also reamed with woodpacked tools. These include both straight and tapered surfaces, the latter forming the shell seat. The time for this operation varies from four hours on the 75-mm. tube to 24 hours on the 155-mm. tube. Usually two roughing and two finishing reamers are employed.

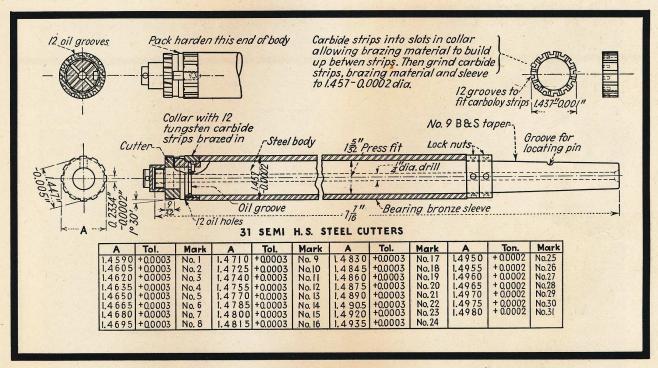
On the 37-mm. gun, however, the powder chamber is first bored on a turret lathe with the cutter guided along the contour of the chamber by means of a cam slot. The final finish is given on a Bryant chucking grinder in which the wheel is similarly guided. The

smooth finish thus obtained is desirable, especially when this gun is used with a semi-automatic breech. At the time of explosion the cartridge case is expanded against the walls of the powder chamber. Any surface roughness will make the case difficult to eject and may cause jamming where the semi-automatic breech is used. Grinding not only avoids this possibility, but also cuts the time of finishing the chamber from three to two hours.

In the 37-mm. gun the powder chamber is finished after the bore is honed. In the larger sizes of tubes, where wood-packed reamers are used, the powder chamber is completed before the bore is honed. The

37-mm. gun and 160 r.p.m. on the 75-mm. gun so the peripheral ft. per min. run from 80 to 120. Aluminum oxide stones, 320 grain with a soft bond are used. About 0.005 in. of metal is removed in honing. Usually only one honing tool is used, but on the 155-mm. size two hones are put through the bore, the finisher removing only 0.001 in. of metal. For honing, the cutting lubricant is a sulphur base oil mixed with kerosene in the ratio of 60 to 40.

Probably the most ticklish job on the gun bore is rifling. Upon the shallow helical slots that are cut in the bore of the tube depends the twist given the projectile as it leaves the gun muzzle. These slots



This bar and set of broaching tools perform the rifling on the 37-mm. gun

chambering reamers have pilots which are guided in the finish reamed bore. If these pilots leave any mark in the tube, it is removed during the honing operation. Where grinding is used on the powder chamber, as in the 37-mm. size, a pilot is unnecessary.

Honing is now used as the final finishing operation on the bores of all medium caliber guns. The tube is held stationary while the honing stones, supported in a floating head, reciprocate and revolve along its entire length. Honing time ranges from one hour on the 37-mm. gun to 3 hours on the 155-mm. size. Reciprocations are about 60 ft. per min. on the larger sizes and 70 to 80 ft. on the 37- and 75-mm. sizes. The hone revolves about 250 r.p.m. on the

must be accurate as to size and helix angle; and above all they must be smoothly finished, for any surface roughness will certainly shorten the life of the gun tube.

For years the White head has been used for this work. The cutter blades are held in the head, extending around its periphery. They have micrometer adjustment and are arranged to recede into the head when a stop strikes the end of the cutter bar, driving back a tapered plug. This action prevents the cutters from dragging against the work on the return stroke. At the end of the return stroke the operator sets the cutters to their previous position, and then by means of the micrometer adjustment, expands them 0.001 in.

which gives the additional amount for the next cut.

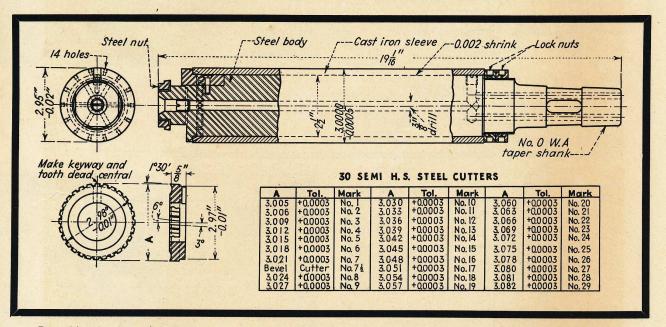
Because of the need for fine finish, only part of the grooves are cut at one time when the White head is used. For example, on the 90-mm. A.A. gun, which has 32 grooves, only eight are cut at a time. Each group of grooves requires about 50 passes of the cutter head; the speed of the cut is about 8 ft. per min. Because of this, and the necessity of stopping the bar at the end of each stroke to adjust the cutters, the process is a slow one. For the 37-mm. tube, rifling takes about eight hours with the White head. The 3-in. A.A. and the 90-mm. A.A. gun tubes each take about sixteen hours; the shorter 105-mm. howitzer consumes about twelve hours in rifling.

The broaching process has now been applied to rifling with considerable success. Broaching tools

sleeve of bearing bronze forms the pilot. Each broach cuts all grooves simultaneously. It is pushed through the bore from the muzzle end and is removed at the breech end to prevent scoring the grooves on the return stroke of the bar.

Twelve radial oil holes in the toolholder connect the central channel with points just behind each cutting tip in such a way that the cutting oil is forced against the bore just ahead of the bronze sleeve, but behind the cutter. This arrangement effectively flushes the chips ahead of the tool and keeps them from marring the bearing surface which guides the bar. A 3:1 mixture of kerosene and pure lard oil is used as the lubricant. A pressure of 70 lb. per sq.in. is maintained.

At the periphery of the section between the cutter



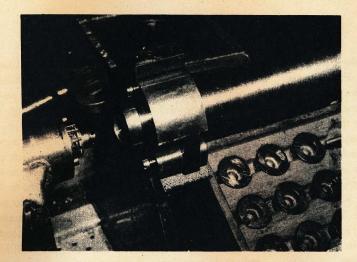
Broaching has also been applied to the 3-in. A.A. gun. Here are shown the shank and the broaching disks

have been made for the 37-mm., the 75-mm. guns, the 3-in. and the 90-mm. A.A. guns. For the 37-mm. tube rifling time has been reduced to two hours by broaching. On this size, 30 broaching tools are employed. Using a LeBlond machine, each tool is successively pushed through the bore; the first tools remove 0.0015 to 0.003 in. of metal, and the last ones 0.0005 to 0.001 in. The tools are inspected by means of optical comparators to make certain that they are of exact size and shape.

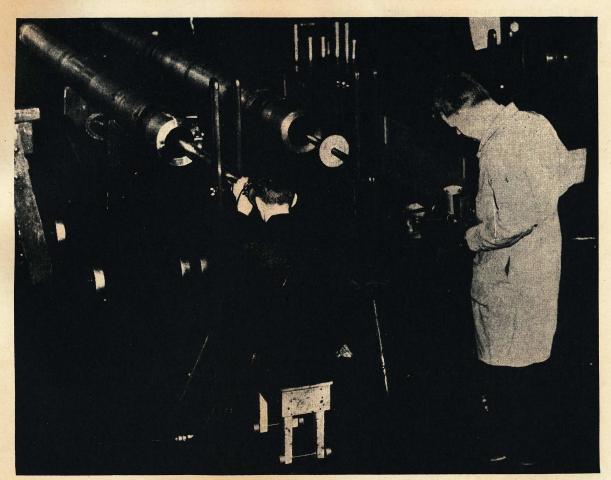
In the 37-mm. tube, there are twelve grooves, 0.02 in. deep, and 0.234 in. wide. The broaching disks are mounted in the ends of a bar having a steel body through which is drilled a central oil hole. An outer

and the bronze sleeve, carbide inserts are brazed into the bar to form a wearing surface which prevents looseness between the bar and the bore.

Various arrangements are employed to give the helical twist to the cutter bar. At Watervliet Arsenal the body of the bar carries a helical groove into which a stationary key is fitted. As the bar is fed forward the key gives it a twist. Ball thrust bearings are provided to make this action easy. Also, the key and slot are lubricated with white lead. A counterweight at the end of the mechanism is arranged so that the bar will bear against one side of the key only. This device avoids any lost motion and maintains uniformity of the helix, even though the key becomes worn.



Broaching brings economies in rifling. Successive disks are pushed through the bore, each cutting all grooves simultaneously



Honed bores are inspected by the Boroscope (left) for quality and the star gage (right) for size



The 37-mm. gun fills four different needs. The barrel shown is equipped with drop-block breech but a semi-automatic breech is used on certain types

For large gun tubes broaching works equally as well with corresponding saving in time. For instance, on the 3-in. gun, the broaching job can be done in three hours as against fourteen to sixteen hours by the older method. This size of tube requires 32 broaching disks. The 75-mm. gun uses rounded rifling grooves which makes the operation much easier. With this design only sixteen disks are needed, and the work can be completed in one hour. Cutting speed is approximately 8 ft. per min. For this size of gun, and for the larger sizes, a cast iron pilot is preferred to the bearing bronze.

While not all sizes of guns have been tooled up for broaching as yet, there is no reason why all of them, up to the 155-mm. size, cannot be rifled in this way.

The gun tube is made about 2 in. oversize in overall length, the extra stock is retained until after rifling when it is cut off and the muzzle end of the bore is chamfered. This procedure is followed because when the rifling tools first enter the bore they tend to chatter; after the initial impact and when the pressure of the cut becomes uniform the chatter disappears. Cutting off the end of the tube removes the

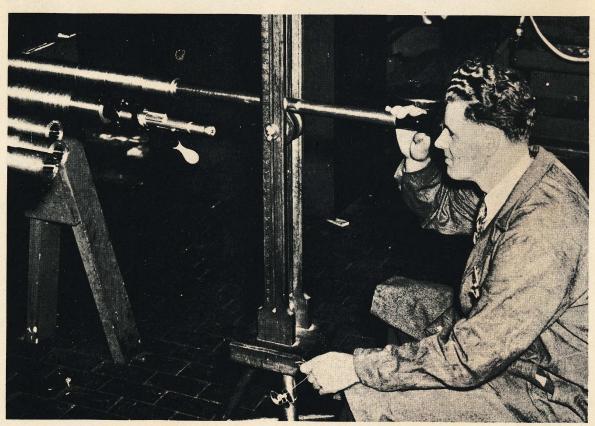
surface roughness at the end of the rifling grooves.

Gun tube bores are subjected to extremely strict inspection. They are checked carefully by trained inspectors after honing, and again after rifling. The principal inspection devices are the Boroscope and the star gage.

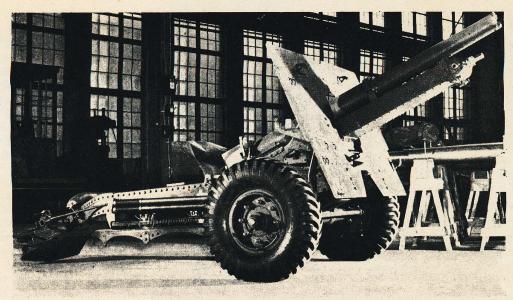
The Boroscope gives a visual inspection. A tube is put into the bore of the gun and by means of suitable mirrors and lenses projects a view of the surface of a 3 to 1 magnification to the outer end of the tube.

The star gage is an adoption of the vernier micrometer, also constructed on a long tube. Three points at one end of the star gage come in contact with the bore, while settings and readings are taken at the opposite end. Gun tubes are measured along every inch of the surface after the honing operation. The gage is passed through the tube inch by inch, first with two points down and one contact point up. When readings are taken, withdrawing the gage, with two points up and one down.

After rifling, the star gage readings are taken at the bottom of the groove. Each groove is checked every 5 in. along its length.



Another complete inspection follows the rifling operation including a visual check with the Boroscope



The 25-pounder gun now largely replaces the 18-pounder familiar during the World War. It is Britain's prize field piece

STEEL SCRAP TO 25-POUNDERS

Sorel Industries, Ltd., new from the ground up, has become an outstanding supplier for Canadian and British armies

The 25-pounder gun proper consists of the barrel, the jacket and the breech mechanism, the largest components of which are the breech ring and the breech block. The steel scrap from which these parts are made is received on river barges which are unloaded by means of a huge crane and transported on flat cars to the scrap storage pile. The selected scrap used is cut up into appropriate sizes for furnace charging by shears or by the oxyacetylene torch. Such material as billet croppings, railroad wheels, scrap shell and machine turnings, are used. Under the careful control of the metallurgical laboratory, this material is melted in two electric furnaces of four and eight tons capacity respectively. The charge is combined with alloying elements including about three percent nickel.

When the melting process is complete, the furnace is tapped into a ladle, and the molten metal is cast into ingot molds. After solidifying, the ingots are kept in a coaking pit until ready for blooming which is done in a 2,000-ton press.

Further fabrication to bring the steels to workable size, is carried on in forging presses

and in steam and air hammers. In the forge shop, parts ranging from small drop forgings to large billets for the barrels, jackets, breech rings and breech blocks are formed. For smaller sized bars a rolling mill has been installed. It is interesting to note that this mill is the same one that was used by the Ford Motor Company in its exhibit at the Chicago Fair.

Billets for the barrels are cut off on the ends in a cold saw and then centered by means of portable drills. The next operation is rough turning which is done on a double-carriage engine lathe. Then the barrels are rough drilled in a center-drive machine with the drills fed from both ends simultaneously. High-speed drills are used with tips shaped much like the ends of twist drills. A heavy flow of cutting compounds flushes the cnips.

At this point the barrels are normalized. For this operation and for other heat-treatment on the barrels and jackets, ten vertical electric furnaces are installed at Sorel. Eight of these are capable of handling barrels up to 28 ft. in length.

After normalizing, the barrels are straight-

Sorel is unique in that its operations embrace virtually every step from the scrap pile to finished gun. Here an electric furnace is being tapped into a ladle prior to casting the ingots

ened, if necessary, in a hydraulic press and are then rough and finish bored in engine lathes. Double edges high-speed steel cutters are used with the bars guided by bronze pilots. Cutting oil is supplied through holes in the boring bars. The barrel chamber is then roughed out.

Following this, the bore is honed. The outside diameter is again turned and polished smooth at four points along its length for the auto-frettaging process which comes next.

Auto-frettaging is a process which gives desirable characteristics of strength and wear to heavy steel tubes. It consists of expanding the tube radially by applying hydraulic pressure to the bore; the pressure used is sufficient

to exceed the elastic limit of the metal in the bore. This action causes the metal in the bore to yield plastically and maintain a permanent set. The outer layers, which are not stressed beyond their elastic limit attempt to return to their original dimensions.

The result is much the same as when steel hoops are shrunk on the outside of a tube. The inner wall is in a state of residual compression and the outer wall in a state of residual tension resulting from the cold working received during the process.

As performed, on the 25-pounder gun barrel, the two ends of the barrel are counterbored, reamed and threaded to a shoulder. This permits making the appropriate connections. One end of the barrel is connected through a high pressure pump, while the other is connected to a specially designed valve which releases the liquid, a combination of water and glycerine, through a pressure gage.

Core Bar Reduces Liquid Required

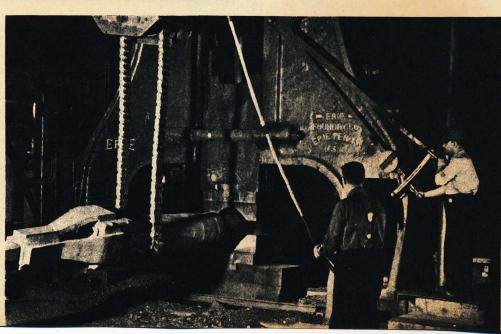
Before the gun is set up, a steel core bar is placed in the bore. This core is bored for a short distance at both ends, and at the inner end of each of these holes, a radial hole is drilled. The course of the liquid is through the core out through the first radial hole to the outside diameter where it passes along between the barrel and the core bar and reenters the second radial hole at the opposite end. This arrangement reduces the quantity, of liquid required.

After the pipe connections have been made, indicators are placed at the four points along the length to obtain readings on diameters 90 deg. apart. The pressure is applied in four steps with readings taken at 20, 24, 28 and 32 tons per sq. in.

An interesting feature of the pressure valve



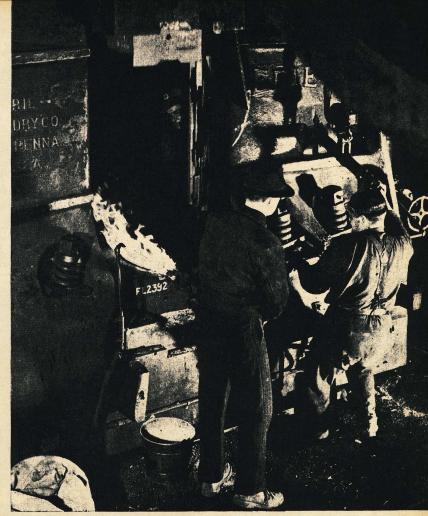
Barrels and jackets are hot worked in a steam hammer to form billets of suitable dimensions for the turning operations which follow

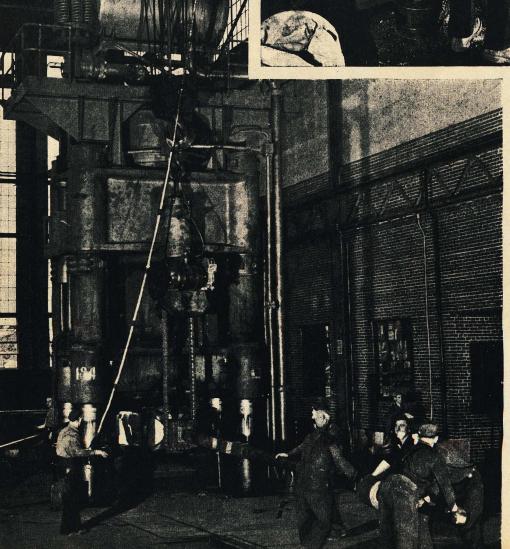


is that it is equipped with an accurate scale to measure pressures up to 50 tons. The dial of the gages is calibrated on a scale at the plant to obtain accurate readings.

Before the barrel is set up for auto-frettaging it is carefully measured in the bore and on the outside at the four spots polished in the lathe. Outside measurements are made with micrometers and inside measurements with a pullover gage and micrometer. At each increment of pressure the outside diameter of the barrel is again measured at the same four points at two diameters at right angles to each other. These readings are taken by precision dial gages reading to 0.0001 in.

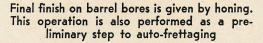
The readings taken while the pressure is being applied are plotted on charts and their positions noted in relation to standard stress curves. From this it is possible to ascertain the amount the elastic limit has been exceeded which is an indication of the degree of cold working of the gun bore. Variations in the size at points along the length make possible





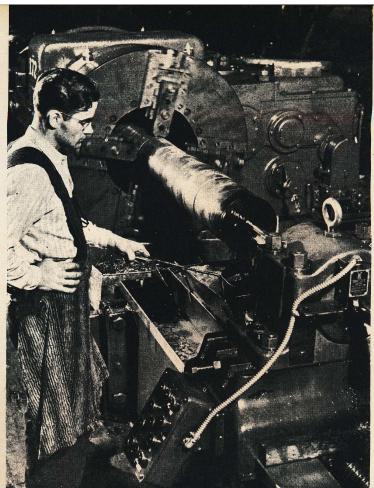
Small parts are drop forged. This forging will become the elevating arc, one of the components of the carriage

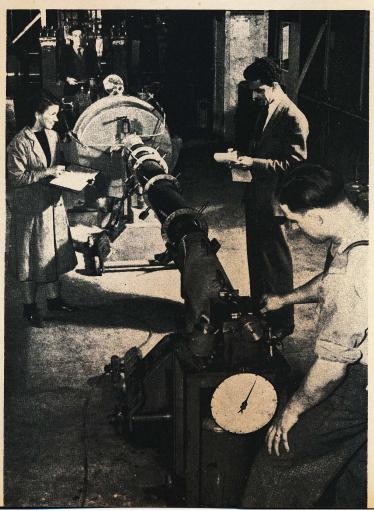
A huge blooming press performs the first steps in bringing the hot ingot down to size and shape for further forging operations Barrels are drilled in a center drive lathe of modern design which permits working simultaneously from both ends. Chips are flushed out by a heavy flow of cutting oil





During the auto-frettaging process dimensional readings along the outside of the barrel are taken while the internal pressure is increased. The man at the near end operates the pressure valve and controls the pump by means of a foot switch





the detection of any irregularity in the expansion of the metal under pressure.

After the 32 tons per sq. in. load, the pressure is released and the liquid is drained out of the barrel. It is then given a low-temperature anneal in one of the vertical electric furnaces previously mentioned. Auto-frettaged steel barrels are unstable and must be aged or followed by a low temperature heat-treatment. If over tension is followed by a low temperature anneal, the steel recovers and the elastic limit increases to a value equal to or greater than the auto-frettaging pressure.

Pressure Applied Second Time

After annealing, the barrel is again returned to the auto-frettage set-up for a test pressure. This time the hydraulic pressure is brought up to the maximum of 32 tons per sq. in. in a single step, and dimensional readings are taken again. If any irregularity has been caused by the treatment it can be noted at this time. After the pressure is removed readings are taken on the outside diameter and in the bore at the same four points.

Auto-frettaging expands gun barrels of this size from 0.012 to 0.020 in. in the bore and from 0.006 to 0.010. in on the outside. The difference between these two figures measures the permanent set of the barrel. The steel on the inside has been compressed which changes the structure throughout approximately half the cross section of the wall.

After the pressure test the barrel is given a second heat-treatment. Then the ends are cut off including the threaded portions which were used solely for connecting the fittings during auto-frettaging.

The barrels are again set up in a lathe and bored to 3.35 in. Then they are set up on plugs in an engine lathe for a second turning operation on the outside diameter. Another boring operation brings the barrel to 3.440 in. inside diameter.

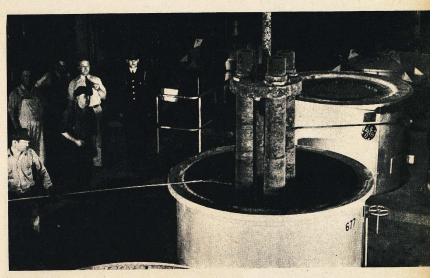
At this point it is necessary to rehone the bore. The first honing was done in order to obtain a good gaging surface for the autofrettage operation, and the finish obtained is subsequently destroyed by heat-treating and reboring. Rehoning brings the bore to final size and destores the highly finished surface.

A centering plug is then put in the muzzle end of the barrel and held in a chuck while the breech end is held in a steadyrest. In this set-up the final chambering operations are performed.

The outside surface is then ground for the jacket; the barrel is given a slight taper. In two lathe operations the outside of the breech end is finished, the front cone is turned and the barrel faced to length.

The rifling operation follows. This is done in a machine which uses a sine bar mechanism for generating the helix of the rifling groove. As the carriage for the rifling bar travels along the bed of the machine it carries with it a slide, the end of which is guided by the sine bar attached to the bed. To the underside of the slide is bolted a rack which meshes with a pinion keyed to the rifling bar. As the carriage moves longitudinally the rifling bar is given a rotary motion according to the degree of angularity of the sine bar.

The forward end of the rifling bar carries a two-toothed cutter which machines two rifling grooves simultaneously. These cutters collapse into the bar automatically at the end of the stroke so they will not drag on the return stroke and mar the grooves. After the bar is withdrawn from the bore the cutters are pushed out to their initial position and are



then expanded an additional amount for the next cut. This procedure continues until all the grooves have been completed. After each pair of grooves is finished the bar is indexed to the next two with the cutters reset to their starting position. As in all rifling set-ups a liberal supply of cutting lubricant is forced through the hollow bar to wash the chips away so they will not damage the cut.

With the exception of a few milling and drilling operations, this makes the barrel ready for fitting. Extractor clearances and a flat on the muzzle end for the climometer are milled and air release holes are drilled in separate operations after rifling is completed.

In general the turning and boring operations on the jacket parallel those on the barrel. However, a few variations should be noted. Jackets are first machined in pairs;

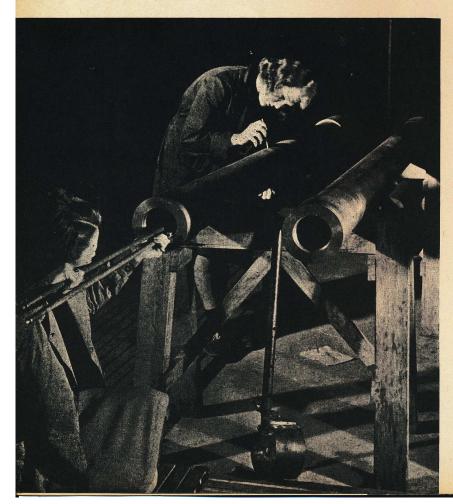
The full effect of auto-frettaging is brought out by heat-treatment. These electric furnaces are used for barrels and extend to a depth of 28 ft.

that is, the stock is rough turned and drilled in sufficient lengths to provide for two jackets. After rough drilling, the jackets are cut to 55-in. lengths in a cold saw. At this point samples for chemical analyses are taken. Jackets are given only one heat-treatment which immediately follows this operation.

Since the jacket bore is larger than that for the barrel it is possible to use multiple tooling. A bar with seven tools is used, and these are set up with each one slightly higher than that preceding it in order to approximate a taper. A wood packing guides the bar. Then a continuous cut is taken to give the jacket bore its taper, leaving about 0.015 in. for grinding. The grinding operation is done with a special grinding attachment mounted on the tool carriage of an engine lathe.

Two other steps on the jacket differ from those on the barrel because of its design. A buttress thread must be cut on the breech end to receive the breech ring. In addition the jacket is fitted with three annular segments or thrust bands which engage the recuperator block and transmit the force of the recoil to the recuperator niechanism. These details are first roughed out and then finished in lathe set-ups. Since both the buttress thread and the thrust bands are interrupted, the unwanted

After auto-frettaging and the subsequent test pressure, barrels are gaged inside and out. Bore dimensions are checked by using a micrometer over the outer end of the pullover gage



portions of them are removed in the milling machine.

After this work has been done, the jacket is carefully laid out, and the horizontal and vertical axes are marked. The jacket is then ready for assembly with the barrel.

Billets for the breech rings and the breech blocks are descaled by the oxyacetylene flame before machining in long lengths on four sides. These operations are done on a planer before the billets are cut to suitable lengths for making the individual parts. About fourteen breech blocks and eleven breech rings are obtained from a billet. After the parts have been sawed apart, the front and back faces are milled in horizontal milling machines.

The breech ring then has a $2\frac{1}{2}$ -in. hole drilled in the center in a radial drilling machine. It is then bored part way through a $3\frac{1}{2}$ -in. diameter in a second milling machine set-up. At this point it is heat-treated, drawn and tests coupons cut or trepanned out.

The breech opening is roughed and finished in a vertical milling machine and the actuating shaft clearance is cut. The breech side of the ring is surface ground in order to square that face for setting up for the turning operations. In a lathe set-up, it is rough and finish bored and threaded to match the jacket; then located from the threads, the piece is returned to a vertical milling machine while the outer surfaces are machined. These surfaces are then ground in a large surface grinder.

Many Milling Cuts Used

A large number of milling operations follow and include cuts on the breech opening, the recesses for the block and the angles on both sides. The hinge holes and actuating shaft clearances are bored and faced in a horizontal boring machine.

At this point a master breech block is fitted to the ring, and two bronze bushings are pressed into place. Interruptions in the buttress threads are removed in a vertical slotter with the ring located from its bore. Another series of minor milling operations perform such steps as chamfering the angles and radii on all sides of the ring, cutting the climometer recess and firing bracket pocket and machining the breech block stop. Drilling and fitting makes the breech ring ready for assembly with the jacket.

As has been pointed out, the first operations on the breech block are similar to those for the breech ring. After the blocks are cut off from the long billets, the load holes and cartridge gaps are rough drilled before the blocks are heat-treated. As with the breech ring most of the operations on the block are performed



A block which slides in a sine bar gives a rotary motion to the rifling bar as the carriage travels back and forth along the bed

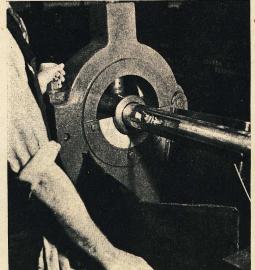
in milling machine set-ups. The faces are ground on a surface grinder on four sides, four blocks being set up on the table at a time.

Another piece that is machined from a long billet is the recuperator block. The ends of the billet are sawed off, and then the block is planed eight pieces at a time. These operations include top, bottom and sides with the bottoms being cut into steps to reduce the amount of stock necessary to remove later by form milling. The breech end face is then machined in a shaper. The top profile is also planed and then rough form milled including the radius to form the storage tank.

It should be explained that the recuperator block contains four bores running through its entire length which control the recoil and recuperator mechanism. These cylinders are drilled in a lathe using a special fixture. The block is mounted in a frame which consists essentially of a pair of rings a little farther apart than the length of the block and held together at opposing points on their diameters by cross bracings. One of the rings is clamped to the faceplate while the other runs in a steadyrest. A hole in the center of the ring away from the faceplate carries a drill bushing.

ing.

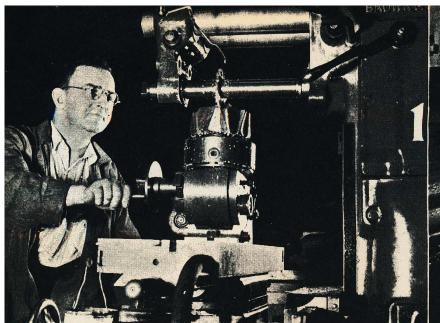
The block is located by its corners against fixed stops in the rings which brings the air cylinder directly in line with the spindle of the lathe and the hole in the bushing. In this position the air cylinder is drilled. Similar fixtures are used for drilling the buffer cylinder, the recuperator cylinder and the storage tank, which is also a cylinder designed to re-



The rifling cutter automatically recedes into the bar on the return stroke and comes out during the cut. It is adjusted outward an additional amount for the feed

A ticklish operation on the breech ring is done in this engine lathe set-up. Here the ring is bored, counterbored and threaded, using a fourposition toolpost







Sorel has its own toolroom where it makes special cutters, gages and fixtures. This large milling cutter set up on a dividing head is typical of this department's output

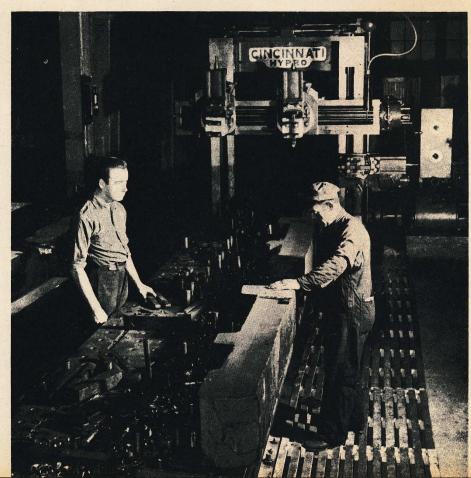
Another operation on the recuperator block is to mill the bearing brackets which engage the gun jacket on assembly. This view shows some of the form milling cuts previously taken

ceive the recoil dampening liquid when the gun is fired.

After the drilling operations, the block is again planed, top and bottom and both sides, leaving 0.100 in. at the corners for finish. This operation trues up the block and corrects any distortion that have occurred during the drilling. Then the block is bored, two holes at a time by means of a special fixture on an engine lathe. By means of a gear train, two boring bars are driven simultaneously from the headstock and are supported on the tail-

stock of the machine. A special table attached to the lathe carriage locates the recuperator block. When set up in this position, the block is carried along the length of the lathe bed while the boring bars first rough and then finish bore the holes. The two remaining cylinders are rough and finsh bored separately.

After the ends of the cylinders are counterbored the block is again put on a planer to finish the corners to their final dimensions. With the exception of the storage tank the cylinders in the recuperator block are honed.



Recuperator blocks forged from ingots from Sorel's own steel furnaces are set up on a planer for the first machining operation This is done on the same type of machine used for the barrels. From 0.012 to 0.015 in. is removed by honing.

The block is tested and then subjected to a hydraulic pressure test. Test pressures on the various cylinders range from 3,000 to 5,000 lb. per sq. in. except for the storage tank which is tested at 40 lb. per sq. in.

The cylinders after the test are counterbored, undercut and threaded. A number of smaller drilling and milling operations follow to form a number of port and valve openings and locating points for the bearings.

The buffer cylinder is rifled with grooves that are approximately $\frac{1}{2}$ in. wide and 0.100 in. deep. These grooves have a slight helix angle and are used to operate the valve mechanisms incidental to the functioning of the recuperator mechanism. They are cut in the same kind of machine used for the barrels.

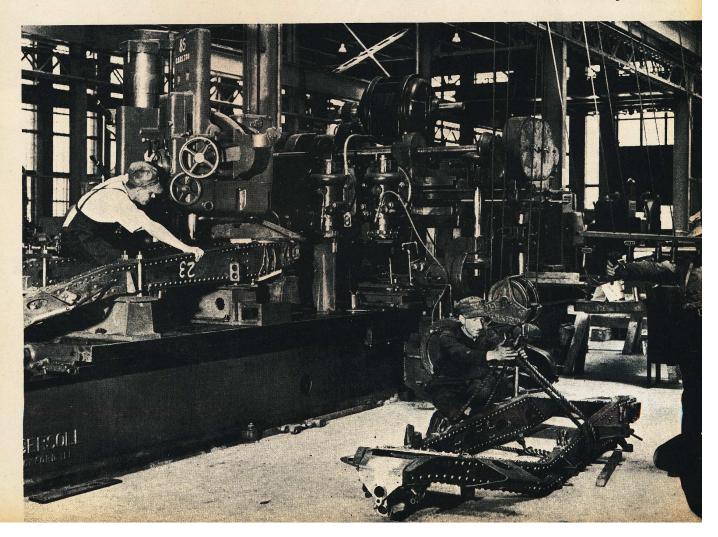
A series of small cuts on drilling and milling machines following the rifling operation makes the blocks ready for assembly. The first step in assembly is to add the liners which are on the outside of the block at the four corners. These are fastened to the block with countersunk screws and are then planed in place. The block is then inspected all over and the cylinder plugs are fitted. The recuperator

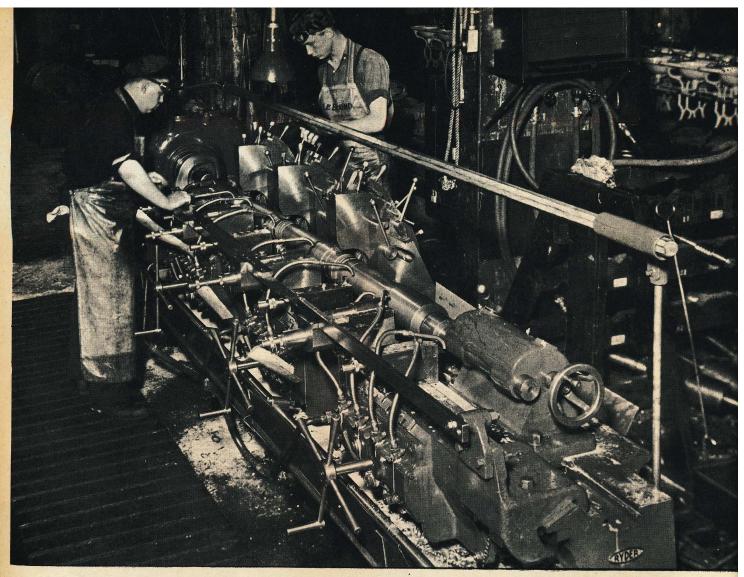
block engages the thrust rings in the jacket and in turn slides in a component called the cradle which is of fabricated steel.

In addition to the gun proper, 25-pounder gun carriages are made at Sorel. The carriage is a fabricated job built up chiefly from structural shapes and plates purchased from outside venders. The plates are cut to shape either by the oxyacetylene flame in shears or on nibbling machines. Rivet holes are punched in the plates using gang set-ups where possible to save time.

The gun carriage shop occupies one of the large manufacturing buildings at Sorel. The main components of the carriage are the trail, the saddle, the firing platform, the shield and the axle. Of these components only the axle requires any considerable machining. Since this is merely a cylinderical shaft turned down at the ends the operations on it are entirely conventional. The shield is bulletproof and like the trail, firing platform and saddle is made up of plates assembled by rivets. Some of these parts, particularly the firing platform, resort extensively to the use of assembly jigs. In this way their accurate alignment is assured, and the high degree of workmanship employed on the gun proper is carried through the entire assembly.

