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CHAPTER VI

CONSTRUCTION OF NAVAL GUNS

HOME INDEX

CHAPTER VI.

CONSTRUCTION OF NAVAL GUNS.

Section I.—Manufacture of Gun Forgings.

601. **Furnace practice.**—Nickel steel and gun steel for gun forgings are made in acid open-hearth furnaces and in electric furnaces, because of the increased probability of blowholes and gas bubbles in steel converted by the basic open-hearth process, due undoubtedly to the fact that such steel is likely to be more highly charged with oxygen. The furnace charge is made up of about one-third pig iron low in phosphorus and about two-thirds plain or nickel-steel scrap, such scrap being parts of old ingots, cuttings, and turnings. The exact proportions of pig and scrap depend on the quality and quantity of the scrap obtainable, and also on the analysis of the pig iron (particularly its silicon content); but the pig iron generally constitutes from 20 to 30 per cent of the charge. The scrap, if the product is to be nickel steel, contains from 2 to 2½ per cent nickel.

From 6 to 8 hours are required to break down and thoroughly melt the charge, and as soon as this occurs samples are taken. A fracture test enables an experienced person to closely estimate the percentage of carbon in the charge. Other samples are sent to the chemical laboratory, where analysis is made for carbon, manganese, silicon, sulphur, phosphorus, and nickel. The nickel is not oxidized, and remains constant, and the amount to be added, if any, is determined from the analysis and introduced in the form of pure nickel blocks or "plaques."

Every half-hour after the charge is melted a carbon test is made, until the carbon has been reduced to the desired percentage by oreing down. This consists of adding iron ore from time to time, Lake Superior hematite being generally used, the reaction being $Fe_2O_3+3C=2Fe+3CO$. For nickel-steel tubes and liners the carbon is reduced to between .35 per cent and .42 per cent, but for "gun steel" the amount of carbon will run between .42 per cent and .50 per cent. From the results of the analyses the various necessary additions are made to bring the manganese and chromium up to the required amount. Ferromanganese or spiegeleisen is added to increase the carbon and manganese, the former being used when a smaller increase of carbon is desired. Ferrochrome is added if necessary. Loam is put in to increase the slag, limestone to thin the slag.

From 10 to 20 hours after the bath is melted, it is tapped into ladles. Ferrosilicon is added to the ladle to bring the silicon up to the required amount. The molten metal is allowed to run into a large refractory-lined ladle, and as the tap hole of the furnace is below the slag line, only a small amount of slag goes into the ladle, and this remains at the top; by using bottom-pouring ladles the amount of slag is still further reduced.

The following table gives the average chemical composition of gun forgings:

	Gun Steel.	Nickel Steel
Carbon	.50%	.40%
Manganese	.70 "	.70 "
Silicon	.27 "	.27 "
Phosphorus	.03 "	.03 "
Sulphur	.03 "	.03 "
Nickel	.....	3.00 "

602. Ingots.—Two kinds of ingots are used—the corrugated ingot for gun forgings and the fluid-compressed ingot. The ingot molds are tapered from top to bottom, the top being smaller. The size of the ingot is its diameter at the middle of its height. The ingots are top- or bottom-poured indifferently; some manufacturers top-pour all ingots, others bottom-pour, and some one-half bottom-pour and one-half top-pour. A tong hold is left at the top of ingots to assist in handling, which also serves as a sink head to take care of most of the slag, segregation, and piping.

603. The Whitworth process of fluid compression frees the cylindrical ingot of much of its gas content and thus reduces the amount of blowholes and piping. The liquid metal is subjected to slowly increasing pressure until about 2,300 pounds per square inch is reached. This pressure is held for four or five hours, or until the metal has entirely solidified.

The last samples, three in number, are taken during the pouring of the ingot; two are analyzed for carbon, manganese, silicon, phosphorus, sulphur, and nickel, and the result of the analyses is sent to the forge, where it is used in determining the forging heat. The third sample is taken to a small forge and, without treatment, is forged into test bars to ascertain the approximate physical qualities; this, known as the "heat test," gives an idea as to what can be expected of the metal.

As soon as the ingot is cold enough, it is stripped from the mold and a number is placed on it; this number remains with it for identification until it has passed through all of the processes and forms a part of a finished gun. The ingot is immediately taken to an annealing furnace, where it is slowly and uniformly heated. Soft coal is used for heating, and the furnaces are provided with baffle walls for protecting the ingot from the direct action of the flame. The ingot enters the furnace at a temperature of about 1,400° F., and is kept at this temperature for about five hours, after which time the fires are allowed to die down and the ingot cools slowly with the furnace. From three to four days are required for the cooling of a large ingot.

The ingot is now sent to a machine shop, where it is slung on a large lathe, and the specified amounts of top and bottom discard are removed. If the ingot is to be used for hollow forging, it is put in a boring mill and rough-bored to the required diameter. After the discard has been removed, and after boring (if this operation is required), the ingot, if not to be forged in one piece, is cut into blocks of the required sizes. This is done in the lathe used in cutting off the discards.

A separate number is stamped on each block made from an ingot, using the ingot number as the first part, and following it with letters and numbers to indicate the relative position of the block in the ingot. These numbers always begin at the breech or bottom end of the ingot; thus, if ingot No. 12345 were cut into four pieces, the bottom block would be No. 12345B1, the second block from the bottom No. 12345B2, and so on. If the whole ingot, after discards have been removed, is to be used in a single forging, it carries its ingot number and is designated B1. If any of these blocks are afterwards cut into smaller pieces, the number given these pieces would be No. 12345B1F1, No. 12345B1F2, etc., numbered from breech end of block. (The "F" stands for "forging.")

Before leaving the machine shop the block is examined by a subinspector for signs of piping, blowholes, and other defects, and the amount of discard is checked.

604. Forgings.—Forgings for pieces whose finished interior dimensions are small are forged solid; larger pieces are bored before being forged. For instance, the tube and jacket and B hoops of a 14-inch gun would be forged solid; the C and D hoops would be bored before being forged.

From the machine shop the block is taken to the forge, where it is brought to the desired forging temperature in an acid-lined regenerative, producer gas furnace, or other similar furnace. This temperature is usually about 2,100° F. If the block is a long one, one end is heated at a time; the other end, projecting from the furnace, is used for handling the piece during the forging operations, the ends being alternately heated and forged under a hydraulic press. Small blocks go entirely in the furnace, and are heated uniformly. The length of time required to bring the block to forging heat depends on the size of the block, and the quality of the steel. Great care is taken not to heat too rapidly, this being particularly important with alloy steels.

The block, having been brought to forging heat, is balanced by means of a porter bar, and taken by an overhead crane to the hydraulic forging press. There the operation depends upon the kind and shape of forgings to be made.

If to be forged solid, the block is forged down and drawn out by repeated workings, the forging being supported in a V-shaped anvil under a slightly concave die secured to the *tup* or head of the press, the pressure being applied gradually for about three seconds, with about one-second intervals between pressures. As the forging operation is generally discontinued when the block has cooled to about 1,550° F., several heats are necessary for tubes and liners.

The hollow forgings are forged on a mandrel which snugly fits in them. The forging is done as above described, between the V-shaped anvil and concave tup, as in the case of solid forgings; and in this manner the hole is not enlarged, but the wall thickness is reduced, and the metal is drawn out along the mandrel. With large forgings about eight heats are required for this operation, the mandrel being removed each time before the forging is put back in the furnace.

Short hoops of large diameter are forged on an *enlarging bar*, the ends of which are supported on rests, or *jacks*, on each side of the press, with the forging hanging free on the bar between them and under the tup. By this means the thickness of wall is reduced and the hole enlarged without an appreciable change in the length of the forging. If it is necessary to lengthen a hoop thus enlarged, a mandrel is used for drawing it out as explained above.

Breech bushings, or screw-box liners, are first forged or drawn down before being bored. Thus, a forging of this kind for a 12-inch or 14-inch gun is made from an 84-inch corrugated ingot, forged down to a diameter of 54 inches, annealed to relieve it of forging strains, bored through the center, heated for reforging, put on an enlarging bar, and the hole enlarged to the required dimensions. As these bushings are made of nickel-chrome steel, which is very apt to crack while under the press, they must be carefully nursed, and two or more reheats are necessary —one called the shaping heat, and one the finishing heat. Large breech bushings are always forged in pairs with their breech faces together, each end of the forging being forged down in steps as required by the drawings. After forging and subsequent annealing, they are cut apart in the lathe before being sent to the treatment department.

When the forging operation has been completed, the manufacturer sends a forging report and sketch of the rough forging to the inspector. The report contains the order number, drawing number, description of article, forging number, weight of discard, top and bottom, and size of bore. The sketch shows the general shape of the forging, with dimensions, and from this the forging reductions are figured.

From the forge all gun forgings are returned to the annealing furnace, and there annealed at a high temperature (about 75° above critical) for a considerable length of time to remove strains and to break up the previous structure. This annealing is done generally in an oil furnace. A button is taken and examined under the microscope to determine whether the metal is ready for tempering.

605. Machining.—After annealing, the forgings are sent to the machine shop, where the rough ends are cut off, steady rest bearings turned, and the scale removed. If a solid forging, it is put in a boring lathe and bored out to about 1 inch less than finished dimensions. When these operations are completed, the forging is examined for cracks, signs of piping, or other defects. From the machine shop the forging is sent to the treatment department. On short pieces sufficient metal is left on the inside and outside to allow for warping in treatment; on larger pieces the forgings are machined to the required rough forging dimensions, and if warped in treatment are straightened under a press. Sufficient excess metal is left on each end of the forging to provide test specimens required by the specifications.

606. Treatment—tempering and annealing.—The method of treating and annealing the forgings, and a general description of the furnaces used by one of the larger manufacturing plants, are here given without any attempt to discuss the theory of heat treatment or special processes or details. Gun liners, tubes, and hoops are lowered vertically by means of holding rods and crane into pit furnaces and there brought to heat for tempering. These pits are of various sizes and depths, the largest being 60 feet deep and 70 inches in diameter. They are lined with fire brick and heated with producer gas supplied through a number of nozzles or tuyères piercing the furnace in rings equally spaced; the direction of these nozzles being tangential to the walls of the furnace, the forging is not exposed to the direct action of the flame. The length of time that a forging remains in a furnace depends on the size of the forging, its carbon content, and the temperature of the furnace. Ten to twelve hours are generally required to thoroughly soak a forging to the desired temperature.

The oil wells into which the forging is immediately immersed after removal from the furnace are about the same size as the heating pits, and are also sunk in the ground. Forgings are immersed in the direction of their longitudinal axis. The oil is kept continually in circulation by means of a pump which forces it up through the bottom of the well, the overflow being carried off by a pipe at the top to a tank outside the building. After about 12 minutes have elapsed, the forging is taken out and put into the annealing furnace, where it is supported, in a horizontal position, on narrow uprights, and gradually brought to the desired temperature. This takes from six to eight hours. The annealing furnaces are heated with producer gas, and the forging is protected from the direct action of the flame. Self-recording pyrometers are used for measuring the temperature. After being brought to proper heat, the forging is allowed to cool slowly. This is accomplished by a complete or partial reduction of the flame, as may be required, depending on the condition of the furnace. When cooled to about 300° F., the forging is removed from the furnace.

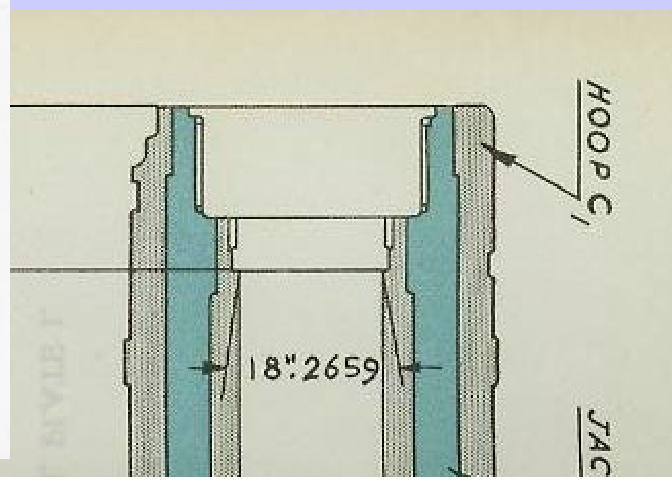
When entirely cool, the forging, if a tube, liner, or long hoop, is tested for straightness; and if warped enough to make this operation necessary, it is again heated (not over 850° F.) and straightened. It is then re-annealed from a temperature slightly above that given it for straightening. The forging is now ready for the company's test. Trial bars are taken, and if, in the opinion of the company, the forging is in proper condition, official submission is made on a form which gives the forging number, description, and order number, and on the back of the form the record of the last trial tests. Upon receipt of this form the inspector refers to his records; and if the treatment of the piece is satisfactory, the official test bars are laid out as prescribed by the specifications. These bars are slotted out and machined in a special shop, which is a branch of the treatment department and wherein only this class of work is done. The stamping of test bars and the witnessing of the test is done by a sub-inspector.