Most of the work on the gun carriages consists in fabrication by forming and riveting. However, an interesting machining set-up on the trail uses a radial drill and a planer type milling machine to take eight cuts





The breech end, the adjacent parallel section and the taper are rough and semi-finish turned in two set-ups on a "Lo-Swing" lathe. Combining operations saves time, affords better concentricity of the various surfaces

ANTI-AIRCRAFT GUN BARRELS

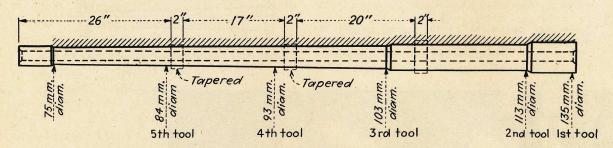
EARLY IN JULY a Canadian plant with no previous experience in manufacturing cannon got under way upon a large British contract for Bofors anti-aircraft gun barrels. Fourteen weeks later the first barrel passed inspection. October, the fourth month of production, witnessed completion of a sizable quota on time. The quota for November was twice that for the previous month, but it was finished several

days in advance. Further lifts in production await delivery of much-needed American machine tools.

This record is made more remarkable by the fact that the shop started with 70 per cent unskilled labor. Technical school boys were chiefly selected for training under the direction of the few skilled men available. Gun making can be likened to "production toolmaking." As the shop superintendent expressed it, "the boys do not know what a tenth or better is, so they go ahead and work to it." Of course, each machine set-up and its tooling were carefully worked out in advance to achieve and maintain accuracy at each step. The boys are drilled in the routine of a given set-up under the direction of a skilled man, after which the operator imparts job knowledge to one or two learners, before being rotated to other jobs. At present, the training program on the primary operations has grown to the point where some boys have been transferred to the domestic-goods ma-

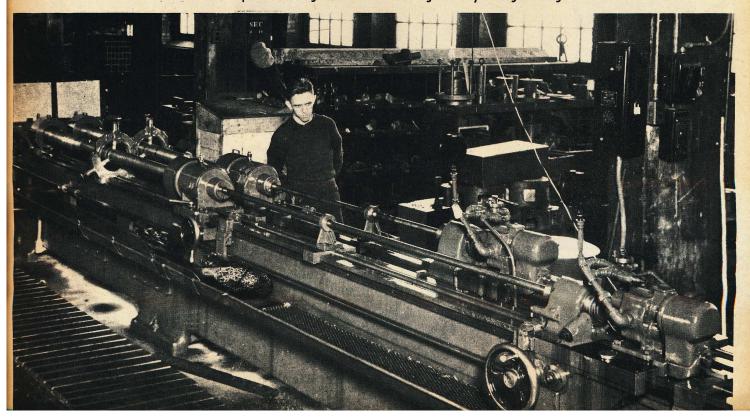
chine shop, until such time as additional equipment is received.

The production sequence for the barrel has undergone several changes since the original plan was laid down in late 1939. The number of turning operations upon the barrel, for example has been cut down. To minimize error, well-supported roughing and semi-finishing cuts on the parallel and tapered sections of the barrel are handled in two set-ups on a multi-cut lathe instead of taking several light cuts here and there on engine lathes. A milling machine does all six operations on the breech end in one set-up in order to hold the

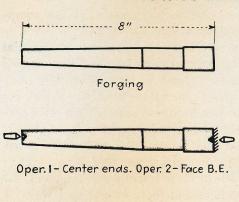


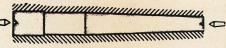
To support the barrel properly in the Lo-Swing, three roller tracks are turned by auxiliary toolslides before the roughing or the semi-finish turning operations

Deep drilling of the barrel is carried out on a Pratt & Whitney duplex machine. Muzzle end of the barrel is held in a tapered bushing and the drill bar is guided by a long bushing



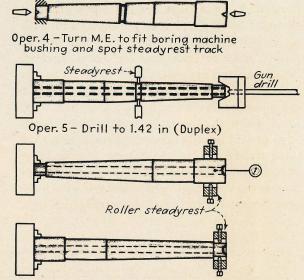
HOW TO MACHINE BOFORS GUN BARRELS



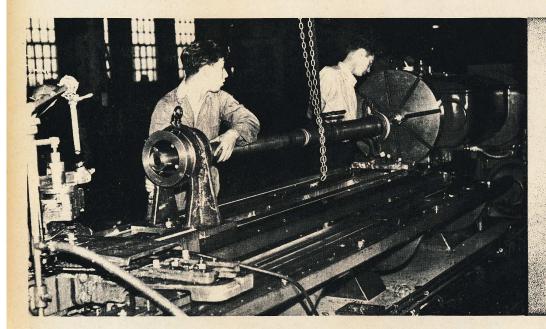


Oper. 3-Turn O.D., leaving 8 mm., and spot

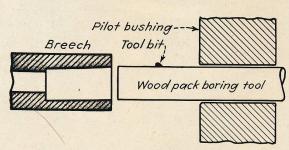
Preliminary operations on the barrel forging are designed to throw error from the drilled hole to the rough-turned O.D.



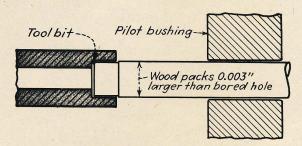
Oper. 6 & 7 - Cone breech end and muzzle end



Operations like coning and chambering, wherein the hole must be set up to run dead true at both ends, are performed on heavy engine lathes fitted with roller steadyrests. The end at the faceplate is caused to run true by means of an indicator bearing on an external test spot, while the opposite end is set true by an indicator contacting the hole periphery



Inaccurate Boring Set-up. If pilot boring is not "dead true," the boring tool will not correct the misalignment but will follow the pilot hole



Correct Boring Method. The boring tool cuts its own start, and the oversize woodpacks are shaved to size by the newly cut edge of the hole

vital surfaces in correct relationship with the datum line. By and large, the production sequence is fully established, but one or two operations may be changed in order to speed up output. An example is broaching the rifling instead of draw cutting with a single-point tool.

A Bofors gun barrel is not an easy piece to machine. Forgings are supplied in the heattreated condition, and show an average hardness of 300 Brinell. The material is a nickelchromium-molybdenum steel of 0.25-0.35 carbon and possesses a yield point of 45 British tons. Machining speeds and feeds are not set at the maximum for two reasons: (1) it is considered better practice to take a 1/16-in. cut at fine feed where a 1/8-in. cut with heavier feed might be thought possible, in order to maintain the desired accuracy and not set up strains in the forging, and (2) primary operations need not be run at the highest feasible speed until operators achieve greater skill, because there is no need to pile up seyeral hundred gun barrels ahead of the finishing operations, where the bottlenecks exist. This policy has reduced scrap to an extremely low figure, while quotas have always been met or exceeded.

Seven primary operations are needed to convert the forging into a rough-turned and drilled barrel, with the hole established as the locating point for subsequent semi-finishing operations leading to boring. The first and second operations consist of centering the forging and facing the breech end, respectively. Facing the breech is done to provide a new surface for the forging heat number and barrel number, which must be transferred from the mid-section prior to rough turning.

Operation 3 involves rough-turning in two stages upon a "Lo-Swing" lathe. Before either cut is taken, three small steadyrest spots are turned on the barrel by means of three small auxiliary toolslides and three small steadyrests. After the spots are turned, the main steadyrest rolls are positioned on the spots and the main tool slides are advanced to machine the breech section, the adjacent parallel section and the long taper to the muzzle end. Two tools work on the tapered portion. From 3/16-3% in. of metal

is removed, the work speed being 25 r.p.m. and the feed 0.013 in. The second cut removes another ½ in. of metal and brings the piece to within 8.0 mm. of final size. The feed remains at 0.013 in. for the second roughing cut, but the work speed is increased to 45 r.p.m. Total time for the operation amounts to 170 min. High-speed steel tools are satisfactory for this operation. They are ground to special gages because the tools actually lie above center and must be ground to cut at the center of the work.

In Operation 4, the muzzle end of the barrel is turned to 83 mm. diameter in an engine lathe, to fit the bushing in the Pratt & Whitney duplex deep-hole drilling machine. A steadyrest spot is also turned at the center for subsequent use on the deep drill.

For deep-hole drilling, Operation 5, the work is indicated and securely chucked at the breech end, the central turned spot is supported by a steadyrest and the muzzle end fits snugly into a free-running bushing that is slightly tapered internally. The special Pratt & Whitney single-lip drill bit is keyed and pinned to the bar which does not rotate, but which is fed through the muzzle bushing and into the work at 0.0011 in. feed per revolution. Work speed is 142 r.p.m. Sulphur-base oil is fed through the hollow bar and drill bit at a pressure of 175 lb. per sq. in. to clear out the chips. The drill bit is reground after each barrel, being set up for that purpose in a home-made fixture, with a step cam ground to the form of the drill-bit contour.

In a length of 8 ft. the hole is bound to deviate two or three thousandths from the barrel axis at the far end, and therefore no reliance is placed on the hole for further locating purposes. Hence, the barrel is coned in Operations 6 and 7. For coning, the breech or the muzzle end is chucked as the case may be, and the turned spot on the opposite end is inserted in a steadyrest. By means of four adjusting screws and an indicator, the runout of the hole is set to zero all around the periphery. The hole is then coned by means of the lathe's compound rest. The piece is reversed and the operations are carried out on the opposite end. By this means, any error is thrown to the outside of the piece, where it

can be eliminated in succeeding operations.

To true up the external surfaces of the barrel, prior to boring the hole, two operations must be performed. In Operation 8, the barrel is again placed in the Lo-Swing for semi-finish turning to within 3 mm. of final size. The same tools are used as in the roughing operation, but the tool slides are set in to the new dimension. Steadyrest spots are turned by means of the auxiliary tool slides and steadyrests prior to the semi-finish turning operation.

Three locating surfaces for the boring setup are machined on an engine lathe in Operation 9. The muzzle end is turned to 80.11 mm. diameter to fit the bushing in the boring machine, a central steadyrest spot is turned, and the breech section is skimmed 3 in. from the breech-end shoulder to provide a test spot concentric with the hole. Checking and straightening follow in Operation 10. Usually barrels require no straightening because of the care taken in setting up and machining during prior operations.

Every effort must be made to bore out the drilled hole in a manner that will assure minimum eccentricity, a high finish and little if any deviation relative to the axis in a distance of approximately 8 ft. Pilot boring was first tried. A pilot hole was bored to a depth of approximately 4 in., the wood-packed boring tool inserted and the complete hole bored. If the pilot boring was not chucked dead true (an operation requiring a skilled operator), the hole at the opposite end might be 0.010 in. off center. Once pilot boring was done, the boring tool could not correct misalignment. Besides, the wood packs were subject to uneven wear from running in an eccentric hole, thus contributing to further misalignment of the hole at the opposite end.

To overcome these conditions, the long wood-packed boring tool now runs in an extended pilot bushing which holds the tool in correct alignment while it cuts its own start. The bushing I.D. accommodates wood packs 0.003 in. larger in diameter than the 1.550 in. hole being bored. After the single-point cutting tool enters the hole, the over-size packs are shaved down to the hole size by running against the sharp edge of the newly

cut hole. With the hole started correctly and the wood packs fitting the hole accurately, boring should be nearly dead true unless hard spots are encountered or the wood packs wear non-uniformly. Thus, the opposite end of the hole ordinarily comes true with the part axis within 0.002-0.003 in.

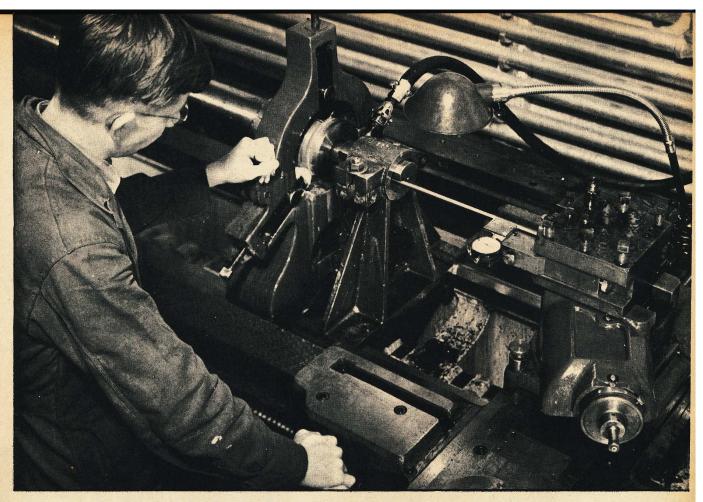
The feed per revolution is extremely small, since the work speed is 142 r.p.m. and the boring-bar feed (hydraulic) is set at ½ in. per min. The tool now used cuts on an extremely small radius, but may be superseded with a Davis-type arrangement. Total boring time averages about 3½ hours, floor-to-floor, some 20 min. being needed for set-up.

A second coning of the muzzle and breech ends of the barrel, Operations 12 and 13, throws any eccentricity remaining between the bore and O.D. surfaces to the outside of the barrel.

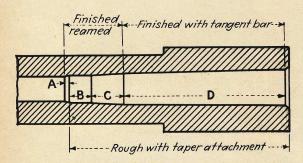
To speed up the finish-turning process, the parallel section adjacent to the breech is turned on one engine lathe, Operation 14, and the taper section is machined on a second engine lathe, Operation 15. In both set-ups it is required to finish turn the barrel to 0.5 mm. of final size, thus leaving about 0.020 in. for grinding. If necessary, the barrel is straightened during the checking process carried out in Operation 16. Only one barrel has been straightened so far.

Approximately 0.025 in. are removed from the bore by the honing process, which starts with the diameter of 1.550 in. and ends up with a 40-mm. hole, 0.01 mm. -0.00. This operation is carried out on a horizontal Barnes machine. If the barrel becomes too warm it is done in two stages; that is, all but the final couple of thousandths are removed and the barrel is set aside to cool thoroughly. The second honing brings the barrel to final dimension, and is easily done when necessary because setup time is not important. Total floor-to-floor time amounts to 23/4 hours. The honing tool is fitted with No. 38320 stones, I grade, and the stones last for approximately three barrels.

The parallel section and the taper are ground to size (0.020 in. being removed) in Operation 18. Grinding is a faster process than attempting to finish-turn to size, and



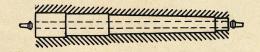
A tangent-bar fixture finish bores the long taper in the chamber. The tool-holder is contained within a dovetail slot in the tangent bar and is fed into the work by means of the pushrod fixed in the toolpost



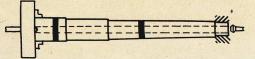
Outline of chamber in Bofor santi-aircraft gun.
Tapers B, C and D are rough bored in one set-up.
Taper D is finish bored with the tangent bar. Taper
reamers are used after finish boring to cut taper A
in order to blend taper B with the honed bore and
to finish tapers B and C

Prior to boring, test spots and locating surfaces are turned on the semi-finish turned barrel in order to set up the hole so that it runs dead true at each end

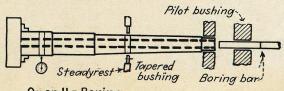
INTERMEDIATE OPERATIONS



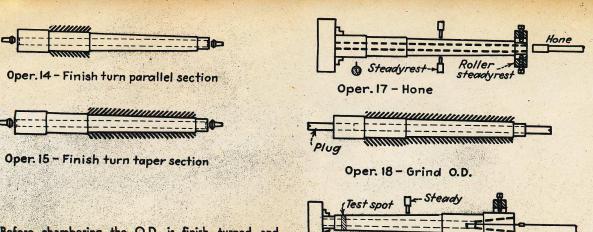
Oper. 8 - Semi-finish straight and taper sections and steadyrest spot



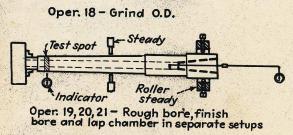
Oper. 9 - Turn muzzle end, turn test spot and skim breech end shoulder

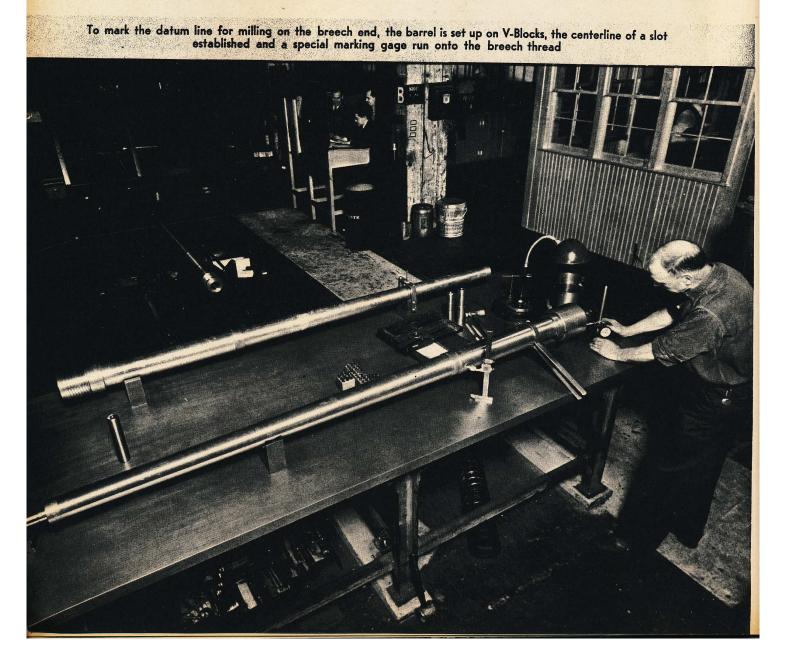


Oper.II - Boring



Before chambering the O.D. is finish turned and ground concentric with the honed bore





besides the resulting surface is free of tool marks that might promote cracks during firing. It is essential to grind the parallel section to 109.04 mm. diameter to fit the collet in the milling fixture employed during operations on the breech face.

The process of chambering is the most vital operation in the gun maker's manual, but it is also the slowest, and most difficult. Reasons: (1) the chamber must be dead true with the axis of the bore, (2) all tapers must be smoothly blended and a mirror finish is essential, (3) the chamber must show a 100 per cent bearing with the master plug gage.

The present chambering process involves three steps: (1) "rough boring" three tapers, a process that requires an average of two hours, (2) finish boring and reaming on a second lathe, a step that consumes six hours now but took longer while operators were being broken in, and (3) lapping with fine abrasive cloth on a third lathe, a process that is indeterminate in respect to time consumed. Three barrels may be lapped in five hours or one barrel may take three hours or longer.

Rough boring the chamber, Operation 19, is done on a Bertram engine lathe modified in the following manner: (1) a special tool block was fitted to the compound rest and bored in place to receive the boring bar after the compound rest was doweled to its slide and the cross-slide was doweled to the carriage, and (2) the taper bar on the taper attachment was removed in favor of a special cam bar incorporating the tapers.

The muzzle end of the barrel is chucked on the straight-turned end section and indicated on the test spot, and the breech end of the hole is indicated dead true in a roller steadyrest. The indicator for the breech end has a long 1:1 pivot bar that contacts the honed bore beyond the chambering depth.

For finish boring, Operation 20, the roughchambered barrel is transferred to a second Bertram lathe, which has a tangent bar attachment for guiding the finish-boring cutter. The tangent bar consists of a taper plug with a dovetail slot along one side for the toolholder and a bronze bushing that supports the free end of the bar in the honed hole. The other end of the bar is rigidly supported in a heavy bracket that can be clamped securely to the machine ways.

The first step in finish boring is to secure an accurate set-up of the barrel so that its bore runs dead true. This is accomplished by indicating the test spot at the muzzle end and setting the bore dead true at the breech end by means of a tell-tale indicator reaching beyond the rough chamber. Second step is to position the tangent bar attachment so that its axis coincides with the hole axis, and so that the depth of insertion is a definite amount. Third step is to slide the dovetail toolholder containing a 5/16-in. bit into the tangent-bar slot and connect the free end with a push rod fixed in the turret. After all elements of the set-up are completed, a laborious and exacting procedure, the long taper is finish bored ready for lapping. Depth of boring is controlled by the turret indicator, which contacts the finished face of the tangent-bar bracket. Finish boring removes 0.0075 in. per side of hole. When tested with a plug gage, the long taper must show a 100 per cent bearing and its surface must be free of rough tool marks and scratches.

During reaming, the roughing reamer removes 0.005 in. from the two short tapers B and C, and cuts taper A to remove the ridge between the honed hole and taper B, as left by rough boring. Finishing reamers remove the final 0.002-0.0025 in. Reamed tapers must be free of tool marks and show 100 per cent bearing with plug gages.

British standard practice is used in checking the interior of the chamber. It consists of laying a thick strip of warmed gutta percha upon a hardwood wedge, inserting the whole into the chamber and driving in a second wedge, so that the gutta percha flows and makes an impression about 1½ in. on the arc by the full length of the chamber. Every tool mark and the condition of the blend or lack of it at taper junctions is clearly revealed on the gutta percha. This convenient test shows the operator what condition must be corrected prior to lapping.

For lapping the chamber, Operation 21, the barrel is transferred to a third engine lathe. Lapping is done with strips of abrasive cloth fixed to a hardwood stick approxi-

mately 4 ft. long. The stick is fulcrumed in the turret and the free end is weighted to apply light pressure to the lapping end. Guttapercha impressions of the chamber are made periodically to check the degree of polish imparted by the lapping action. The final impression must be free of all tool marks and the tapers must blend smoothly.

Several operations are required upon the exterior of the breech. These are combined on an engine lathe in Operation 22. The work involves turning the breech end to final diameter, facing the shoulder to length, grooving, peening a brass ring in the groove, turning the ring, and parting-off surplus metal from the breech face. Milling the buttress thread on the breech is done in Operation 23.

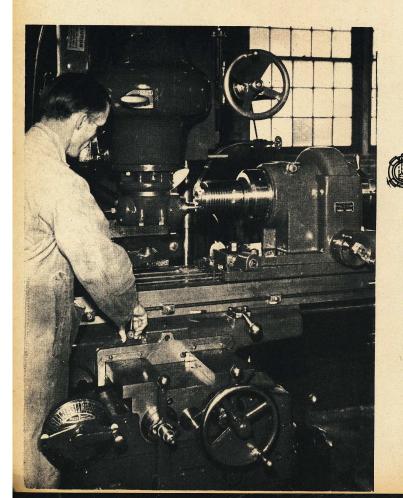
Rifling is at present done with a singlepoint tool, but this method may be superseded by broaching. The barrel is set up in a Le Blond rifling machine, which is provided with a fixture for cutting the long helical groove in the rifling bar. This operation is done initially when setting up the machine to a given rifling twist and need not be repeated until a new bar is required.

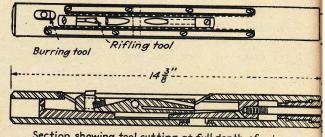
The rifling tool is of the draw-cut type and

is fastened to the rifling bar. A draw rod passes through tool and bar and is connected to a geared feed wheel. When the rifling tool is pushed through the barrel, the draw rod collapses the toolbit below the rifling-tool O.D. in order to prevent scratching the bore. After indexing to the next cut and just as the draw cut begins, the toolbit is raised out to the set cutting depth by the action of the draw rod. The feed can be increased in small increments because a 3 in. graduated sector on the feed wheel represents 0.001 in.

Rifling is a time-consuming process because of the number of cuts involved. Sixteen grooves 0.022 in. deep must be machined around the periphery of the bore, but each cut amounts to not more than 0.0015 in. for the first 0.020 in. in depth. Previously, more shallow cuts were taken. Since the rifling is 0.022 in. deep, several finishing passes are required after the roughing cuts have reached the 0.020 in. depth. One part of lard oil to four parts of kerosene is used as a cutting compound. A brush fixed to the end of the rifling tool acts to clear stray chips.

Before the end face of the breech can be milled, it is necessary to set up the barrel





Section showing tool cutting at full depth of cut

Through the action of a draw rod passing through the pull bar, wedge surfaces within the rifling tool cause the toolbit to raise and lower. The toolbit is col-

Six milling operations are performed upon the breech face in correct relationship to the datum line. The barrel is set up in a Kearney & Trecker vertical miller equipped with a special power-operated and swiveling fixture. Here the operator is milling the extractor slots, which must be accurate, or else the extractor fingers will fail in high-speed firing of the gun

upon a surface plate and indicate the centerline at each end within 0.001 in. The centerline is indicated in relationship to a cross slot milled in the breech end-face during thread milling, and a special thread gage is applied to scribe a datum line in relation to the start of the milled thread. Milling and datum lines are marked in Operation 24.

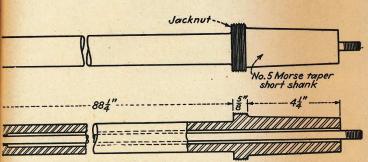
Six cuts involving angular slots and a cam face must be milled in one set-up to assure accurate relationships. A Kearney & Trecker vertical miller fitted with a special pivoted power-driven fixture is chosen for this purpose, which is known as Operation 25. The barrel is held on the ground parallel section by the fixture collet and the outer end is raised to the horizontal centerline by means of a tapered bushing resting on a special stand. A steadyrest is also applied to hold the center.

All milling operations are performed in correct angular relationship to the datum line. The barrel is rotated by means of a graduated collar and two central locating slots are milled. One of these is 12 mm. wide and at a certain angle to the breech face, the fixture being pivoted to the correct angle with respect to the machine bed. The

second slot is milled at a steeper angle, and is wider. After these cuts, the piece is rotated 180 deg., and the extractor slots are milled. These are spaced a definite distance above and below the horizontal centerline of the piece in the established position. Part of each extractor slot is at right angles to the bore, and the remainder at an angle.

The milled cam face around the periphery of the breech end is obtained by rotary power feed of the fixture head through a telescopic drive from the low-lead gearbox. As a final operation, a slight taper is milled around the breech behind the thread.

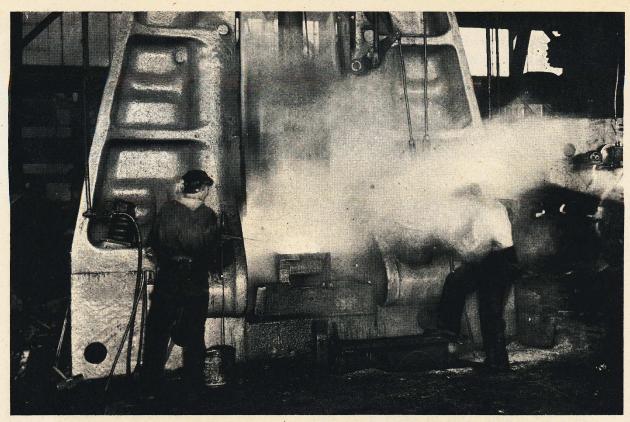
Relatively minor operations are needed to complete the barrel. Interruptions in the thread are shaped in Operation 27. Five operations are combined on an engine lathe, being grouped in Operation 28. These consist of turning center steps, cutting the center thread, turning and threading the muzzle end for the flame guard and parting off excess stock on the muzzle. Five fitting, sub-assembly, drilling, parkerizing and final assembly operations bring the grand total of operations upon the barrel to thirty-three. Barrels are shipped elsewhere for proof testing.



lapsed into the body of the tool while pushing it through the bore for the next stroke and is raised to feed depth by the draw rod at the commencement of the return stroke for the draw out

Minor fitting operations are necessary upon the breech before final assembly





A 20,000-lb. hammer produces the forging using a double-cavity die

Big Forging for Tank Gun

BY HERBERT CHASE

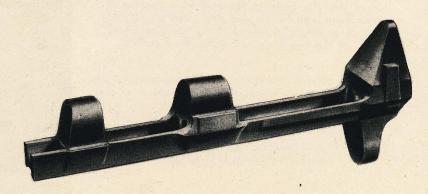
AMONG THE numerous forgings being produced for armament and other applications by the Kropp Forge Company, that known as the "slipper" for a 40-mm. tank gun mount is of unusual size. It weighs 222 lb. and involves a considerable flow of metal; three heavy portions are spaced apart by much lighter ones of considerable length. The material is SAE 2340 bar stock heated to forging temperature in a box furnace; the forging is completed in a single heat. All the work is done under a 20,000-lb. Chambersburg hammer, said to be one of the largest in use west of Pittsburgh.

The die employed has two cavities in

The 222-lb. finished forging is used to make the "slipper" for 40-mm. tank gun recuperator mechanism

the first of which the stock is roughed forged. Next, the piece is drawn or rolled over an edge formed in the die, then it is blocked and finish-forged in the final cavity. The forging is transferred immediately to a 600-ton Toledo

press where it is trimmed and restruck. All this work is performed by a five-man crew which handles the stock and forging with trolley tongs. After forgings have cooled they are Magnafluxed to make sure no flaws are present.



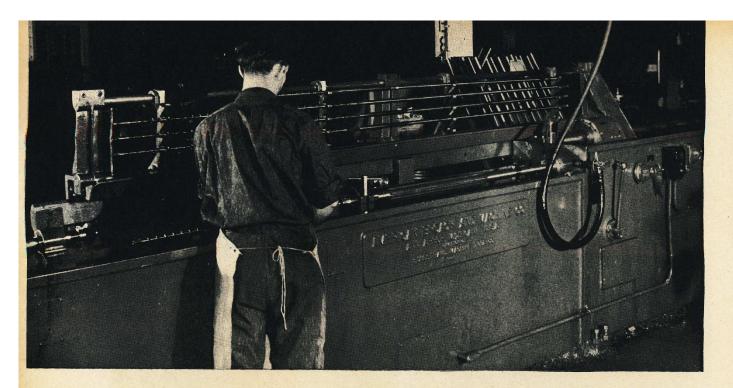


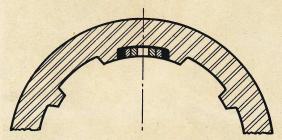
Honing the breech-block hole in the breech casing is done on a Barnes Drill Company machine. The hone must be kept to size at the front end since it works to a shoulder

WAR FINDS THE Pontiac Motor Division of General Motors well started on the production of assembled 20-mm. Oerlikon anti-aircraft guns for the Navy. At the end of May, the division's Defense Plant No. 4 possessed relatively few machine tools, mostly suitable machines which could be located in the automotive manufacturing departments. During intervening months Pontiac has installed hundreds of new machine tools in a plant that will eventually employ 5,000 men.

Pontiac has subcontracted 175 out of 195 parts for the weapon, but elected to manufacture the remaining 20 more difficult pieces. These include the gun barrel and breech mechanism, which account for 45 percent of the value of the gun because of the large number of tedious operations which must be performed on nearly every piece. The breech casing, an extreme example of complexity, requires some 250 operations. Obviously few suppliers would have over 100 specialized machine tools to handle the production of this piece, to say nothing of the inadvisability of splitting off the making of one vital component from others that must be produced in close relationship.

The gun parts manufactured by Pontiac involve an enormous amount of milling. Perhaps 90 percent of the operations include milling, and of these three-quarters are form milling. Many of the set-ups on Oerlikon gun parts are not remarkable, except as they





Broach Paths Through Rifling Groove

Broach No.1 Broach No.3 Broach No.4

Pull broaching the rifling grooves is performed with four broaches having integral broach buttons. Developed for 20-mm. and larger cannon bores, the American Broach Company method involves a pulling head by which the tool is caused to follow a definite helical path under the guidance of a splined master bar

Four broaches are required to rifle the 20-mm. barrel. Broacnes Nos. I to 3 cut increasingly greater widths of groove, while Broach No. 4 finishes the sides and bottom of the groove. Each broach cuts all nine splines at once

form a picture of high-class fixtures and modern machine tools. Milling to close limits is not the primary skill of automotive labor and young men drawn from farming communities. Dial indicators have been applied to table movements to assist the operator in milling to size and avoid over-running the cut. But tedious operations take their toll in momentary inattention and resulting scrap losses. As a consequence, Pontiac is equipping knee-type millers and other equipment as rapidly as possible with duplicating attachments.

In a contract of the magnitude handled at Pontiac's Defense Plant No. 4, processing methods are subject to constant change to speed output and improve quality. There has been no hesitancy to depart from so-called conventional methods.

Barrel manufacture is no problem at Pontiac. The original method was laid out to include eight straightening operations at strategic points in the sequence.

But to avoid corrective operations, such as straightening, and to produce a barrel with inherently better service characteristics, the experience of producing millions of automobile crankshafts has been turned to good account. The forge shop is instructed to stress relieve the barrel forgings for five hours at 950 F., and to hot straighten the forgings. These two precautions minimize residual stresses in the barrel forging, which would cause bowing during machining and heat warpage in service firing.

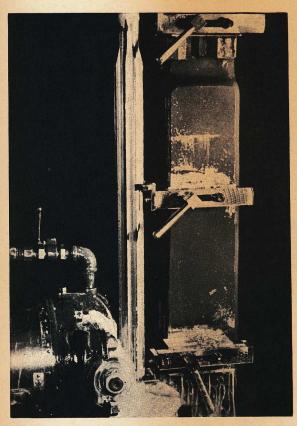
As a result of these practices, fewer than ten percent of barrels need be straightened after removing ¼ in. of stock per side in a single rough cut on LoSwing lathes; this percentage of barrels does not have a runout exceeding 0.005 in. Even hobbing the longitudinal cooling fins rarely causes distortion that requires straightening, and thereafter straightening is never needed.

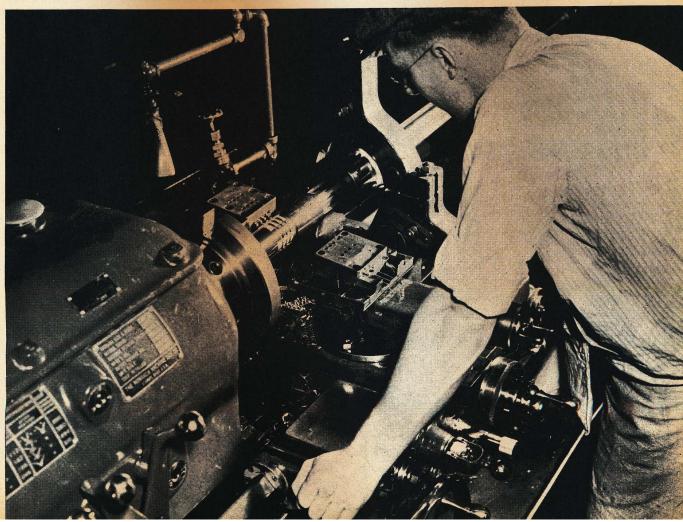
In setting up methods to machine the 20-mm.

Oerlikon barrel, Pontiac did not follow either the small-arms or ordnance methods for machining the bore. In the small-arms method, usual practice is to gun drill, ream, hone and rifle; in ordnance plants, to drill, rough and finish pack bore, hone and push broach with disk cutters. Pontiac gun drills on conventional Pratt & Whitney two-station gun drills, rough and semi-finish reams on special Flannery Bolt Company vertical multiple-station reaming machines, finish reams on Pratt & Whitney pull-type reaming machines, and pull broaches on American Broach Company machines, using four multiple-button broaches in sequence. Pull broaching requires 10 min. per barrel, as compared with $3\frac{1}{2}$ hr. for two barrels

Eight longitudinal grooves approximately 27 in. long are hobbed on the Oerlikon barrel to produce cooling fins. Hobbing distributes the cut around the barrel, thereby avoiding distortion. Conventional hobbing was unsatisfactory, but climb hobbing gives good tool life

Locking grooves on the barrel are machined on a Monarch lathe in a set-up approximating pistongrooving practice, with the exception that limits are much closer

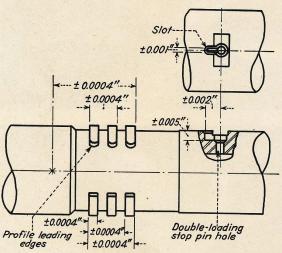




on conventional equipment using single-point rifling tools.

Chambering is currently done on a Warner & Swasey turret lathe fitted with a special fixture passing through the headstock bore and holding the barrel at either end in chucks. This set-up will be changed for increased production to a Kreuger multiple-station semi-automatic chambering machine such as employed at AC Spark Plug.

While most of the operations on the Oerlikon barrel are done in a familiar manner, there are certain set-ups which display the automotive technique in tooling up. The eight cooling fins in the barrel were originally cut one at a time on a horizontal milling machine. But distortion arises in milling from removing material from one side of the barrel at a time, while hobbing distributes the cut around the outside diameter of the barrel. Moreover, only one groove



Spacing Tolerances for Locking Grooves and Stop Pin Hole

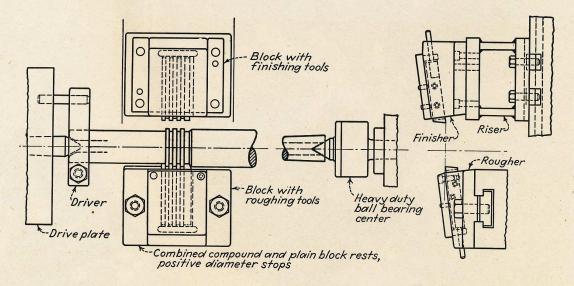
was obtained per cutter grind, causing much lost time for cutter changes and tying up numerous milling machines and cutters on one operation. The method was changed to climb hobbing on a vertical Cleveland hobber. There is no distortion of the barrel, even though the cut starts at the weakest portion of the piece. At each location of the hob, one barrel is grooved complete, after which the hob is shifted 0.200 in. laterally for the next piece. Fourteen barrels are obtained per hob grind. Tool changes are so minimized in relation to the time of cutting that one operator can handle three hobbers certainly, and perhaps four. Floor-to-floor time is one hour and tenminutes per barrel.