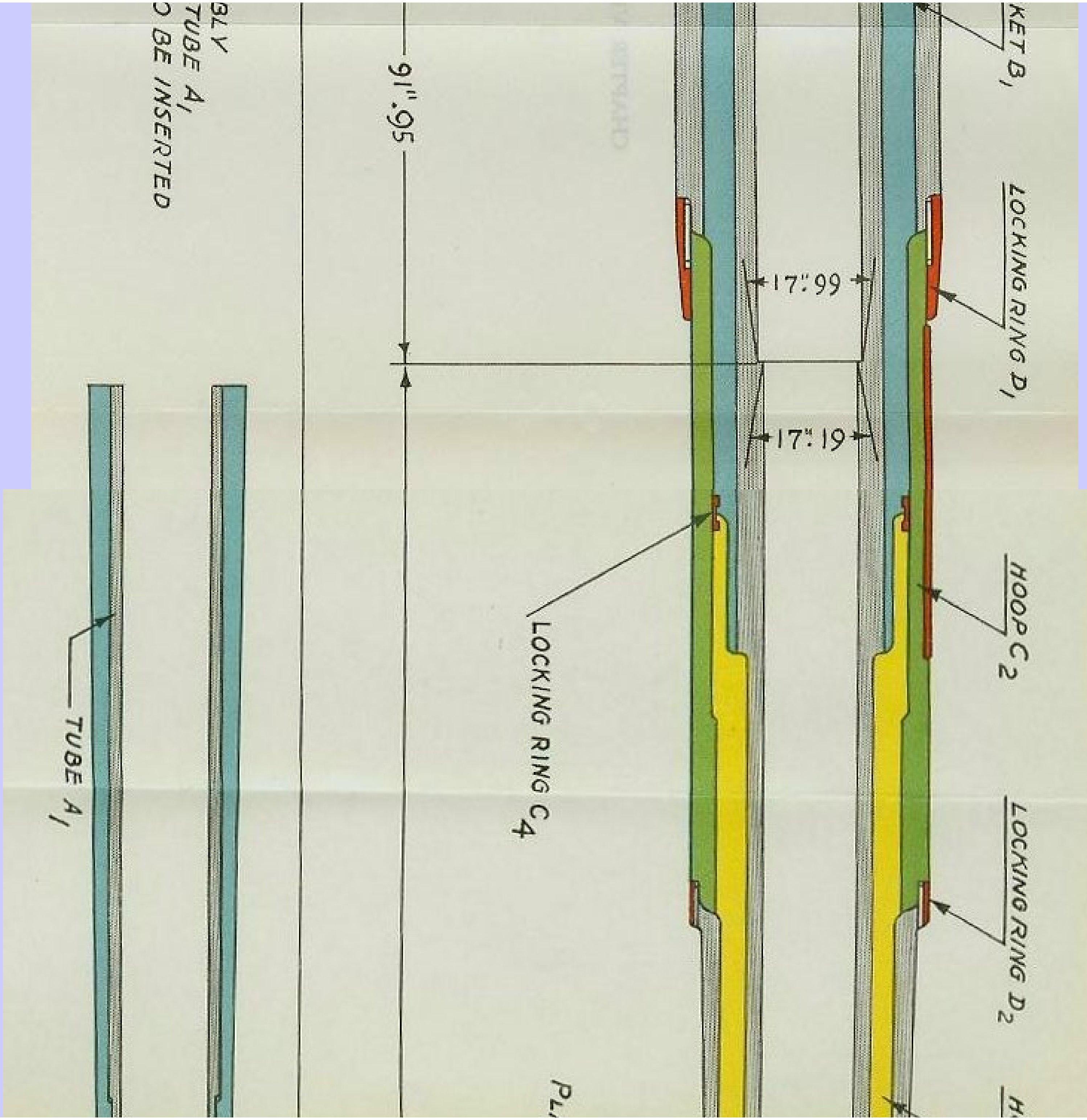
607. Determination of physical properties.—When steel for any of the above purposes is produced, tests are made to establish its suitability for the particular purpose for which it was intended. These tests involve subjecting specimens of the metal to the action of different stresses in testing machines, and observing, by means of accurate measuring instruments, the deformations produced by these stresses.

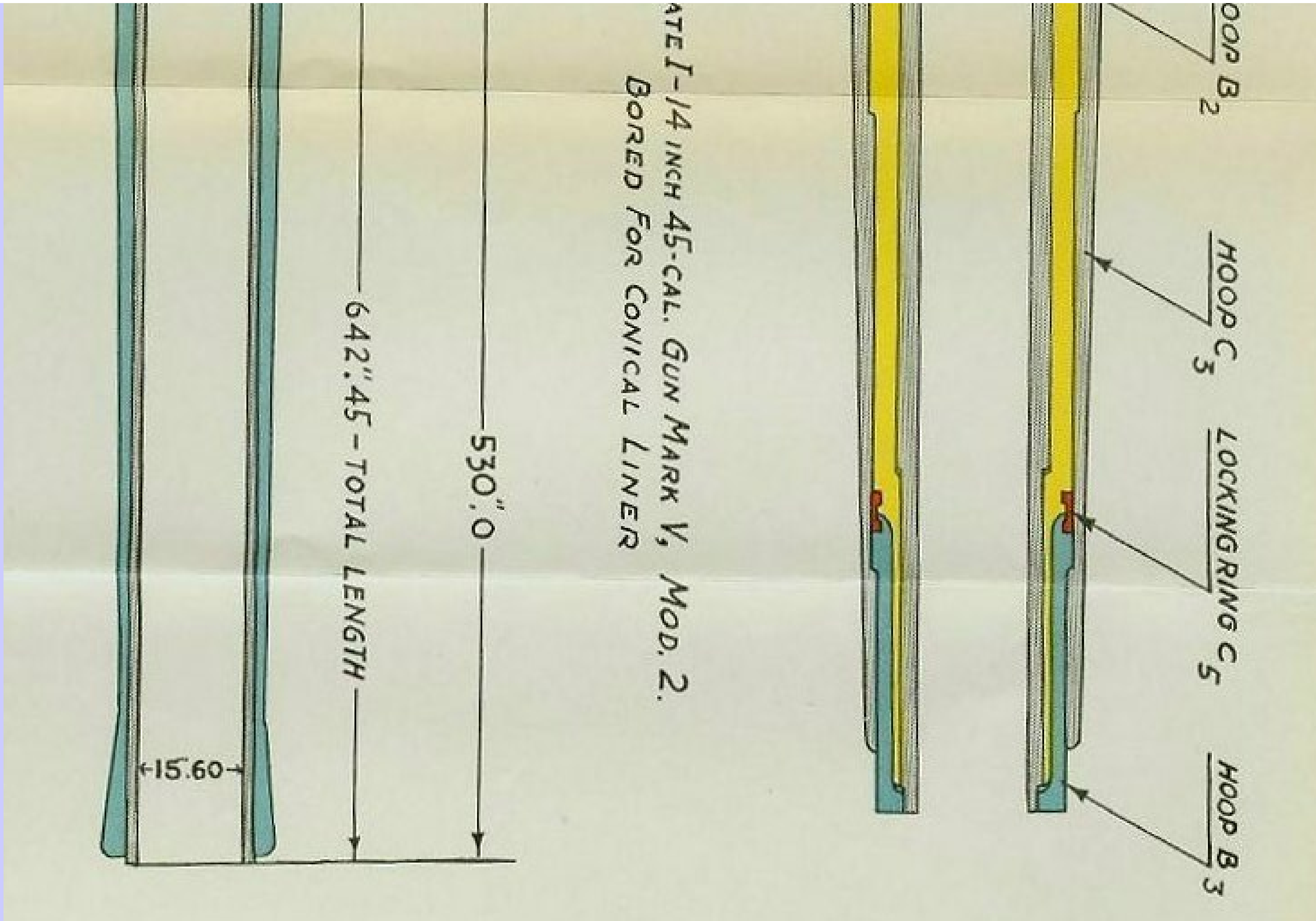
608. Testing machines.—The testing machines are generally a combination of levers for recording the stress, and a system of gearing or hydraulic machinery by which the stress is produced.

609. Test specimens are usually prepared to an adopted shape. In the case of gun forgings they are cylindrical, and are turned to the same diameter for a certain length, usually not less than 2 inches and not more than 10 inches for tensile tests; and in addition, ends are allowed

CHAPTER VI, PLATE I




TUBE A₁
91".95
LOCKING RING C₄
17".99
17".19
LOCKING RING D₁
HOOP C₂
LOCKING RING D₂



for the purpose of attaching the specimen to the machine. For compressive tests the specimen is also cylindrical, the height being twice the diameter. The capacity of the machine limits the diameter of these specimens.

In making a tensile test, the specimen is marked at two points as far apart as the finished length between grips will allow, and the length is carefully measured between these points. The diameter is also measured by micrometer calipers. It is then placed in the machine and subjected to successive tensile stresses, the elongation being noted for each stress, both when the load is on and after it has been removed.

610. Specifications governing the manufacture of ordnance material, which are changed from time to time to keep abreast of the best metallurgical practices and results, state the physical requirements the material must fulfill, and these requirements are carefully checked by inspections, by analysis, in the testing machines, and by various proof tests at the Proving Ground.

Section II.—The Manufacture of Built-up Guns.[1]

611. Introduction.—In this section there will be given briefly a general description of gun shop practice in the manufacture of built-up guns from the receipt of the rough forgings to the finished gun. As the subject of design has been previously discussed, it will not be again considered. The description given is, in general, that followed at the Naval Gun Factory, Washington, D.C.

612. Places of manufacture.—Guns for the naval service are manufactured at the Naval Gun Factory, at private plants, such as the Bethlehem Steel Company and the Midvale Steel Company, and also at the United States Army Arsenal, Watervliet, N. Y. The greater portion of the work, however, is done at the Naval Gun Factory.

613. Summary of the various steps of manufacture of a built-up gun.—The following is a summary of the steps of manufacture:

(1) Receipt and inspection of forgings.
(2) Machining the forgings to the required dimensions.
(3) Assembling the various parts in the shrinkage pit.
(4) Finishing the gun:
  (a) Machining the bore to final diameter.
  (b) Machining the chamber.
  (c) Machining the outside surface to finished dimensions.
  (d) Rifling the bore.

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[1] For additional details of the construction of built-up guns, reference is made to Chapter IX, *Naval Ordnance 1933*. Many details of the latter chapter have been omitted in this edition as unnecessary in the course of instruction for midshipmen.

(e) Determining the droop.
(f) Cutting the screw-box liner thread.
(g) Lapping the bore.
(h) Fitting the breech mechanism and reaming the gas-check seat.
(i) Milling the keyway and inserting the key.
(j) Installing the yoke.
(k) Final inspection prior to proof.

(5) Sending to the Proving Ground for proof. Returning to Gun Factory for inspection prior to issue to service.

MACHINING THE FORGINGS.

614. **Receipt and inspection of forgings.**—Forgings, when received at the gun factory, are examined for the marks required to be placed on them by the Naval Inspector of Ordnance at the place of manufacture. They are measured to see if they are within the allowed tolerance, weighed, and inspected for defects. Except for the smaller forgings they are rough bored by the manufacturer.

615. **Turning.**—After a forging has been centered in the turning lathe, a light cut is taken just deep enough to remove the scale. The work is revolved while the tool is fed along in its carriage. This cut is the only *outside* cut taken until the parts to be assembled over it have been bored and star-gauged (see Art. 619), and the shrinkage sheets completed.