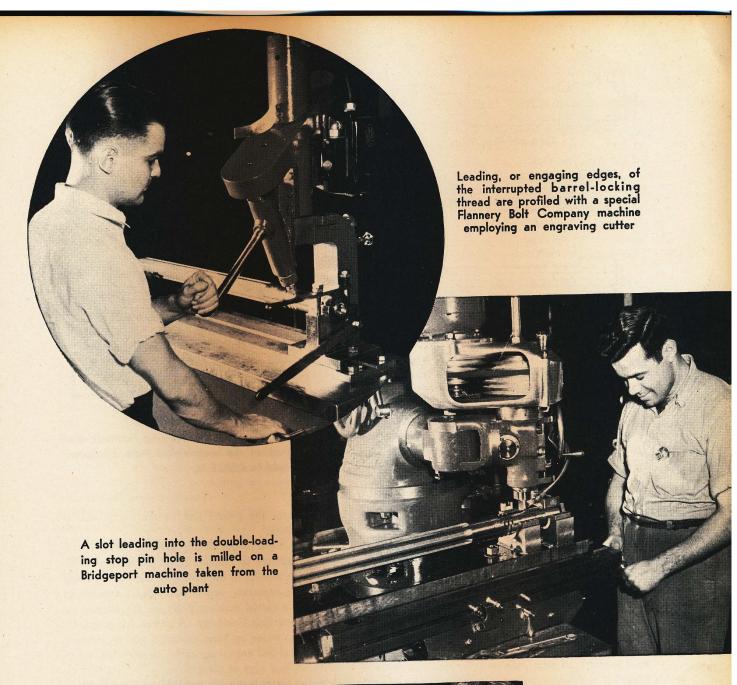
Locking Grooves Interchangeable

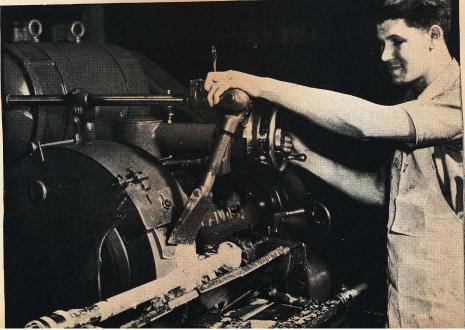
Perhaps the most outstanding operation at the Pontiac Defense Plant No. 4 is that of turning the locking grooves on the breech end of the barrel. Each Oerlikon gun is supplied with two interchangeable barrels which must lock properly in the breech casing. Each of the three locking grooves is held to a total limit of 0.0008 in. in spacing, the cumulative limit over all three grooves is 0.0008 in., and the over-

Limits of 0.0008 in. for spacing, and cumulative error over three grooves limited to 0.0008 in., required the development of production equipment capable of working to gage accuracy

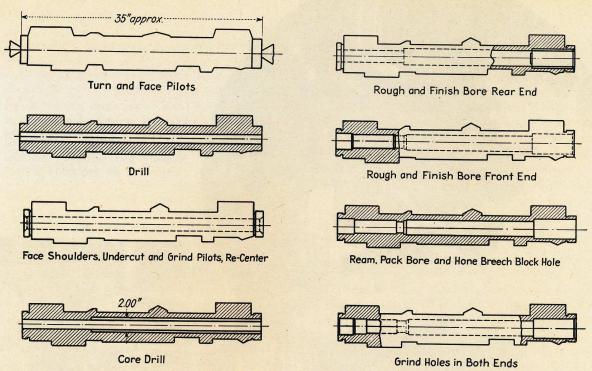
Blade-type grooving tools and spacers are lapped to 0.00005 in. for width before assembly in the front and rear toolblocks. The special cross-slide is fed to positive stops







Three tapers at the muzzle end of the Oerlikon barrel are ground with a wide wheel on a Landis machine. The wheel is formed to finish two radii as well as the tapers, thereby avoiding laborious hand work



Since the breech-block hole at the central portion of the bore is "blind", the processing methods must be such as to secure close limits on concentricity and runout. Bottom of the breech-block hole is approximately 25 in. inside the part but runout is held to 0.0025 in.

all distance between a reference dimension and the outer groove is held to 0.0008 in. Actually, the shop holds production pieces for all of these critical dimensions to a 0.0004-in. limit.

Work in tenths requires extreme care in the manufacture of tools and a proper machine set-up. The operation is carried out in a Monarch 16×78-in. lathe equipped with special cross-slide which mounts front and rear tool-blocks and feeds to positive stops. Tools are tightly fitted into these blocks with hardened spacers. In effect, the set-up is akin to a piston-grooving operation, except that the tolerances are much closer.

The grooving tools are purchased 0.001 in. oversize for width and are lapped in the Pontiac toolroom to half a tenth. The greatest care must be exercised in making these tools to maintain size and clearance angles, and to obtain keen edges free from minute nicks. Tool angles are: front clearance, 5 deg.; side clearance, 1 deg.; plus a $\frac{1}{32}$ -in. top land. Tools are checked with a master gage to a 0.0002-in. limit for spacing and cumulative error.

It has been found best to mill the interruptions in the locking grooves prior to turning the grooves. This practice avoids throwing up a heavy burr between the grooves, as would be the case if the interruptions were milled after grooving. Besides, when turning the grooves, the chip is no longer than the length of the groove and cannot carry around with the work.

Leading edges of the locking grooves on the barrel must be radiused to promote ready engagement with the locking grooves in the breech casing. Hand filing is a tedious operation, and is now largely avoided by the use of a special machine built for the purpose by the Flannery Bolt Company. A power-driven spindle is caused to swing by hand around a post or column, and the modified engraving cutter profiles the radius on the leading edge of the groove. The burr thrown up by the cutter is quickly removed by a minimum of hand filing and polishing. This method of profiling the radius has cut the labor requirements from three to four bench hands to a part-time job for one man and has improved quality.

Many Milling Operations

Milling the slot leading into the double-loading stop-pin hole is indicative of the tedious, small milling operations frequently found in gun work. Rather than to set up this operation on an expensive milling machine, the job is applied to a Bridgeport miller. After milling the slot to the limits shown on an accompanying sketch, the operator exchanges cutters for milling the 45-deg. chamfer around the slot. The hole has previously been drilled, reamed and counterbored on a No. 2B Edlund drill press.

Grinding is employed to finish the three tapers at the muzzle end of the barrel and radius the outer tapers to adjoining straight surfaces. This method is much faster than finish turning and hand finishing the radii. A Landis cylindrical grinder is used for the purpose, a wide formed wheel being employed. After dressing the wheel with the special attachment provided, the operator grinds the 30-deg. taper near the cooling fins, the taper near the muzzle and then the long central taper connecting the two steeper tapers.

Close Limits on Breech Casing

To machine the stepped-diameter holes in the breech casing to specifications for concentricity and size presents a number of problems. Four critical diameters have the following limits: for the two ground diameters at the front of the breech casing and the ground diameter at the rear of the breech casing—concentricity within 0.0025 in. indicator reading; 0.0012 in. for size. The honed breech-block hole must not have a runout exceeding 0.0025 in. and the limit on size is 0.0029 in. The centrally located breech-block hole, which is approximately 19 in. long is blind, a circumstance which has caused development of an unusual processing layout and special tools to obtain the desired accuracy together with economical manufacture.

The breech block requires some 250 operations in all, and 44 of them are done prior to drilling the 1.492-1.500-in. hole through the axis of the part. These initial operations are mostly concerned with heavy slab and form milling of external surfaces,

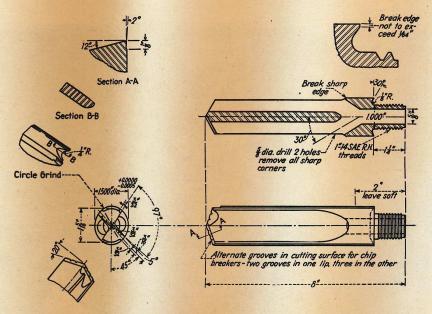
leaving 0.060-0.080 in. of material for finish milling after the stepped-diameter holes are completed. The casing is centered and the stub ends turned for pilots prior to drilling the through hole.

Drilling is carried out on a W. F. & John Barnes two-spindle horizontal machine; the operation is similar to gun drilling, except that a special two-lip drill is employed instead of a gun drill. The tool is supported by a long hardened bushing as it enters the work. Runout in the hole length of approximately 35 in. occasionally may reach 0.050 in., but usually is 0.015 to 0.020 in.

The two-lip drill, developed by the machine vendor, has been modified to some extent by: (1) notching chip breakers in the cutting edges, (2) adding more clearance at the drill point behind the cutting edges to promote rearward flow of chips, and (3) using a greater radius at the junction of the threaded stem and the tool body to overcome breakage at that portion. Cutting oil flows along a channel between two lands on the edges of each flute, washes chips down the roots of the flutes and out orifices at the rear end of the tool. Flutes must be polished to prevent the chips from jamming. Drilling is carried out at a feed of approximately $\frac{3}{4}$ in. per min. After being drilled, the breech casing is heat-treated to 286–321 Brinell.

The part is recentered, shoulders are faced adjacent to the pilots, the pilots are undercut and ground to a 0.0005-in. limit in a series of operations which condition the part for the more accurate work in connection with producing the stepped diameters.

The drilled hole is opened out to 2.00 in. in diame-



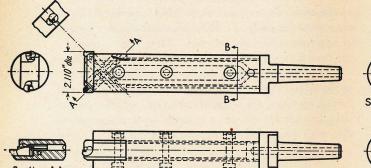
Faster drilling is secured with this special two-lip drill than by the gun-drilling method, although this tool is also held stationary. It is made of Rex AAA or molybdenum high-speed steel. All corners are blended and polished a fter machining. Chips are forced down the flutes and out orifices in the base of the tool

ter for a depth of approximately 25 in. by core drilling. A five-flute core drill gives satisfactory results when ground properly. Chips are forced out the drilled hole ahead of the core drill. The core drill is driven by an oil tube; the oil passes through the drilled hole in the tool to orifice holes at an angle to the axis about an inch back of the point. It has been found that the orifices in the tool tend to clog, and new core drills will be solid, the orifices being located in the cil tube. Oil will flow from these orifices to surround the entire core drill and force chips into the previously drilled hole. Original core drills were 5 in. long. Current drills are 11 in. long and are guided at the start of the cut by a full-length hardened bushing. As a consequence, runout of the drilled hole (which may reach 0.050 in.) is reduced to 0.010 in. at this stage.

To promote accurate and rapid location of the breech casing in all operations connected with machining the stepped-diameter holes, Pontiac is applying hinged steadyrests to both headstock and tailstock.

By loosening two clamping nuts, the operator can open up the two steadyrests simultaneously and remove the part easily by an overhead hoist. A female center was used at the headstock in conjunction with a four-jaw chuck, but it has been found that operators may overlook checking runout of the piece with dial indicators before proceeding with the operation. Hence, a hinged-type steadyrest with hardened steel semicircular inserts is now being incorporated in a pot chuck on the headstock. The steadyrest at the tail-stock end is fitted with Ampco bronze inserts to take wear. These Ampco inserts are trued up at intervals.

In the original processing layout, the stepped diameters at either end of the piece were opened out after the breech-block hole had been reamed, pack bored and honed. This meant that tools had to feed approximately 25 in. But since the rear hole must be machined to a larger diameter, it was decided to open it out first, and save the time of feeding the reamers and pack bore through 6 in. of metal which would be removed later anyway. Warner & Swasey No. 3A

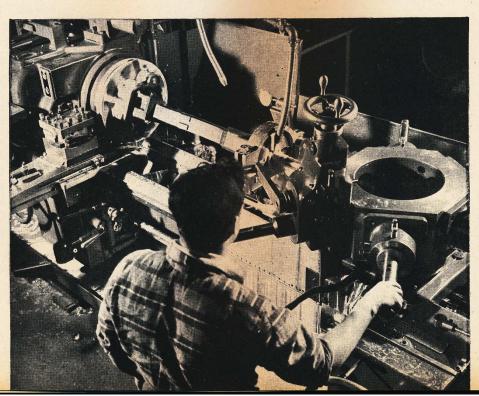






Babbitt guides on the pack-boring tool have a length of three and one-half times the bore diameter to prevent runout of the tool. A long steel bushing guides the tool as it cuts its own start in the previously reamed hole

Three diameters at the front end of the breech casing are bored, recessed and counterbored on a Warner & Swasey turret lathe. Doing this operation before boring the through hole, reduces the distance through which the packboring tool must cut



turret lathes are employed to rough and finish bore the rear end of the breech case and rough and semifinish three diameters at the front end.

The 2.00-in. core-drilled breech-block hole has now been reduced to approximately 19 in. in length. The current set-up provides for rough-line boring to 2.110 in. Pack boring is then done to 2.161–2.163 in., using long babbitt bearing surfaces on the tool insted of wood packs. The pack bore is guided by a hardened steel bushing entering the hole at the rear of the breech casing. After the breech-block hole is honed, the two principal diameters at the front end and the hole at the rear are ground.

This set-up will be changed as follows: After core drilling to 2.000 in., the 19-in. long breech-block hole will be line bored wit ha double-blade tool. The two bits will open the core-drilled hole to 2.100 in. and 2.140 in. respectively. Critical hole diameters will then be ground, so that hardened steel bushings can be entered at both ends of the piece to guide the final line-boring bar, which will finish the breech-block

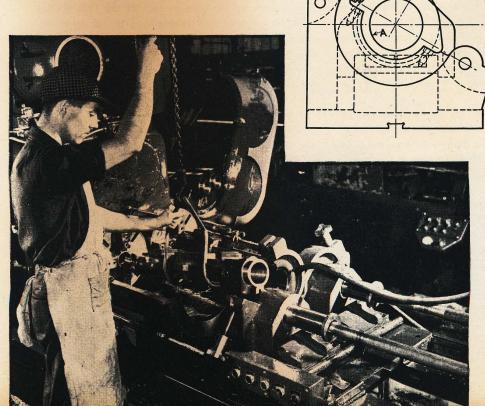
hole to 2.161–2.163 in. In other words, the packboring operation will be eliminated. Pack boring has given a good job—a maximum of a 0.0025-in. runout—but line boring in a lathe will be faster, because the boring bar will rotate, not the work. Besides the runout will probably be much less. Honing the breech-block hole to 2.1654–2.1683 in. will thus become the last operation in the sequence related to producing this group of holes.

Specifications for the assembly of the buffer plate to the breech casing pose several manufacturing problems. The buffer plate has four prongs that fit closely in four radial slots milled parallel to the axis of the breech case. The prongs bear against twelve buffer springs in holes which continue beyond the radial slots, but these prongs must fit snugly and yet slide properly in the slots. The radial slots are produced by milling out the webs between buffer spring holes to a depth of approximately 3 in.

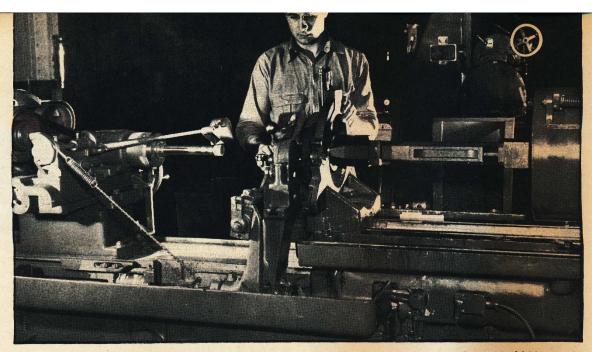
The twelve holes could be drilled in three ways.

(1) by deep-hole drilling equipment costing over

To prevent set-up errors through failure to indicate the breech casing, and to speed up placement and removal of the work piece in the machine. Pontiac has developed this type of steadyrest. Hardened-steel locating rings A are used on pot chucks; Ampco bronze rings for dead centers



Pack - boring the breech - block hole reduces the runout from 0.010 to 0.0025 in. maximum. The steel bushing, shown partially pulled out of its bearing, enters the large hole at the rear end of the breech casing, to guide the babbitted pack-boring tool



Two diameters at the front of the breech casing and one at the rear must be ground on a Heald No. 72-A5 internal grinder to concentricity limits of 0.0025 in. and size limits of 0.0012 in. Stock removal at the front end of the part is 0.010 in.; at the rear, 0.0125 in.

\$100,000, (2) by step drilling, and (3) by multiple-head drilling three holes at a time and indexing four times. The last method was chosen, and an automotive-plant horizontal Natco machine was tooled up for the job. These holes are 0.457 in. in diameter and are drilled 10 in. deep with an oil-hole drill. Runout is held to 0.015 in. maximum. The machine has an automatic cycle whereby the drillhead is advanced $\frac{1}{2}$ in. into the work, then withdrawn to permit flushing out chips. Feed is hydraulic so that drills are not broken by hard spots or concentration of alloy constituents in the forging. In a secondary drilling operation, performed on a drill press, the bottom of each drilled hole is finished with a flat-bottom drill.

The holes are then reamed on another Natco set-up identical with the multiple-spindle drilling operation. Special oil-hole reamers are used to enlarge the holes to 0.472 in. diameter, but the operation is principally employed to straighten the holes, not to size them. Runout is reduced to 0.001 in. per in.

Carbide Drills to Be Tried

Not daunted by departure from tradition, Pontiac has experimented with the use of gun drills for this component. The drills are rotated by the drillhead, not held stationary as is customary. The runout has been cut in half as compared to the drilled and reamed hole. All holes were the same size and could be

checked with the same arbor. Carboloy tips will also be tried upon *rotating* gun drills driven by a higher speed machine now on order. Feed will be reduced, but with the Carboloy tools it is expected that reaming can be eliminated, production increased and tool changes decreased.

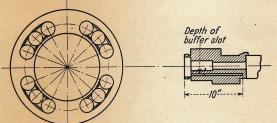
The radial buffer slots in the breech case are obtained by removing the webs (for a distance of 3 in.) between the holes in each of the four groups of holes. A butt drill is employed to cut away the webs. To finish the radial slots two milling cuts are taken. The inner wall of the slot is thin. Cutting pressure of the end mill tends to collapse the inner wall, so that after the cut is taken the wall springs back, causing an interference fit with the prongs on the buffer plate. To prevent this situation, a hand-tightened expansion plug is inserted in the bore of the breech casing prior to milling the buffer slots.

Approximately 0.018 in. per side of slot is removed by milling. The rough cut removes 0.010 in. and is performed with a right-hand spiral, right-hand-cut end mill. Finishing removes 0.008 in. and is done with a left-hand spiral, right-hand-cut and mill. In other words, the finishing end mill cuts across the pattern produced by the roughing cutter.

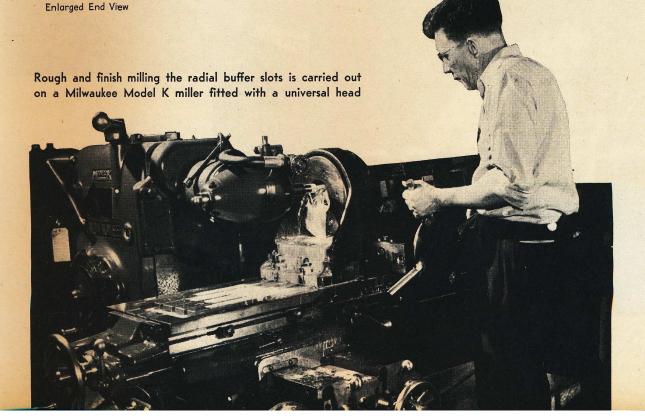
Two threads on the breech casing are ground from the solid, because of the limits involved. These operations are performed on an Ex-Cell-O thread grinder fitted with an internal attachment. When chining the stepped-diameter holes involves fifteen checks

Inspection of the breech casing after ma-

Multiple - spindle drillheads are employed on Natco equipment for producing twelve buffer spring holes in the end of the breech case. The operator is shown checking the holes after reaming



Milling the metal left after butt drilling the webs between buffer spring holes requires support of the thin inner wall by means of an expansion plug



the machine is set up for external grinding, an Acme position-type thread is ground behind the triggerbox portion of the breech casing. This thread must be positioned within ±30 min. of a reference point, so that a locking cap will screw up tightly and lock against a machined surface. Grinding is done with a wheel speed of 1,000 r.p.m. and a work speed of 3 r.p.m. An interrupted 60-deg. thread is ground in one of the holes in the breech casing, the operation being performed on batches of parts after setting up the internal grinding attachment on the machine.

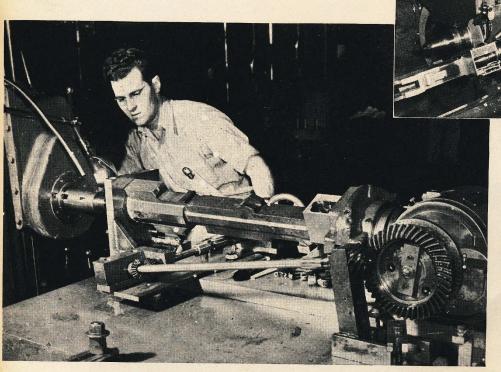
Internal Grooves Slotted

Internal locking grooves in the breech casing must be machined to the same limits for spacing and accumulated error as the locking grooves on the barrel—0.0008 in. total limit. Prior to cutting the grooves, interruptions in the thread-like locking elements are produced by cutting radial slots parallel to the part axis. A milling set-up was tried for this operation but proved too flexible because of the overhang. The

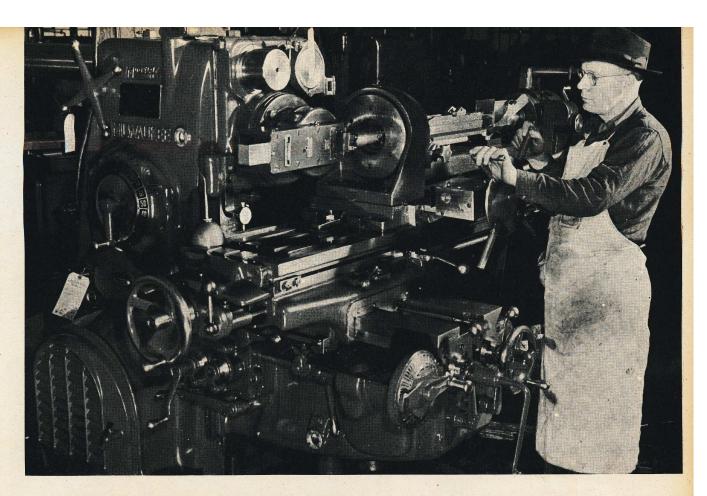
grooves are located approximately $3\frac{1}{2}$ in. within the body of the breech casing. A slotting attachment was set up on a Milwaukee miller and fitted with a heavy toolholder, of such diameter that there is just clearance for bar and tool within the hole. This holder is fitted with a single toolbit, or flat form tool, which is ground on a Pratt & Whitney profile grinder. Profile of the toolbit's cutting edge consists of a round nose at the center and a radius at either side. Thus the tool finishes the junctions between the radial slot and the interrupted surface in which the locking grooves will be cut.

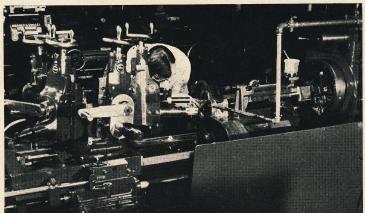
The machining of the internal locking grooves of the breech casing is just as difficult as the external locking grooves on the barrel, but is carried out on a Warner & Swasey turret lathe instead of an engine lathe. Each of several turret tool bars employed for roughing, semi-finishing and finishing the grooves is fitted with a special toolholder. This toolholder fits into a recess in the tool bar and is accurately located with dowels. Set-up of the toolbits in the toolholders

An Ex-Cello-O thread grinder is employed to grind the position-type external Acme thread on the breech casing, and an interrupted 60-deg. internal thread in one of the holes



To get operations underway, milling the radial buffer slots was started on a Universal horizontal boring machine. The homemade fixture for rotating the part includes an ingenious application of automobile differential gears connected to a standard dividing head





Interruptions in the internal locking grooves, by which the barrel is held in the breech casing, are slotted with an attachment fitted to a Milwaukee milling machine

Internal locking grooves are machined in the breech casing by single-point tools. Three toolbits are held in a special toolholder fitted to each turret tool bar

is checked in the toolroom prior to installation on the lathe. Single-point tools are found best for this operation. To avoid the set-up and grinding time required for individual toolbits, Pontiac attempted to use a single circular form tool designed to cut all three slots at once. The close limits for size and proper relationship on the part defeated this objective, because any movement of the turret would cause the circular form tool to cut over-size for groove spacing.

Approximately 20 operations were required in the original processing layout for the trigger box opening in the breech casing. This opening includes several rectangular openings, deep slots, pockets and pads.

The complexity of the operations involved has compelled the adoption of new methods for some operations and the consideration of revisions on parts prints to accomplish faster manufacture.

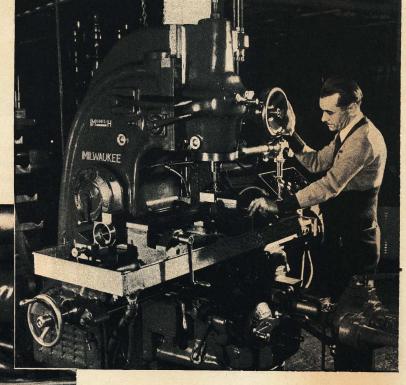
The opening is started by drilling three $1\frac{1}{2}$ -in. holes through the wall and into the bore. Webs between the drilled holes are removed with a butt drill. Principal task is to make the rectangular opening square, and with the sides blending with corner radii. These radii are small, and are conducive to trouble in finishing the sides and ends of the opening to required limits and blending them with the radii. Finishing the sides of the opening must be done with $\frac{5}{16}$ -in. diameter

end mills having a flute length of $2\frac{1}{4}$ in. A sharp cutter and a light feed are required. Roughing cutters have a right-hand spiral, finishing cutters a left-hand spiral to cut across the pattern of scratches produced by the first cutter and remove a few thousandths of metal. Obviously larger-diameter, less flexible cutters would speed up the operation, but a change in corner radius would be required.

The trigger-box opening has a large number of operations involving milling a form or radius to total limits of 0.004 in. The work is tedious, and most of the employees are former auto plant workers and others not accustomed to milling to toolroom accuracy. Accurate locating fixtures have been supplied

on the machines, but it was found that operators might inadvertently ruin a piece which had received over 100 operations. Dial indicators were applied to table movements, but without totally overcoming scrap losses. Hence Pontiac has already equipped a large number of its knee-type millers with duplicating attachments. Upon machines so equipped, the tracer contacts an accurately-made former plate, and is confined within the form so that the cutter cannot be run too deep into the piece. A further advantage of the duplicating attachments is that several related operations can be performed in more rapid sequence, because the operator need change only the former plate, tracer and cutter, instead of making a new set-up.

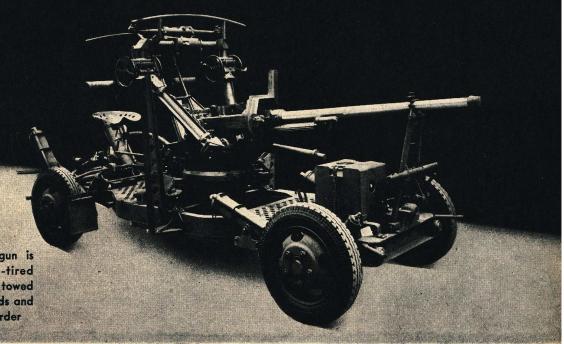
An opening in the trigger box is rough and finish milled on a Milwaukee Model H miller fitted with a Detroit Universal Duplicator attachment. The tracer actuates electrical contacts, which control the hydraulic system powering the table feed



In another duplicating set-up, a Turchan all-hydraulic attachment controls table movement of the Cincinnati machine which mills a pocket at the bottom of a deep slot in the trigger box. Approximately 150 operations have already been performed on the breech casing, and a slip in hand feeding would ruin a valuable piece

Armament

SECTION OF AMERICAN MACHINIST



The 37-mm. anti-aircraft gun is mounted on a pneumatic-tired four-wheel chassis. It can be towed behind a truck at high speeds and put into action in short order

ARC WELDED GUN CARRIAGES

Close control of welding operations aids Bartlett Hayward in turning out 37-mm. anti-aircraft gun carriages

THIS IS THE fourth war in which the Bartlett Hayward, Division of Koppers Company, has played an active part. Back in Civil War days this 104-year old firm supplied cast cannon balls. Again during the Spanish-American War it furnished ordnance equipment to the U. S. Army. In the World War period, this company handled contracts in excess of \$100,000,000 which among other things called for making 8,798,475 shells for the U. S. Government, 750,000 for Russia and 150,000 for Great Britain. Now Bartlett Hayward is manufacturing welded guncarriages for 37-mm. anti-aircraft guns.

This weapon is a troop accompanying field piece designed for high mobility and rapid fire. While not having range enough to reach high flying enemy aircraft, it is effective against strafing attacks. It fills the gap between the cal. 0.50 machine gun and the 3-in. A.A. gun.

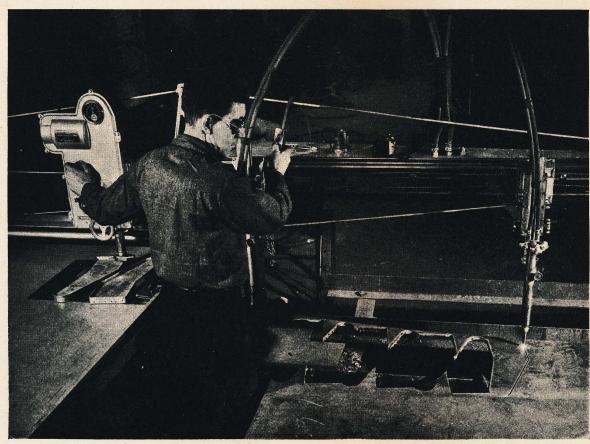
The 37-mm. gun is sighted by two men from seats mounted on the carriage. The sights have remote control by means of a fire predictor which allows for lead, windage and trajectory; all the gun crew has to do is keep on the target.

When en route the gun is supported on a rigid



One way to prepare steel plate for use in weldments is by means of a nibbling machine. Here a reinforcing rib is being formed with the tool guided by a templet

Another method of cutting flat pieces for a welded assembly is to use a flame-cutting machine. This shows the front-support plate being cut with metal - bound wooden templets guiding the torch

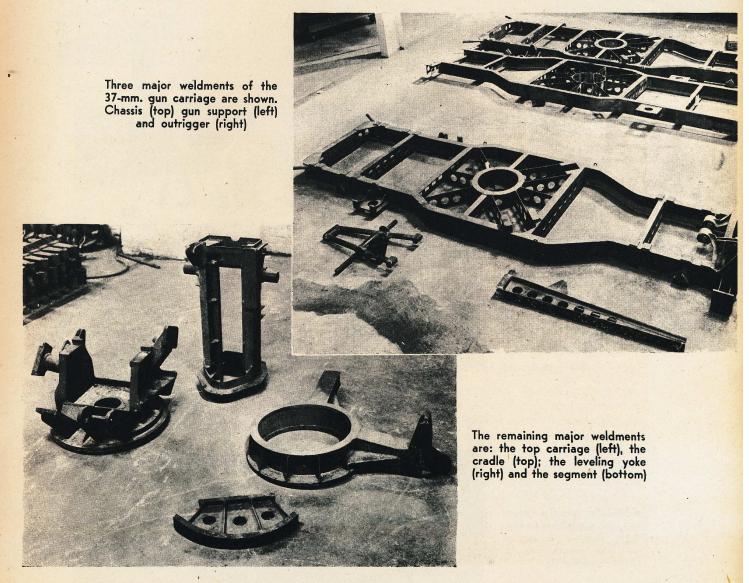


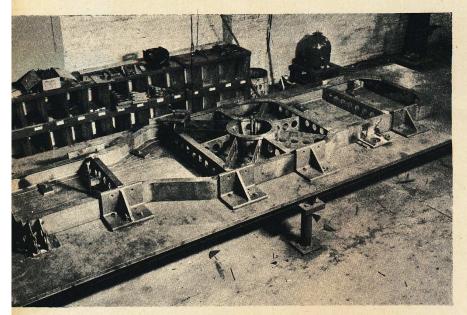
chassis carried on four pneumatic tires. Each wheel is pivoted and is equipped with a counterpoise cylinder which balances the weight of the chassis. In addition a buffer cylinder holds each wheel in the running position and acts as a shock absorber. To fire the gun the buffer cylinders are swung clear of the wheels, the chassis is lowered to the ground by pushing downward on handles at the four corners, the wheels are pivoted clear of the ground and two outriggers are dropped for side support. It is said that an experienced gun crew can perform these operations in two minutes.

The 37 mm. A.A. carriage consists of eight major weldments. The chassis, the leveling yoke, the top carriage, the gun support, the gun cradle, the elevating segment and two outriggers. In addition there are 29 other weldments, which include the counter-

poise and buffer cylinders already mentioned and an equilibrator cylinder which balances the weight of the gun itself. The weldments contain 511 separate pieces; the entire carriage, exclusive of the sighting system, the water chest and the gun itself, which are not furnished by Bartlett Hayward, includes 2,769 pieces made of 23 different types of material. Rough and finished materials for 644 parts are furnished by 128 vendors. The completed gun and carriage weighs 5,750 lb.

This brief summary of the make-up of a single gun carriage shows that it is not the simple fabricated structure a brief glance might lead one to imagine. But the multiplicity of parts is not the whole story; every weld must be clean and sound. Every part must be finished to close limits; those components that affect the pointing of the gun are held to toler-



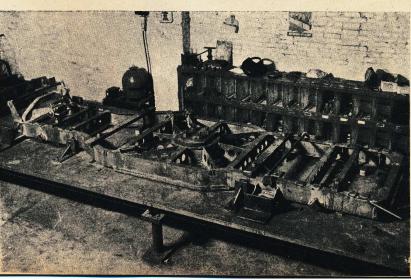


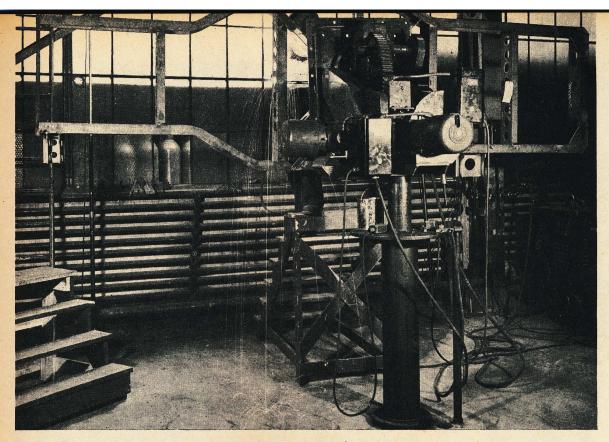
All major weldments are first set up in a jig and tack welded. This is the first set-up for the chassis. Here the five cross braces, the center ring, ten radial ribs and the counterpoise brackets are combined with the side channels. The ring and brackets have previously been subassembled

In the second assembly the bottom pan is fitted (as shown) and the "spade", four vertical steel strips, are added. These are, in turn, tack welded to the chassis



Additional pads and brackets are added in the third step in assembly with the chassis held in another jig





Positioners are used where they are necessary to secure down-hand welding. In this first welding set-up on the chassis the positioner is mounted on a hydraulic lift for operations on the ends. A temporary brace on the left end helps keep the structure straight

ances varying from a half to two thousandths of an inch.

The manufacture of gun carriages was a radical departure from Bartlett Hayward's former major activity in the construction of gas plants and gas containers. The transition was from single-lot engineering construction to mass production. However, this organization has learned to be adaptable by turning out a wide variety of products during its years of existence. It had had some current experience in quantity production because of the Fast self-aligning coupling which it has manufactured since 1920; but the gun carriage called for new methods, new equipment and new men.

To get into production of the gun mount, the company had to turn one of its old foundry buildings into a weldery. It added 59 welding machines, 40 welding positioners, annealing, sandblast and X-ray equipment, Magnaflux inspection outfits and a large number of machine tools including lathes, drilling machines, milling machines, boring mills, thread millers, vertical shapers shears, nibblers and a jig borer. Over 500 jigs and fixtures were required to tool up for this job.

Weldments are made of low alloy steel. The raw material is in the form of structural shapes, pipe or flat plate. The general procedure is to cut each component to size, punch and form it, and weld it, first into a subassembly, then into a final assembly.

For cutting to size, shears, nibblers and flame-cutting machines are employed. Holes may be punched, nibbled or flame cut. Forming is done in a steam hammer or press. Where plate-edge beveling is needed, it is done either by chipping or by using an oxyacetylene torch.

Flame cutting is a convenient method of fabricating pieces of irregular contour. For this work two flame-cutting machines have been installed. Wooden templets edged with strip aluminum are used to guide the cutting torches.

A. C. Welding Equipment Used

All joints are arc welded. Bartlett Hayward prefers the a.c. method because of the close-grained, clean weld produced and has one of the largest installations in the eastern part of the United States of this type.

A.c. transformer type welders eliminate arc blow which is particularly noticeable when welding corners, sharp V angles or any work where the heavy magnetic field developed by the d.c. arc sets up a counter force in the steel members being fabricated; this causes the arc to lose direction. The a.c. equipment also has higher over-all efficiency. The welders used by Bartlett Hayward have built-in capacitor

The chassis goes into the third and final positioner to complete its fabrication. In this as in all welding operations complete instructions are given as to the direction and sequence of welds

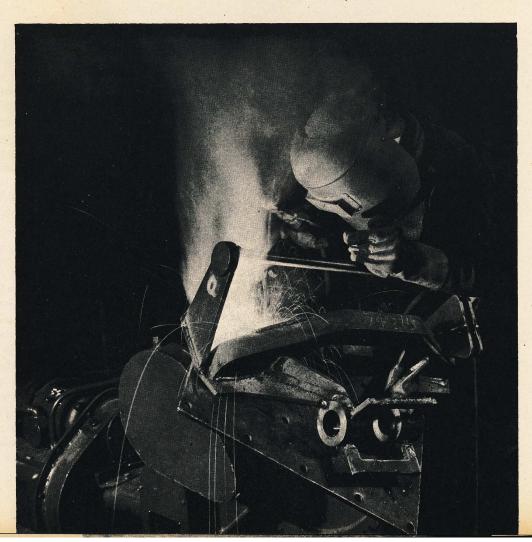
ARC WELDED GUN CARRIAGES

units for power factor correction. The result is that the power factor is in the neighborhood of 90 percent.

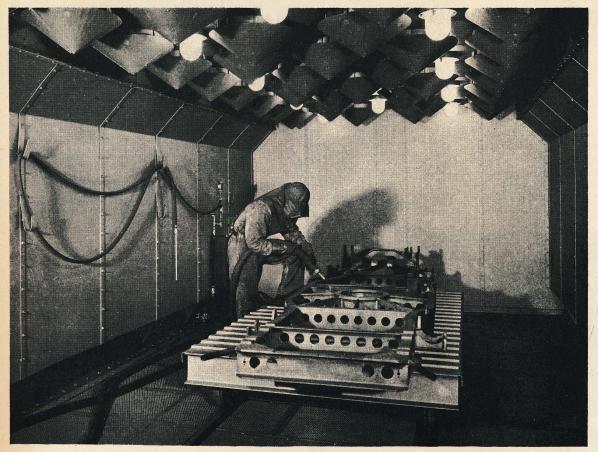
Coated electrodes are used exclusively; in fact bare electrodes cannot be used with a.c. transformer welders. For nearly all joints on the gun carriage, two passes of the arc are used to complete each weld.

The drastic increase in the use of arc welding meant that new operators had to be secured. Trained men were not available so the company had to educate welders for its requirements. To expedite the process, men are hired who have had at least one year's experience in welding. Then they are given a six weeks' intensive course to fit them for the exacting demands of this work. Before new men can start on gun carriages, they must pass the army test and an additional test of Bartlett Hayward's own devising. The army test consists in making sample welds which are subject to physical and X-ray analysis. The company's test involves the fabrication of a small weldment which includes all the types of weld that are used on the gun carriage.

Parts of each weldment are jig assembled and tack



For smaller assemblies, suitable jigs and positioners are also provided. Here the welder is at work on a front axle



Modern sand-blast rooms are arranged for safe and efficient operation. Chassis assemblies carried on a truck are cleaned before and after annealing

welded. Since all welding is down hand, positioners are used whenever required. The positioners are inclosed in booths of dark green fireproof fabric that effectively shields the arc from the eyes of other workmen.

The blueprint for each weldment includes full instructions as to how each weld is to be made. Type and size of rod are specified, and the kinds of weld have been classified and standardized so they can be designated by the letters of the alphabet on the blueprint. But this is not enough. The sequence of the welds on each weldment, the number of passes and the direction of making each weld are also specified. Nothing is left to chance or the option of the individual workman.

As an example of the procedure, the steps in making the chassis, the largest weldment in the gun carriage, will be followed. The side frames of the chassis are two pieces of standard channel iron, each having a double offset. The channel is heated at the section to be bent in a small muffle furnace and then formed in a steam hammer. It is squeezed first and then given several sharp blows in the forming die. The channel is then reversed for heating and forming the offset at

the other end. It is drilled before welding and the ends are die cut in a press.

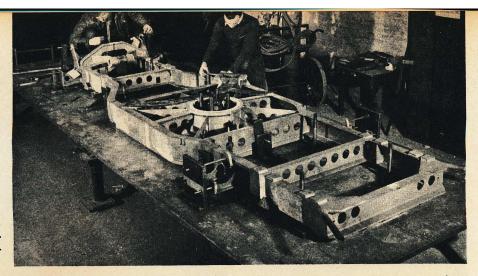
A piece of pipe is used for the center ring of the chassis. Pieces are cut from a long length in the machine shop and after cleaning are welded to a heavy flange. Reinforcing ribs are then welded around the inside diameter.

The side channels are assembled in a jig to five cross braces which have previously been perforated in a punch press. Then the center ring is added, and ten radial ribs are tacked in place. The assembly is then carried to a booth and placed on a motor-driven positioner for welding.

Here the instructions are strictly followed. For example, the radial ribs must be welded in a definite sequence. One of the longitudinal ribs is welded in place first, then the one opposite to it. Next, one at right angles to the first two is welded and the one opposite it. This procedure gives solid bracing in four directions after which the remaining six radial ribs can be welded. However, if the ribs were taken in sequence around the circumference of the hub, the weldment would be pulled on one side and distorted. Some weldments have to be turned over a number of

After all welding is completed the chassis is carefully inspected in a jig to check its alignment

Every chassis and many other gun carriage parts are X-ray inspected. This step enables the inspector to spot all defects that defy superficial examination





times before they are finally fabricated in order to equalize the pull of the newly formed joints. In every case the procedure is specified.

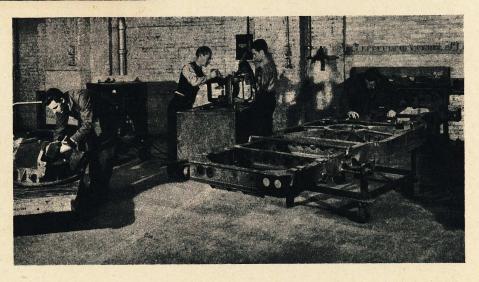
The chassis then goes to another jig where the bottom pan—a large square steel plate—is added. At right angles to the pan, and vertical as the chassis stands in the gun carriage, are four steel strips which form a rectangle around the pan. These strips are called the "spade" since they dig into the ground when the wheels are swung out of the way to bring the carriage into firing position.

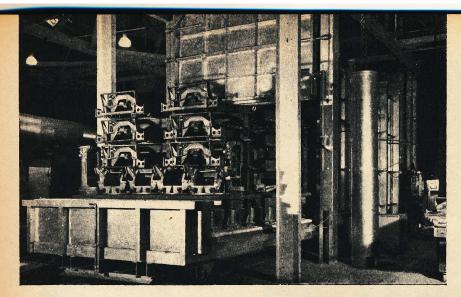
Again the chassis goes to a welding booth for mounting on a positioner. Here the pan and the spade sections are securely arc welded.

In a third jig set-up still more parts are added. These consist of various supporting pads, bearing pads, bumper retainers, the bracket for the leveler shaft and the front axle support which has previously been fabricated as a sub-weldment. These parts are then tacked. The entire unit is put in a positioner again for the final steps in arc welding.

Standard positioners are used for this work, but

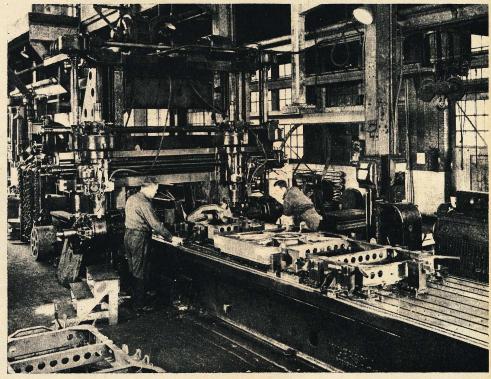
As an additional precaution the Magnaflux test is used. The fine powder used in this test shows up faults in the welding beads when a low voltage current is passed through them





Six chassis can be annealed in one oven loading. A heating cycle has been worked out that insures uniform temperature change throughout the assemblies

Machining operations? for the most part, are performed on conventional machines. For instance this milling machine finishes most of the flat surfaces on the chassis, top and bottom



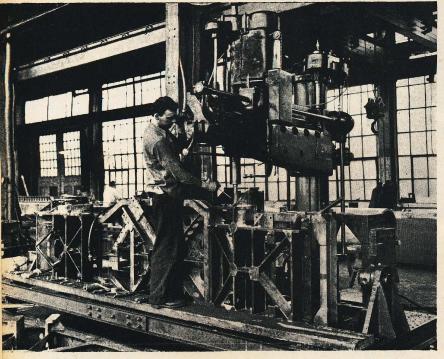
in several booths, Bartlett Hayward has added a feature of its own design. Where the chassis must be lifted high for work on the ends, the positioner is mounted on a hydraulic lift, of the type used in automobile service stations. The arrangement gives rapid vertical as well as angular adjustment.

Welds are inspected in three ways after the weldment has been sandblasted: visually, by X-ray and by Magnaflux. Visual inspection is done with a flashlight and magnifying glass to aid in detecting any surface porosity or interruption in the welded seam. Twenty X-ray pictures are required on each carriage; seven of these are on the chassis. Parts of the weldment are not inspected until fabrication is completed. Every inch of weld is checked by the Magnaflux

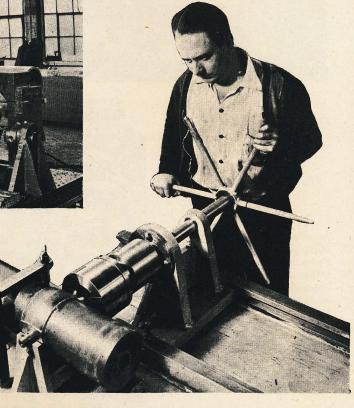
method. On large weldments the two terminals of the Magnaflux machine are put at each end of a joint while the powder is sprinkled along the weld between them. Defects are indicated by interruptions in the lines of magnetic flow as shown by the pattern of the Magnaflux powder.

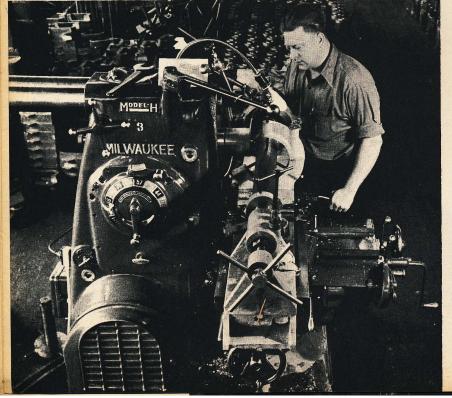
The chassis weldment is then stress annealed. Six chassis can be put into the annealing oven at one time. They are brought up to a temperature of 1150 F. over a period of $3\frac{1}{2}$ hrs. in three stages with 20 min. soaking periods at 550 F. and 900 F. The soaking periods insure uniformity of heating. The weldments are held at 1150 F. for 2 hrs. and then allowed to cool in $3\frac{1}{2}$ hrs. to complete the cycle.

The welded chassis is set up on a surface plate for



Drilling is done on a trunnion fixture that permits the chassis to be turned at any angle. Jig plates are placed over the weldment to locate the holes. The entire fixture is mounted on rails





To save machine tool set-ups and release major equipment for other work, Bartlett Hayward has developed a number of hand-operated fixtures. This arrangement for threading the trunnions on the counterpoise cylinder is a good example

Machining fixtures are carefully designed to insure interchangeability of the various components. In this set-up an equilibrator cylinder is lined up while the trunnions are hollow milled

inspection. It is checked with templets and gages; where any misalignment is detected it is corrected.

Each chassis is sandblasted again and set up in an inspection jig which accurately checks the machining allowances on all surfaces that are to be machined. The work is positioned lengthwise and sidewise by means of adjusting screws; then all important surfaces are compared with corresponding jig faces by means of a straight edge. Key dimensions are scaled as an added check. Upon passing all inspections, the chassis goes to the machine shop.

Machine Tools Are Standard

For the most part standard machine tools and conventional set-ups are used. Chassis pads are machined on a planer-type milling machine. For the drilling operations, a special trunnion fixture mounted on track is used. By this means the chassis can be revolved through 360 deg., to permit drilling on all four sides, and traversed along the track to bring all holes within the reach of the radial arm. Two trunnion fixtures are now used to meet the production schedule with part of the holes done on each. Jig plates are mounted on the side to be drilled as the

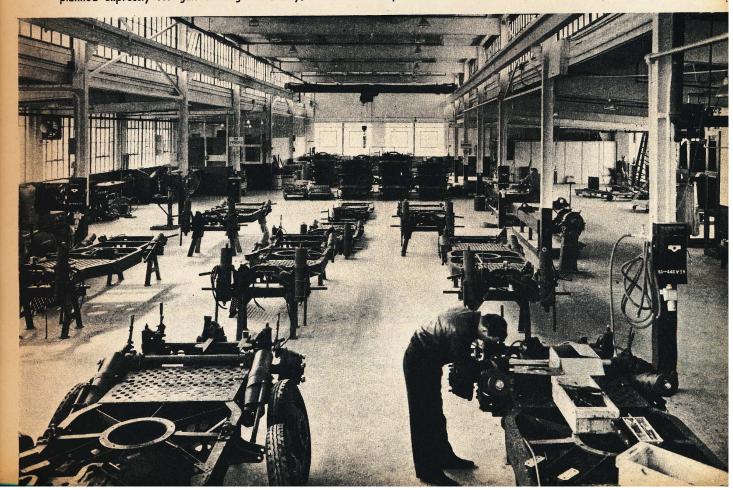
various sides of the chassis are brought into position.

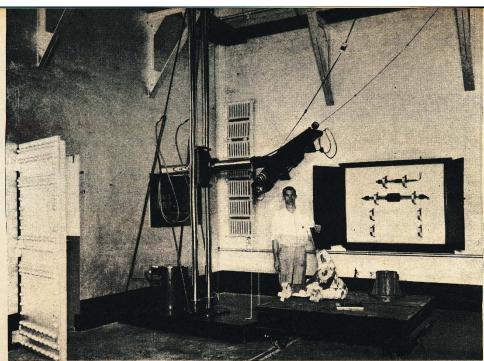
The leveling yoke has a spherical seat which rests on a corresponding surface of the gun support. The yoke is machined on a lathe equipped with a special radius-forming attachment for machining the seat. In order to make sure of a good fit, the yoke and gun support are lapped together by means of an eccentric arm held in the spindle of a drill press. The combination rotary and wobbling motion resulting when the drill spindle revolves produces the lapping action.

A new building has been erected for assembly. It is provided with painting facilities and crane service. Small parts are dipped, and large parts are sprayed in booths provided with exhaust outlets. Three coats of paint are applied.

Gun carriages are assembled in three parallel lines with six stations in each line. The chassis is laid down first and then lifted from one station to the next as the other subassemblies and parts are added. The assembly is supported on wooden horses until the wheels and tires are installed. It is shipped after being passed by army inspectors by towing it away behind a truck. Guns are mounted by the army at the Aberdeen Proving Grounds.

Although no conveyor system is employed, progressive assembly is used by carrying the gun mounts in three parallel lines through work stations where specified operations are completed. This is a new building, planned expressly for gun carriage assembly; it houses the paint booths as well as the assembly floor





X-RAY IN AN ARSENAL

ABOUT FIVE YEARS AGO Rock Island Arsenal installed X-ray apparatus as a part of its continued program for improving the quality of national defense material. Recent additions have improved flexibility and capacity.

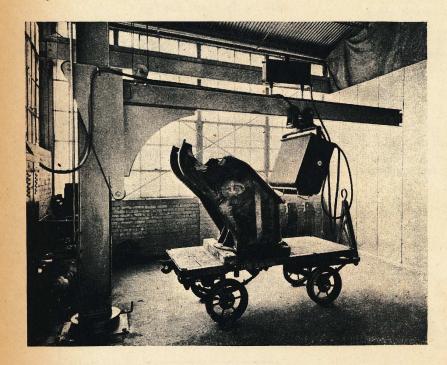
The original installation, having a maximum capacity of 500,000 volts, is used for the investigation and inspection of castings and welded parts. Walls of the room in which this equipment is installed are of 24-in. concrete, with lead doors for maximum protection to the operator.

The new equipment consists of a complete X-ray laboratory adjacent to the welding shop. This equipment, having a 220,000 volt capacity, is used to inspect all stressed areas in gun carriages and other welded parts. Enough random views are taken to check uniformity of the welding. The installation provides maximum flexibility, and the arrangement of the complete X-ray department combines adequate space with compactness.

The tube itself is mounted in a shock-proof housing which has an 8-ft. travel on the arm of a jib crane. An electric lift with remote control makes it easy for the operator to change the vertical position of the tube. Since only secondary radiation is emitted from the tube housing, the outside two walls of the room—which have only an occasional passer-by—are not lined. The two working walls and doors are lined with ½-in. lead sheets.

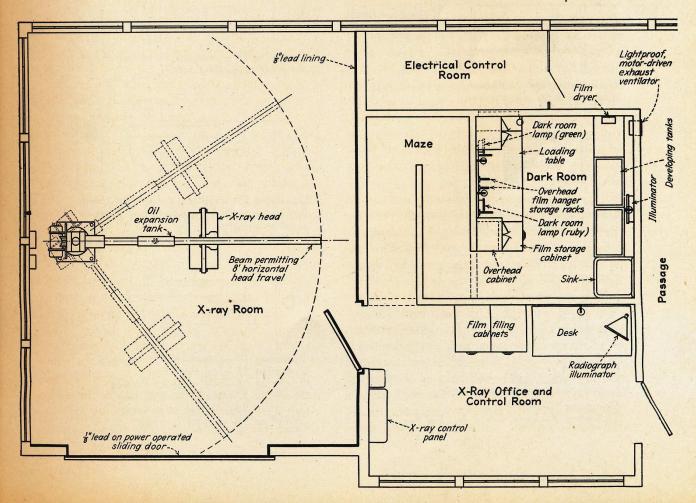
A standard rubber-tired shop trailer carries the parts into the X-ray room. The cart also makes a readily movable support for the parts under the tube. Trailers enter the room through a large sliding door which opens directly into the welding shop aisle. An electric motor and speed reducer drive a sprocket and chain which moves the door along an overhead track. Limit switches prevent overtravel. Safety switches are also used on the doors, so that the machine cannot be turned on unless the doors are closed.

With the arrangement of the dark-room shown, it takes about 50 min. from exposure to finished negative. Watch temperature for film development is thermostatically controlled. Negative viewer has a rheostat so that intensity of viewing light can be controlled. Personnel required comprises one man in the X-ray room, one man in the dark room, and one-half time for a laboratory man to view the pictures.



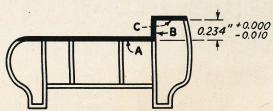
This 200,000-volt X-ray installation permits maximum flexibility for inspecting welds of many awkward-shaped castings. It is installed immediately adjacent to the welding shop. Lead sheets \(\frac{1}{8} \) in thick prevent injury to plant personnel

Minimum space and maximum convenience are achieved in this compact layout of a complete X-ray inspection laboratory. Finished negatives can be viewed in less than an hour after exposure

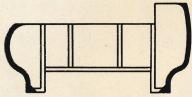




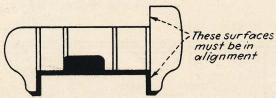
Operation 1—Grind top and bottom of SAE 1035 WD forging. Hold on magnetic chuck on table of grinder.



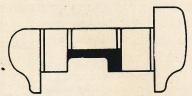
Operation 2—Gang mill upper edge. Note: All subsequent operations are located from these surfaces.



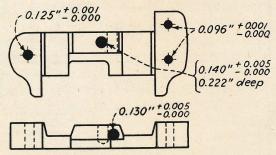
Operation 3—Form mill right end. Operation 4—Form mill left end. Note: These two operations are performed in alternate sides of same fixture. See Fig. 2.



Operation 5—Mill slot and lower edge, including slot for pivot screw.



Operation 6—End mill side of lug so surface is level across body of slide.

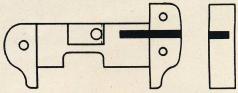


Operation 7—Drill five holes.

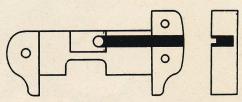
Operation 8—Ream five holes. See Fig. 3.



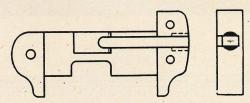
Operation 9—Rough and finish mill clearance for sight leaf. See Fig. 4.



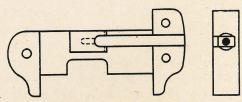
Operation 10—Rough mill slot for half-nut, using Woodruff keyway cutter.



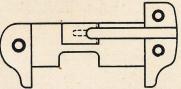
Operation 11—Finish mill slot for half-nut, using 0.140 in. diameter end mill in bench lathe. See Fig. 6.



Operation 12—Counterbore at end of halfnut slot for binding screw.



Operation 13—Drill hole for half-nut spring. Bushing in drill jig supports drill close to point of entrance.



Operation 14—Countersink three holes.
Operation 15—Tap three holes.
Operation 16—File in bench fixture.
Operation 17—Stamp part number.
Operation 18—Blacken in furnace.
Operation 19—Inspect in gage.

REAR SIGHTS FOR BROWNING MACHINE GUNS

BY ALLEN G. BURDETT

Vice-President, Service Machine Company

OF THE TEN component parts, not including small screws and pins, which make up the assembly of the rear sight for the .30 calibre Browning machine gun (M-1917), the leaf, the rear-side slide and the drift slide require the largest number of machine operations. This sight is of simple design, yet all of the component parts must be made accurately if the sight is to function properly under service conditions.

As the operations on the rear-side slide are typical of those performed on the other major parts, they are shown in detail in Fig. 1. While most of the dimensions on this slide have a maximum tolerance of 0.002 in., and a few have even larger tolerances, it has been found desirable to hold all of the dimensions on this and other parts close to the nominal sizes shown on the drawings.

A Thompson hydraulic surface grinder is used for the first operation on the rear-side slide, which consists of grinding the top and bottom sides of the SAE1035 W.D. forging. The forgings are placed side by side on a magnetic chuck on the table of the grinder, so that a number can be finished at the same time.

Since all subsequent operations on the rearside slide are located from surfaces A and B as finished in operation 2 (Fig. 1), it is essential that these surfaces be milled accurately with a fine finish. Two cutters are used. The slab mill used for surface A has

been ground specially with side cutting teeth so that it also cuts surface B, while the second cutter machines surface C. As in the case with all other milling fixtures used for this slide, the fixture for operation 2 is doweled to the machine table, so that it can be removed and then replaced accurately without aid from a skilled set-up man. Semi-skilled operators find it easy to perform the operations on the component parts for this rear sight, because all of the tooling has been carefully designed and it is practically impossible either to position the part incorrectly or to insert a part that has not been machined to proper dimensions

in previous operations.

In Fig. 2 is shown the milling fixture for operations 3 and 4 on the rear-side slide. Here, a few accurately positioned plates and clamp bars fitted to a standard Yankee machine vise make up an accurate milling fixture which holds sixteen pieces on one side for form milling the right end, and 16 pieces on the other side for form milling the left end. Once the first sixteen pieces have been milled on the right end, a total of 16 finished pieces are obtained in each pass of this fixture under the milling cutters. Pieces finished in the first side of the fixture are transferred as a group to the second side of the fixture for machining on the other end in the next pass. While these two surfaces do not mate with other parts of the sight, they form the surfaces against which the fingers of the gunner rests when adjusting the sight, and they are kept as smooth as possible. Burrs raised by the milling operation in this set-up, and in others on the component parts for the sight, are removed with a file by the milling machine

Fig. I—In all, nineteen operations are needed to finish a rear-side slide for these sights from an annealed and pickled SAE1035 W.D. forging. There are nine other major component parts operator before the parts are moved along to the next operation.

The milling of the slot and lower edge of the rear-side slide is indicated as operation 5 in Fig. 1. Here, again, cutters are ganged on the machine arbor. This operation is performed in a milling machine, while the next operation, which consists of end milling the side of the lug, is done in a special set-up on a

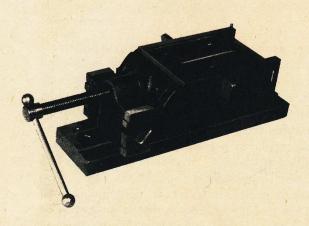


Fig. 2—Operations 3 and 4 on the rear-side slide forging are performed in a milling fixture built around a standard Yankee machine vise. The form cutters for the right and left ends of the slide are mounted side by side on the milling machine arbor and sixteen pieces are placed in each side of the fixture, location is against surfaces A and B machined in operation 2

bench lathe, where the part is mounted on a fixture attached to the cross slide, and the end mill is held in the lathe spindle.

After operation 6, these slides are delivered to the sensitive drill press, where five holes are drilled, and then reamed, in operations 7 and 8. The jig used is shown in Fig. 3. Again, the part is located from surfaces A and R milled in operation 2. Simple cam clamps hold the part in position against stop pins fitted in the cold rolled steel plate which constitutes the principal part of the jig. Feet are welded at each end of this plate to make up the body of the jig. After four holes are drilled through the top of the piece, the jig is turned on its side for drilling the 0.130 in. hole. Not only must these five holes be accurately positioned, they also must be of correct size. Particularly is this true in the case of the two 0.096 in. and the one 0.125 holes which later are tapped for Class 3 screw fits.

Three standard side-cutting milling cutters are assembled on the arbor of the milling machine for gang milling clearance for the sight leaf in operation 9. A roughing and a finishing cut is taken, since the surfaces produced must be smooth. The set-up for this operation is shown in Fig. 4. Here, it will be noted, a very simple fixture is used, with heavy clamps to hold the piece tightly in position. Also shown in Fig. 5 are the go and not-go gages used to check the two slots produced in this

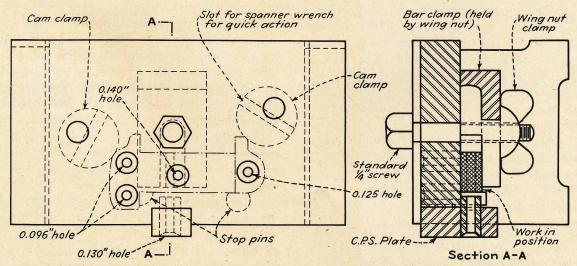


Fig. 3—The seventh operation on the rear-side slide forging consists in drilling four holes from the top and one from the side. The drill jig for this operation locates surfaces A and B (operation 2, Fig. 1) against stop pins with cam clamps

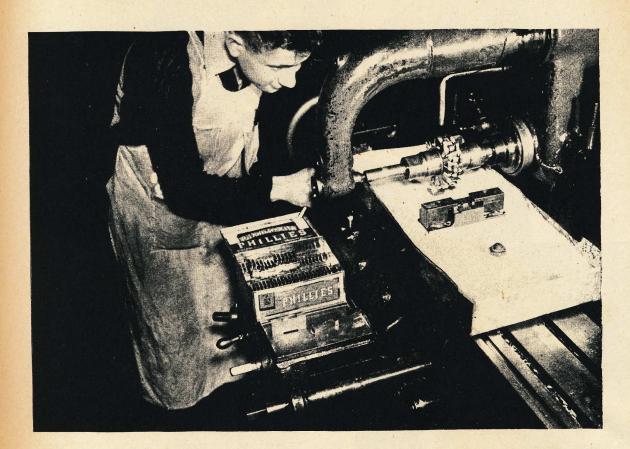
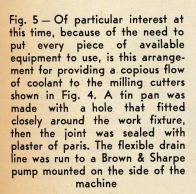
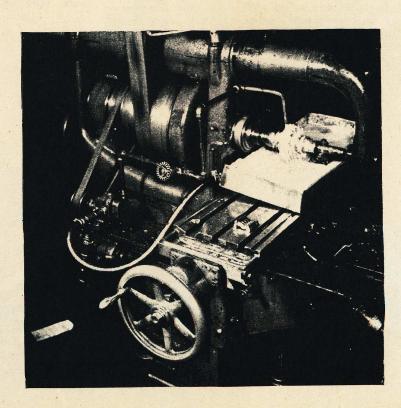
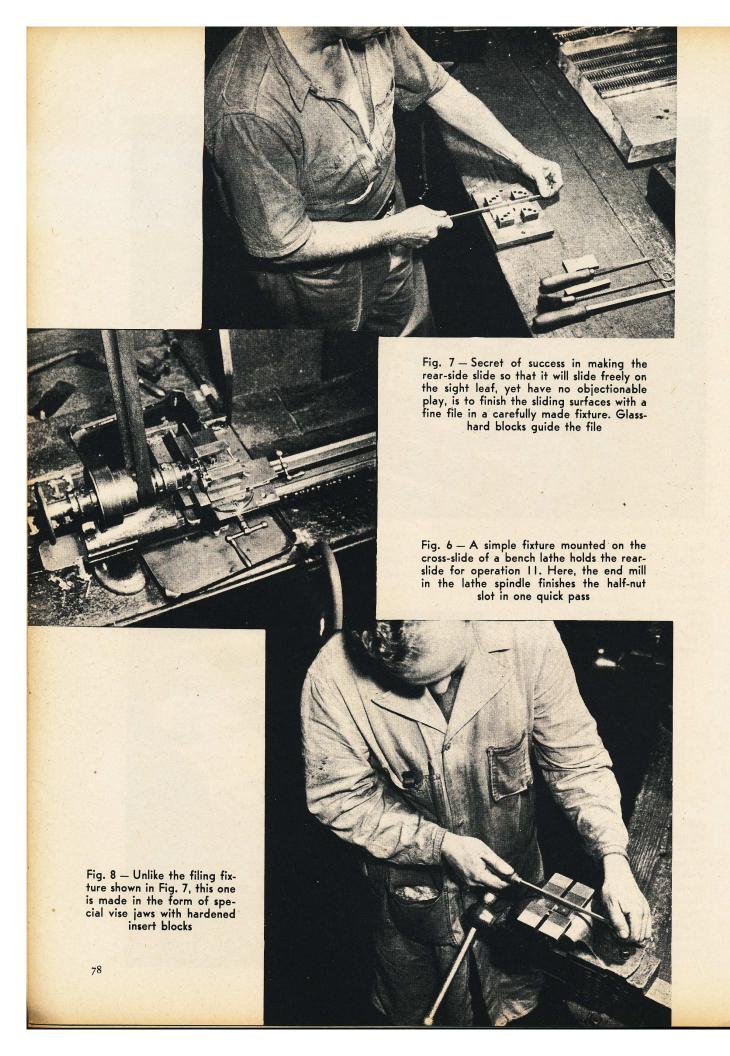


Fig. 4 — Three standard milling cutters are assembled on the milling machine arbor for the ninth operation on the rear-side slide. Accuracy of cut and fine finish are essentials in this operation. Parts are milled one at a time, being held in a simple locating fixture doweled to the machine table







milling operation. A straightening operation is performed between the rough and finish milling cuts of operation 9. This straightening operation is critical because of the differences in section involved, and a skilled operator is used.

Because a miller equipped for coolant was not available for operation 9, an inexpensive arrangement was developed which probably will have application in other shops. A simple pan of sufficient size to fit the table of the milling machine was bent up from tinplate and soldered to make the pan watertight. Then, a hole was cut in the bottom of the pan so that it would fit closely around the fixture mounted on the machine table. The pan next was clamped in position on the table and plaster of paris was used to seal the opening around the fixture. A short piece of pipe was soldered in a hole in one end of the pan, and a piece of hose was used to connect this outlet to a standard Brown & Sharpe pump mounted on the side of the miller. Discharge from the pump is through a pipe arrangement, as shown in Fig. 5, with a valve being provided so that flow of coolant can be shut off between cuts. Drive for the pump is by belt from the small step on the cone pulley drive for the machine.

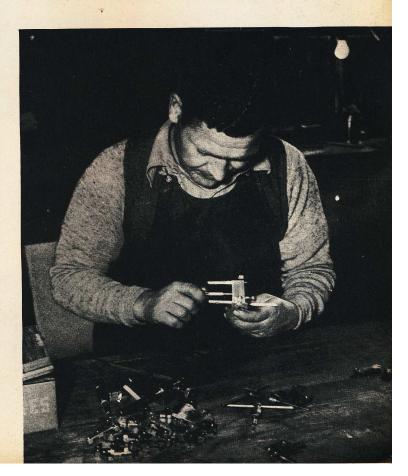
This rear-side slide must fit accurately on the sight leaf, so finished dimensions produced in operation 9 are held to the low limits, thus providing material for filing to finished size in a later operation. A hand miller with a Woodruff keyway cutter is used for rough-milling the half-nut slot in operation 10, Fig. 1. Finishing of this slot, operation 11, is done with an end mill in a bench lathe set-up as shown in Fig. 6. Here, the holding fixture is mounted on the cross slide of a simple bench lathe, as the cutter is held in the spindle collet. With such a set-up, a semiskilled operator can machine parts rapidly to a high degree of accuracy.

Clearance for the binding screw on the half-nut assembly is provided by counterbor-

Fig. 9—Each rear-side slide receives 100 per cent inspection with go and not-go gages. In this gage all five "go" plugs must enter freely the holes drilled in the part ing at the end of the slot in operation 12. This is a simple drill press operation requiring only an inexpensive locating fixture. The next operation, which consists of drilling a hole in the lug for the half-nut spring, is more critical, since the drill must start against a curved surface. The drill jig for this operation is arranged to support the drill close to its point of entrance into the work. There is not much clearance at this point for a guide bushing, but by requiring some care on the part of the operator the light section used has proven satisfactory.

Next, the three holes through the two ends of the rear-side of the slide are countersunk on both sides, and these holes are tapped in one pass with Class 3 special spiral-point Bath taps. Final sizing of this part is done in special bench filing fixtures, see Figs. 7 and 8. Glass-hard slots in these fixtures guide the file so that finish dimensions on the part are held within close limits. It has been found best to make the parts with an easy slip fit on the go gages, while holding the dimensions so that the not-go gages will not enter. Hand filing in these fixtures is less expensive than grinding, and releases the surface grinder for other operations.

After the inspector has checked the filed



parts, they are stamped with the part number and are delivered to the heat-treating department, in this case to a sub-contractor, where an oil black finish is applied. Upon return to the machine shop, these parts are given a final inspection in Ordnance Department gages, as shown in Fig. 9, and they are then delivered to the storeroom for later assembly into the finished sight.

The other part which requires a considerable number of operations is the sight leaf, Fig. 10, which also is machined from a forging. This part, like the rear-side slide, is inspected at frequent intervals during and between the machining operations, go and not-go gages being used. Further, all jigs and fixtures are so designed that parts not to proper size will not fit into position, and so automatically are discovered before additional machine work has been performed.

Interesting set-ups in the manufacture of this part are shown in Figs. 11, 12 and 14. Since quantity requirements were low, purchase of additional manufacturing equipment was not justified and existing equipment was adapted to the job by making jigs and fixtures. For instance, in Fig. 11 is shown the use of a hand turret lathe for a straddle milling operation. Here, the work holding fixture is mounted on the rear slide, ordinarily used for cut-off operations, with the slide clamped in the forward position, and the work bed down between the milling cutters by hand operation of the screw feed.

Because of the size of the center slot in this leaf, and the relative thinness of the material surrounding the slot, it constitutes a major problem when manufacturing costs must be held to a minimum. The operation line-up for producing this slot includes rough milling with a side cutter after holes have been drilled at each end of the slot. Then, the parts are delivered to a punch press where the die set shown in Figs. 12 and 13 finishes this slot, including the squaring of the two ends. Of interest in this operation is the method used to prevent closing of the holes drilled to provide clearance for the adjusting screw at the two ends of the slot. If the punching operation were performed with these holes empty, they would be closed up because

of the pressures exerted. To prevent this, common wire nails of diameters to fit closely in the two drilled holes are inserted just before the punching operation. The nails are destroyed in the punching operation, since the punch shears through the metal on the center line of the drilled holes.

Also the leaf is bent to some extent due to the punching pressure and a straightening operation is necessary. This has been incorporated in the punching operation, by providing for coining of the piece at the bottom of the punch stroke. How this is done is indicated in the drawing of the die set shown in Fig. 13.