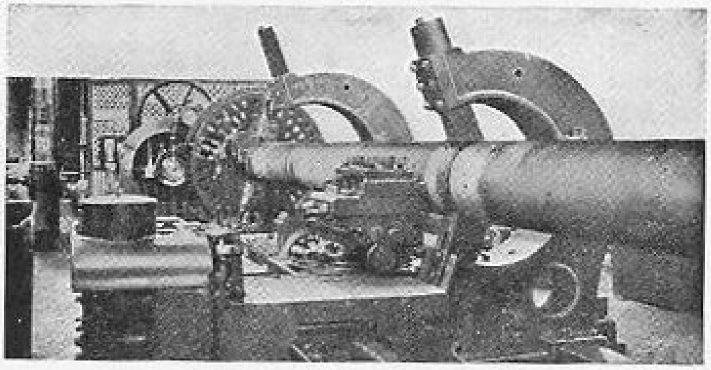
After the shrinkage sheets have been made out, the turning is continued, sometimes as many as four tools being employed at the same time on two or more carriages. For finishing cuts, tools 1 to 2 inches wide are used. Dimensions are kept within the tolerance specified on the shrinkage sheet, usually within 0.001 inch. Snap-gauges, set by rods of known length, or beam-calipers, are used to check the diameters.

Plate II shows the forging for a 14-inch tube set for turning.

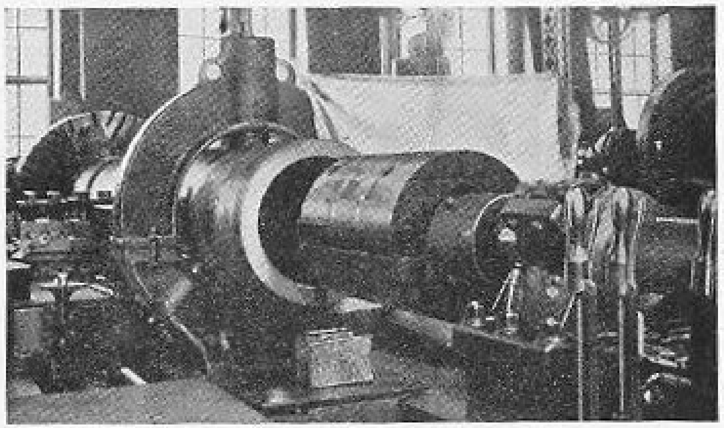
616. **Boring.**—For boring short hoops a *boring bar* with a cutting tool attached at its end is used. The bar is held and fed along by a carriage as the forging is revolved.

For long cylinders, owing to the sag and spring of a boring bar, a *packed bit* is necessary. A packed bit, as shown in Plates III, IV, and V, consists of a cylinder of oak, about 4 calibers long, built on a steel frame. Two cutters, diametrically opposite, are set in a frame at its forward edge to the size of the hole it is intended to bore. The diameter of the wood packing is maintained a few thousandths greater than the diameter of the cutters in order, by its forced fit in the bore, to furnish

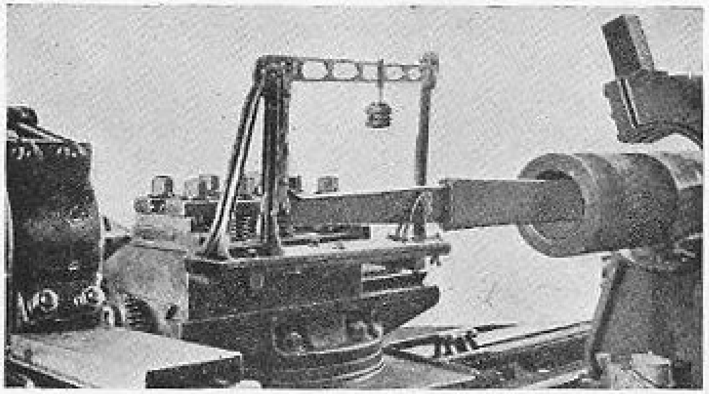
CHAPTER VI, PLATE II.



14-INCH TUBE IN LATHE FOR TURNING.

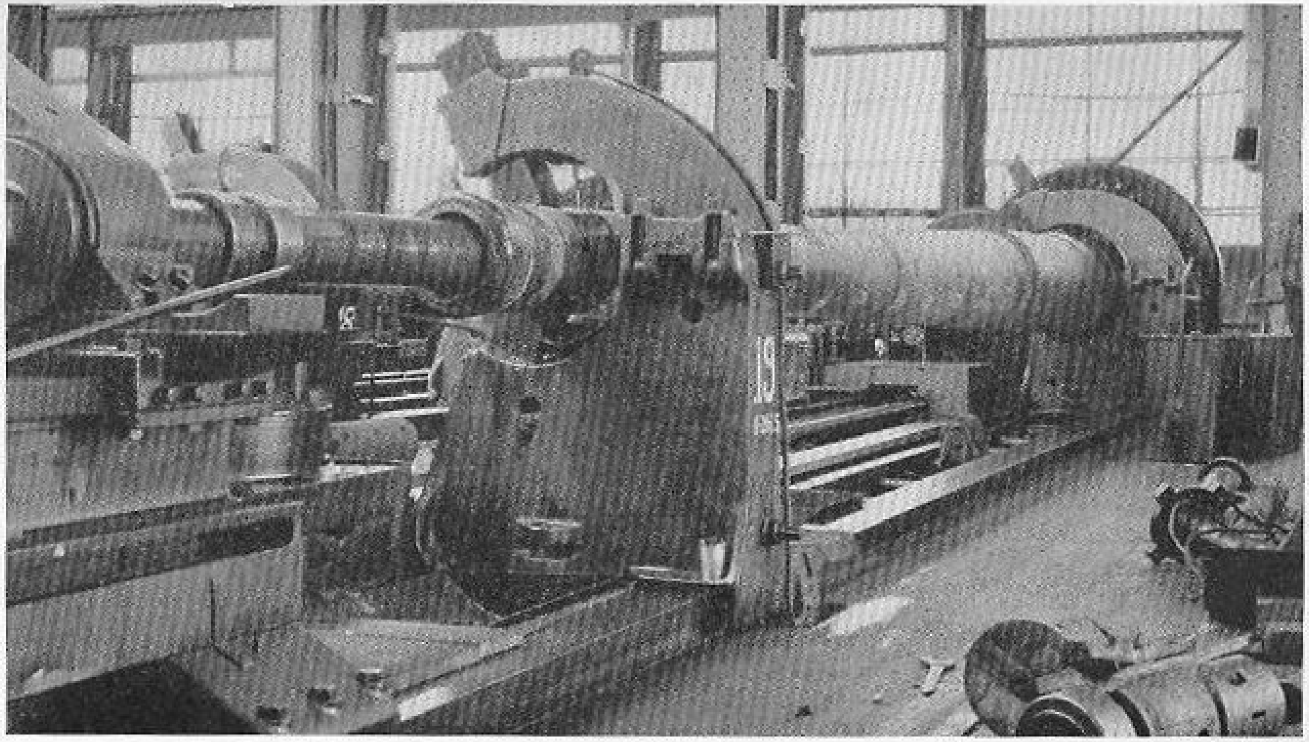


14-INCH C1 HOOP, SET FOR BORING, SHOWING PACKED BIT.



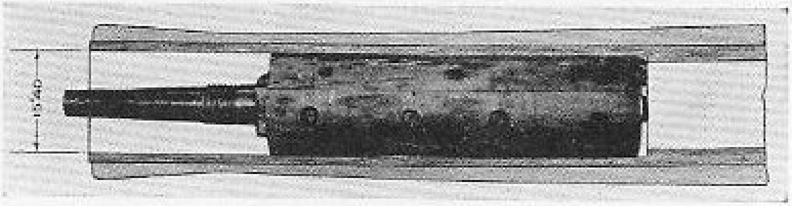
INDICATOR MOUNTED ON TOOL CARRIAGE.

CHAPTER VI, PLATE III.

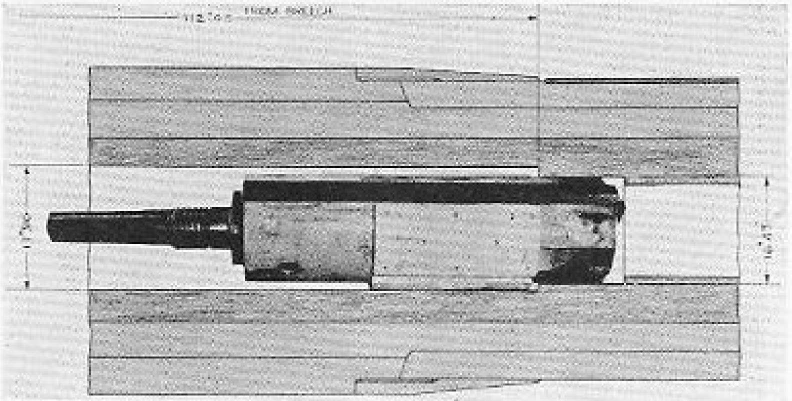


BORING A 14-INCH GUN.

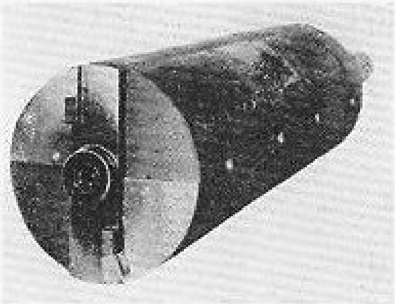
CHAPTER VI, PLATE IV.



1st CYLINDRICAL BORING FROM MUZZLE END 15".40 DIAMETER THROUGH TO CHAMBER OF GUN.

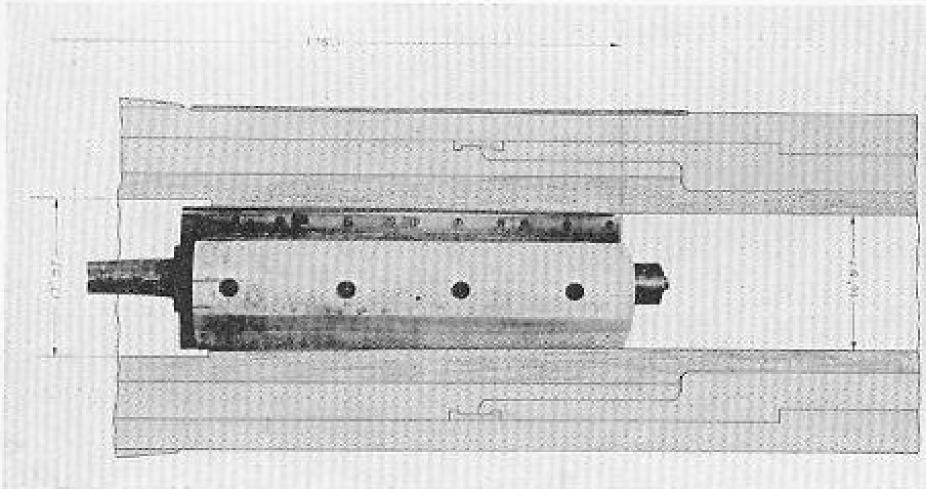


3d CYLINDRICAL BIT BORING FROM BREECH END 16".47 DIAMETER LAGGED FROM 17".9 BORE.

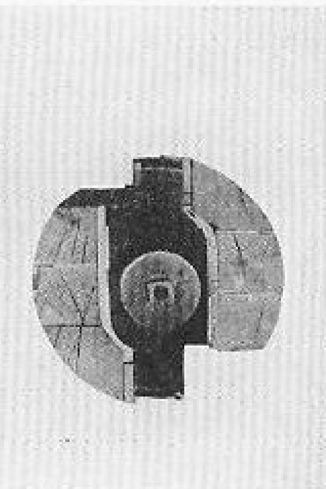


CYLINDRICAL BORING BIT AFTER LAGGING IS REMOVED. SHOWING CONSTRUCTION OF BIT.

CYLINDRICAL BORING OF 14-INCH, 45-CAL. GUN.