The half-round slot in the right-hand side of the leaf for the elevating screw is finished by milling with a special convex Woodruff-type cutter in a bench miller. The set-up and fixture used are shown in Figs. 14 and 15. Like all other operations on parts for this

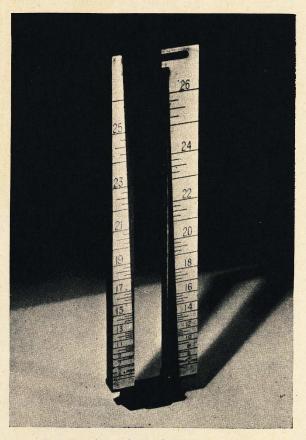


Fig. 10—The sight leaf is machined from a SAE1035 W.D. forging and must be held within close dimensional tolerances

Fig. 11—Another example of the possibilities of adapting available equipment for defense work through the use of proper tooling is this use of a hand turret lathe for straddle milling the hinge lug on the end of the sight lead forging. Here the fixture is mounted on the cut-off tool slide

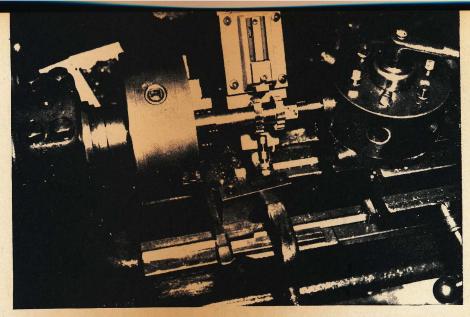


Fig. 12—Several punch press operations are performed on the sight leaf and the drift slide. This set-up, for which the die is shown in Fig. 13, is used to square the ends of the slot in the sight leaf and is arranged to coin the pieces for straightening at the bottom of the stroke

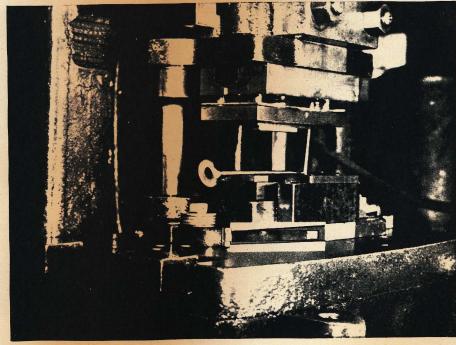
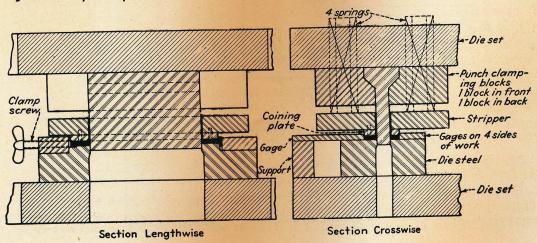


Fig. 13—This die set finishes the slots in the sight leaf forging, including squaring the two ends of the slot. The two punch clamping blocks are of such height that at the bottom of the stroke they strike the stripper plate, forcing the coining plate against the piece so as to remove any bending caused by the punch



machine gun sight, the tolerances on this groove are close, so light feeds are used and light cuts are taken.

The engraving of elevation lines and numerals on the face of this leaf requires considerable care, as no sight of this type can be more accurate than its markings. Further, since the sights must be interchangeable, the engravings must be such that the reference line always is in a fixed relation to the trunnion hole through the bottom of the leaf. All of this is checked carefully with a special Ord-

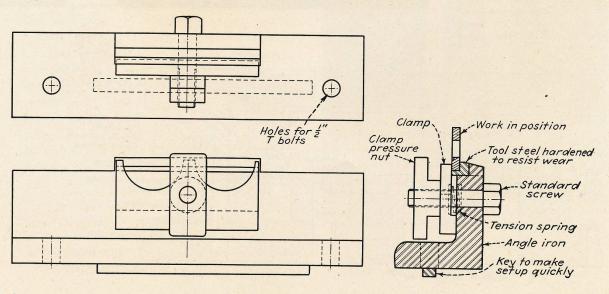
nance Department gage after the leaf has been completed. All surfaces on this leaf are oil blackened, and then this coloring is removed by polishing the two engraved surfaces at each side of the leaf.

Because of the care used in machining the component parts for the rear sight, assembly of the completed sight presents no major problems. It is merely a matter of drawing the proper parts out of the stockroom and putting the necessary components together with standard machine screws and pins.

Fig. 14—Half-slot in the sight leaf for the elevating screw is milled from the solid in this set-up on a No. 4 Burke bench miller. Fixture used is shown in Fig. 15. A special convex Woodruff keyway cutter is used for the half-round adjusting-screw slot



Fig. 15—A simple, inexpensive fixture holds the sight leaf for milling the elevating screw slot, as shown in Fig. 14. Like all other fixtures used for the machine gun sight, this tool is doweled to the table of the machine

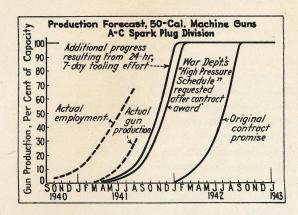


FROM MOTOR CARS TO MACHINE GUNS

MASTER MECHANICS and manufacturing engineers in the General Motors' machine-gun plants do not profess to be gun experts. Handed the job of making cal. 0.30 and cal. 0.50 machine guns in mass-production quantities, they immediately sought the assistance of the arsenals, gun plants like Colt, and the machine tool builders. That the AC Spark Plug and Saginaw Steering Gear Divisions commenced actual production ten months ahead of schedule is based upon the help received from these sources, plus the ability to set up large manufacturing operations in a hurry. The Frigidaire and Brown-Lipe-Chapin plants have followed the same procedure and will produce their first guns this summer.

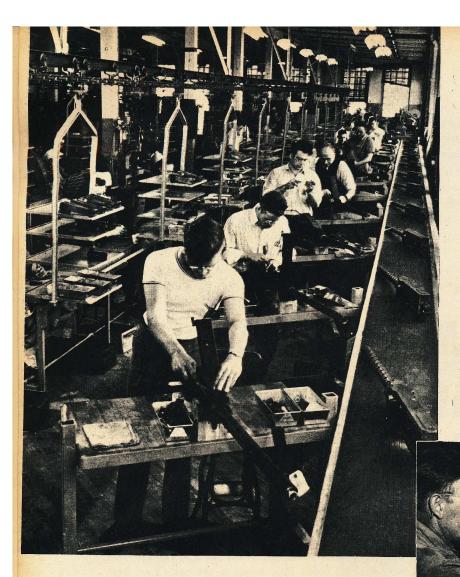
Plans were made to tool up by conventional methods for perhaps two-thirds of the daily production required under initial contracts, and to use the time available before that production level could be reached to develop new methods for mass production. Some gun-making operations have not undergone much change for many years because production quantities would not warrant the expense of development programs and new high-production machinery. General Motors' machine-gun plants have attacked a number of conventional methods in order to speed output and save labor, the last becoming increasingly important because of potential labor shortages. Marked gains in production have already been obtained on certain slow operations through the application of automotive technique. Some trouble may be experienced with the new methods, but as machining problems they are no more difficult than jobs encountered from year to year in the automotive industry. Part design changes have also been made with the approval of the War Department, when it was found that application of new techniques would save operations and produce an equally satisfactory or better product.

Since the Colt Patent Fire Arms Company was already in mass-production on the cal. 0.50 gun assigned to the AC Spark Plug Division, the eastern concern cooperated with the Flint plant by supplying tool and fixture drawings. Some of these drawings were al-



AC Spark Plugs Divisions' dramatic achievement of machine-gun production ten months ahead of schedule exceeds even the "high pressure schedule" advocated by the War Department after signing the original contract in September, 1940. Saginaw Steer-

ing Gear Division can show similar progress



First conveyorized final-assembly line in the United States for machine guns. AC Spark Plugs expects that installation of materials-handling equipment in this department will save an appreciable percentage of the man hours ordinarily expended

Rough bars, purchased approximately to length, are milled to length in two stages and center dilled on this five-station, drum-type Davis & Thompson machine. Bars are supported close to the ends and at the center by three recessed drum disks and clamped by link chains, in such a manner that drilling coincides with the bar axis

tered, new ones were made when it was necessary to choose a different method for the quantities involved. The initial tooling-up problem involved the purchase of 1,300 machine tools, and the rebuilding and motorizing of 332 machines obtained from the Rock Island and Springfield Arsenals. Some 5,913 tools had to be listed and purchased, plus 1,446 fixtures. Gage procurement was a large item in itself, involving 2,960 manufacturing gages and 600 government gages. Finally, arrangements were made to buy 97 out of 290 parts in the gun, thereby shifting an appreciable percentage of man-hours to sub-contractors.

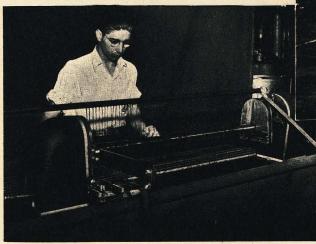
While hundreds of operations at the AC Spark Plug Division duplicate practice at Colt or the arsenals, the plant is serving as the focal point in production research for the four General Motors machine-gun plants. Scattered throughout the various manufacturing departments are numerous examples of how the automotive background changes production methods when production quantities warrant. Its influence is most strongly shown, however, in the barrel-manufacturing department. Conveyors have been installed to save fatigue and work handling. Cemented-carbide tools

are being utilized 100 per cent for barrel turning and experiments are under way with the hard cutting materials for gun-barrel drilling, rifling and eventually broaching. As stated previously, adequate equipment of the conventional type has been installed to handle rising production demands for months to come. The sequence of operations with this equipment follows Springfield Arsenal practice. Attention will be confined to the new methods and machine tools developed for gun barrel drilling, reaming, broaching the bore and rifling, and chambering.

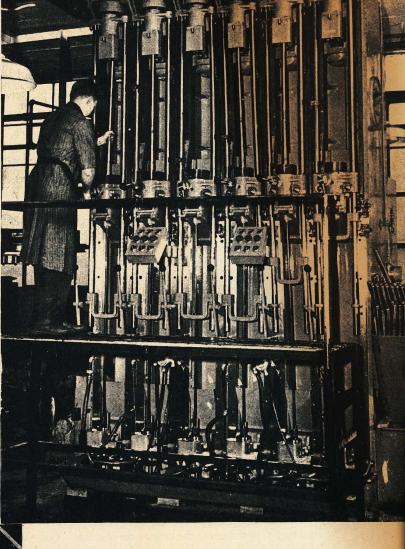
Barrels for cal. 0.50 guns are 36 and 45 in. long and turned from 113-in. heat-treated bars having a hardness of 280-310 Brinnell. Lo-Swing and Fay automatic lathes of the type conventionally used in gun

First installation of its kind, this vertical W. F. & John Barnes gun-barrel drilling machine portrays the automotive influence, fits into a conveyorized background. Each of the spindles is independent in operation. Experiments are being conducted with Carboloy-tipped drills with the idea of eventually cutting drilling time by 50 percent

An innovation in Magnafluxing roughturned bars is the supply of fluid in finely divided streams, a time and labor saving feature. Fluorescent lighting of high candlepower assists the operator in finding cracks or flaws



work are employed. AC Spark Plug has standardized upon cemented-carbide turning tools for the roughing and finishing operations, in order to increase output, decrease tool changes and tool cost. Cutting speeds of 200 ft. per min. are standard, and tool settings are approximately 4½ to 6 in. apart. Cemented-carbidetipped tools at \$4.50 each are said to be cheaper than solid tools made from high-speed steel and the hourly output is four to five times greater than with steel tools. On the rough-turning operation, the hourly output averaged over the shift is approximately 20 barrels, while on the finishing operation, nearly 25 barrels are secured. High-quality finish is obtained, and no straightening is needed. In fact, less than one per cent of the barrels require straightening at any point in the



production sequence. Forgings will soon be used for both barrels to save one rough turning operation as well as material. Experiments are also being conducted with forging the tapered section of the barrel, leaving 0.010 in. for cleaning up, and saving numerous additional machining operations.

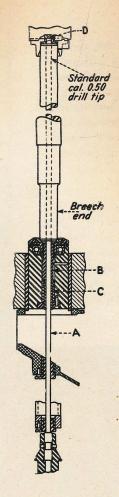
A considerable number of conventional horizontal gun-barrel drilling machines were installed immediately at the Flint machine-gun plant, in accordance with AC's policy of providing ample production facilities of the proved type. To experiment with new highproduction equipment, two W. F. & John Barnes sixspindle upright machines have also been put into operation, and four more ordered. At present these machines, which face each other, are served by an operator standing on a platform some distance from the floor. The machines tower almost to the ceiling, and it is necessary for the machine tender to be able to work at various levels. Hence it is planned to install a hydraulically elevated platform, so that he can raise himself quickly to the upper position for loading and unloading barrels, then drop to the lower position to remove the drill or inspect it. Barrels are picked off the conveyor which loops around the gun-barrel turning and drilling department.

When two Barnes six-spindle machines are set up facing one another, 85 per cent of the floor space required for twelve horizontal single-spindle machines is saved. The operator walks about on the small platform, easily observes the progress of drilling on any of the twelve independent spindles, and production is naturally speeded up in the automotive manner. Each spindle is individually controlled by pushbuttons at that station. After loading the work, the operator pushes the buttons to cause the particular spindle to go through its hydraulically controlled automatic cycle of rapid approach of the revolving barrel to the stationary drill, drilling, rapid return and stop. A feature of the "closed" hydraulic feeding system is that chatter is avoided because the work will not jump when the drill encounters hard or soft spots, and furthermore the drill can be withdrawn from a partially drilled hole and returned to the cut without ill-effect.

To load a given spindle, the operator inserts the muzzle end of the barrel in a three-jaw self-centering chuck in the headstock, which is integral with a slide at the upper part of the machine. Automatic actuation is provided for the chuck. The breech end of the barrel is held in a 120-deg. cone center in the tailstock. The tailstock is clamped to tie bars that are connected to the headstock, so that headstock and tailstock move down as an integral unit.

A stationary single-lip drill is held in a toolholder mounted on a slide near the base of the machine. The revolving barrel is fed down over the drill, which is caused to cut a true start by a long bushing in the tailstock. Three essentials must be observed with respect to the bushing: (1) Looseness of the non-rotating drill in the stationary bushing must be avoided, or the tool will run out, and hence a fit in the order of 0.001 in. maximum must be maintained, (2) the bushing must be held tightly against the breech end of the barrel by heavy spring pressure to prevent accumulation of small chips and escape of cutting oil, and (3) a back taper of 0.0004 to 0.0008 in. on the drill bit is required to keep clearance at a minimum in the bushing until the drill has cut its own path. When the drill breaks through the muzzle end of the barrel, it enters a steel plug behind the chuck jaws, thus preventing escape of cutting oil.

Each of the spindles is individually driven by its own cartridge-type motor through V-belts. On the first machine, five spindles were supplied for 1;100 r.p.m. to accommodate high-speed gun drills, while the sixth had a speed of 1,800 r.p.m. for experimentation with tungsten-carbide tipped tools. The Carboloy Company and the H. R. Krueger Company were called in by AC to develop tool design and procedure. Encouraging

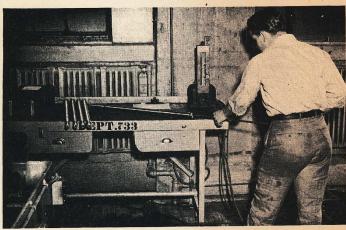


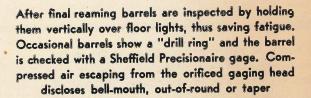
At each spindle of the Barnes machine, the muzzle is held in a threejaw self-centering chuck at the upper, or headstock, end and the breech is centered and clamped by a 120-deg. cone in the tailstock. Gun drill A has a 0.001 in. fit in guide bushing B. Spring C keeps the bushing tightly against the breech to prevent escape of cutting oil and chip lodgement. Loose piece D prevents oil from escaping and steadies the drill when it breaks through the muzzle end. Run - out normally is held to less than 1/32 inch

progress can be reported but it may be some time before barrel drilling with carbide tools becomes a thoroughly evaluated process.

Experimental set-ups have involved considerable variation of cutting speed. Some carbide drilling has been carried out at 1,700 r.p.m., and occasional tests made at 2,400 r.p.m. with good results. Vibration of the barrel does not cause drill run-out, but this vibration in combination with whip of the gun-drill oil tube, induced by column action arising from heavy cutting pressure transmitted to a light-walled tube, has posed a number of problems. Whip of the oil tube is the factor limiting the feed on all types of gun barrel drilling. Experimentation has been done with various grades of cemented carbide, with the most recent trend toward the hardest grade. H. R. Krueger is developing a stiffer oil-tube construction. Several modifications have been made in tool design, including a change from the conventional grind in order to secure more free cutting action. With production lots of new drills, tests will be carried out at 1,250 r.p.m. Successful attainment of higher speeds such as 1,700 or 2,400 r.p.m.

Time is saved on the first and second rough-reaming operations by the concentration of effort at this twelve-spindle Baush machine. The barrel is held in a carriage and pulled upward and over the push-type reamer. At the top of the stroke, the reamer is stopped automatically and the barrel drops down over the tool to the original position





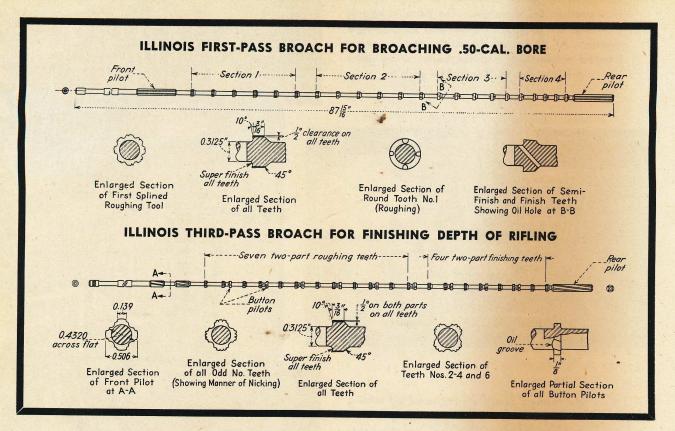
in production, with a parallel gain in feed rate, which is desirable with carbide tools, depends upon whether further modifications in tool design or setup are involved. Some type of vibration dampener upon barrel or gun-drill tube, or on both, may prove necessary.

Tipped gun drills have a piece of Carboloy about 1 in. long brazed to a tool steel section approximately $2\frac{1}{2}$ in. long, the tool steel being brazed to an oil tube. The tool has a 0.0004 to 0.0008 in. per in. back taper from the tip. The tool-steel section of the tip will have a hardness of 50-55 Rockwell to prevent galling when passing through the close-fitting hardened guide bushing.

Drilling results have been extremely variable with both types of tool materials, although carbide tips have shown a four- to five-fold advantage in number of barrels per grind. Some high-speed steel tools have drilled several barrels before dulling, others have drilled only a few inches. The average result is close to two barrels per grind. Drills are ground after each two barrels, regardless of condition, in order to save damage to the clearance angle. A feed rate of 1 in. per min. has

Three operations are customarily employed by the AC Spark Plug to ream the drilled machine-gun barrel. AC was the first to install Baush twelve-spindle vertical reaming machines, which are currently employed for the first two operations only. Installation of these machines has not speeded up the reaming cycle on the individual spindle, but floor space is saved,

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Three broaches are employed to broach the bore and the rifling, according to the Illinois method. The round broach finishes the bore diameter. The first rifling broach, not shown, finishes the width of the grooves and cuts them approximately two-thirds deep. The second finishing broach has a splined pilot, as shown, and follows the path of the first rifling broach to cut the grooves to full depth but without affecting the width

handling is reduced and the operator is able to handle about twice the number of spindles possible with conventional equipment. Drilled barrels are brought to him by conveyor.

The gun barrel has been drilled to 0.489–0.001, and must be reamed to 0.5010–0.001 in. In the first ream on Baush equipment, the hole size is increased to 0.4943–0.001 in., and in the second ream to 0.498–0.002 in., the third reaming on conventional equipment is done to 0.5010–0.001 in.

In effect, the Baush machines consist of twelve independent motorized reaming spindles which are operated at conventional reaming speed and feed, using a standard push-type reamer threaded into a tube. The barrel is mounted in a carriage and pulled up and over the reamer by means of a chain passing over a sheave and connected to a hydraulic cylinder at the back. At the lower end, the barrel is positioned in a cone center, while the upper end rests in a V-block and is held by a swing clamp. At the top of the stroke, the spindle driving clutch is disengaged, the reamer stops, and the barrel is dropped down over the reamer to the unloading position. Reamer marks within the hole are of no

importance because finish reaming will be done later with conventional equipment. The feed rate is set at 6 in. per min., but can be changed if desired.

Through considerable experience in application of carbide tools to the cutting of steel, the AC Spark Plug plant was convinced that inserts on rifling cutters would expedite production and attain satisfactory finish. Conventional rifling cutters were fitted with inserts and used in Pratt & Whitney two-spindle barrel rifling machines. It has been possible to boost the cutting speed of the machine up to the return speed, or from 20 to 60 ft. per min., and the quality of finish is excellent. As compared with high-speed steel rifling tools, carbide tools have boosted production from one to four barrels per hour and the number of barrels per grind from approximately one to twelve. Two effects are forecast through this development: (1) the conventional rifling equipment now installed will have a far greater output than originally contemplated and (2) plans to broach the rifling and eventually the finished bore diameter are now predicated upon the use of carbide broaches operating at 60 ft. per min., although high-speed steel broaches will be used until

satisfactory carbide broaches are developed. Rifling with carbide tools is still on an experimental basis.

The interest displayed by small-arms plants in broaching the bore and rifling springs from these factors: (1) one broaching machine has approximately twenty times the production capacity of conventional two-spindle rifling machines, to say nothing of finish-reaming machines displaced, (2) the cost of a broaching machine, a special sharpening machine and the inspection fixture—all of which are essential to a plant set-up—is approximately one-tenth that of the twenty rifling machines, (3) the amount of labor can be reduced by broaching, and (4) firing tests indicate that a target pattern made with a newly broached barrel is equivalent to and perhaps more uniform than the pattern made with a reamed and rifled barrel, and that

To broach the bore or rifling on Illinois equipment, the proper broach is inserted in the barrel, and the oil-retaining tube at the far right is slipped over the broach and is locked before the cutting oil is turned on. The oil flows in the direction of the cut, washing chips ahead of the broach teeth and into spaces between them



after several thousand rounds have been fired, the pattern for the broached barrel is superior to a new barrel in respect to accuracy and uniformity. These benefits are believed to arise because all tool marks in the broached barrel are parallel to the helical flight of the bullet, and there are no crosswise scratches to load with particles from the projectile.

AC Spark Plug has installed an Illinois horizontal, single-spindle broaching machine that handles the bore and the rifling with three broaches used in sequence. A LaPointe multi-broach station-type machine has been ordered. Five broaches are passed through the barrel in sequence and mechanically retrieved, thus promising to speed production by avoiding manual broach handling. Five barrels are in process at one time and the sixth station on the drum is used for loading and unloading. Recent developments indicate that perhaps three broaches will handle the job.

One of the chief problems faced by mass-production gun plants such as AC Spark Plug is that of securing broaches at a cost that will make the adoption of rifle broaching feasible on an economic basis. It is estimated that broaches will produce from 50 to 100 barrels per grind, and with twenty grinds permissible, from 1,000 to 2,000 barrels can be secured during the life of the tool. Because of the necessary complexity of the broach, its first cost and its maintenance cost are high at present, despite its productivity. Expansion of the country's broach industry is considered essential by manufacturing engineers in order to accommodate new and heavy loads imposed upon it by mass-production small-arms plants.

Three slender broaches $87\frac{1}{16}$ in. long with a root diameter of 0.3125 in. are required to broach the cal. 0.50 barrel, according to the original method devised by the Rock Island Arsenal in conjunction with the Illinois Tool Works and now being tried on an experimental basis by the AC Spark Plug Division. The broaches to be described show the general principle, but are undergoing detail refinement, especially to reduce the length.

The first broach finishes the bore as reamed on the second Baush machine. There are four groups of teeth. Section 1 has six splined roughing teeth ranging in diameter from 0.4970 to 0.4998 in. in 0.0007-in. increments. Section 2 consists of six round roughing teeth in the same size range, and operating to remove the eight lands left by the splined roughing teeth. Section 3 embraces five round semi-finishing teeth increasing in 0.0002-in. increments from 0.5001 to 0.5009 in. Section 4 has five round finishing teeth of 0.5010-in. diameter to finish the bore. This broach eliminates the conventional finish-reaming setup.

Rifling actually commences with the second broach. At the front end there is a round "diameter" pilot, but

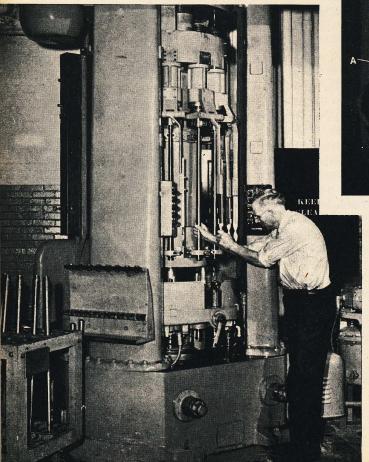
the tool cuts its own helical path. The tool is gripped in a ball-bearing pulling head and is thus free to follow the helical lead cut by the broach teeth. This broach has eight teeth in the roughing section, the teeth increasing in diameter from 0.5014 to 0.5070 in. in 0.0008-in. increments. Thus, the rifling grooves are roughed to a depth of 0.0030 in. by the roughing section. The four finishing teeth on this broach are all of the same diameter, 0.5078 in. Eight grooves are cut to a depth of 0.0034 in. (approximately two-thirds of final depth) and to a width of 0.139 in. This is a finishing broach in that the width of the groove is finished.

Broach No. 3 has a four-splined pilot that fits in the previously broached rifling grooves. Seven roughing teeth range in diameter from 0.5074 to 0.5104 in. in increments of 0.0005 in. In other words, the roughing teeth remove a chip two and one-half tenths thick.

Four finishing teeth are all 0.5109 in. in diameter. Consequently, rifling grooves are cut 0.0049 in. deep in two broachings, whereas by conventional rifling methods, using a single cutter and taking a 0.0002-in. chip, nearly 200 indexings would be required.

Certain peculiarities should be noted in these broaches. The bore broach has oil holes drilled at an angle through the semi-finishing and finishing teeth so that high-pressure cutting oil can wash the chips in the direction of the cut. The early rifling tools, broaches Nos. 2 and 3, actually have two-part teeth; that is, a front and rear part. Each part has four opposed cutting edges. The splines on the rear part are 45 deg. from the centerlines of the splines on the front part. In other words, one part cuts four grooves; the other, the remaining four grooves. To shorten the two rifling broaches almost by half, the front and rear parts of each "tooth" will be combined, thereby broaching eight

Outstanding in showing the influence of automotive technique in obsoleting traditional methods of machine-gun manufacture is this ten-station Krueger chambering machine. Production is approximately six times as fast as hand-operated chambering machines



B

Nine reamers, only eight of which are shown, are employed in the Krueger chambering machine. Tools are shown in the fixture which presets them to gage length. Surface A represents the datum plane of the machine. Buttons B represent the junction of the chamber with the bore. Tools are set to length by means of various gaging sleeves C and the micrometer adjustment nut D. Reamers follow designs employed by the Springfield Arsenal except that Nos. I and 2 divide up the roughing cut in the long taper

splines instead of four with each tooth. Behind each tooth there is an oil-grooved pilot that should have a diameter clearance of 0.0003 to 0.0005 in. to maintain the rifling grooves concentric with the bore. The face of the button probably should be straight to prevent picking up a "bug" and seizing.

The Illinois pull-broaching machine, in which these broaches are used, is fitted with a screw feed instead of an hydraulic feed to avoid chatter arising from broach flutter. The broach is inserted in a guide bushing at the breech end of the barrel, and an oil retaining tube with a seal is placed over the broach and tightened in position with a twist of the wrist. Then with the pull bar engaging the broach, the high-pressure cutting oil can be turned on and the feed engaged.

For high-speed steel broaches, such as currently available, the cutting speed is 20 ft. per min., but the machine is capable of 60 ft. per min., because of AC's anticipation that satisfactory cemented-carbide broaches can be developed. Effort to pull the broach through the barrel is in the order of 700 lb., which indicates that no trouble should be experienced with loosening cemented-carbide broach disks brazed to a steel bar. The chief problems with satisfactory carbide broaches will be: (1) to grind and stone the teeth to practically perfect uniformity in chip-taking action, and (2) to train a sufficient number of men in the art of broach maintenance for mass production.

Under present circumstances, barrels should be broached completed with three passes on Illinois equipment at the rate of fifteen to twenty barrels per hour, and on the LaPointe machine at the rate of 30 to 40 per hour. Whether broaching will displace finish reaming and rifling depends upon the economics of tool cost and tool maintenance. It now appears that broach cost will be reduced sharply and that further cost reductions can be effected when their manufacture is put on a production basis. Finish reaming requires fifteen minutes per barrel, while rifling takes one hour with a conventional tool and fifteen minutes with a carbide-tipped hook cutter. At best, these two operations require 30 min. per barrel, so it may be predicted that broaching will be done from ten to twenty times as fast as the displaced operations and probably faster when carbide broaches are developed.

Opening out the finished bore at the breech end of the barrel to form the complex-contoured chamber for the cartridge is considered one of the fine arts in the gun-making trade. Precision workmanship has been obtained only with aptitude and adequate training in operating hand-fed machines that use slip reamers interchangeably in a special tailstock or reamers held in an indexing turret. Production averages five to seven chambered barrels per hour. If operators depart from painstaking care, tool breakage and machine downtime become serious impediments to desired output.

Master mechanics and tool engineers in the auto industry have no appreciable background in the gunmaking tradition, but are characteristically impatient with slow methods and soon take steps to find faster ones and especially to remove the variabilities of the human element from the operation. After purchasing a number of the up-to-date chambering machines such as used by arsenals, so as to insure adequate production on this operation in the months to come, L. H. Benson, master mechanic, AC Spark Plug Machine Gun Division, worked with H. R. Krueger, of H. R. Krueger & Company, upon the idea for a mass-production chambering machine. The result is the Krueger ten-station mass-production chambering machine, which keeps all chambering tools in use simultaneously and does not depend upon the operator's skill. Production at first will average 30 chambered barrels per hour, with the machine operating at slower than normal feed, and 40 barrels per hour when adequate experience has been obtained with the new method.

The fundamental concept of the Krueger machine envisages: (1) all tools preset to a common gaging level, or datum plane, (2) barrels chucked in such a manner that the breech ends shall be a specified distance above the gaging level, (3) each tool to be fed a definite distance into the barrel above at a feed rate most suitable for the particular chambering operation involved. Construction details have been worked out as follows:

The ten-station barrel carried indexes automatically around the central column at the specified point in the cycle. Each barrel is held at the upper, or muzzle end in a lever-operated collet chuck and caused to run true at the lower end in a steadyrest. Each of the steadyrest points is backed by springs to allow some float of the barrel to the reamer.

Below the indexing barrel carrier there is a tool carrier that can be automatically raised and lowered to engage or clear the tools with the barrels in the stations above. In the case of the cal. 0.50 set-up, this distance is established as 5 in. To proceed with chambering operations at the respective stations, the independently actuated tool quills are moved upward an additional distance by feed cams. A cam ring below the tool carrier is fitted with nine cams, each having a rise suitable for feeding the given tool. The cam ring oscillates through an arc of 36 deg. (one-tenth circle). On the forward stroke the tools are allowed to return to the original position.

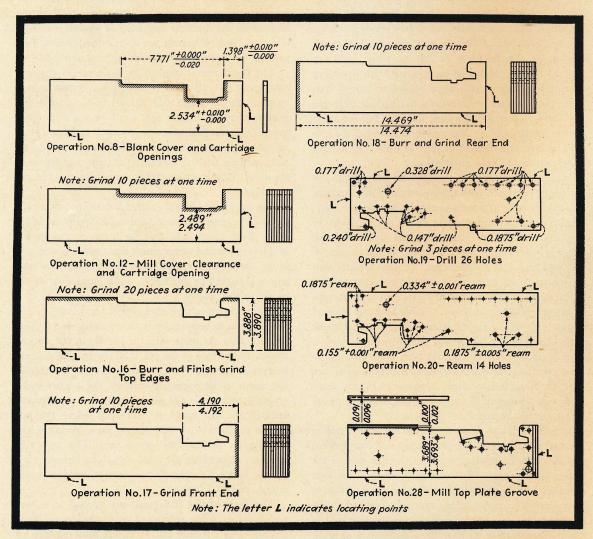
Top faces of the tool quills are ground in a horizontal plane, which represents the gaging level. Tools are preset in a fixture affixed to the machine column. Each tool is locked in a toolholder, which has a micrometer nut and ground fine-series thread. Over the

piloted end of the tool is slipped a gaging sleeve, which has a short internal taper corresponding to the reference taper on the end of the pilot. To adjust the tool height in reference to proper extension beyond the spindle quill, the above assembly is slipped between the gaging surface in the fixture and a hardened button. The micrometer nut is then adjusted until it seats upon the gaging surface of the fixture. Buttons in the fixture are equidistant from the gaging surface, tool heights being fixed by gaging sleeves.

To load the barrel properly, end-wise locating means are provided at the loading station No. 1 to position the breech end at a specified distance above the gaging level. At this station there is a loading pilot which has vertical travel by means of a crank. The breech end of the barrel is placed on this loadinig pilot, the crank turned and the muzzle end of the barrel en-

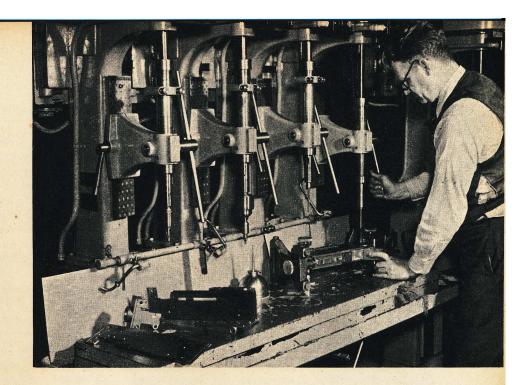
tered in the collet chuck. The crank lifts the breech end a specified distance as dictated by a positive stop. After closing the collet chuck and the steadyrest, accurate positioning of the breech face of the barrel is checked with a swing-type dial-indicator fixture. If correct, the index button is pressed and the cycle proceeds automatically. Each barrel is rotated at the proper cutting speed for chambering operation.

Because of the production characteristics of the Krueger machine, consideration is being given to development of Carboloy tools in order to minimize offgage chambers and down time for tool changes. One of the features of the machine that will assist in preventing rejected work is the overload device on each spindle. If a tool catches in the work or cutting effort exceeds suitable limits, the overload device trips a switch, which causes the tool carrier to return to the



Principal operations in manufacturing a left-hand side plate for a Browning cal. 0.30 machine gun. Prior to drilling and milling, the piece is ground on all six sides to achieve accurate locating surfaces

Building up a Machine Gun Case—Forty operations of the I,800 required to produce a cal. 0.30 Browning machine gun are consumed in assembling the several components of the gun case. Here an operator has assembled the right- and left-hand side plates, the top plate, the bottom plate and the trunnion block (all parts of the case) upon a harness, or box fixture, for line-reaming and countersinking the rivet holes in four operations



down position and the machine to stop. A red light flashes on a panel to indicate which tool, or chambering operation, is giving trouble.

From the World War until operations commenced in April at the new machine gun plant of the Saginaw Steering Gear Division of General Motors, the cal. 0.30 Browning had not been made in production. Without an up-to-date pattern to follow, the Division was forced to tool up from scratch, relying upon its production "know how" to equip and tool its plant for this gun in a very few months.

There are 189 individual parts in the cal. 0.30 Browning, of which 153 are made at Saginaw by application of 1,800 distinct operations. Some of these parts may need only a dozen or so operations, but more complex items require considerably more, the bolt for example including 83 hand and machine stages in its manufacture. Machine gun work is largely a matter of "worrying the metal away." Parts are comparatively small, most cuts are light, and milling in various forms plays a predominate part in the manufacturing processes. So far as possible, skill is transferred from the man to a modern machine fitted with a highly accurate fixture because untrained labor must be recruited and taught to handle one simple operation. The tooling methods obviously seek to attain accuracy at initial operations and maintain that accuracy throughout the entire manufacturing process in order to avoid a high percentage of scrap.

The initial contract called for the production of a large number of guns per day plus spare parts (the latter require expenditure of an equal amount of labor). So far as practicable complete production lines are set up for each component, although to provide permanent setups for every machining operation would

entail double the number of machines, many of which would be idle for part of the time. For this reason 1,300 machines were specified, of which 1,165 are new and 135 were obtained from storage at the Rock Island Arsenal, then rebuilt and motorized. The plant was approximately one-half equipped on the first of May, gun assemblies were accelerating since the first gun was made in April, ten months ahead of schedule, and approximately 800 workers were distributed over three shifts. By February, 1942, in excess of 4,000 workers will have been hired and trained.

The tooling problem involved production of 8,000 tool drawings and design or specification of 6,000 initial tools. This process will consume 62,000 man hours of engineering labor, while the building of the tools, jigs and fixtures will cause expenditure of 250,000 man hours of labor in vendor's plants.

In setting up operation schedules for machine-gun parts, Saginaw's engineers drew freely from the methods of automotive-parts manufacture. It is inescapable, of course, that many operations must be performed singly, but even here type and design of fixture bespeak the automotive tool engineer in respect to incorporation of accurate locating means, "fool-proof" loading and quick-acting positive clamps. Parts are often doubled up in fixtures, or the fixture built so that it will accommodate a right- or a left-hand piece, to decrease machine set-ups. Occasionally, the high-production note is seen, especially in multiple-spindle drilling and the use of a chucking machine instead of a battery of turret lathes.

Hundred of machine set-ups in the Saginaw plant are much alike, the principle of fixture and tool being repeated over and over and merely adapted to the particular operation. Principal gun components require

too many operations for detailed comment, but skeletonized operation sequences and discussion of equipment and fixtures used will give an idea of the manner in which an automotive-parts plant has embarked upon machine-gun manufacture. Examples chosen are the side plate for the gun body, the trunnion block and the bolt. Some set-ups for the cal. 0.50 parts produced by the AC Spark Plug Division are included to show the different approach to the tooling problem because of variations in part design or production technique.

Production methods for side plates of the gun body are indicative of the tooling philosophy employed by the Saginaw Steering Gear Division for many machined parts. In this case, the raw material happens to be strip stock rolled to close tolerances for thickness and flatness and with round edges to save mill time and cost. Before the final stages of drilling and especially the milling of four accurately located grooves, it is essential to grind all six surfaces.

After sawing the strip to rough lengths, square edges and ends are obtained by milling in gang set-ups. In slab milling the edges and straddle milling the ends, an allowance is made for finish grinding. One side of the blank is also surface ground to present a scale-free surface to the punch when blanking out the cover clearance and cartridge opening. To rough mill this contour would prove a time-consuming operation; hence it is blanked, leaving enough stock for finish milling. The press is set up with two dies, one for a left-hand and the other for a right-hand blank, since the contours differ.

To overcome distortion arising from the blanking operation, the unfinished side of the piece and the bottom edge (opposite the blanked edge) are surface ground. With two parallel sides and a square bottom edge on the piece, it is now possible to stack the side plates ten at once in a machine vise for finish milling the cover clearance and cartridge opening, with the exception of a bottom slot and a bullet clearance contour which are handled in two additional milling setups. Gang cutters were originally employed for finish milling the main contour, but have since given way to a form milling cutter.

At this stage, the two sides and the bottom edge of the piece have been finish ground. It remains to grind the other three sides prior to drilling numerous holes and milling four grooves. The top edge is ground first to establish the finished width of the piece within a tolerance of 0.002 in. Twenty pieces are stacked in a vise, being located from the bottom ground edge. This operation is performed on a No. 34 Abrasive verticalspindle surface grinder. The ends are ground in two further set-ups on an 18-in. Abrasive face grinder. Separate fixtures are employed for right- and left-hand side plates. To grind the front end, location is taken

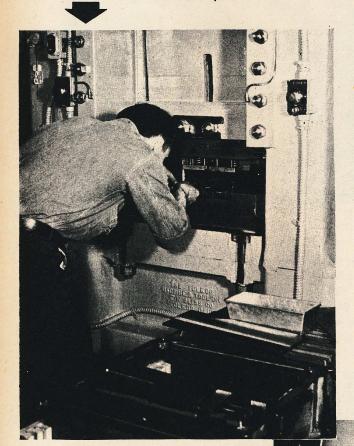
from the finished bottom edge and from a face in the milled contour. To grind the rear end of the side plate, location is taken from the newly ground front end and the bottom edge. The last locating points are employed in subsequent operations.

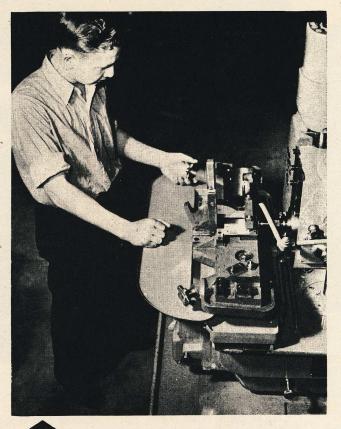
The next major operation involves drilling practically all of the holes in the side plate at once on a Natco multiple-spindle machine instead of numerous single spindle set-ups. Spacing of the 26 holes drilled in this operation does not permit handling all holes in one operation. To save set-up time and a second machine, a two-position fixture is employed, three pieces being drilled at once. In the rear position twelve holes are drilled, after which the fixture is slid on rails to the front position for drilling the remaining fourteen holes. In either position the fixture registers against adjustable stops. Guide bushings in the bushing plate register with guide pins in the fixture, when the head is brought down. The spindle head on the machine is adjustable to accommodate changes in hole spacing if desired at any time.

While an essentially mass-production set-up was chosen for drilling the side plates, the following operation of reaming fourteen holes is carried out on a four-spindle gang-type machine. The side plate is loaded into loose box-type fixtures, one for each of the multiple-spindle reaming heads. In this case it is cheaper to use more labor, whereas in drilling the number of holes and the length of the operation suggested a more expensive machine and fixture.

The reason for grinding the part on all six sides to tolerances of 0.002 in. becomes apparent when the side plate progresses to the four grooving operations. The most important of these happens to be that of milling a through slot parallel to the front edge. Correct depth and width of the slot and distance from the slot to the front edge of the side plate are important because this groove takes the impact of the recoil mechanism through the trunnion block. Right- and left-hand fixtures are set up on a Cincinnati knee-type machine so that the trunnion-block groove can be milled in right- and left-hand pieces at the same time. The other three grooves—top plate groove, back plate groove and the lock-frame guidepin groove—are milled in three succeeding set-ups on Cincinnati rise-and-fall milling machines. In each case one fixture is provided and one piece is milled at a time because the machine is fitted with cams for milling one groove only. The fixture is however fitted with duplex locating elements, so as to accommodate a piece of either hand. Foolproof loading is attained by pins that prevent improper location of a piece of a particular hand.

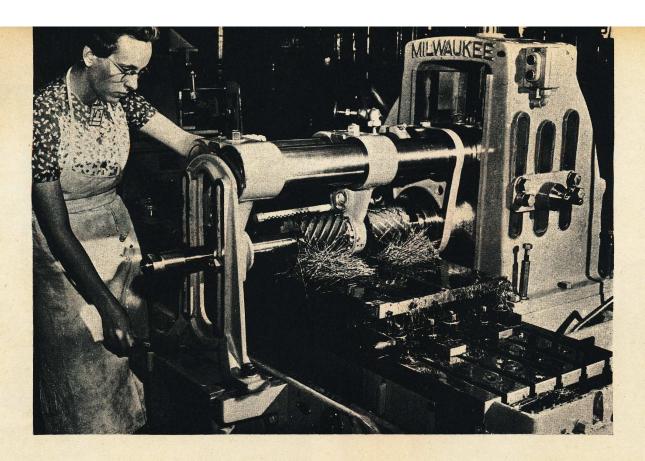
Further evidence of the automotive influence upon machine gun tooling is shown by the equipment chosen Three of the grooves in the sideplate are blind at the ends, hence are most conveniently produced on Cincinnati rise-and-fall millers. In this set-up, the double-position fixture accommodates a left or right-hand side plate





Blanking the cover clearance and the cartridge opening saves a tedious milling operation, leaves only a few thousandths stock for finishing milling. Dies are placed in a Bliss No. 3061/2 crank press for blanking one right- and one left-hand plate per stroke

To save numerous set-ups, 26 holes are drilled in side plates (three at once) using a Natco machine with multiple-spindle head. Close center distances compels drilling the holes in a two-position fixture, which slides on rails. At the first, or rear, position fourteen holes are produced, and the remaining twelve at the front fixture position



One of the heaviest milling cuts in machine gun work is that of slab milling two cal. 0.50 side plates at once at the AC Spark Plug Division. This operation is required to reduce the stock thickness over the majority of the side plate's area, leaving a thicker section at one end for cutting the trunnion-block groove. Magnetic chucks firmly hold two side plates while 13 cu.in. of metal is removed from each plate by climb milling. AC plans to eliminate slab milling by upsetting one end of thinner side plate material

for drilling the cal. 0.30 and cal. 0.50 trunnion blocks. These parts vary greatly in size and the drilling problems are totally unlike.

To avoid the long time cycle of drilling through 1,9 in. of metal, the Saginaw Steering Gear Division has tooled up to drill the cal. 0.30 trunnion block half way through from one side, reverse the part in a second fixture for drilling the remainder of the hole depth from the opposite side and ream at a third station. The set-up involves a three-spindle Allen drill press fitted with power feed and automatic return mechanisms on each spindle. Each station involves the use of a multiple-spindle U.S. drillhead, which is fitted with guide bars to the bushing plate, and the bushing plate is also guided upon pins in the fixture. With this set-up, one operator handles drilling and reaming the two rivet holes and one mount hole in the part, and spends the largest percentage of his time in actually loading and unloading parts rather than waiting for the drills to break through.

A totally different problem arises in drilling the

rivet holes in the cal. 0.50 trunnion block processed by the AC Spark Plug Division. In this case the part happens to be larger, but the drilling time is akin to that required for the right- and left-hand side plates because the actual depth of metal to be penetrated does not vary too much. The reason for this circumstance is apparent from the nature of the cal. 0.50 trunnion block, which has the sides relieved so that drilling is done through flanges rather than a couple of inches of solid metal.

Since it is desirable to drill rivet holes in all three parts in the same set-up, so as to obtain 100 per cent interchangeability and alignment upon assembly, an essentially high-production machine was chosen. A Natco "Hole-steel" drill with 50 spindles in the fixed-center gear-driven head is arranged actually to drill 108 holes of 0.187 in. diameter because of fixture and spindle layout. There are 41 rivet holes in the right-hand side plate, 37 in the left-hand side plate and 15 drilled through each flange in the trunnion block (flanges are drilled from opposite sides). Close cen-

ter distances forbid drilling all holes in any part at one station. Hence the machine is provided with an automatically indexing rotary table having four fixtures—one for a left-hand side plate, another for a right-hand side plate and the remaining two for loading the trunnion block from the top and bottom respectively.

Only one part is processed at a time on the machine. In a side plate, for example, part of the holes will be drilled at the first station, more at the second station and the remainder at the third position, the fourth station being the unloading position. It was a nice problem to lay out the spindles and the fixtures (each of which takes part location differently) so that the drills register properly at any of the three working positions. Output is 45 right- or left-hand side plates per hour; or 15 trunnion blocks, which must be run through the machine twice. Obviously the machine will not be operated continuously, but its labor and equipment-saving characteristics as compared to single-spindle set-ups more than justify the high original cost.

The bolt is the most intricate part of the Browning machine gun, and its proper functioning depends upon adherence to rigid manufacturing specifications. The cal. 0.30 weapon employs a much smaller bolt than does the cal. 0.50, and the other chief difference is that the former has one belt-feed cam slot, whereas the latter has two slots crossing in an X-shaped pat-



Forge welding has displaced cold riveting at AC Spark Plug Division for making gun-case assemblies. Here an operator is electrically riveting a cam to a side plate. The cam is first positioned on the side plate by means of a jig and the rivet is inserted. Upon transfer to the National welder, the hold-down cylinder grips the parts tightly together. Advancing under a controllable time cycle, a second cylinder causes the electrode to contact the rivet

Because of the long drilling cycle, Saginaw Steering Gear chose to drill three holes half way through at each of the first two stations and ream at the third, instead of using separate low-production set-ups



tern. In other words, the infantry weapon can be fed ammunition from one side, whereas the aircraft gun must be operable from either side.

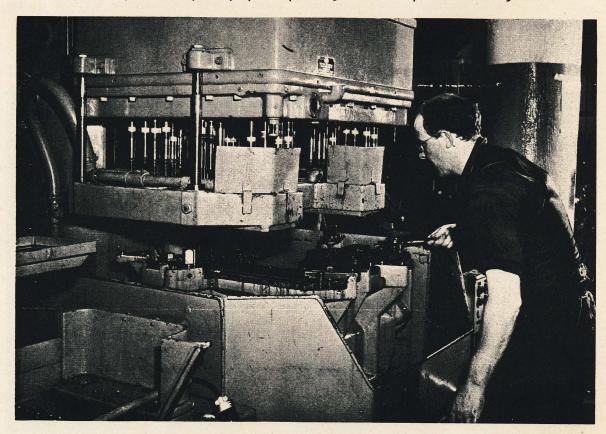
Eighty-three operations have been laid out by the Saginaw Steering Gear Division for production of the bolt for the cal. 0.30 gun. An accompanying skeletonized series of work-picture drawings (each operator gets a work picture for the job done at his machine) indicates that scores of operations involve milling a little here or a little there. Accurate locating surfaces are absolutely essential, and as with side plates the part is ground all over. In the case of the bolt, however, the four sides and the two ends are completely ground much earlier in the production process.

For form milling operations, arsenals have used profile ground cutters. These must be sharpened on the profile, a circumstance that compels the use of a cam and special profile grinder. Saginaw Steering Gear Division discovered that cutter manufacturers could not handle the volume of work involved in supplying initial tools or replacements and that delivery time of special profile grinders would prevent the plant from getting under way as planned. So it

was decided to use the eccentric-form relief type of profile cutter wherever possible. These require grinding on the front face only of the teeth and can be sharpened repeatedly. Tooth spacing is coarser than in the profile-form ground type, but good finish is being secured.

Some profiles cannot be machined with form cutters, hence numerous operations involve the use of hand-operated profile millers, in which the operator guides the cutter manually while keeping a tracer spindle in contact with a form. One of the most interesting of these is Operation 60 on the cal. 0.50 bolt produced by the AC Spark Plug Division. A 30deg. angle must be profiled on the cartridge starting face of the bolt. The job involves milling a tapered face along a roughly semi-circular path and blending the ends of the cut with the points on two guide rails on the bolt as well as blending the tapered face with the "floor." From the nature of the job, two cutters must be employed. Hence the machine is supplied with two cutter spindles. A taper cutter in the righthand spindle roughs the floor and the central sector of the 30-deg. tapered face. To mill the corners and

Fifty spindles properly located with respect to four fixtures permit this rotary-table Natco to handle the drilling of 108 rivet holes in the two side plates and the trunnion block of the cal. 0.50 gun. The three parts are processed separately by AC Spark Plug but are 100 percent interchangeable



blend the taper with the "floor," a flat cutter in the left-hand spindle is employed. The spindle head in this case is caused to rise and fall, as determined by the tracer bearing against the form plate. Complex hand-profiling jobs of this type require exceptionally qualified operators.

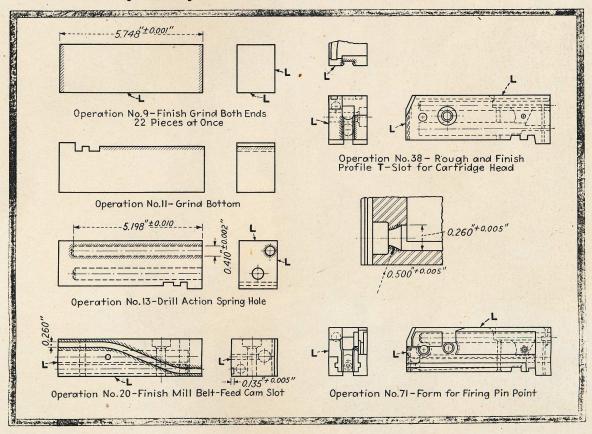
Of the several score parts required in a machine gun, a large number have very sharp edges and light burrs after machining. To round the corners smoothly and uniformly is a production problem of the first magnitude because many of the parts have a number of intricate surfaces which are not readily accessible, while other pieces are small and difficult to hold. Filing methods would be unsatisfactory on two counts: (1) the excessive labor burden of handling massproduction quantities, and (2) difficulty in meeting part specifications for degree of corner rounding and finish. Fortunately the AC Spark Plug Division discovered an idea at the Springfield Arsenal for a machine method of doing the work and has had the process—tumbling—under continuous development for a number of months. Tumbled parts usually have

Eighty-three operations have been laid out by Saginaw for production of the bolt for the cal. 0.30

Browning machine gun

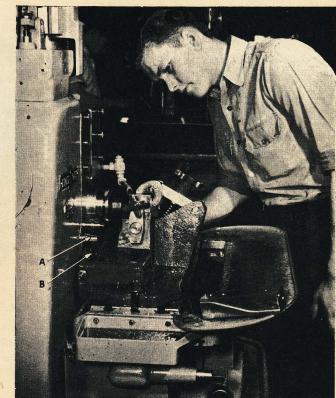


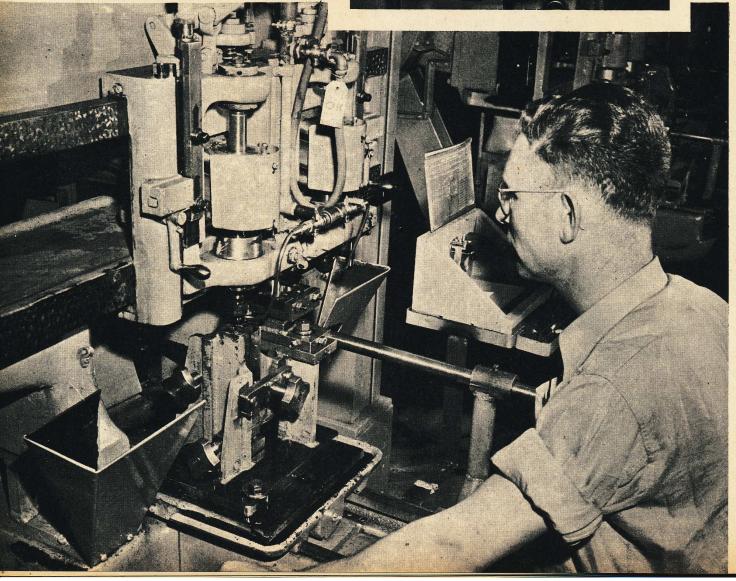
A home-made device saves time at AC Spark Plug in countersinking rivet holes. A foot plate containing a gear drive reaches between the flanges of the cal. 0.50 trunnion block to countersink the inner end of the holes, thereby saving the tedious work of using a loose cutter slipped over a spindle reaching through the opposite hole



Two similar set-ups are employed at Saginaw for rough and finish milling the single belt-feed cam track in the cal. 0.30 bolt. Constant downward hydraulic pressure on the floating cutter head keeps the tracer A in constant engagement with a cam plate B embodied in the fixture. Conventional movement of the table causes the cutter spindle to move up or down as the cam moves past the tracer

To hand profile the cartridge starting face on the cal. 0.50 bolt, AC Spark Plug Division has fitted a profiling machine with two spindles, in order to accommodate tapered and flat cutters respectively in the same set-up. The left-hand finishing spindle has a rise and fall movement obtained by the tracer riding on a tapered cam



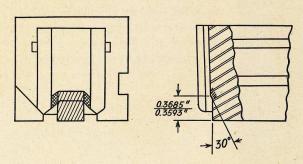


a dull-gray matte finish, and the corners can be rounded or kept square as desired.

Tumbling for corner rounding and burr removal is distinctly different from burnishing. The principle is to separate the work pieces with an abrasive-soluble oil mixture which may or may not contain slugs, and to rotate the charge at low barrel speeds so that the work pieces do not fall against and damage one another. This idea applies only to parts which are not bulky or do not have considerable mass. There are some machine gun parts which are not suitable for free action in a tumbling barrel and hence must be mounted on fixtures within a special barrel, the abrasive mixture sliding over the fixture-held pieces as the barrel rotates.

Several precautions are taken to prevent the parts from damaging one another within the tumbling barrel. In the first place, the charge is never more than one-half the barrel capacity and frequently much less. Second, barrel speeds are from 25 to 35 r.p.m. As a net result, the parts slide over one another rather than tossing about. Third, barrels are fitted with a ½-in. thick Neoprene lining to prevent the parts from sliding against or bumping the metal interior of the barrel.

Only sufficient soluble oil is added to the charge to wet the parts, the abrasive, and the slugs if used. In other words, a liquid mixture is not desirable because it would prevent holding the abrasive and slugs in suspension at the low rotative speeds employed. Thus, when operating bench-type Mercil tumbling barrels with a 26-in. bottle diameter, the amount of soluble oil in the charge may run between $\frac{1}{4}$ to $\frac{1}{2}$ pt., whereas



Operation 60 on cal. 0.50 bolt—profile cartridge starting face. The single cross-hatched area indicates the "floor" and part of the tapered cartridge starting face, which are hand profiled with one spindle. Double cross-hatched corners are milled and blended with adjacent rails and the floor finished with the second spindle

in the larger Baird No. 2B sheet-steel bottle tumbling barrels from 3 to 4 qt. of oil may be used.

Three types of abrasives are employed: (1) silica wash, (2) No. 8 semi-silica flour, and (3) banding sand. The last is used only for certain tumbling operations in Baird three-compartment horizontal tumbling barrels. Quantities of abrasive customarily used in bench-type barrels vary from 3 to 6 oz., while 3 to 4 lb. may be employed in the Model 2B machines.

Slugs are not always required. Their use depends upon the permissible degree of corner rounding, the type of burr, and the prospect of damage to the piece by a peening action. All slugs are dead soft. Balls from $\frac{1}{8}$ to $\frac{5}{16}$ in. in diameter, $\frac{1}{4}$ in. balcones or stamping waste can be used. Selection of the ball size is important, because balls will pack in holes of similar diameter. Slugs are not commonly used in the bench-type barrels, but cases arise when it is necessary to use slugs with small quantities of work or small



Right- and left-hand guideways on the cal. 0.50 bolt are ground with an Ex-Cell-O high-speed grinding attachment. Six surfaces in each guideway must be ground to a tolerance of 0.0017 in. and an obstruction prevents the use of a large wheel. Hence, a small wheel operating at high speed not only gets to the required surfaces but saves time

parts in order to make up a mass of sufficient weight for proper tumbling. Balls or balcones in weights of approximately 100 lb. are supplied to charges tumbled in the Model 2B Baird machines.

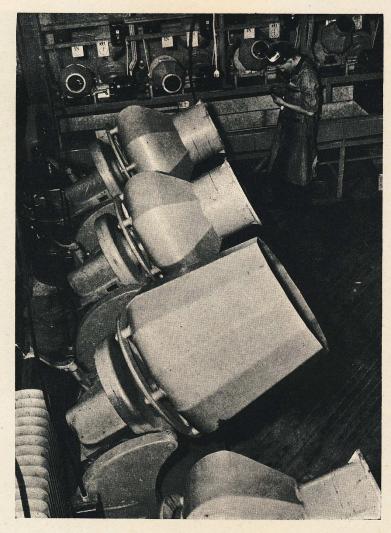
Tumbling time varies with the part, the permissible corner rounding action, the type of burr and whether or not the piece has been hardened. From 3 to 6 hr. is customary.

Most tumbling is done at the completion of machining operations. A growing application is the removal of light grinding burrs on blanks prior to machining to save the time an operator would spend in hand filing such burrs before loading into machine fixtures. Heat-treat scale is removed from hardened parts by the same process. In both applications, tumbling requires less time than corner rounding and removal of burrs from machined parts by the usual hand methods.

Some parts are not tumbled until after hardening

because excessive peening action has been found to occur or the corners are rubbed off too much. Longer time is required to tumble hardened work but the load size can be increased because the damage from impingement is lessened.

AC Spark Plug Division is continually expanding the uses of the tumbling process. It should be understood, however, that the new method is not employed for removing heavy burrs thrown up at intermediate machining stages. Burrs other than of the light variety would be bent over onto the machined surfaces by the tumbling process. While heavy burrs could be cut away in the barrel, extra long tumbling cycles would be required and excessive dimensional changes would occur in the part. Heavy burrs are broken off at intermediate machining stages by the operators, in order to load the piece properly in the next machine fixture. Avoidance of heavy burrs at intermediate stages is a subject in itself.



A battery of tumbling barrels at a centralized location removes sharp corners and burrs from machine gun parts coming from several production departments. Work pieces are separated with an abrasive-soluble oil mixture which may or may not contain slugs. Barrels are rotated at low speeds so as not to damage the work

Guns ahead of schedule

PRODUCTION of the first Canadian-made Bren gun five months ahead of schedule, marked fruition of plans to establish machine gun manufacture in the Dominion. No one had built machine guns in Canada before, and few Canadian mechanics had any knowledge of the gun-making art. The letting of a contract for Bren guns to a Canadian plant was largely a matter of faith in the organizing ability and technical skill of its officers.

There were good reasons why military planning boards had estimated that it would take at least two and a half years to set up production of the Bren in Canada. While it was true that the experience of a British plant could be drawn upon, it was necessary to bring together a large number of precision machine tools, to make thousands of tools, gages and fixtures, and to revise British tool drawings where deemed advisable, in order to suit the equipment obtainable for the Canadian plant. In addition it was necessary to recruit highly skilled men for tool-making activities, to hire first-class mechanics for the production department and to acquaint the personnel with gun making.

The first Canadian-made Bren gun was produced in less than two years from the date when three plant officials sailed to England for the purpose of familiarizing themselves with the methods used in the British plant for Bren production and with the gun-making art as a whole. Upon return two and a half months later, the company made plans to secure 600 machine tools, to make or buy 17,604 fixtures, tools and gages, and to bring together and train a supervisory and production force.

One of the first steps was to write specifications for equipment and secure approval from authorities at Ottawa. This procedure was necessary because all equipment used in the production of Bren guns is the property of the government, the manufacturer operating on a cost-plus basis. All machine tools were tested to close standards of accuracy and performance, before acceptance.

To England for Training

While awaiting delivery of equipment, the company hired foremen and specialists and sent them to England for training at the British plant. Toolroom activities got under way first because of the immense job of building thousands of accurate fixtures, tools and gages to the precision standards involved in gun work.

There are plenty of toolmakers in the Dominion, but the gun factory needed men accustomed to working a ten-thousandth of an inch. By scouring all parts of Canada, the company was fortunate to secure 100 men who would be a credit to any toolroom. Incidentally it is a requirement that all persons connected with Bren machine gun manufacture must be British subjects.

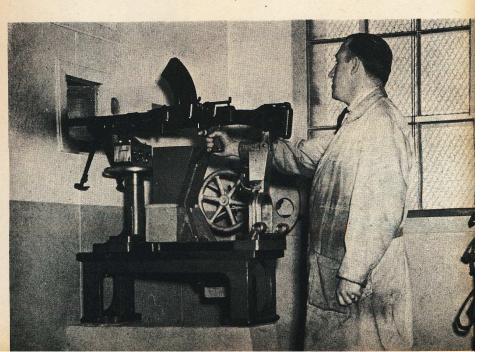
Expert tool designers, time-study men, and set-up men were brought in as the first production machines began to arrive in July, 1939. From then on the training of machine operators became a major problem. These people had experience in handling machine tools, but not in connection with the precision required for machine guns. But by March, 1940, some 500 operators and inspectors were functioning well enough so that good sized batches of finished parts were meeting the critical examination of independent government inspectors. Several women are on the factory payroll and are being shifted from job to job. With experience they will be able to break in others if the men are called to the colors.

The Bren gun is made entirely from Canadian materials except for the walnut stock. Fifteen special alloy steels are produced in Dominion plants under exacting government control. Thus, the Bren contract is serving to educate Canadian plants and personnel with the production of war material. The experience so gained should stand the Empire in good stead as Canada expands output of war goods, and the technical skill acquired will prove of material benefit when peace returns.

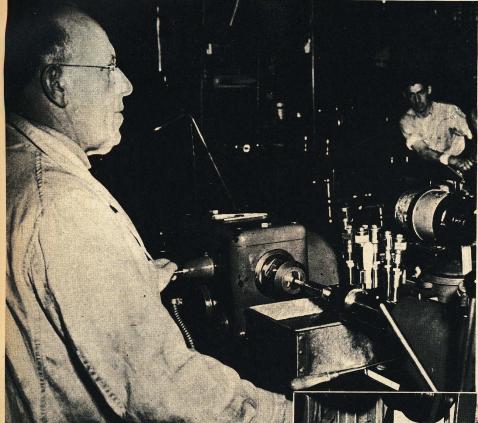
The difference between commercial production and machine-gun manufacture is typified by one of ten periodic inspections used on the Bren machine gun body. Laid out above the bench are 80 distinct gages that must be used in this single periodic check; the body is only one of 161 parts requiring inspection



During the functioning test the inspector stands erect because he does not have to sight the gun. Another rest is used when the gun is fired for accuracy



Barrels for the Bren



THE FIRING RATE of the air-cooled Bren machine gun is so high that the barrel overheats. For this reason, two or three barrels are supplied with each gun. When one barrel gets hot, it is unclamped, dropped on the ground or into water and a cool barrel is snapped in place in less time than it takes to read this sentence.

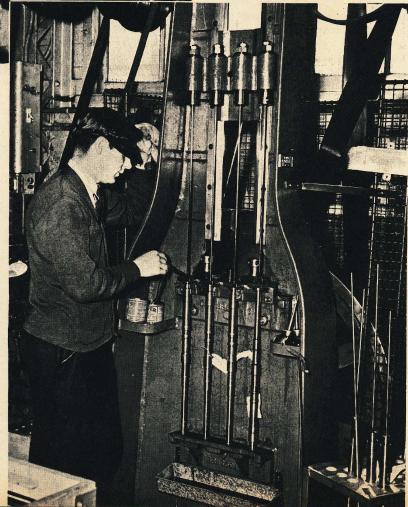
Barrels must be interchangeable and able to withstand the abuse incident to combat conditions without losing accuracy for thousands of rounds. It is said that the first Canadian Brengun fired 8,000 shots without noticeable change in accuracy.

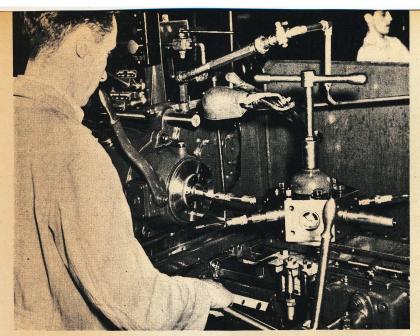
To meet military specifications, 80 operations are required on the barrel, including several periodic inspections on a number of vital dimensions and several straightenings. Many of the barrel operations used by the Canadian Bren plant are common practice in English and American gun plants, although some practices correspond only with methods in force at the British Bren plant.

Every bar, which measures $23\frac{1}{2}$ in. long by $1\frac{3}{8}$ in. in diameter, is inspected before application of the

Eight slip reamers bring the chamber to a 100 per cent bearing with an absolute dimension gage. Practically no material is removed at any stage in finish reaming. High-carbon reamers are chosen because of their ability to retain a keen edge for long periods.

For polishing the rifling, a lead draw lap is cast on a draw rod to fit the individual barrel. The draw rod is removed from the barrel and the lead lap is nicked to catch lapping compound, after which the lap is placed with its barrel in a draw lapping machine. Usually the lap is entered from the breech end, but may be reversed to polish out any blemishes discovered during the lapping process. Laps run in the barrels for about a half hour, are fed with lapping compound. Should the barrel become warm to the touch, the compound is thinned with No. 60 spindle oil. Chucks for the draw rods operate in ball bearings to permit the laps to follow the rifling freely





Roughing and semi-finishing the vital chamber in the breech are done upon a Ward turret lathe. Three slip reamers are used at the third turret position

batch number. After facing the ends and centering, barrel forgings are roughed and semi-finished on three BSA lathes that are equipped for form turning where necessary. After the first nine operations, the barrel receives its first periodic check in the inspection department. These periodic checks may involve use of a score or more gages.

After inspection, the barrel is ready for rifle drilling. This operation is done on conventional equipment, but the oil pressure to the D-bit is maintained at 1,000 lb. per sq. in. A special filtering system removes any fine particles or chips from the recirculated oil. The combination of high oil pressure and exceptionally clean oil is given credit for trouble-free rifle drilling.

Centers were lost in the drilling operation, so the ends are re-coned before reaming. Straightening follows by the shadow method imported from the British plant. The barrel is held to the eye and pointed at the north sky just below the overhead black canopy. A cone-shaped shadow will be seen in the bottom of the barrel. After six months training the operator becomes proficient in judging where the barrel is out of true by the irregularities in the shadow, and is able to turn out more straightened work per hour than by other methods.

At this point it is desirable to perform a number of operations on the barrel exterior because they have a

tendency to distort it. To avoid inaccuracies, the barrel is straightened, re-coned and reamed three times before finishing the bore.

Bore-finishing includes practices used at the British plant. "Spill boring", or pack reaming, is an example. A long tool with two flat sides and two parabolic sides roughly approximating a square is backed up by a spill of wood. The two cutting edges are placed 180 deg. apart, but only one of them scrapes the bore as the tool is fed into the barrel. The spill bore is ground by hand on a grind-stone and its cutting edges are not true straight edges. Practically no material is removed in the process,

but it does produce a highly polished straight hole.

Rifling is done by conventional methods. To lap the rifling, the Canadian Bren plant has developed a vertical draw lap that does four barrels at once. The lead lap for the rifling is cast to the individual barrel, but the cylinder lap for polishing the lands is not.

Last stage in production of the barrel is chambering. Gun makers regard chambering as an art. It is necessary to produce the chamber to 21 "star" dimensions, there being no allowable limit on any part of the chamber. The plug gage must show 100 per cent bearing at the point checked. So-called roughing is done on a Ward turret lathe, six tools being used. Finishing is done on a Holroyd reaming machine, as many as nine reamers being employed in sequence to scrape infinitesmal amounts of metal from various points in the chamber. The reamers float and are of the slip type for ready interchangeability upon the reaming

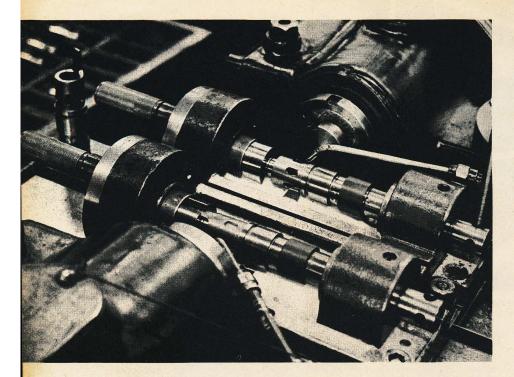
A final straightening by the shadow method and 100 per cent inspection must precede turning over the barrel to government inspectors. An Army officer and his staff check barrels during various stages in manufacture and make rejections on anything which does not meet with their approval. Dimensional accuracy, finish, how surfaces are blended, and freedom from scratches are among the points checked by the government.

Parts made by milling

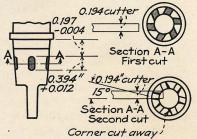
RAW STEEL required for each Bren gun weighs 101 lb., but the finished parts weigh only 18 lb. Thus 83 per cent of the original metal is converted into chips; and most of these chips are made by milling cutters.

Milling machines are needed for the larger share of the 2846 operations on each gun, because of their versatility in handling cuts. Even the barrel is rotary milled. In fact, almost every type of milling operation is called for in the manufacture of the varied parts of the Bren machine gun. So much dependence is placed upon milling that 350 out of 500 machine tools used in production are the latest-pattern English, American and Canadian millers of diverse types. Some of these machines are permanently set up, but the majority must be adaptable to the quick changes required in batch manufacture of 161 parts.

In buying milling machines, the management attempted to obtain equipment with a minimum number of motions and slides. It was believed



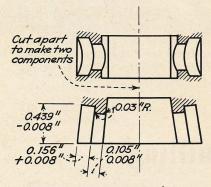
Six elongated holes around the periphery of the gas cylinder are spline milled on an Asquith machine. Infeed of the cutter spindles is controlled by cams, sixteen cycles a minute. After the cutters are fed 0.0048 in. at each stroke, the table is traversed by a crank feed that can be varied between 4.7 and 36 in. per min. Cutter speed is 1,000 r.p.m. in this set-up. Slots are milled straight through in one fixture, then the gas cylinder is relocated in a second fixture to mill one inner edge of the elongated hole



that many millers are essentially toolroom types, with an excess of motions, slides, speeds and feeds for simple production set-ups. These features were suspected of being probable sources of trouble in close work on hardened steel. Finish is just as important as dimensional accuracy in machine-gun work, because cuts must be blended without noticeable variation in surface quality.