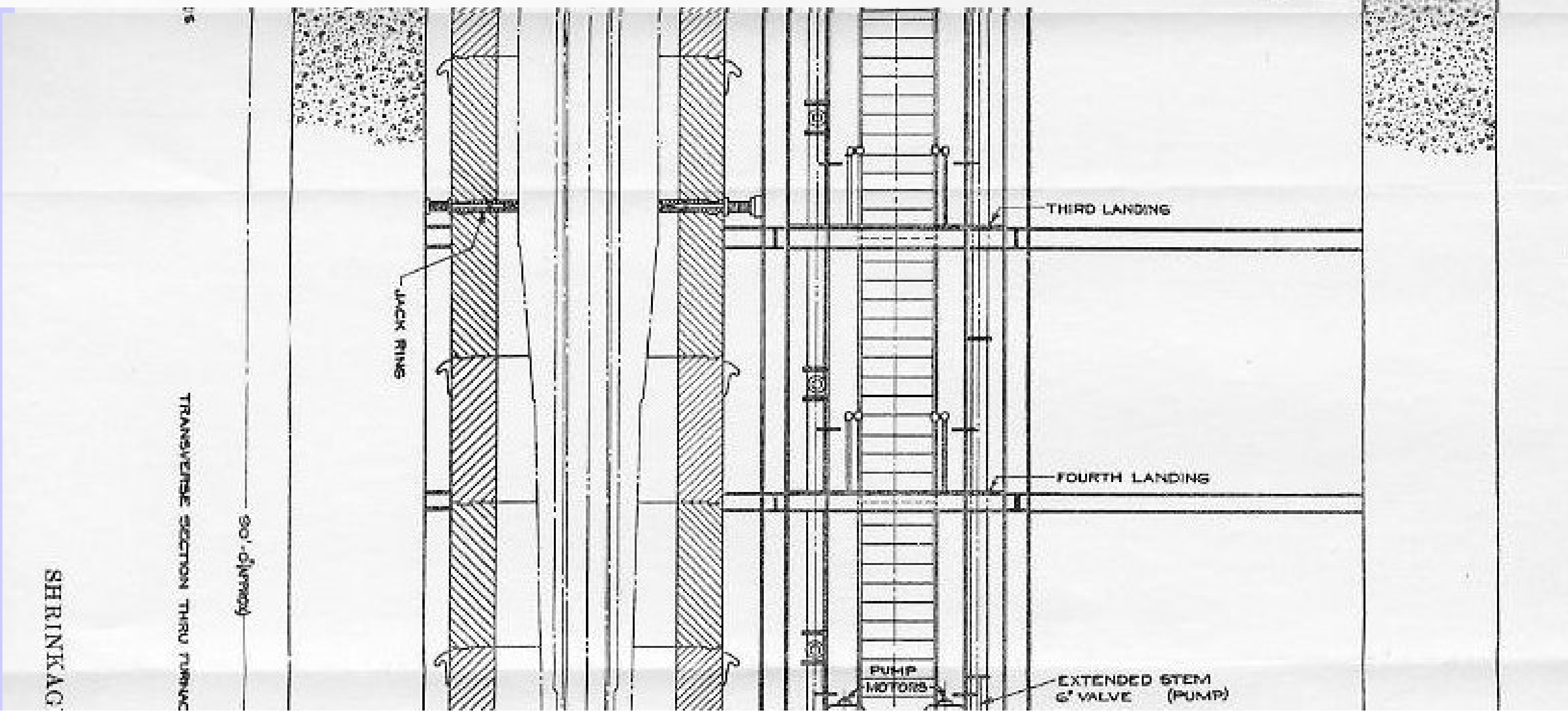


NO. 3 CONICAL BIT. FIRST CONICAL BORE 175".11 FROM BREECH.
DIAMETRAL TAPER = ".003 PER INCH OF LENGTH.



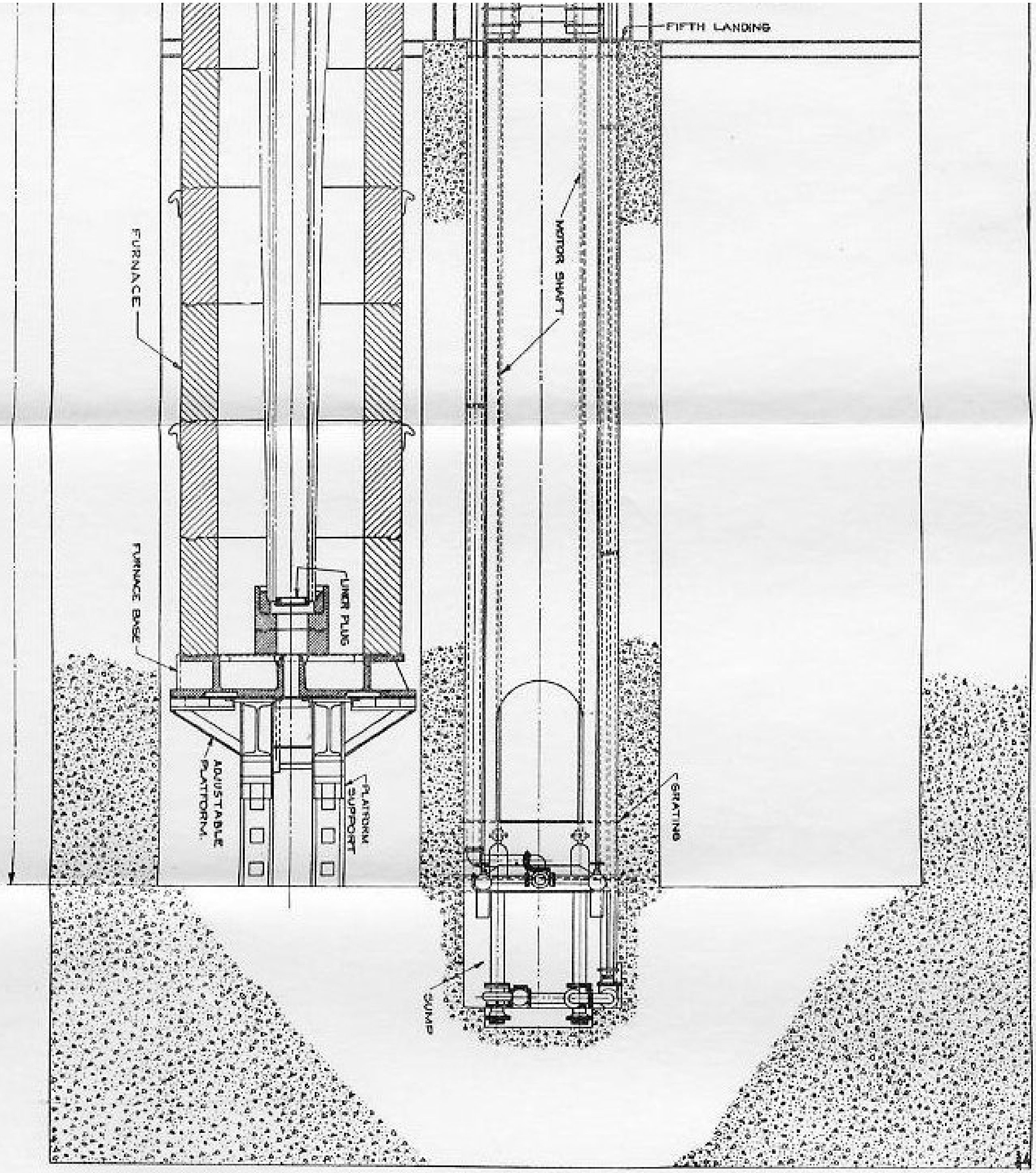
CONICAL BORING BIT, SHOWING CONSTRUCTION.

CONICAL BORING OF 14-INCH, 45-CAL. GUN.



CHAPTER VI, PLATE IX.

E PIT, TRANSVERSE SECTION.



a steady bearing for the cutters. In boring out cylinders which have two or more internal diameters, the after end of the bit is fitted with pieces of wood lagging turned to the diameter of the larger bore. A *conical* or *tapered bit* (see Art. 624) is used for boring the tube to the required taper to receive the liner. The shank of the bit is secured to a boring bar by means of a threaded section. The packed bit boring bar is a long bar which is supported in several bearings and which is driven longitudinally by a motor drive.

Frequent inspections are made during the boring to see that the hole is true. Every few inches the bit is withdrawn and the hole is *indicated* and tested by star-gauging. Four cuts are usually required to finish a bore, two rough and two fine.

617. Indicators.—To ascertain whether a bore has been turned true, it is *indicated* for eccentricity by the use of a *balance rod*, an *indicator*, or a *dial indicator*.

The principle of the *balance rod* is shown in Fig. 601. The end of the

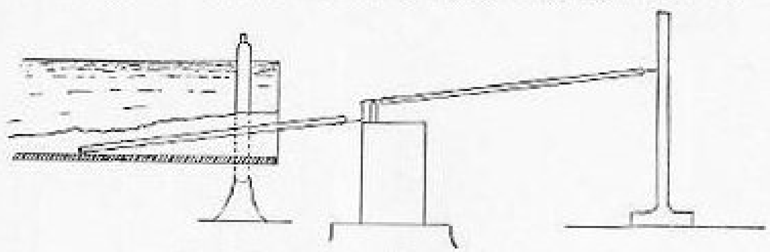


FIG. 601.—BALANCE-ROD, OR INDICATOR.

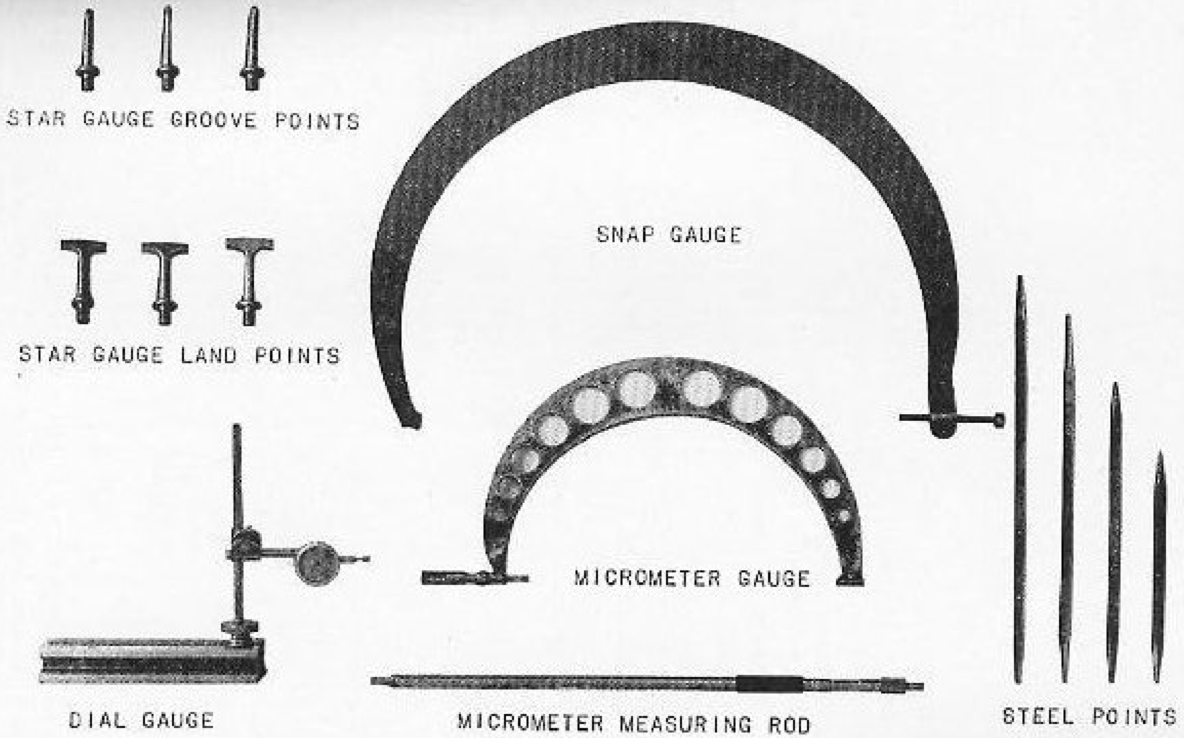
rod in the bore is fitted with a small roller and the other end with a pointer. An arbitrary zero mark is established for the pointer, and, if the bore is not eccentric, the pointer will not move from the zero mark as the forging is revolved. The bore is indicated every few inches.

The *indicator* operates on the same principle as the balance rod, but is more compact. It is shown in the lower picture of Plate II. The long pointer of the balance rod is replaced by a short arm whose movement is multiplied by a series of levers. The weight of the long arm in the bore is compensated by a counterweight.

For more accurate indication a *dial indicator* (see Plate VI), which is mounted on the end of a long telescopic pipe placed in the bore, is used. As the forging is revolved, the eccentricities of the bore, pressing against a spring-loaded arm, cause a hand on the face of the dial to rotate in either direction, giving plus or minus readings in thousandths of an inch. A telescope enables the observer to read the illuminated dial face.

618. Bore searching.—After every cut the bore is inspected by means of a *bore searcher* for discoloration, cracks, streaks, or other flaws

CHAPTER VI, PLATE VI.



MEASURING INSTRUMENTS USED IN GUN CONSTRUCTION.

that may have developed. A bore searcher, as shown in Plate VII, consists of a long handle holding a mirror inclined 45° to the axis of the handle and incandescent electric lights, which are hooded to throw their rays out radially. The observer, sighting through a telescope, observes the side of the bore reflected in the mirror. If any flaws are noticed, they may be scratched with a *pricker* to determine their depth. A pricker is a sharp steel point mounted on a light wooden rod and at right angles to it.

619. Star guage.—A *star gauge* (Plate VIII) is used to measure accurately the inner diameters of any large cylinder. It consists of a head, at the end of a long tube, with three metal points extending radially through it, 120° apart. Different points of lengths suitable to the bore to be measured are employed. Springs keep the bases of the points in contact with a cone inside the head. As the cone is advanced axially by means of a rod passing through the length of the tube, it forces the points radially outward, the amount of movement being read on a vernier on the handle end of the rod. The zero mark of the vernier is checked by pressing the points into a ring of known diameter. A first set of readings is taken with the points set thus: ☮, and a second set with the points thus: Ⓨ. The average of the two readings is taken as the average diameter of the bore at that point. Three-pointed centering rests are clamped to the tube at intervals properly to support it. Both the tube and rod come in sections to adapt the gauge to any required length.

After a gun has been rifled (see Art. 628), the grooves and the lands are star-gauged. Special points with ends shaped to fit either the grooves or the surface of the lands, respectively, are employed (see Plate VI).

All star-gauge readings are entered on a gun record sheet.

620. Shrinkage.—The *shrinkages* between the various cylinders are worked out in the design of the gun. Shrinkage between two cylinders is the difference, before assembly and when both parts are cold, between the internal diameter of the outer one and the external diameter of the inner one. The shrinkage between two cylinders is not necessarily the same throughout their lengths, but may, and usually does, vary.

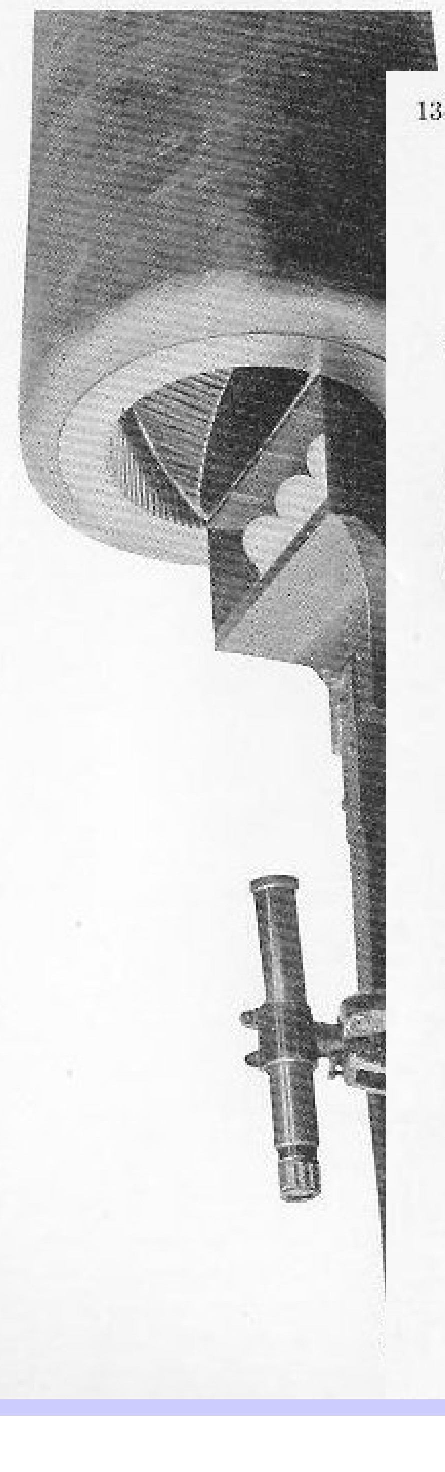
ASSEMBLING THE GUN.

621. The modern heavy built-up naval guns are designed and constructed with shrunk-in conical liners. This design expedites the reconditioning of the gun by relining after it has been worn out in service.

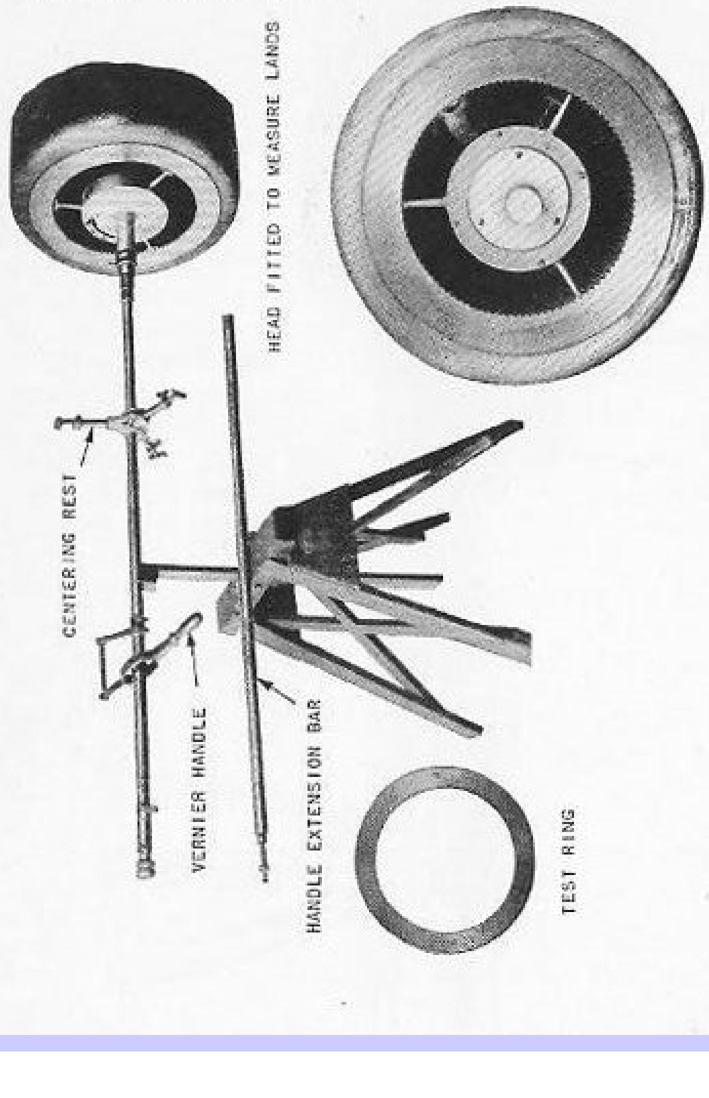
The steps in building up the gun are as follows:

(a) Assembling the B hoops on the tube A1.

CHAPTER VI, PLATE VII.



CHAPTER VI, PLATE VIII.



STAR GAUGE INSTRUMENT MOUNTED AND READY FOR USE.

(b) Assembling the C hoops on the B hoops; and then the D hoops, if any, on the C hoops.

(c) Conical boring of the tube.

(d) Assembling the conical liner in the gun.

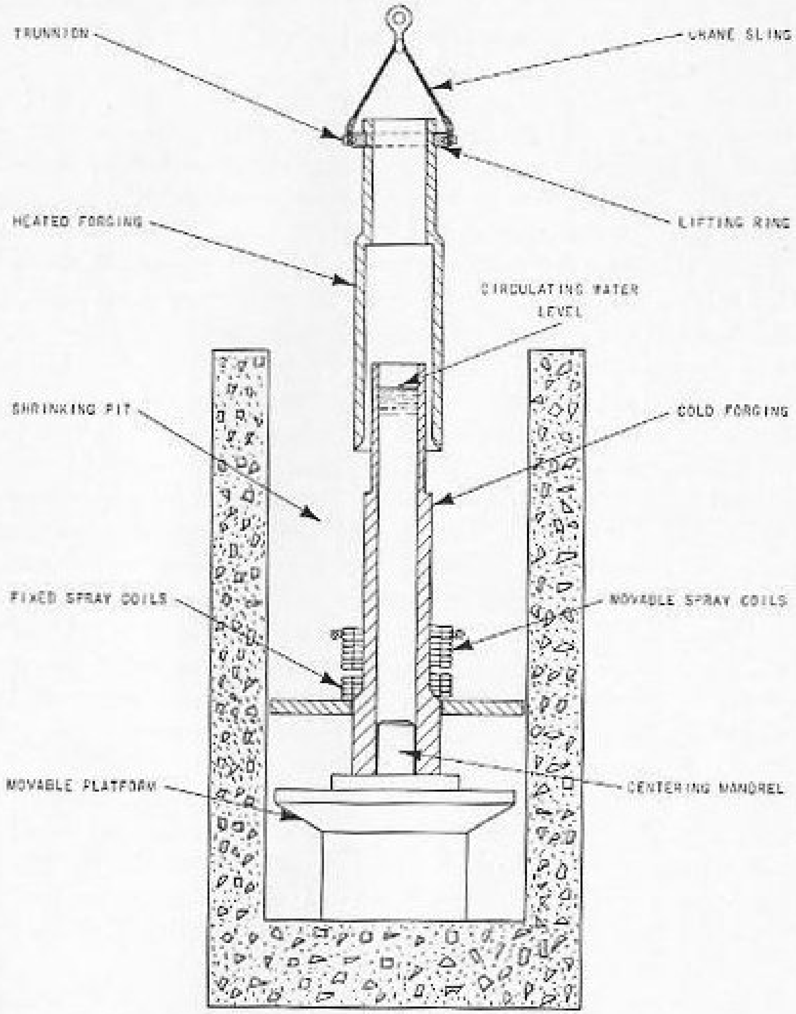


FIG. 602.—SHRINKAGE PIT—SHOWING HEATED FORGING SUSPENDED AND READY FOR ASSEMBLY.

622. Shrinkage pit.—The parts of a gun are assembled in a deep rectangular *shrinkage pit* (Fig. 602 and Plate IX). At the bottom of the pit is an adjustable platform, capable of being set at various levels to suit the length of the forgings to be assembled. Above this platform is the floor, in the middle of which is located a metal pot or centering mandrel into which the end of the tube or gun is placed. Holes in the center of the pot permit pipes for cooling water to enter the bored forging. The length of the electric cylindrical furnace, which is built in sections, may be varied to suit the forging to be heated. Temperatures as high as 800° F. are used, depending upon the size of the forging and the shrinkage desired.

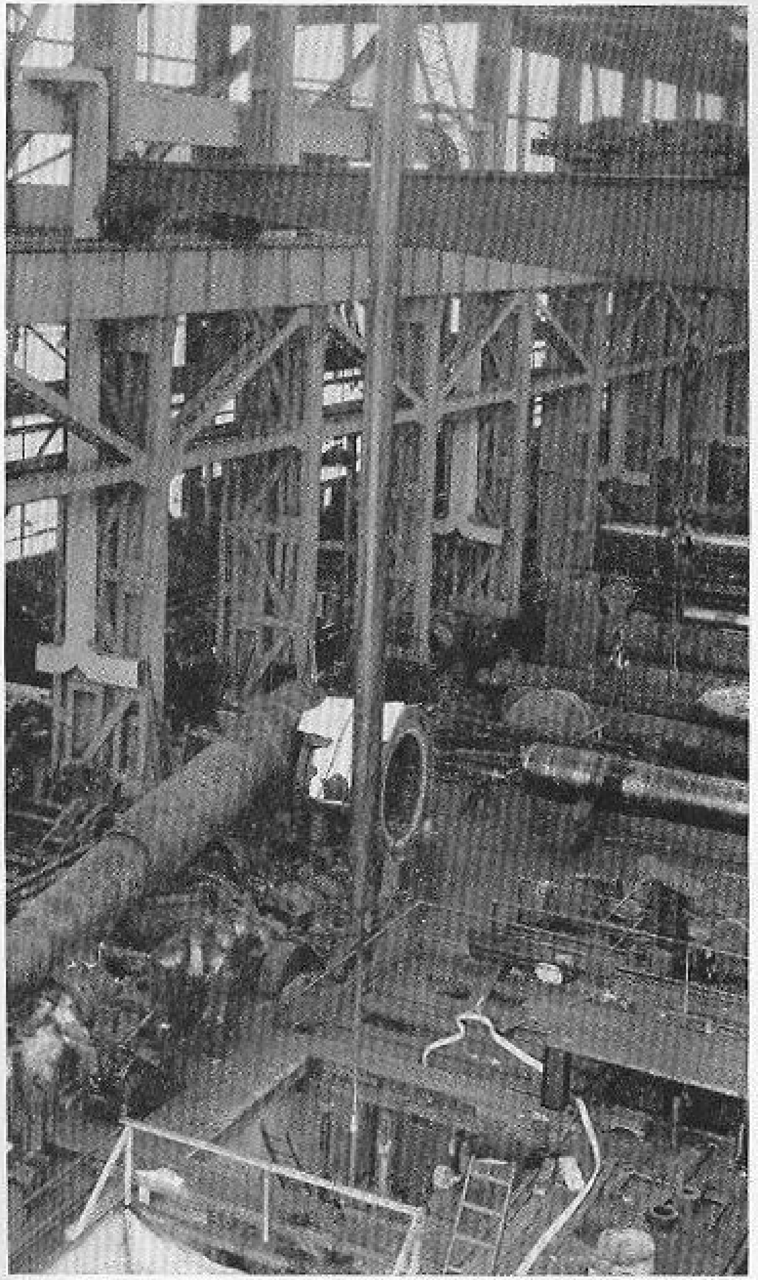
One pit at the Naval Gun Factory is sunk to a depth of 100 feet (Plate IX) and is divided into ten wells or platform levels, five on a side, which are served by a stairway and an elevator. A sump tank collects the drainage water used in cooling the assemblies. Electric pumps are employed for carrying off this water.