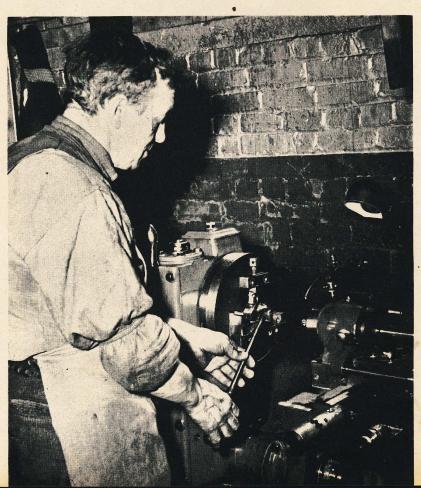
The management's desire to obtain

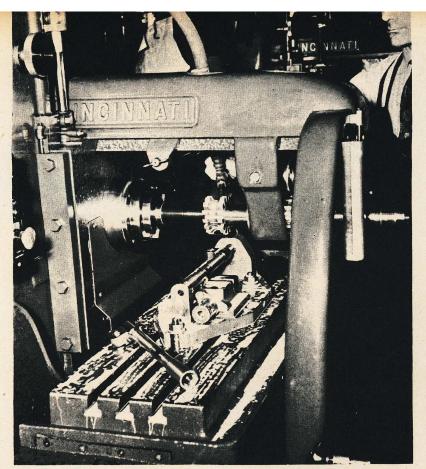
equipment with a solid bed and table construction is credited with furthering development of the production-type automatic rise and fall milling machine. In gun work, it is often necessary to mill behind an obstruc
(Continued on page 324)

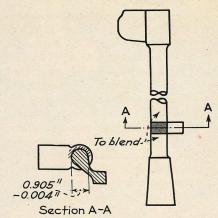


Two extractors are rotary milled at once to avoid holding difficulties, and are sawed apart at a later operation

Rotary milling the groove and rounded end on the extractor is done on a Coventry machine fitted with a roughing and a finishing spindle. Practically no clearance is allowed in the work-head fixture, so the piece must be pried out with a screwdriver



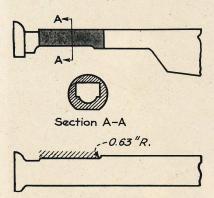




Rise and fall milling on a Cincinnati avoids the difficulties attendent to using a knee-type machine on work where end obstructions will not permit the table to be traversed directly to the cut. The automatic cycle of this machine permits relatively unskilled operators to mill the part without damage. Time per piece, 3½ min. Form turning of the sleeve barrel is interrupted by the lug. To blend the two contours shown requires a machine with a solid table and bed construction, in the opinion of the gun manufacturer. Hence, a rise and fall miller was selected for the operation

Another rise and fall milling operation is involved on the machine gun body. This part requires literally hundreds of precision operations. The job of milling a highly finished and accurate pad just beyond an obstruction at the end of the body is credited with hastening development of the rise and fall milling machine

Milling the pad on the body is done at a spindle speed of 254 r.p.m. and a table feed of 1½ in. per min.





tion. Knee-type machines were criticized on several grounds: (1) that knee-type construction is not sufficiently rigid for gun work, (2) there is danger of running the cutter into the piece and running a part upon which perhaps scores of costly operations have already been performed, (3) operation of the knee-type miller is too slow for production purposes. With a rise and fall miller, having an automatic cycle, the operator need know only how to put the piece in the fixture correctly and to push the start-

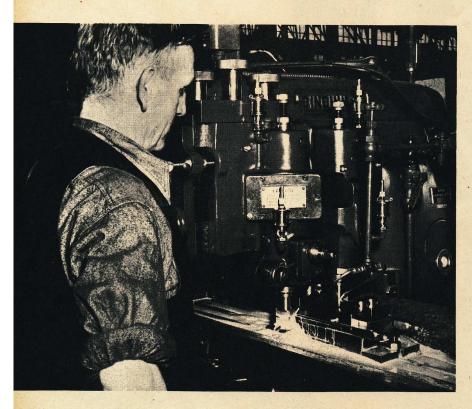
ing button. Women can run such machines if the necessity arises.

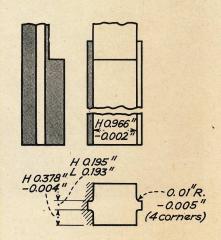
English milling machines were given preference. It was desired to duplicate set-ups at the British plant, which has had several years of experience in making the Bren gun. Furthermore, English machines are considerably cheaper in Canada; their simplified construction is well adapted to gun work. Special features that enhance production are seldom needed because of the length of cutting time.

Fifteen types of steel are milled,

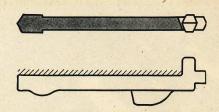
most of them heat-treated to maximum physical properties consistent with use and good machining. The general practice is to specify a cutting speed of 80 ft. per min. and a feed of 0.002 in. per tooth. On some jobs the speed is raised to 105 ft. per min., particularly where the heat conductivity is good.

The illustrations show selected examples of the type of unusual operation met in machine-gun manufacture. For every unusual operation there are a score of the ordinary variety.

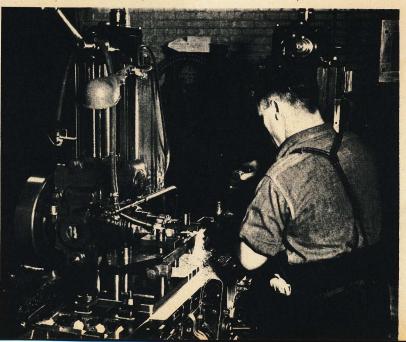


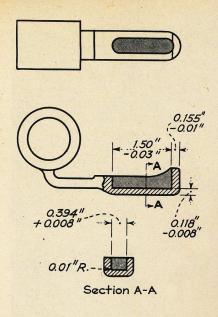


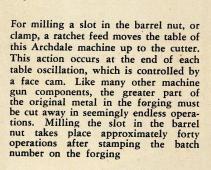
Finish milling the ribs on each side of the piston extension requires a machine that can work to a 0.002 in. limit despite variation in the cut. Furthermore, the finish must be acceptable for a part that is subject to rapid endwise movement. No grinding follows. The guiding ledge on one side of the piston is milled, then the piece is reversed in the fixture. The fixture holds two pieces, duplex vertical heads being provided on the machine

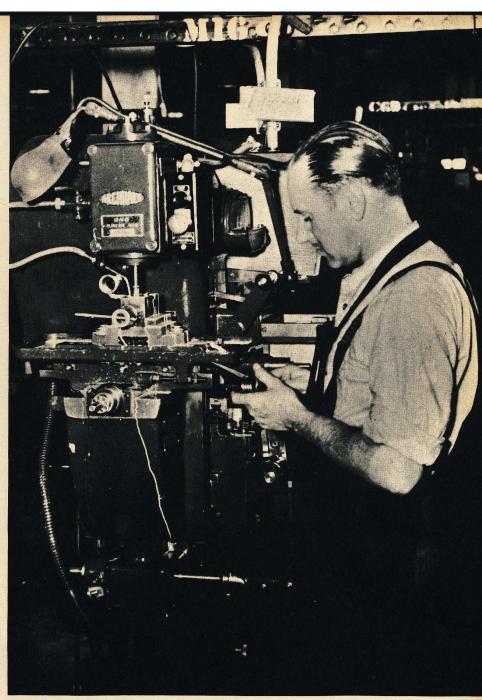


Two slide butts are rough milled simultaneously on a duplex Archdale. The forging is hardened and tempered to a D.P.N. of 220-270 (diamond pyramid number in Vickers hardness testing system), but the cutting speed is 61 surface ft. per min., and the feed is 1.65 in. per min. Time for rough milling the slide butt is $10\frac{3}{4}$ min.









Tooling against time

BEFORE BEGINNING components of the Bren gun, it was necessary to set up and staff a toolroom capable of making 17,604 fixtures, tools and gages. For strategic and cost reasons it was essential to make acceptable parts as early as possible and to keep up a steady flow of inspected material into the assembly department. It was argued that it is poor economy to

stint or slight on toolroom work and be faced with heavy rejections after many costly operations have been performed.

This policy has begun to pay dividends. For one thing, it contributed largely to commencing actual assemblies five months ahead of schedule. Secondly, the first Canadian Brengun was accepted in proving tests.

Rejections are kept to a low figure.

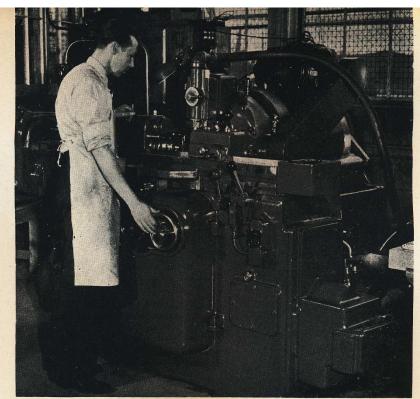
A toolroom capable of producing a large volume of work to high precision standards is not a happenstance. The equipment used represents the best products of at least four countries. The men represent the pick of Canadian mechanics drawn from all parts of the Dominion. Most of them

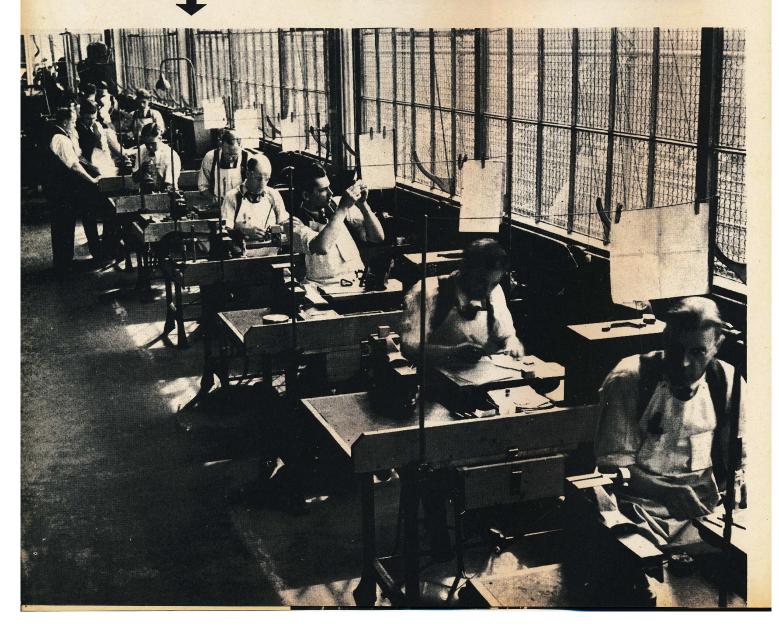
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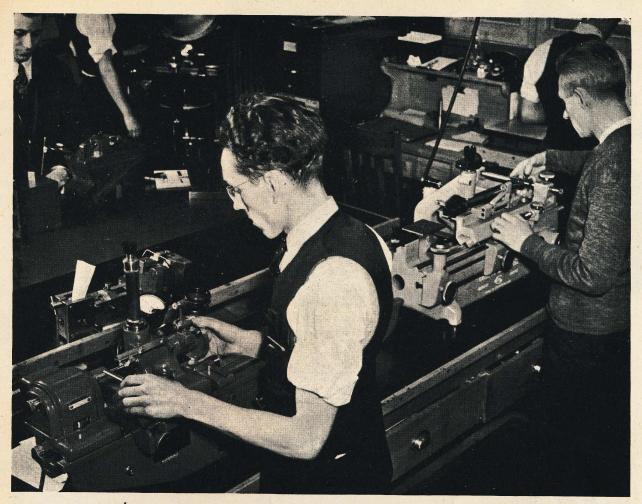
Accurate grinding of Whitworth thread gages to a tenth is an art in itself. This Jones & Lamson machine handles pitches from 14-48 threads per inch. Wheel dressing diamonds must be maintained to small radii. These radii are: 0.007 in. for pitches from 14-22; 0.004 in. for pitches from 23-32, and 0.0025 in. for pitches from 33-48.



First-class gage makers, drawn from all parts of Canada, work under ideal conditions. They are provided with every precision facility required in their work, including surface plates, angle blocks, channels, sine bars and several large sets of English and American precision measuring blocks





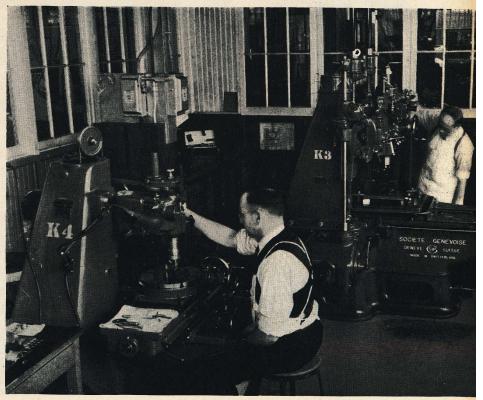


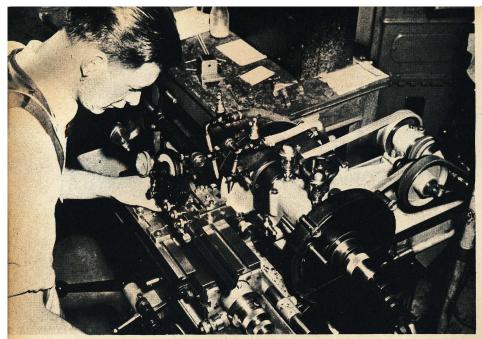
All gages, tools and fixtures produced by the toolroom, or purchased outside, must meet approval of the standards room, which is fitted out with highly accurate measuring equipment. Typical examples are the Pratt & Whitney electric gage that measures to 0.00001 in. and the Societe Genevoise machine that is adaptable to a wide variety of inspection operations, including three-wire measurement of thread gages. The standards room is maintained at a temperature of 68 F. the year around

Accuracy to a tenth or better is assured in jig and fixture work through the use of these Swiss borers

have had 15 to 20 years of experience, and they are all personally known to the master mechanic. About 100 men are employed, divided about equally on gage, tool and fixture work.

Workers in the toolroom are not hurried. Yet the combination of experience and ability possessed by these men promotes toolmaking without





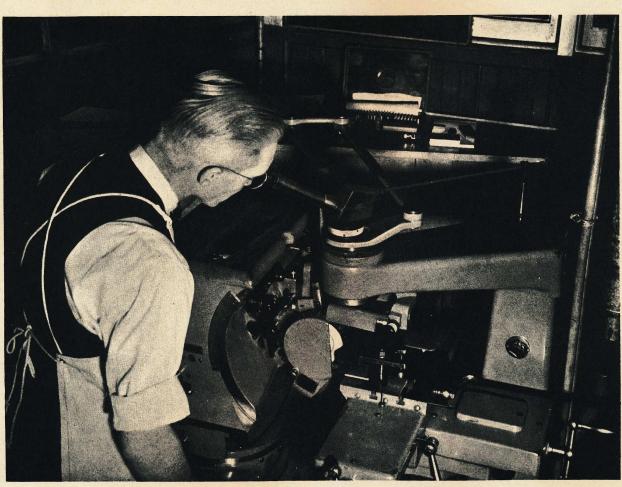
Double snap gages are being produced directly from heat-treated and sandblasted Brown & Sharpe flat stock in an average of two hours per gage. This practice affords important savings in time and cost; hundreds of such gages are required in production and inspection. The operator works to a tenth on a Studer combination grinding and lapping machine. The gage is held on three pins in the fixture. This method eliminates lack of parallelism between gage faces, a condition that often arises when flat stock distorts after the usual surface grinding and is then clamped on a gap grinder. Squareness is assured in the lapping operation because the table and fixture are traversed to the lapping wheel

waste effort and often with important time savings.

Abilities and capacities of outside vendors have been studied for the purpose of supplementing the production of the toolroom. At present, about fifteen vendors are used. It is said that the experience they have gained in gun work has raised the general level of ability in Canadian tool shops. Therefore, manufacture of the Bren gun in Canada has paved the way for other precision parts required by the military establishment.



A Loewe optical profile grinder rapidly turns out involved contours to a tenth, wheel movement being controlled by a 50:1 reduction from the drawn layout. The job in the machine is done in a day instead of several days by other methods. Male and female contour gages are made so accurately that they fit together with practically no light showing through at the mating surfaces



Position-Thread Gage

Canada's method of making an accurate "check" for position-thread gages may prove helpful in American defense programs

ELEMENTS OF CHECK AND ITS GRINDING FIXTURE Master ring gage Grinding fixture with crosspin inserted Check, or master section of part Typical gun component requiring a position thread Spacer block placed under end of check when grinding Reference point B Section C-C Check Grinding Fixture for "Check"

Dimension A, on the gun component, must be within 0.002 in. of the specified dimension. Point B must be held close to centerline of cross slot

MANY DIFFICULT PROBLEMS fall to the lot of a toolroom engaged in making inspection and machine fixtures for machine-gun parts manufacture. One of the "skullcrackers" solved by the toolroom in the Canadian-Bren plant is the method of making the *check*, or master piece, used for setting up both types of fixtures employed on work involving "position threads." A position thread may be defined as one in which a definite dimension must be maintained between a point on the thread helix angle and either an end face or some other location on the piece.

For the gun component sketched, dimension A between the end face and reference point B on the thread helix angle may have a tolerance of plus nothing, minus 0.002 in. Moreover, point B must lie on the centerline of the cross slot within a minute or two of arc.

The major difficulty centered about making a fixture for grinding the end face of the check, at a definite dimension from point B and with due regard to the angular position of the cross lot. The following solution was worked out after much study:

A rectangular steel block is ground with all six sides square within a tenth, and a through hole bored square with the sides within a tenth. A slot is milled in one end of the block and a cross-pin hole is drilled at approximately distance A from the end face. Two steps are ground on the end of the block, one equal to distance A from the crosspin hole and the other a tenth of an inch less.

To grind the check, the part is inserted into the larger hole, with the slotted end clearing the stepped end of the block. A slip gage is inserted in the slots in the end of the block and work, after which an accurate cross pin is inserted in the cross hole so that a tit firmly bears against the thread flank at point B. It is now a simple matter to grind the tongues of the check flush with the respective steps on the block.

The check is used in setting up machine fixtures as follows. Prior to milling the slot on the gun component, the check is screwed into a ring-gage element in the fixture. Then a spotting face is positioned against the end of the check. Thus, when work is screwed into the fixture and against the spotting face, it protrudes the correct distance for milling the slot. The same general idea is used when setting up to grind the end face.

Inspection fixtures have adjustable locating surfaces that are positioned daily in relation to the master check. For example, the check is laid in the fixture and a master ring gage of correct thickness is screwed onto the check, so that the slots can be aligned with a slip gage and the surfaces of check and ring gage are flush. Next, locating surfaces in the fixture are positioned against the master ring gage. Upon removal of the check and master ring gage, work pieces can be laid in the fixture and a ring gage run onto the threaded end and against the locating surfaces, to establish that dimension A is being maintained in production, and also that other dimensions bearing a relation to dimension A are coming within established tolerances.

Without an accurately made *check* it would be impossible to establish accurate setups on position-threaded work, either for machine or inspection fixtures. But before an accurate *check* could be made, a method of producing its grinding fixture had to be developed.

officially the U. S. 30R M1, but popularly known as the Garand after its toolmaker-inventor John C. Garand, a civilian employee of the Springfield Armory. What is news is that production of the weapons at Springfield Armory is proceeding satisfactorily with the objective of 1,000 a day early in 1941.

Thanks to Mr. Garand's years of painstaking development, the U. S. doughboy will be equipped with a rifle that has no bolt action requiring manual operation. He will be able to fire eight aimed shots without taking his eye off the target, and his average firing rate will be some $2\frac{1}{2}$ times faster than with the old Springfield. All the soldier has to do is to squeeze the trigger for each shot since the rifle's action is semi-automatic. Its light recoil or "kick" is another feature that facilitates his aim.

The first Garands were literally hand-made. It took Mr. Garand and eighteen toolmakers about two years to turn out the initial lot of 80. Then larger quantities were manufactured on the Armory's old equipment that had formerly been used for making the Springfield rifle.

Since then great strides have been made in putting the rifle into mass production, both at the Armory and in plants of private manufacturers working under government orders. This story will show how the best thought of the Armory personnel, machine tool builders and small tool suppliers has gone into the 1,500 separate operations required to make a Garand rifle.

Only two years ago, Springfield Armory was struggling along with antiquated equipment. Few machines had been acquired since the World War, many were of Spanish-American War vintage and a few units dated back to Civil War days. An article published early last year (AM—Vol. 83, page 48a) showed that, at that time, three quarters of the equipment in Springfield Armory was over twenty years old.

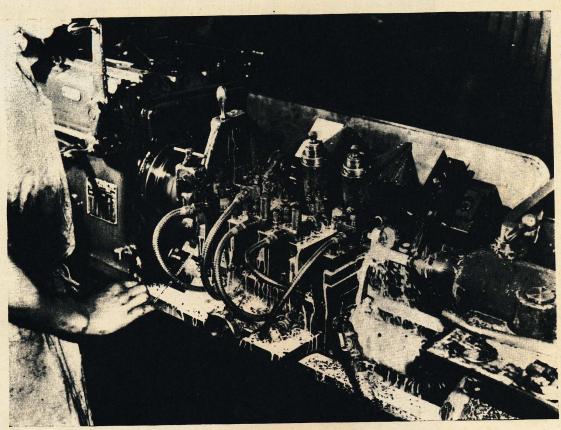
Today all this is changed. Modern machines hum away on Garand rifle parts using modern cutting tools, multiple cuts and the many other developments in mass production that the machine tool industry has been able to devise. In fact, the Armory has pioneered many methods in advance of those found in private practice.

For instance, its application of surface broaching to light parts is outstanding. It

1000 GARANDS

has also adopted drawn steel bars of special shape for many rifle parts, thus avoiding literally dozens of machining operations. It has utilized precision coining in the manufacture of certain components which were formerly machined all over at considerable expense. And it has applied the principles of progressive automatic die work to some of its sheet metal parts.

Probably no industry has been so steeped in tradition as that of rifle manufacture. The rifle is said to be the first product to use interchangeable manufacture; but having been the subject of this early advance in manufacturing technique, the old methods persisted until the current revolutionary changes were put to use. Until recently rifle parts



Rough operations on the Garand rifle barrel are performed in a Fay automatic lathe. Here five tools are taking a longitudinal cut at the front of the machine, while two tools are used on the backrest for shouldering and chamfering

practically without exception were made by a tedious succession of single machine cuts supplemented by hand operations. The contrast with present methods makes the new set-up all the more dramatic.

The Garand rifle has some 72 parts; since the machine operations on these parts range from 1 to over a 100, it would take a goodsized volume to describe them all in detail. In order to exemplify the methods employed, certain of the rifle parts have been selected for description; these reflect the wide variety of work used in rifle manufacture and show some of the methods developed at Springfield. The parts chosen for such description are the barrel, the rear sight base, the follower slide, the safety and the front hand guard ferrule.

The barrel is made from chromium-molybdenum steel (SAE 4150) heat-treated at the supplier's plant to 269-311 Brinell hardness. This steel is selected for good strength at moderately high temperatures; also even though of high strength, it has reasonably good machining properties.

OPERATION SHEET—Rifle Barrel. 11/4-in. dia. steel, SAE 4150

Grind spots for Brinell impression.

Make and record Brinell impression (269 to 311).

Cut to working length 24.200 — 0.010 in. and center ends.

Stamp stock mark on end of stock opposite Brinell mark; end with stock mark to be muzzle end.

Spin on rolls and straighten stock to max. runout 1/32 in. 3½ in. from end of barrel, opposite stock marked end, grind rest spot.

8 in. from end of barrel (opposite end to center rest spot) grind two roll rest spots.

Turn muzzle end 0.895 — 0.020 in. tapered to 1.00 — 0.020 in. at end of cut shoulder of which is 6% — 1/8 in. from breech end; chamfer muzzle.

Turn end opposite to stock mark to 1.355-0.01 in.; from % in. R. to 0.875-0.010 dia.; turn 0.875-0.010 dia. straight to 10.237 in. -0.020 in. from breech end; chamfer breech end.

Spin on centers and straighten to max. runout of 1/64 in. Inspect 100% (Magnaflux) (after rough turn operation for imperfections in stock construction).

Ream bore to 0.295 \pm 0.001 in. (Start reamer at breech).

C'sink both ends simultaneously 0.250 — 0.0075 over 0.375 in. ball in muzzle end, c'sink to end of barrel and 0.250 — 0.0075 over 0.375 in. ball in breech end, c'sink to end of barrel.

Spot grind, rest spot for back roll rest 9 3/16 in. from muzzle end.

Turn taper from 0.6751-0.005 in. muzzle end to 0.850-0.01 in. located $6\frac{1}{8} - 1/16$ in. from breech end (To remove surplus stock only).

Wash.

Line straighten bore.

Spot grind rest spot.

Turn major thread dia. rough (breech end) 0.985 — 0.005 in. square gage tenon shoulder and 0.975 — 0.003 in. dia. at 1.130 — 0.005 in. dia. shoulder; turn muzzle end 0.625 — 0.005 in dia.

Line straighten.

Spot grind muzzle end, rear of gas cyl. bearing 0.599 — 0.005 in. dia.

Turn taper sections from 0.637 — 0.005 in. dia. located 17.400 in. from breech end thread shoulder to 0.700 — 0.016 in. dia. at lower band bearing, and 0.770 — 0.005 in. at lower band bearing location up to and including ± ½ in. radius.

Line straighten.

Turn muzzle end 0.540 — 0.005 in. and 0.5613 — 0.0054 in. major thread dia.; form groove.

Burr bore on muzzle and breech end of barrel to permit free entrance for centers.

Chamfer 30° angle on both sides of 9/16-32 P. thd. and form 45° angle on end of gas cyl. bearing.

Finish face gas cylinder lock seat and shoulder of thread. Grind breech end to 1.115 — 0.001 in. dia. (rough).

Mill thread on breech end and tenon dia., topping nob to produce no larger than 0.972 in. major dia. of thread, 0.917 — 0.002 in. tenon dia., and 0.913 — 0.005 in. dia.

Form mill top (rough and finish) two at a time.

Wash.

Stamp stock mark and piecemark on stock.

Line straighten.

Grind lower band bearing 0.726 — 0.002 in. dia.

Mill rear hand guard grooves (R & L).

Ring straighten.

Spot grind 0.628 - 0.005 in. dia.

Grind muzzle end (finish) 0.514 - 0.002 in. dia.

Finish grind breech end 1.100 - 0.001 in. dia.

Grind $1 + \frac{1}{4}$ in. radius.

Grind gas cylinder bearing 0.660 — 0.001 in. dia.

Mill three cuts for gas cylinder splines, symmetrical and concentric.

Ream chamber (rough) and c'sink breech end 45° to remove surplus stock on breech end of barrel.

Wash

Rough and finish ramp including 0.01 R + 0.01 in.

Ream bore 0.298 + 0.001 in. dia. (Cut ream oper.) Start reamer at breech end.

Wash.

Ring straighten.

Ream bore (finish) 0.300 + 0.001 in.

Wash.

Rifle bore (hook cut).

Ream chamber (finish) (Cut reamers only used).

Wash.

Broach lower band pin retaining slot.

Form 0.035 + 0.005 R at intersection of ramp and chamber.

Form 0.020 R + 0.005 in. at mouth of ramp.

Mill bullet nose clearance cuts.

Cut thread muzzle end.

C'sink, face and chamfer muzzle end of barrel to finished length 23.310 — 0.01 in.

Hone chamber.

Wash.

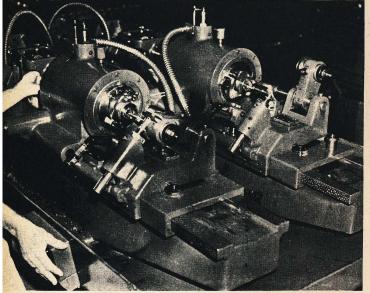
Mark manufacturer's initials, month of year and year of manufacture.

An operation sheet is given for the rifle barrel. It will be noted, that the number of steps is relatively great; this is because of the need at all times of maintaining a uniform wall thickness. The rough barrel forging weighs approximately eight pounds while the finished part weighs only 2½ pounds. As is well known, the removal of any great amount of metal from a long, slender piece of this kind tends to distort it. For this reason, frequent straightening operations are required so that when the next step it taken in machin-

ing, the wall thickness will remain uniform.

There are two general methods employed at Springfield Armory for inspecting and correcting bore straightness: the line method and the ring method. The line method is quicker but can be used only before the bore is rifled. The ring method can be used before or after rifling; it is somewhat slower, requires greater skill but is extremely accurate.

In the line method, the inspector holds the barrel in a screw jack and sights through the bore at a straight line scribed on a ground This is the end of an Ex-Cell-O barrel risling machine which controls the radial speed of the cutters. The cutter bar is rotated while a fixed socket holds stationary a nut at the end of the bar, thus setting up a tapered pin which pushes the cutters outward. The helical motion of the bars is controlled by precision guide screws at the opposite end of the machine





The top of the barrel is form milled in this double fixture using an equalizing clamp on a Brown & Sharpe milling machine

glass window some 20 ft. away. With his eye slightly above the center of the bore, he looks downward to see the reflection of this line in the bore's reamed surface. If the bore is straight, the line looks like two converging railroad tracks running about half the length of the barrel. A long curve indicates a gradual bend in the bore. A short kink indicates a sharp bend. The barrel is revolved and inspected from both the muzzle and the breech end. When the curves or kinks appear, they are removed by applying the jackscrew. Where to apply pressure and how much is a matter of experience.

In the ring test a painted glass cap, upon which a ring has been scribed to let the light through, is placed over the end of the bore. The light is reflected again and again to form a series of rings along half the length of the barrel, magnifying any irregularities. Out of roundness or lack of concentricity in the rings means that the bore is bowed or kinked. The barrel is rotated on rollers and inspected from both ends. Straightening is done with a copper hammer. Again the inspector has to learn where to hit and how hard.

Both line and ring tests have a high degree of accuracy and are repeated in the course of barrel manufacture to prevent variation in wall thickness. Otherwise a "walking" barrel will result; that is, the heating of the barrel when fired will result in uneven expansion, causing the barrel to "walk off" the target.

While many of the rifle barrel operations are familiar in machine shop practice, they represent a departure from older methods of making these parts. For instance, turning is now done on automatic lathes of the Fay type. In the first rough turning operation which takes cuts on the muzzle end, five turning tools are used at the front of the machine while two additional tools are used at the back for

Because of the fact that rifle reaming is a critical and delicate operation, the cutting edges of the tools must be lapped. These two fixtures, one for the outer radius and one for the cutter face are used to hold these tools while lapping





facing a shoulder and chamfering the muzzle. Cemented carbide tools have been found to speed production.

It will be noted, too, that after the barrel has been rough machined at both ends a 100 per cent Magnaflux inspection is used. The employment of this magnetic method of testing so early in the process shows up any flaws before a large amount of work has been done on the barrel.

More specialized are the operations for drilling, reaming and rifling the bore. For drilling a hollow, single-fluted drill is used which consists of a high-speed steel tip welded to formed seamless tubing. Coolant forced through the drill keeps down the temperature at the tip and washes the chips out of the bore. The barrel is rotated while the drill is fed from the breech end. Size is held to plus 0.0015 in.

Reaming is done in two steps. A newly

designed vertical machine in which the tools are rotated while the barrels are fed upward over them, performs the rough reaming. This machine has twelve spindles each of which is independently push-button controlled. The feed is hydraulic.

After rough reaming, both ends of the barrel are countersunk to provide new centers. The depth of countersink is checked by measurement over 3/8-in, steel balls.

Finish reaming and rifling are done in horizontal machines. For these operations particular attention is paid to tool sharpening. The reamer, for instance, is ground dry on a standard tool and cutter grinder with a grit wheel. Then without changing the set-up, a new extremely fine grit wheel with a shellac bond is used, to remove 0.001-in. of metal at the rate of 0.0002 in. per pass. The next step is to lap with oil and a fine lapping powder by hand using a piece of old gun barrel.

Finally the reamer is honed using triangular sticks of fine India or silicon carbide.

Hooked cutters are now used entirely for rifling at the Springfield Armory. These are somewhat sturdier and give increased production over the older feather-edged cutters. They must be accurately ground and stoned if they are to give the smoothly finished grooves which are so essential. These cutters are sharpened by a method closely paralleling that used for the reamer. For the hand honing operation, special fixtures are used. While held in a bar, such as used in the rifling machine, the cutters are rotated under the honing stone to give a smooth finish to the outside radius. A second fixture holds the cutter at the correct angle while the stone is worked back and forth to finish sharpen the face. Cutting angles are important.

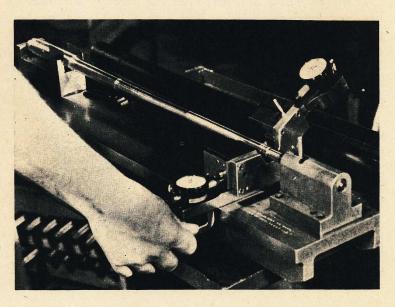
Since rifling is done only in one direction, a special device is used to withdraw the cutters into the bar at the end of the cutting stroke. At the opposite end of the stroke, the cutter bar strikes a stop which again expands the cutters into operating position. In addition a nut at the end of the bar enters a recess which rotates a tapered plug to increase the depth of cut. This feed of the cutters is done at every other stroke of the rifling tool.

The rifling grooves have a depth of 0.004 in. and a twist of one turn in ten inches or approximately two turns in the length of the barrel. Pratt & Whitney and Ex-Cell-O rifling machines are used.

Bore and grooves must be absolutely smooth and within a tolerance of 0.001 in. Dimensions of both are inspected at every inch along the length of the barrel by means of star gages. These gages have expanding fingers which give readings on a vernier micrometer at the end of a long rod. It has been found at Springfield Armory that it is advisable to add a spring to the star gage to give uniform pressure when expanding the measuring points, thus eliminating variations caused by the inspector's touch.

Another set of operations that calls for care is the chambering of the breech end. These operations are done in a machine with a vertical turret having a series of nine tools. Rough boring and reaming are done prior to the reaming of the bore while finish chamber reaming is done afterward. The reason for such care in these operations is that the surfaces so formed provide the bullet seat. Tolerances must be held close to seal the cartridge against the force of the explosive gases and at the same time to permit free

The size and position of gas cylinder splines must be held within close limits. They are checked on this fixture with two dial indicators. The one at the left connects with two expanding contact points which register the width of the groove while that at the right measures the depth



ejection of the bullet after the rifle is fired.

Jigs and fixtures have been devised on practically all the other operations on the Garand rifle barrel. They include devices for form milling the top of the barrel, straddle milling the rear hand guard slots, cutting the gas cylinder splines and milling the bullet nose clearance. Each of these fixtures has been designed to facilitate production by using multiple set-ups, quick-clamping arrangements or special indexing devices.

For form milling the top, barrels are set up two at a time in a fixture. They are supported in adjustable V-slots at either end and clamped by equalizing straps.

Roller toggles are used to clamp the barrel for milling the rear handguard slots. Here again a double fixture is used with the work held against V-blocks by means of pivoted clamps. The clamping screws swing upward for quick release.

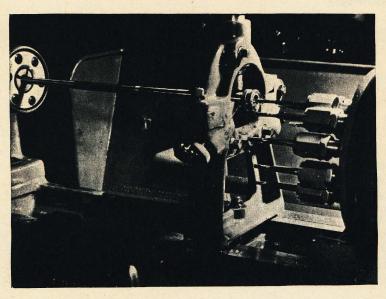
Each barrel has three gas-cylinder spline slots which must be accurate as to size and position. In a triple fixture, three barrels are indexed simultaneously by means of intermeshed gears and located by separate tapered lugs. The work is mounted on its centers.

To cut the bullet-nose clearance in the breech end, a special milling machine fixture is provided. By means of a rotary clamping sleeve, the work may be locked or rotated while the cut is in process. In this set-up the breech end is milled away for approximately 110-deg., and a small notch is cut in addition.

Naturally, cleanliness is essential to insure precision throughout the various operations performed on the barrel. It will be noted from the operation sheet that the barrel passes

Operations on the safety have been reduced from a multiplicity of milling and profiling operations to the simple sequence illustrated. Machining has given way to precision forging, coining, trimming and shaving



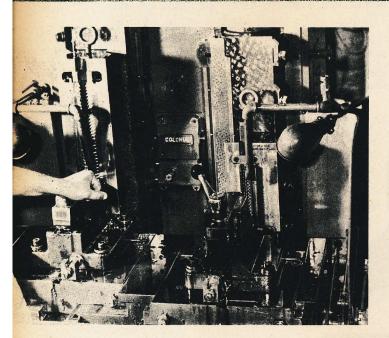


The barrel chamber consists of the surfaces that seat the cartridge, seal it against the force of explosion and still permit free ejection. It is machined in this multi-spindled Pratt & Whitney machine which cuts and reams a number of surfaces which must be accurate as to size and relative position

through numerous washings. In order to facilitate this process, a special set-up has been devised. The barrels are held in wooden racks 100 at a time. The rack is lifted and lowered by means of a hydraulic lift through four stations: loading, cleaning, rinsing and unloading. The cleaning and rinsing tanks contain soda solution and hot water respectively. The hoist is located in the center of these stations and pivots as it lifts the work in and out of the tanks. Its use avoids manual handling of the barrel during this process.