623. Assembling the parts.—The gun is built up around the tube, which is placed breech end down in a cold pit, its end resting in a pot which has a short mandrel extending up into the bore of the tube to steady it. No other support is given the tube. The outer surface is given a coat of a mixture of graphite and light oil. In the meantime the B hoops are placed in furnaces and brought up to heat. The B1 hoop is then removed from its pit and its internal diameter tested by cross-points of known lengths, which are mounted on a long handle. It is then lowered over the tube. To prevent undue absorption of heat in the tube as the hot jacket is lowered over it, circulating water, coming from and discharging through the pipes extending through the mandrel, is constantly run through the tube to keep it cool. Were this not done, the tube might expand and grip the jacket unevenly. When the jacket is in position, a cold water spray from a circular perforated pipe is turned on the breech over the tube shoulder to insure that the jacket will grip there first. A spray from a cage of circular perforated water pipes is then turned on, beginning at the breech end. The spraying cage is then lifted slowly in accordance with a prescribed water schedule along the length of the jacket, gradually cooling the hot forging toward the muzzle. When cool the longitudinal contraction and the diametrical expansion are measured and compared with the calculated values. The other hoops are put on in a similar manner.

When the gun is assembled it is removed from the pit, placed in a lathe, threaded at the joining of the D or outside hoops, and the locking rings screwed on.

624. Lining the gun.—The gun is now ready for conical boring of the tube preparatory to assembling the liner. The boring is accomplished in a boring lathe with a series of conical packed bits, tapering from the diameter at the breech end of the bore to that at the muzzle end. Each of these bits is equipped with two cutting tools spaced 180°

CHAPTER VI, PLATE X.



LINER POSITIONED OVER FURNACE READY FOR ASSEMBLY.

apart and extending throughout the entire length of the bit. After boring the gun is star-gauged for each inch of its length and bore-searched. The shrinkage sheet to be used for machining the liner is then prepared.

The liner is turned, bored, measured, and inspected, similarly to the preparation of other parts, except that the turning lathe is geared so that it will taper the liner the required amount.

The assembly is made by heating the gun in the furnace, muzzle end down. When the gun is heated, the liner and its fittings are suspended from a crane, and held in a standby position near the furnace (Plate X). The liner, having previously been fitted with a water-tight muzzle plug, is then filled with water to prevent undue absorption of heat and expansion while being lowered in the tube. After a center section of the furnace top has been removed and the liner has been centered over the tube bore it is slowly lowered in the gun until it is seated (Plate XI). The holding down yoke and jack are then positioned and hydraulic pressure is applied to hold the liner on the tube shoulder during cooling (Plate XII).

The water is lowered in the liner at a pre-determined time-distance water schedule by lowering the overflow pipe. It is thus possible to control the progress of contact between the liner and tube. The upper section, from which the water is lowered, is permitted to absorb heat, expand, and engage the tube progressively.

The gun is now completely built up and ready for finishing.

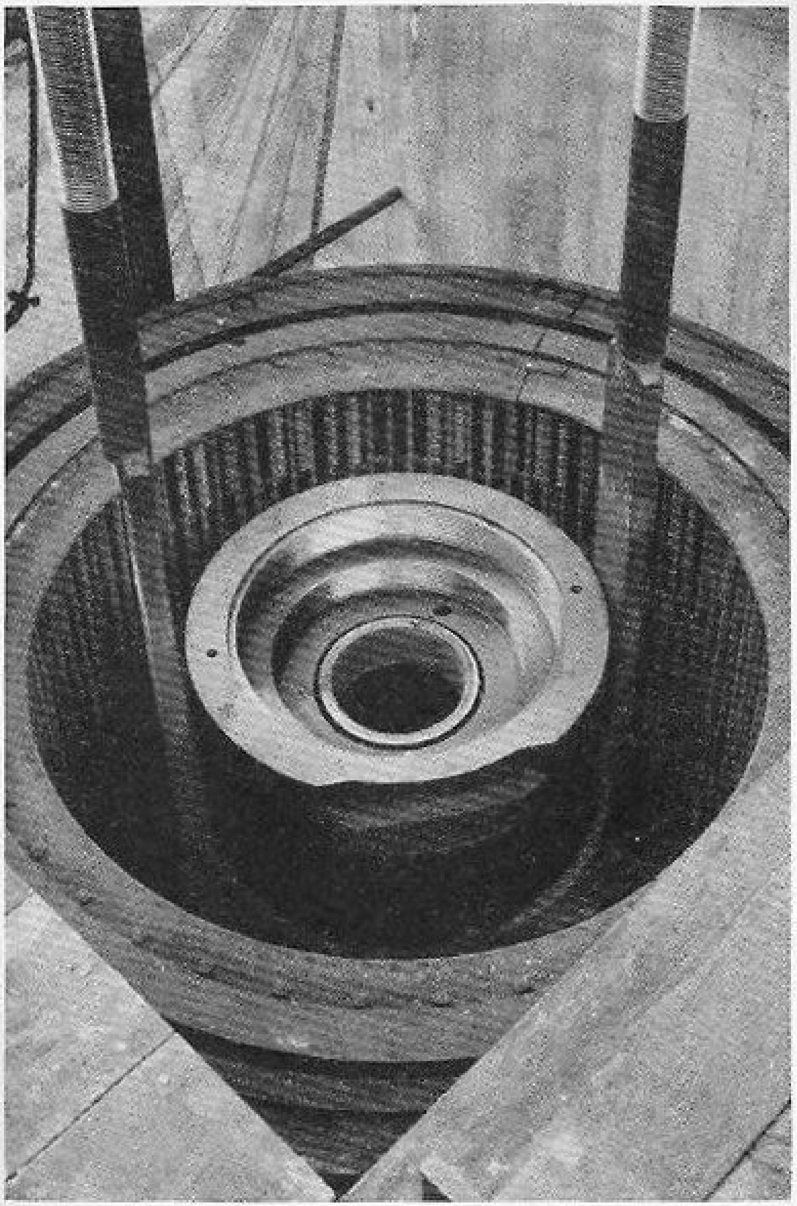
FINISHING THE GUN.

625. Machining the bore to final diameter.—When the gun has cooled to shop temperature, it is star-gauged, the compressions due to shrinkage are recorded, and it is then turned in a turning lathe to within approximately 0".2 of the finished diameters. The bore is next finished to the required diameters, two cuts with packed bits being required. The allowed tolerance in the finish boring is only 0".002 oversize and zero undersize.

626. Chambering.—The chamber is next bored to the finished size. There are two general designs for powder chambers: those for bag guns and those for cartridge-case guns.

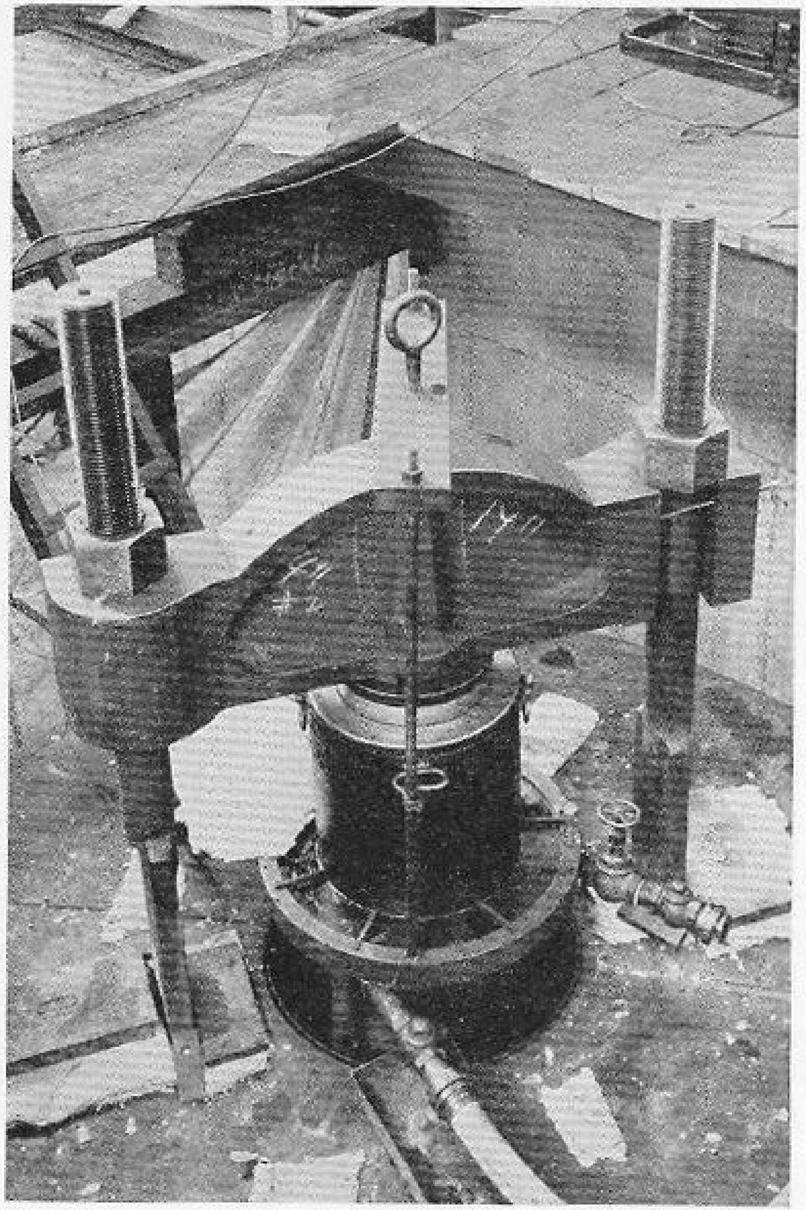
In the former the chamber, during the machining of the bore, is bored out to the diameter of the *choke* (Chapter IV, Plate I). Beginning just forward of the location of the chamber rear slope, the diameter is next enlarged to its full chamber diameter for several inches. The rear slope is then machined by a tool held in the tool carriage. The chamber cylinder is then machined out as far as the chamber front slope. The front slope, the shell centering slope, and the band slopes

CHAPTER VI, PLATE XI.



LINER ASSEMBLED IN GUN, FURNACE TOP REMOVED SHOWING ELECTRIC HEATING ELEMENTS, GUN COOLING BEFORE REMOVAL.

CHAPTER VI, PLATE XII.



LINER ASSEMBLED AND SEATED. HYDRAULIC JACK PRESSURE APPLIED TO HOLD LINER ON SHOULDER DURING COOLING. WATER CIRCULATING THROUGH BORE OF LINER AS A COOLING AGENT.

are then bored by formed cutters. Chambers for cartridge-case guns, which have no choke, are much simpler to bore.

Bag gun chambers are checked by star-gauging and by length rods, while cartridge-case guns are checked by fitting in a gauge made to the maximum dimensions allowed for the cartridge case.

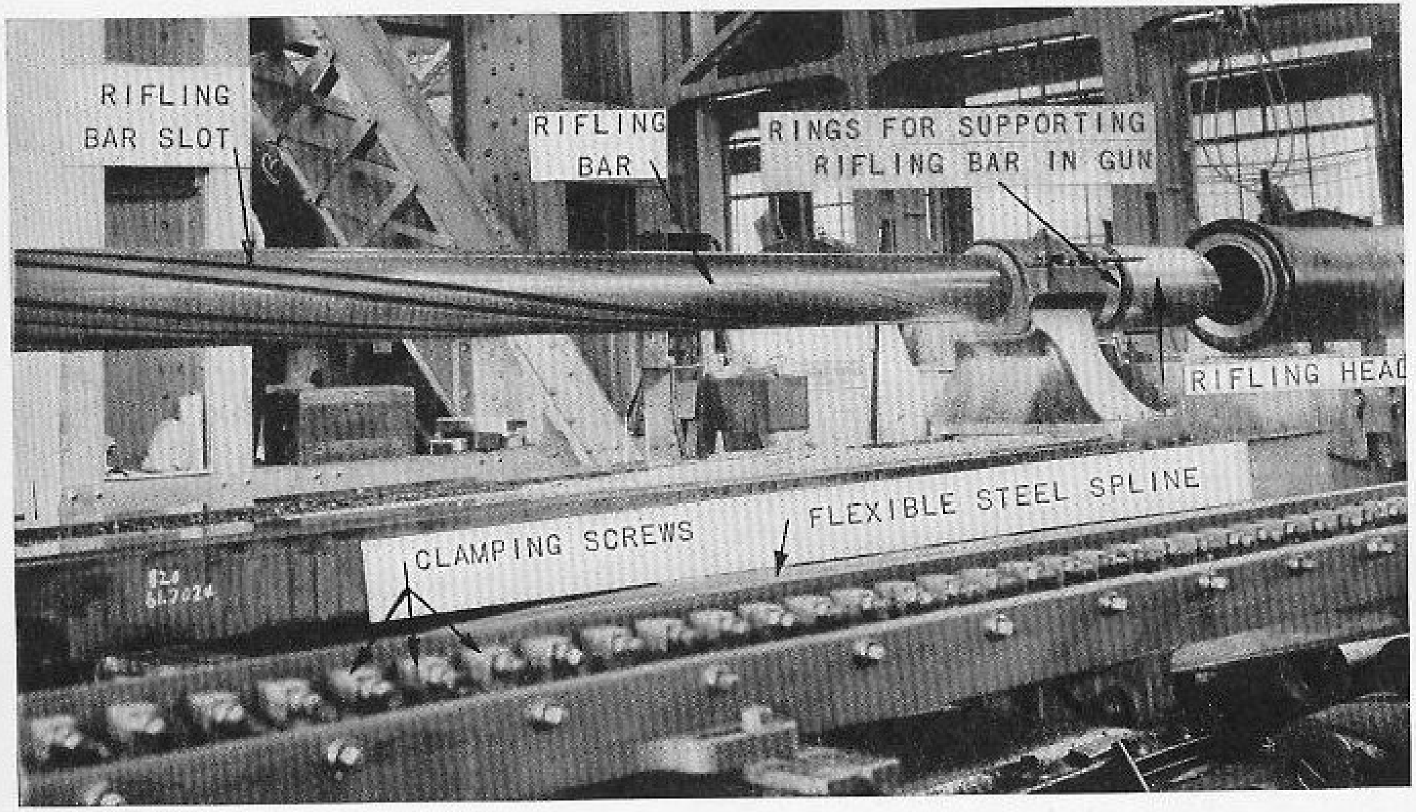
627. Final turning.—Before rifling, the gun is turned down to the finished dimensions, the *bell muzzle* is finished, and the gun is faced off to the correct length. Extra metal during the construction of the gun was left on the outside hoop at the muzzle for the purpose of machining the bell muzzle. The purpose of flaring out the muzzle in the form of a bell is to add extra strength to prevent splitting, as the metal at the extremity of the gun is not supported on the forward side. In guns which are hooped to the muzzle, the tube and liner project about 0.25 inch beyond the end of the hoop.

628. Rifling.—The mechanical process of cutting grooves in the finished bore surface of a gun is known as rifling. They are cut from the *compression slope*, which is known as the *origin of rifling*, to the muzzle. (See Chapter IV, Plate I.) Rifling is done in a machine resembling a boring lathe, except that the rifling bar, which takes the place of the boring bar, has a spiral slot cut in its surface, the pitch of which corresponds to the pitch of the rifling it is desired to cut (Plates XIII and XIV). A different rifling bar, therefore, is required for each type of gun.

The method of cutting the slot in a rifling bar is shown schematically on Plate XIV. An extension of the bed plate alongside the rifling bar carries a steel spline (Plate XIII), which is set to the form of the developed rifling by setscrews. For rifling of uniform twist the development is a straight line; for increasing twist, a curve. By means of the spline, the pinion gearing, and the rack, one end of which is kept pressed against the spline, the rifling bar is revolved at the proper rate as it is fed past the stationary cutting tool.

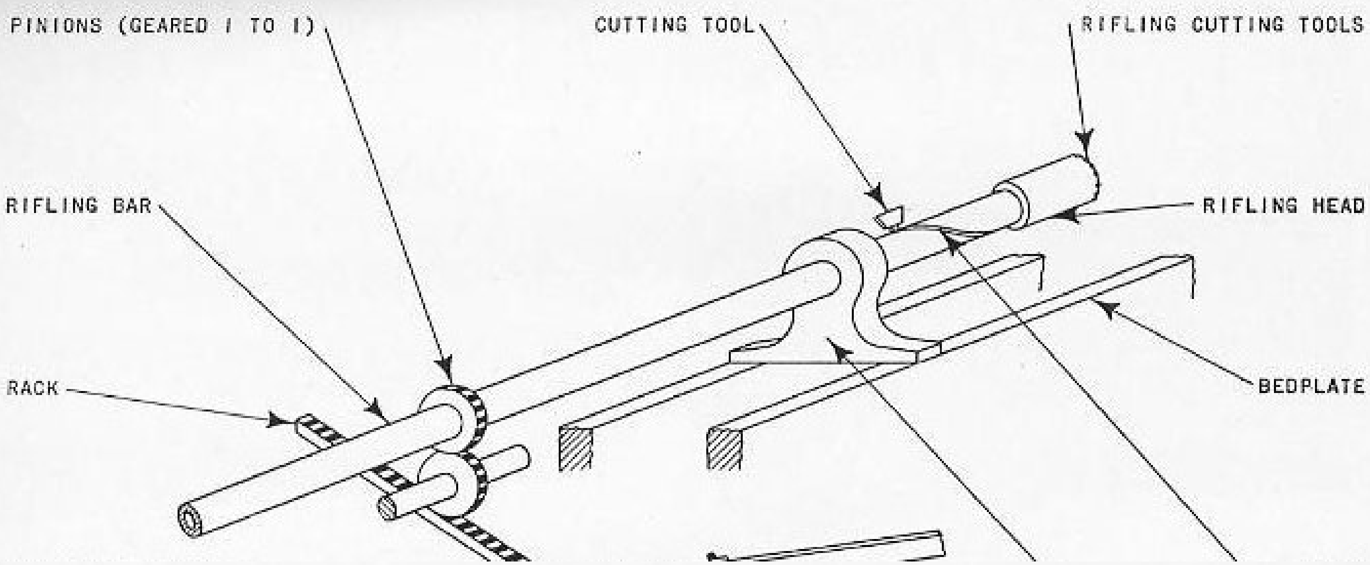
The *rifling head*, a hollow cylinder slightly smaller than the bore of the gun, is keyed in a socket in the end of the rifling bar (Plate XV). The cutting tools are set in pockets placed at equal intervals circumferentially around the forward edge of the head, the number of tools being half the number of grooves to be cut. A cone, which is moved axially inside the head by a screw, is employed to move the tools outward. The screw, which has a vernier to indicate the position of the cutting tools, is reached through an opening in the side of the head. A pin, projecting through the front face of the head, when pushed in, causes the cutters to collapse inward, thus enabling the head to be withdrawn without danger of scoring the bore.

All rifling is done from the muzzle end. After the head has been trued



RIFLING MACHINE, SHOWING RIFLING BAR ABOUT TO ENTER 14-INCH, 45-CAL. GUN.

CHAPTER VI, PLATE XIV.



CONSTRUCTION OF NAVAL GUN

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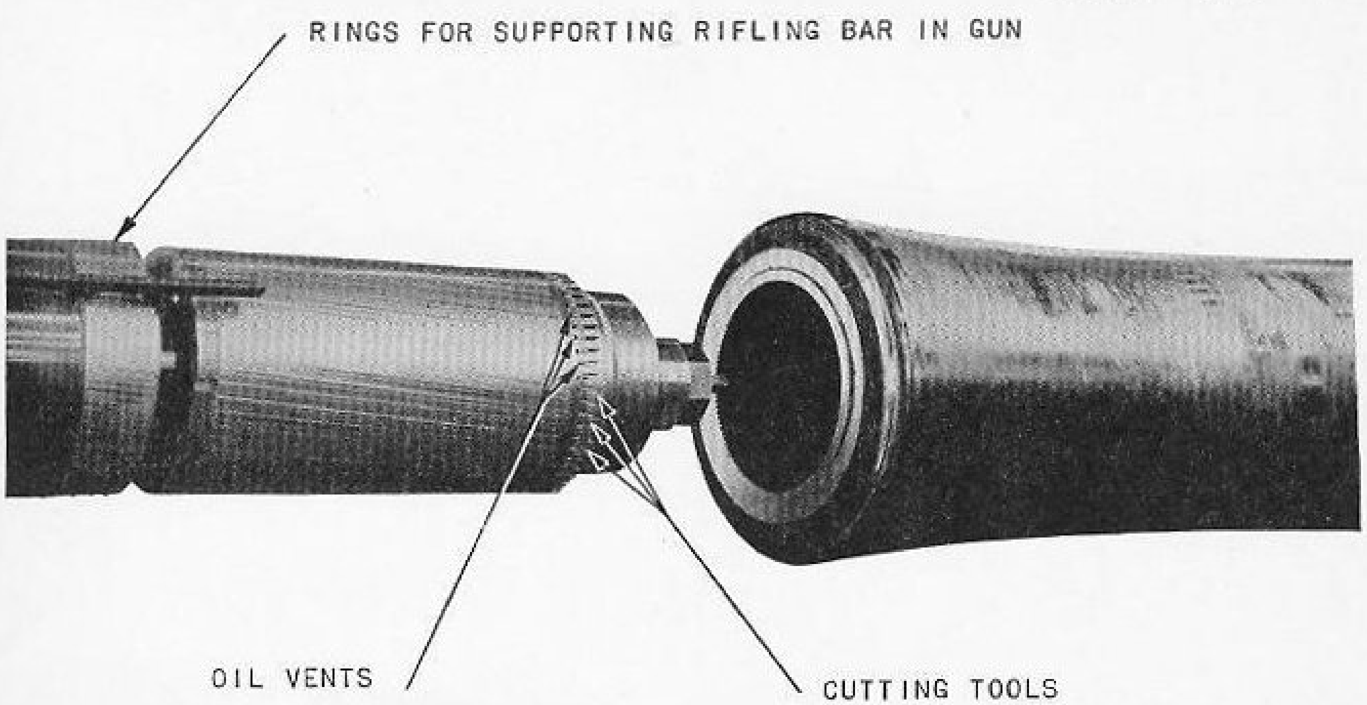
CHAPTER VI, PLATE XV.



RIFLING HEAD READY TO ENTER 14-INCH, 45-CAL. GUN.

NAVAL ORDNANCE

with the bar, the bar is advanced for the first cut. A lug in the forward steady rest bearing engages in the rifling bar slot and rotates the bar as the head is fed into the gun, cutting the grooves with the correct pitch. About 100 to 150 runs of the rifling head are required to complete one-half the grooves in a 14-inch gun. When the first half of the rifling is finished, the head is rotated to bring the cutters into position for the second set of grooves. The cutting tools are reset and the rifling operation begins anew.

After rifling, the lands and grooves are star-gauged.

629. Determination of droop.—In order that the gun, when finally mounted, may be in the most advantageous position, it is now tested to ascertain the point of least droop. It is centered in a lathe, the breech end is gripped by the jaws of the face plate, and the point where the gun will be supported by the trunnions is held by steady rests. The gun is now revolved, and by means of a small spring indicator held against the muzzle, the points of greatest and least comparative droop are determined. The position of the gun in which it shows least droop is noted and marked as the top. The threads for the screw-box liner are located from this line so that the gun and the top of the breech mechanism will correspond when assembled.