Chief interest in the rifle part, known as the safety, centers in the fact that its method of manufacture has been entirely revolutionized. While this piece is small, its many irregular contours involve troublesome operations when the piece is machined all over. Formerly it was the practice to hollow-mill the 0.197 in. pin and then rough and finish mill practically all the other surfaces using both form milling and profiling. These steps required special fixtures for each operation.

Now the safety is made without any machin-



OPERATION SHEET—Base, Rear Sight. Steel forging, SAE X1340

Forge from bar at 1950-2200 F. Normalize at 1600 F. Cool in air.

Anneal at 1525 F. Adjust temp. to obtain Brinell 197-223. Straighten and trim cold.

Broach both ends.

Broach both sides, and circular cut.

Broach bottom contour rough.

Broach top contour.

Broach sides at front end.

Drill, step ream, rough and finish hollow mill, rough tap and rough mill aperture slot.

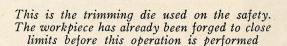
Broach grooves and aperture slot.

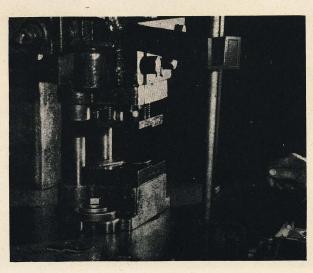
Profile top and back between ears.

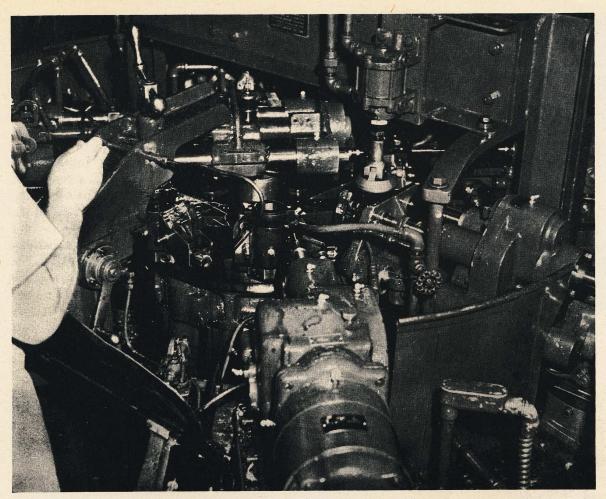
Profile top and back radius on ears.

Finish tap.

This set-up is typical of several broaching operations performed on the rear sight base. A two-ram Colonial machine is used with a pair of fixtures. That at the left trims the sides of the workpiece while that at the right cuts the radius and the under-cut







The Kingsbury drilling machine used on the rear sight base has eight stations; two pieces are chucked in each fixture. The workpiece travels around twice being reversed after the first revolution. Auxiliary hydraulic work clamps are used at two stations where heavy cuts are taken (note overhead cylinders) because of the few surfaces available to grip the work securely. In addition to drilling, this machine roughs out the circular slot

ing operations. Instead of being forged to machining allowances, the part is made as a precision forging. A coining operation brings the piece to final thickness including the proper dimensions on the pin. Only three other steps are required, all press operations. The safety is punched to form two holes, trimmed in a die and then shaved to its final dimensions.

A step in the shaving punch used for the safety divides the shearing action, while a break-up pin cuts the surplus stock. As in other press operations, standard die sets are used wherever possible. The safety is made

of a low carbon chrome-nickel steel, and is case-hardened after it leaves the press shop.

The rear sight base is selected as one of the riflle parts to which surface broaching has been effectively applied. This includes the new circular broaching which performs a difficult operation in a minimum time.

This piece is made from a free cutting medium carbon steel forging (SAE X1340). The base is odd in shape, involving as it does a number of irregular contours and circular grooves. At the same time, since it supports the rear sight, it must be machined to a high

degree of accuracy. Were it not for the use of six broaching operations, each of which cuts a series of surfaces, the machining of this part would indeed be tedious.

One of the external broaching operations is illustrated. As in many rifle part operations, a double-ram machine is used with two fixtures. In this particular set-up, one set of broaching tools cuts the radius, under-cut and top surfaces while the second set of tools, shown at the right, broaches the sides. In each case the piece is held by a clamp in a positioning fixture, while the tools operate. One ram ascends while the other descends to take the cut. Other external broaching operations on this part follow the same general method.

Two additional operations on this part deserve special comment. A Kingsbury multistation machine drills, reams, counterbores, trepans this piece and mills the slot. Because of the fact that this part is small and three sides of it have to be machined, there is very little area left for locating and clamping. For this reason it was found necessary to put on auxiliary air clamps at the stations where the

trepanning or hollow milling operations are performed. The air cylinders for these two clamps are mounted on a cross-rail which reaches across the top of the indexing turret as shown in the illustration.

Each fixture is made to hold two parts as the parts are chucked twice. In this way, once all the fixtures are loaded, a completed part is obtained at each indexing of the turret.

The circular slot is only roughed out in the Kingsbury machine. It is made into a circular T-slot by the use of a circular broaching operation done on a Krueger machine. The circular broaching tool has a final cross-section corresponding to the finished dimensions of the slot. It has also a 54-deg. gap into which the work is inserted in order to start the cut. The fixture which holds the work is mounted on two slides. One of these allows the fixture to be moved to depth; a cross-slide is used to position the work relative to the center of the cutter. After the part is clamped, a push on the starting button causes the hydraulic circuit to advance the fixture against a stop. The cutter then rotates



This Krueger circular broaching machine performs a difficult operation in a minimum of time. One pass of the circular cutter undercuts the circular T-slot. After the piece is clamped in place, a touch on the starter button feeds the fixture forward hydraulically, holds it during the cutting cycle, and returns it to the loading position

through a complete revolution, and the fixture is backed away. The cycle is automatic. The cutter arbor is fitted with a micro-adjustable nut so the broach can be positioned vertically relative to the work-piece. The idea for this circular broach was worked out by Armory engineers with the builders of the equipment.

Two surfaces on the rear slide base which do not lend themselves to broaching are done by profiling. One of these steps is illustrated. The operation is to machine the radius which forms the top and back between the ears; at the same time the center mark by which the sight is set is cut in this surface. The cutter is made up of three parts; two circular cutters with a saw blade between them to mark the center. A working head follows a guide spindle in contact with a master cam of the correct contour in accordance with conventional profiling practice.

Another rifle component in which broaching plays an important part is the follower slide. But this piece has another point of interest in that it is made from cold-drawn chromenickel steel of special shape (SAE 3115). It will be noted that although the part is small, its many irregular surfaces would mean a multiplicity of operations if the piece had to be cut from rectangular stock. Many of these steps are eliminated by the use of the special cold drawn stock.

The illustration of the follower slide in

OPERATION SHEET Slide, Follower. Drawn steel, SAE 3115

Cut to length 4.962 — 0.010 in.

Strain relieve for one hr. at 800 F.

Blank both sides.

Inspect for straightness.

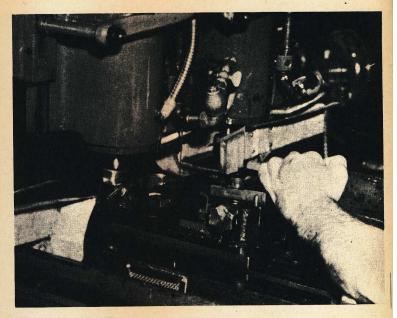
Broach one side.

Broach other side.

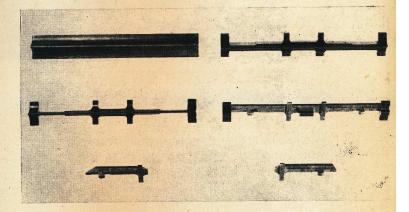
Broach bottom contour.

Mill 54° angle.

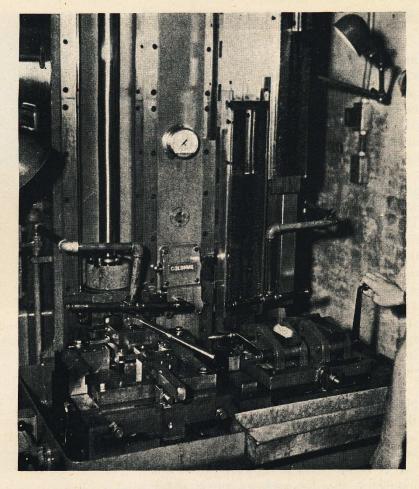
Form mill 20° angle.



One of the two profile milling operations on the rear sight base is shown here. In this set-up the radius between the two side lugs is cut together with the saw mark for the central position. As usual in profiling, the cutter spindle follows a guide pin in contact with the master contour



The follower slide is one of several parts made economically by the use of drawn stock of special shape. Since the irregular contours are formed by the steel drawing die, the balance of the work can be done in comparatively few broaching and milling cuts. It will be noted that the piece as broached makes two of the follower slides



A double-ram Colonial broaching machine does much of the work on the follower slide. This set-up uses a single fixture at the left and a double fixture at the right to cut surfaces in three directions

various stages of completion shows the main steps. After cutting to length by means of a rubber-bonded wheel, the stock is blanked, straightened and then broached, first on one side, then on the other and finally on the bottom. One of the broaching set-ups is shown. Here again a double-ram machine is employed using two fixtures which hold the parts; the ram on the right-hand side, carries two broaching tools for the two sides of the workpiece respectively. The fixture on this set-up has pivoted clamps operated by means of eccentrics. Each piece as broached is cut in half to make two components. The splitting is done when the 54-deg, angle is formed. Another milling machine operation cuts the 20-deg. angle which finishes the piece.

The fixture for this operation holds the

follower slide while the flat 20-deg. surface and a radius are cut in it. When the upper part of the fixture strikes a stop held on the machine frame, it is forced along the base against the pressure of a spring. Meanwhile a rack acting through a pair of gears rotates the workholder to give the desired motion.

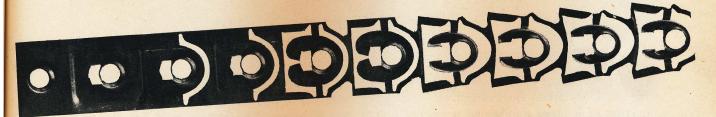
The front hand guard ferrule lends itself to progressive die work. The machine set-up as illustrated, together with a strip of the stock up to the point of shearing off, gives a very good idea of how this part is made. Although it is not part of the rifle proper, the cartridge clip is made by a similar set of tools in the same automatic dieing machine.

The operations as described above are typical of other manufacturing steps performed on other parts. For instance, special drawn



Thus is the Henry & Wright machine on which the front hand guard ferrule is made. A similar set-up is used for stamping out the cartridge clips

The front hand guard ferrule is made of strip steel stock in a continuous automatic dieing machine with the sequence of operations as shown. The use of this method eliminates the many separate steps that would otherwise be required



steel stock is used on the sear, the accelerator and the ejector. Coining is used on the trigger, the follower arm and the gas cylinder as well as the safety. The barrel, of course, is unique.

Nearly all the parts in the rifle are heattreated, following final machining. The barrel is an exception having been heat-treated in the rough.

The parts are assembled to form the finished rifle. While hand operations are used almost entirely, the procedure has been improved and simplified so as to shorten the number of steps and length of time required to put a rifle together.

After inspection the rifle is tested. First it is given a proof test which consists of an overload charge subjecting the mechanism to about a 50 per cent greater pressure than it will

receive from the standard cartridge. Then the rifle is given a functioning test of 64 rounds during which any malfunction is recorded, and if present, the rifle is sent back for disassembly, inspection and correction of the trouble.

Following this, the rifle goes to the ballistic division in which it is fired for accuracy. The rifle is held on a stand, and after three warming shots to heat up the barrel, it is fired at a target. At a distance of 100 yds. five shots must fall within a 3-in. radius in order to have the rifle pass inspection.

The final test of any weapon is how it stands up in the hands of the soldier in the field. Garand rifles are now rapidly being put into service. Experience received in this way is the only good method of proving the merits of this weapon.

MACHINE WORK ON TRENCH MORTARS

Close dimensional tolerances have been held without much difficulty in the production of parts for trench mortars by careful design of small tools

By E. H. FISHER
Works Manager, A. B. Farquhar Company

MANUFACTURE of 81-mm. mortars and mounts for the U. S. Army does not involve the production of a large number of parts per unit, nor is much special manufacturing equipment needed. Standard milling machines, turret and engine lathes, grinders, drill presses and other equipment commonly found in machine shops are all that are necessary. However, these machines must be in good condition, capable of turning out accurate work, and must be equipped with precision jigs, fixtures and cutting tools in order to turn out parts within the dimensional tolerances required.

The four parts for the mortar and mount which involve the most difficult machining operations are the barrel, the base cap, the gear case and the yoke. The latter is machined from a malleable iron casting, using a Cincinnati No. 2 universal miller. Each operation on this part is jigged, in order that the dimensional tolerances of 0.0007 in. for hole spacing and alignment may be met. Drilling is done at 80 to 90 ft. per min. with a feed of about 1 in. per min. Reaming is done at a little lower surface speed, and with $\frac{3}{4}$ in. per min. feed. A tapered dovetail slot at one end

of this yoke must be located accurately with relation to the shock-absorber and traversing screw holes. The fixture used for this slot is indexed for milling the taper, and has hardened tool steel setting blocks for locating the milling cutters accurately.

Tubing Turned for Barrel

The gun barrel shown in Fig. 2 is made from a 48-in. long SAE-2330-W.D. seamless steel tube measuring 4½-in. outside diameter and 3-in. inside diameter as received from the mill. Hardness of this tube is about 220 Brinell. The tube first is rough and semifinish turned, and faced in an American 14-in. heavy-duty engine lathe, using carbide tipped tools at 230 surface ft. per min. The roughing cut removes approximately 3/16 in. on the diameter, while the semi-finishing cuts bring the outside diameters within 0.015 in. of finished size. The turned barrel must be a true cylinder so it will fit centrally in the cradle fixture used for boring operations. Also, the rough bore of the tube must be concentric with the semi-finish turned outside diameter

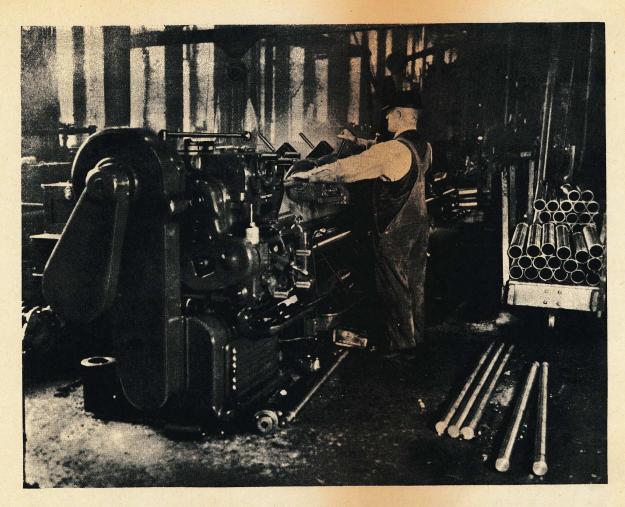
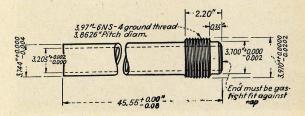


Fig. I—A special cradle mounted on the carriage of this American 18-in. heavy-duty engine lathe, in place of the standard cross-slide, positions the barrel tube for all boring operations and for rolling in the bore for final finishing

Fig. 2—Machined in engine lathes, except for the grinding of threads at the base end, the barrel tube weighs approximately 40 lb. when finished. A Jones & Lamson thread grinder is used by a subcontractor for grinding the Class 4 threads from the solid



in order that an even cut will be removed by the first rough boring operation.

The American 18-in., 16-ft. bed heavy-duty engine lathe used for the boring operations is equipped with a special cradle fixture mounted in place of the regular cross-slide on the carriage. The cradle is removable, so that a cross-slide can be mounted when the lathe is used for other work. The cradle fixture, shown in position in Fig. 1, has guide bearings at each end to support the boring bar. Clamps at each end of the cradle are counter-weighted for easy operation, and hold the barrel central with the axis of the lathe spindle.

Nitrided Bar Withstands Wear

The Davis boring bar used for all boring cuts is $2\frac{1}{2}$ in. in diameter and 12 ft. long. Design of this bar is such that it is locked into the spindle of the lathe for driving, and is supported by a roller bearing center at the tailstock end of the lathe. The bar is nitrided

along that portion of its length that extends through the barrel during the boring operation, so that it will withstand the wear caused by the rubbing of chips.

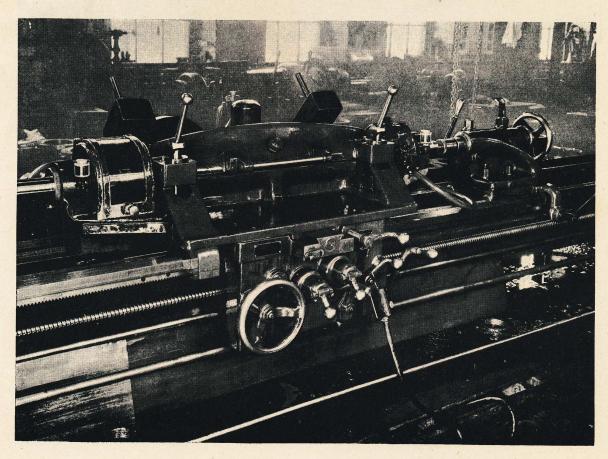
Floating Tool for Finishing

Three boring cuts are taken. The first roughing cut removes about 0.050 in. on the radius, and is taken at 52 r.p.m. Feed is 0.023 in. per rev. In this and other boring cuts, the carriage traverses the barrel along the rotating boring bar, the bar having no axial adjustment in the spindle. Stellite-tipped bits are used in the boring tool blade, which is of standard Davis design.

The second, or semi-finish boring cut also employs Stellite-tipped bits in the cutter head, and is taken with 0.017 in. feed per revolution at 52 r.p.m. Depth of cut is about 0.012 in. A floating tool made from Cobalt steel and shaped somewhat as shown in Fig. 3, used for the finish boring cut. This cut removes

very little stock, and is taken at 38 r.p.m. with 0.017 in. per revolution feed. The finish boring operation produces a bore measuring between 3.204 and 3.205 in. diameter. As is shown in Fig. 3, the floating blade has a sharp lip at each end and is held in the boring bar by means of a setscrew, clearance being provided between the point of the setscrew and the blade, so that the blade will float in the bore. The setscrew is provided only to keep the blade from falling out of the bar when the work is approaching the cutter. Socony-

Fig. 5—Details of the cradle fixture used when boring 81-mm. mortar barrels are shown in this illustration. A straight, accurate bore is obtained by guiding the boring bar in bearings at each end of the fixture mounted on the lathe cross slide



Vacuum DTE oil is used as a cutting lubricant. This oil was selected after extensive tests in which a number of various coolants were tried. Although somewhat more expensive, this oil seems to give the best results when delivered under pressure to the rear end of the tube. Chips are washed out of the tube behind the cutter as it passes through the bore of the barrel.

Barrels Rolled After Boring

After a lot of 40 to 50 barrels have been bored, they again are placed in the cradle on the 18-in. American Lathe for finish-rolling the bore. The Faessler-Maupin roller head used for this operation is adjustable between 3 and 3½ in. with micrometer-adjustment collars. The seven rollers in the head are set at a slight helix angle, and are checked with a micrometer after having been set to size. The head which is similar to that shown in Fig. 4, is flexibly connected to a bar of sufficient length that the head may pass through the entire length of the barrel bore. The other end of the bar is connected to the spindle of the lathe. After the finish-bored barrel has been clamped into position in the cradle, it is brought forward until the rolls are just started into the bore. The lathe then is started and the rotating roller head draws the carriage forward so that the barrel passes over the head. Only the helix angle of the roller head provides feed for the carriage. No hand or other power feed is employed. This operation requires approximately one-half hour with a spindle speed of 52 r.p.m., and gives a mirror finish to the bore. The tolerance of 0.002 in. on the bore diameter is easily held. Oil under pressure is fed into the bore of the barrel during this operation, as it was during the boring operations. Details of the cradle are shown in Fig. 5.

Following the rolling operation, the barrel is removed from the cradle and returned by truck to the 14-in. American lathe for finish turning the outside diameters and facing the tapered seat at the base end. This double chamfer at the base end must be smooth and square with the axis of the bore, so that a tight gas seal will be formed when the base

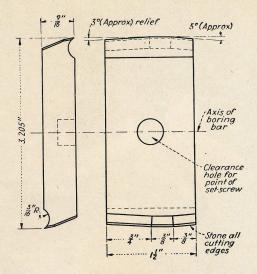


Fig. 3—A floating-reamer blade is fitted in the Davis bar for a final cut in the barrel.

Cobalt steel has given best results

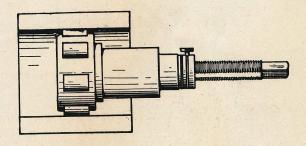
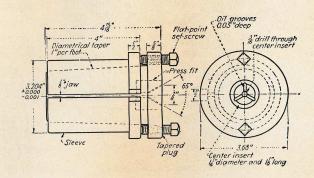
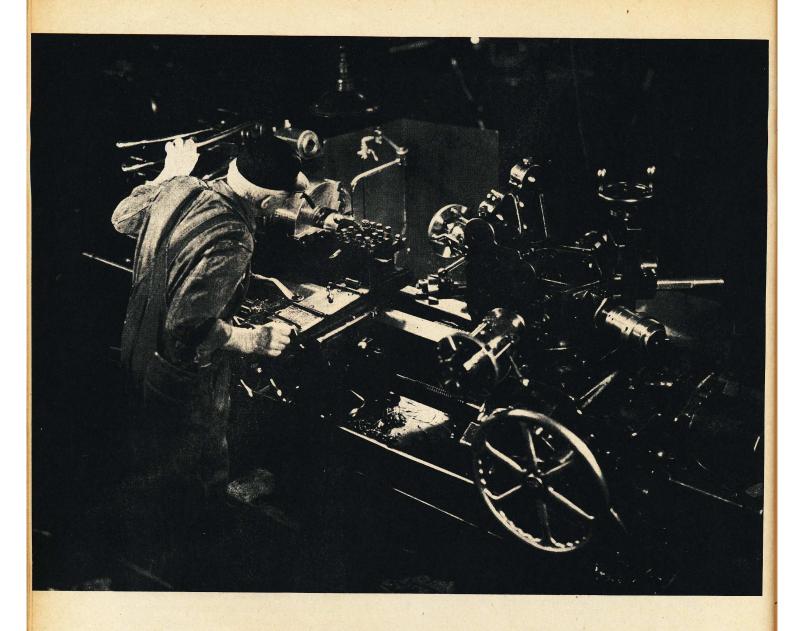


Fig. 4—Originally developed for applying bushings and brasses in railroad shops, the Faessler-Maupin roller head gives a mirror-finish when used in the 81-mm. mortar

Fig. 6—Developed at Watervliet Arsenal, two of these expanding centers are used for the finish turning operations on the barrel tube





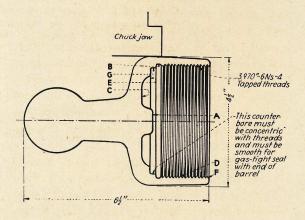


Fig. 7—Two chuckings are necessary for turret lathe operations on the forged-steel base cap. The set-up shown is used for the cup end, a similar arrangement on the same machine finishes the ball end

Fig. 8—Operations on the large end of the forged steel base cap are performed with the tooling set-up shown in Fig 7. The forging, made from SAE1035-W.D. steel, has a Brinell hardness of 200 to 220

cap is assembled on the end of the barrel. For this final turning operation, an expanding center, such as is shown in Fig. 6, is inserted into each end of the bore, so that the outside diameter will be concentric with the bore when finished. Carbide-tipped tools are used for the finish turning operations. The sleeve of the expanding center shown in Fig. 7 is made from SAE-1095 steel, hardened and ground, having a Brinell hardness of from 240 to 260. The tapered plug is turned from SAE-1020 steel, while the hardened center insert in this plug is made from SAE-1095 steel. This insert has three 0.05-in. deep oil grooves, and is pressed into a cavity bored in the outer end of the tapered plug. The two flat-point setscrews are used to release the tapered slug from the sleeve, so that the expanding center can be removed from the end of the barrel at the completion of the finish turning operations.

Following finish turning, the barrels are checked carefully to make certain that all dimensions are within the tolerances allowed on the drawings, then the barrels are shipped to a sub-contractor who grinds the Class 4 threads from the rough in a Jones & Lamson thread grinder. These threads must be held carefully within the allowed limits, and must be concentric with the bore of the barrel.

Threads Finished by Grinding

Finished barrels are delivered to the Ordnance Department inspector for final approval before assembly with base caps to form a finished gun tube. The Ordnance Department inspector examines the barrel carefully for any flaws, and uses a number of very accurate gages to determine whether all dimensions are within permissible tolerance. A Pratt & Whitney star gage is used to check the bore of finished barrels.

Made from a SAE-1035-W.D. steel forging, the base cap is, for the most part machined in a No. 1A Warner & Swasey universal hollow hexagon turret lathe. Two chuckings are used for machining the two ends of this cap, the first set up being shown in Fig. 7. Before delivery to this machine, the cavity is roughed out in a drill press using increas-

ing sizes of standard drills, the last being a flat bottom drill which roughs the cavity to about $3\frac{1}{2}$ in. diameter and $2\frac{1}{8}$ in. deep.

First chucking operations in the turret lathe on this base cap involve the use of tools on both the cross-slide turret and the hexagon turret, as indicated in Figs. 7 and 8. First operation is to face off the back seat A, Fig. 8. with a forged high-speed steel tool held in the cross slide turret. A special gage is used to insure facing this surface to accurate depth. Next, the groove B is machined with another forged high-speed steel tool in the cross-slide turret. A heavy forged high-speed steel tool in the cross-slide turret then is used to hog out material from the relief at C so as to relieve the load on a formed boring tool used in a later operation.

Formed Cutter for Cap

The next operation consists of finish boring surface D for the threaded section. A heavy-duty boring bar carrying a high-speed steel bit is held in the cross slide turret for this operation. Following this boring operation, the surfaces A and C in the bottom of the bore are finished with a special high-speed steel formed cutter supported in the No. 1 position on the hexagon turret. Upon completion of this operation, the turret is indexed 180 deg. and a single-point tool held in a boring bar at the No. 4 position is used to chamfer at F.

The final turret operation before tapping is the rough counterboring of the surface E back of the groove B. This is done with a heavy high-speed steel blade held in the No. 3 position of the hexagon turret. The blade cuts at both ends and floats in its holder so as to maintain an even cut. This arrangement is especially desirable on surface E, as the final finish on this surface must be smooth so that it will provide a gas-tight seal with the end of the mortar barrel.

For tapping, the hexagon turret first is indexed to the No. 2 position, where a Landis collapsible tap of 4-in. capacity equipped with special chasers is used for rough tapping the 3.97-6NS-4 thread. Four to five passes are taken with this roughing tap, expanding the

chasers each time with the ratchet device incorporated in the tap body. A similar tap, held in the No. 6 position on the hexagon turret, is used for finish tapping these threads in one or two passes. The Ordnance Department requirements for smooth, perfectly formed threads make necessary the extra passes of both the roughing and the finishing tap.

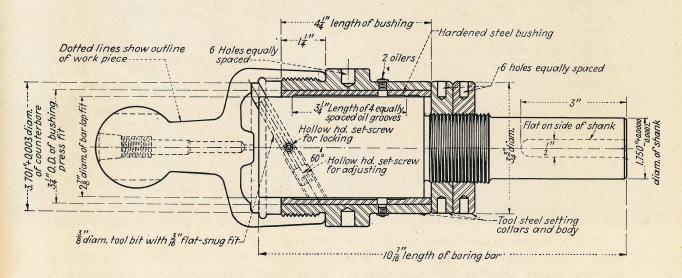
Final operation is the finish boring of surface G and E with a high-speed steel tool bit held in the special guide bushing shown in Fig. 9. This toolholder is mounted at position No. 5 on the hexagon turret, and is arranged to hold the tool bit concentric with the tapped threads in the base cap. The guide bushing revolves with the work piece while the boring bar remains stationary in the turret head. The

spacing collars govern the depth to which the tool bit is fed once the body of the guide bushing is threaded into the work piece. In this tool a hardened steel bushing with oil grooves is fitted into the body to provide a bearing for the boring bar.

Spindle Slowed for Tapping

It has been found that a spindle speed of 84 r.p.m. is satisfactory for all of the above operations on the large end of the base cap, except for tapping. Rough tapping is performed at 27 r.p.m., while the finish tapping is done at about 10 r.p.m., the driving clutch being allowed to slip so that a slow speed can be obtained.

After a lot of 40 to 50 base caps have been



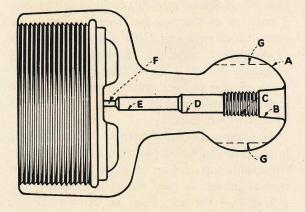
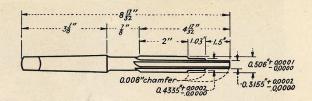


Fig. 9—Used to keep the threads and counterbore in the base cap concentric, this boring tool incorporates a guide bushing which revolves with the workpiece while the boring bar remains stationary in the turret head

Fig. 10—Operations on the ball end of the base cap are performed in a second set-up of the No. IA Warner & Swasey turret lathe. Flats at G are milled in a following operation on a Cincinnati miller



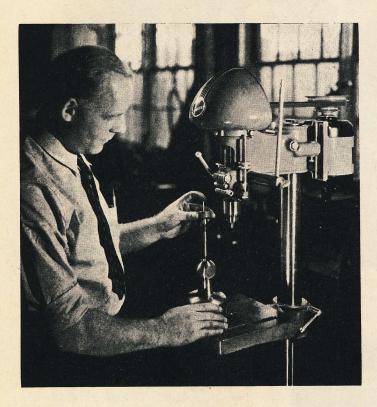
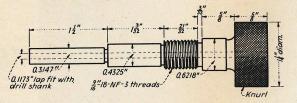


Fig. 11—A three-step reamer with six straight flutes finishes three diameters of the firing pin fit in the base of the cap. It is turned by hand

Fig. 12—A 0.1170 in. drill is used for the final drilling of the hole for the firing pin in the base cap. A special bushing guides the drill in this operation

Fig. 13—Made to fit snugly in the previously drilled, reamed and tapped base cap, this bushing is used as shown in Fig. 12 to guide the 0.1170 in. drill



finished on the large end, the chuck is removed from the turret lathe and a special faceplate having a threaded stud in the center is fitted on the spindle of the lathe. This is accurately centered with an indicator. The stud threads have a close fit with the threaded bore of the cap. A new tooling set-up is made, and then operations on the ball end of the cap are performed, as indicated in Fig. 10.

First, the ball itself is turned with two high-speed steel form tools. Then a hole is started with a center drill, and a larger drill is used to open up hole B. Next a two-step drill is used for holes C and D, and a smaller drill is used for hole E. Hole F is drilled in

a later operation. After drilling, a three-step hand reamer with six straight flutes, as shown in Fig. 11, is used for holes B, C and D. As this forging has a Brinell hardness of 200 to 220, this reaming operation must be done carefully, and the tool must be kept sharp. Next, a pilot tap with Class 3 threads is used for hole C. The base cap then is removed from the turret lathe and trucked to a milling machine where flats along the dotted lines G in Fig. 10 are milled in one pass.

Drilling of the 0.118 in. diameter hole F for the tip of the firing pin is done in a small, sensitive Delta drill press, as shown in Fig. 12. For this operation, a special guide plug

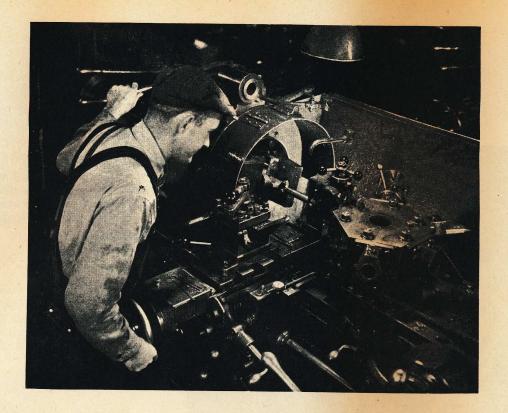




Fig. 14—A special faceplate fixture is employed in this set-up on a No. 5 Warner & Swasey turret lathe for machining forged steel gear cases to close tolerances

Fig. 15—Dimensional and concentricity tolerances on the gear case are very close, and a full set of gages are furnished the operator. The gage shown checks the concentricity of a threaded bore with other surfaces

Fig. 16—This holder is used for finish tapping bronze tension nuts by hand

bushing made as accurately as a plug gage, see Fig. 13, is used to hold the 0.1170 in. drill central. The drill first is inserted in the guide bushing, then the two are placed in the cap and the drill inserted into the chuck. At the start of the drilling operation, the bushing is threaded all the way down into the cap. As the drilling progresses the bushing is slowly returned out of the hole by hand, so as to provide space for chips. The 0.1173 in. hole through the guide bushing is a lap fit with the drill shank, and any attempt to return the drill through this hole with chips would cause the hole to wear. A small quantity of oil is dropped into the cap before the drill and bushing are inserted, so lubrication is provided for the point of the drill.

Gear Case Operations

Made from a solid steel forging which is roughed out by a sub-contractor, the gear case is completely machined in a No. 5 Warner & Swasey turret lathe, single-point tools being used for most boring and chamfering operations. A special fixture is used on the face-plate, so that the gear case can be held in three positions for the necessary operations. The set-up is shown in Fig. 14. Diametrical tolerances are 0.0007 in., and the two axes must be kept within 0.002 in. from counterbored faces. Seats for the bevel gears must be within 0.001 in. of these faces.

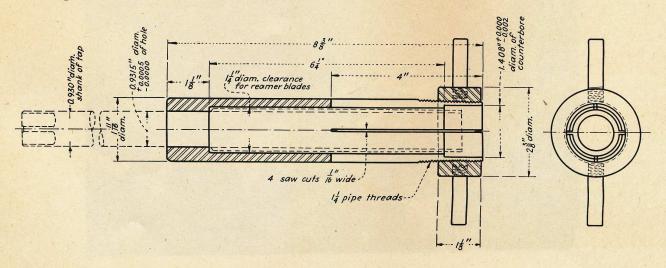
Dial indicators are used for setting the carriage and cross slide so that the diameters

and depth of facing cuts may be held within close limits. A Landis collapsible tap and a solid hand tap are employed in this set-up, both being guided by pilots in previously bored holes. Multi-diameter boring tools are used. Each time the Landis tap is set up in the hexagon turret it is indicated to keep it in alignment with the spindle.

Wear-Resisting Gages Used

Fig. 15 shows the turret lathe operator inspecting one of the gear case fits with a concentricity gage. It has been found necessary to provide a full line of highly accurate gages for the gear case and all other parts for the mortar and mounts, because of the close machining tolerances. Originally, "Stentor" oil-hardening tool steel was used for these gages, but now they are being made of "Hampton" oil-hardening tool steel, also supplied by Carpenter Steel Company, in order that the gages may have higher wear resistance.

One of the other parts which has caused difficulty is the tension nut for the traverse screw. This nut has an outside diameter of 1.404 in. and a width of 0.470 in. It is tapped with a 0.4 in. pitch modified acme thread of $2\frac{1}{2}$ threads per inch. Thus, there is only a little more than a full turn of thread in the nut. The face of the nut must be square with the axis of the thread. After trying to produce the nut in a turret lathe set-up with little success, it has been found necessary to



rough the nut out in the turret lathe and then finish the thread with a hand tap guided into the nut by the holder shown in Fig. 16. The threads on the collet of this holder are right hand, so that the increased pressure on the tap tends to hold the work tighter in the collet during the cut.

High Chromium Screws

Traversing and elevating screws for the mortar mount are machined from a special corrosion resisting steel containing approximately 14 per cent chronium and having a hardness of 200 to 250 Brinell. These screws must be machined in the hard condition, otherwise the corrosion resistance of the steel is lost. The screw stock first is ground on the outside diameter and then the threads are

rough chased in an engine lathe. Finally, the threads are finish milled in one pass in the set-up shown in Fig. 17. The modified acme single-pitch thread has a lead of 0.7 in. and the cutter, which is $4\frac{1}{2}$ in. diameter, is rotated at 142 r.p.m. with a table feed of 35 in. per min. No difficulty has been experienced in holding the required tolerances on these screws, as the Cincinnati miller is in good condition, and the set-up is kept rigid.

The assembly operation on these mortars and mounts which has been the most difficult to solve is that of fitting the base caps to the gun barrels. Since there must be a gas-tight seal at the end of the barrel, it has been found necessary to scrape the cap surface which mates with the end of the barrel. This involves considerable hand work, but has resulted in a satisfactory product.

Fig. 17—Traverse and elevating screws, made from a special corrosion resistant steel, are finished in this thread milling operation after the modified acme threads have been roughed out in an engine lathe