630. Chasing thread for screw-box liner.—In all guns from 3 to 16 inches, inclusive, the screw-box threads are cut in a separate liner which screws into the breech of the gun—in some cases into threads cut in the jacket; in others, as the 14-inch, into threads cut in the C1 and D1 hoops.

Assuming that a 14-inch gun is being constructed the gun is placed in the lathe, muzzle end to the face plate. The after ends of the tube and jacket are faced off as one surface, the C1 hoop faced off an exact distance in rear of the tube and jacket, and finally the D1 hoop faced off an accurately gauged distance in rear of the C1 hoop.

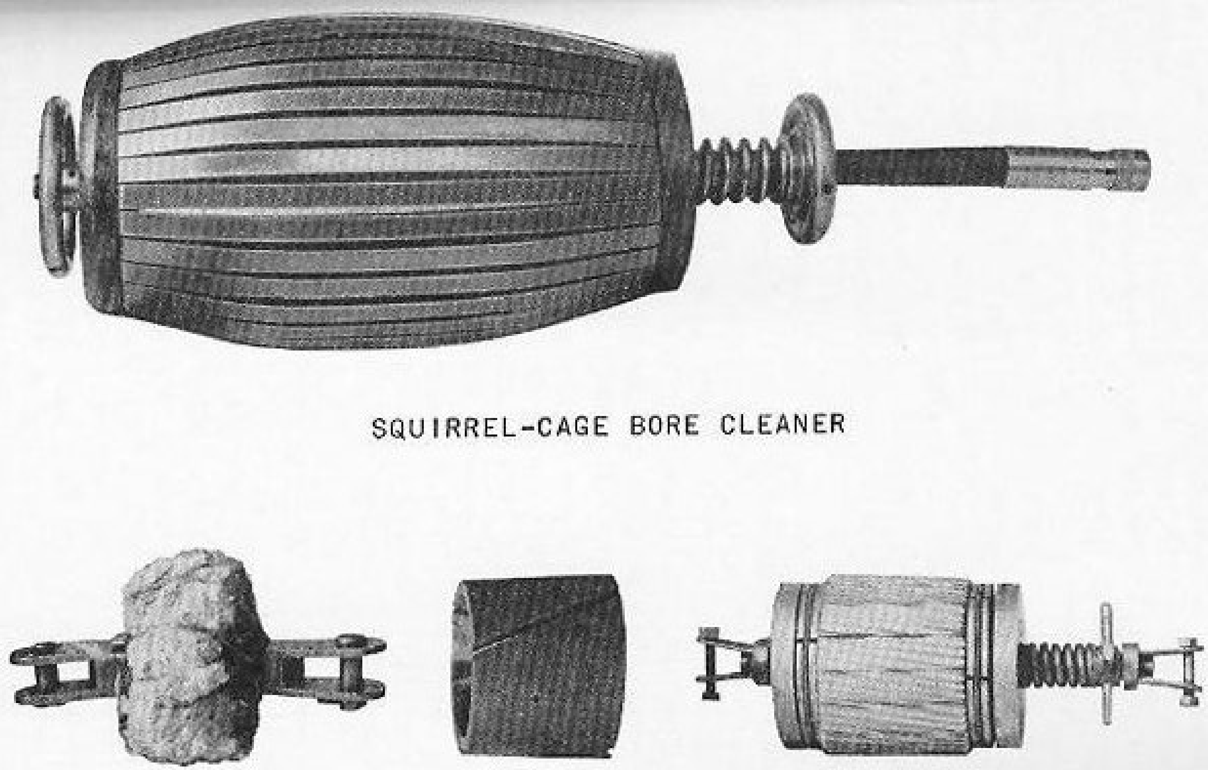
The C1 and D1 hoops are then bored out to exact diameters. The thread is then chased, starting at the point determined by the droop measurements, so that when the screw-box liner is screwed home the correct part of the gun will be up.

The screw-box liner is then fitted to the gun, the liner firmly taking up against the tube, the jacket, and the hoops. When seated properly, two holes are drilled and threaded for large keeper screws which lock the screw-box liner in the gun.

631. Lapping.—The bore is given a final cleaning and polishing known as *lapping*. The gun is placed in rests, and the *lapping head* (Plate XVI) is drawn back and forth on a wire cable which automatically reverses itself at the end of travel. To lap the lands a head is used which has several segments of wood covered with emery cloth held out against the bore by springs. To lap the grooves, a head having segments of lead cut to fit the grooves is used. The groove lapping head is first smeared with fine emery and oil. Finally, a head, such as the squirrel-cage bore cleaner, covered with burlap and waste is run through to clean the bore. The squirrel-cage cleaner, constructed of flexible strips, may be adjusted to fit bores of various sizes by setting up or slackening a threaded hand-wheel nut.

Though not connected with the subject of gun construction, it is well to mention here the question of lapping guns aboard ship. Quite frequently the bores of guns in service become constricted to such an extent that a bore gauge of the same diameter as the projectiles to be fired cannot be pulled through the guns. Ordinarily this constriction is due to an accumulation of copper from the projectiles' rotating bands, and as such is not considered especially harmful or dangerous to the gun. However a constriction is sometimes caused by a shoulder on the liner over-riding the corresponding shoulder on the tube, or by the mandreling effect of the projectile already mentioned, that is, its tendency to "squeeze" before it the metal of the liner, and thus to elongate the tube. The end of the tube thus elongated is caused to project from the muzzle, but is not harmful, and the projection may be faced off when necessary. The gun liners sometimes creep to the rear or breech end. When this occurs it will frequently be found impossible to close the breech plug. The only remedy then is to face off the rear end of the liner and take a light cut off the gas check seat sufficient to permit plug closure. If this liner should subsequently creep forward, in a bag gun, the danger of a blowback is greatly increased. In guns now in service the following methods have been employed to prevent rearward creep of gun liners: (a) Some liners are prevented from creeping to the rear only by the compression of the tube; (b) some liners are welded at the after end to the tube; (c) some liners are secured to the tube at the after end by a locking ring; (d) some liners are held in position at the after end by abutment against the screw-box liner so that the gun liner cannot creep aft except with the tube.

The "squeezing" of the metal is resisted at the shoulders, causing the metal to "pile up" at these points, thus reducing the diameter of the bore. A knowledge of the positions of the shoulders in a gun liner, which may be obtained from the drawing of the gun furnished the vessel, will, therefore, give an indication of the nature of an obstruction disclosed by the bore gauge, that is, whether it is due to copper fouling or to constriction of the liner. In the case of a constriction of the liner it becomes necessary to remove the obstruction by lapping the tops of



SQUIRREL-CAGE BORE CLEANER

SPONGE BORE LAP GROOVE LAPPING HEAD

Lapping Head and Bore Sponge.

the lands. For this purpose it was customary for ships to construct their own lapping heads, usually of blocks of wood set outward by springs against the bore of the gun, the whole head being then covered with emery cloth. A line was attached to each end of the lapping head and drawn back and forth by members of the gun's crew. Care had to be taken not to draw the lapping head beyond the actual limits of the constriction, as shown by measurement of the points where the bore gauge stuck, in order to avoid unnecessary wear on the gun. Such lapping heads were more or less crude in construction, and when possible the work was done at navy yards. The latter are now provided with the necessary equipment and measures are being taken also to supply lapping heads afloat.

632. **Fitting the breech mechanism.**—(1) The necessary holes for fitting the breech mechanism are drilled, the hinge lugs are put in place, and the breech block fitted. Previous to fitting the breech block, it is tried in a dummy gun so that, when the final fitting takes place, the work will not be so difficult. There is always a great deal of hand work required in fitting every breech mechanism.

(2) After the breech plug is in place, the gas-check seat is reamed. This is a most particular operation in the process of fitting the breech mechanism. A perfect fit of the split rings and gas-check pad is necessary to prevent blowbacks. A blowback is the wire drawing of the hot gases of firing to the rear over the gas-check system with the consequent burning of the split rings, pad, and gas-check seat. Such a casualty may readily put a gun out of service. To test the accuracy of the fit, Prussian blue is smeared lightly on the gas-check seat, and the plug closed. A perfect fit is indicated by the split rings and pad showing a light even coating of blue when the plug is again opened. High or low spots in an imperfect fit are, of course, denoted by the presence or absence of blue.

633. **Milling the keyway.**—The keyway on top of the gun is milled out and the key, which keeps the gun from turning in its slide, is inserted and held in place by countersunk screws.

634. **Putting on yoke.**—The yoke, of forged or cast steel, may be put on in several ways. In the smaller guns it is often screwed or shrunk on, but in most large caliber guns, including the 14-inch, it is put on over the breech and abuts against a shoulder on the D1 hoop which prevents its forward movement. Just in rear of the yoke an annular slot is turned in the gun, in which two sections, each about 60°, of a steel ring are secured by countersunk screws, one at the top and one at the bottom of the gun, to prevent backward movement of the yoke. This annular slot for the backing ring is cut whenever con-

venient during the finishing processes of the gun. The yoke is now considered part of the gun.

The rear cylinder and the slide cylinder of late 8-inch guns are of the same diameter so that these guns may be mounted and dismounted through the face plate of the turret, leaving the slide in place. These guns have an annular slot near the breech for securing the gun yoke. A forged steel ring which projects above the gun rear cylinder and which is made up of two 180° sections is secured in this annular slot. The yoke has a shoulder on its forward side which rests against the after side of this steel ring. The yoke is held in place by a bronze locking ring screwed into the yoke from the forward side. The locking ring

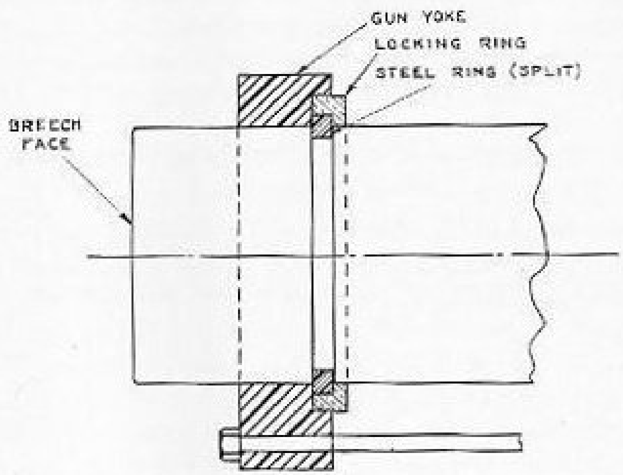


FIG. 603.

has a shoulder on its after side which brings up against the forward side of the steel ring set in the slot (see Fig. 603).

635. Center of gravity.—For the first gun of a type the computed center of gravity is checked by balancing the gun, with its breech mechanism, projectile and charge, on knife-edges.

636. Weight.—The gun, without the breech mechanism, is weighed and the weight stamped on the breech face.

637. Final inspection.—It is given a final inspection, and if satisfactory, marked with the place of manufacture, year, mark, number, weight, and the initials of the superintendent and inspecting officer.

638. Proof.—It is fitted to its slide, and then sent to the Proving Ground for proof. If satisfactory on proof, it is returned to the Gun Factory where it is relapped, bore-searched, star-gauged and issued to service.

639. Relining.—(1) When a gun has fired a considerable number of rounds, the actual number depending on the caliber of the gun and powder pressures used, the bore becomes eroded to such an extent that the gun gives undue dispersion. It then becomes necessary to reline the gun in order to recondition the bore. When relining, the worn liner is withdrawn from the breech end and a new one inserted in its place. The procedure for assembling the new liner is the same as previously described.

(2) To withdraw the liner, the breech end of the liner is threaded and the pulling apparatus is assembled on the gun. The gun is then heated in the furnace to a temperature of 600° F. and 550° F. at the muzzle and breech, respectively. When the gun is heated, the liner is chilled by water circulating rapidly through the bore, causing contraction of the liner relative to the gun. The liner is then unseated by means of hydraulic jacks and lifted clear by a crane.

Section III.—The Manufacture of Guns by Radial Expansion.

640. Preparation of the forging.—After acceptance tests the hollow steel forging is turned down nearly to the maximum outside circumference of the finished gun and is accurately bored slightly smaller than the finished diameter. The breech end is drilled and tapped to receive a high pressure pipe connection from the pressure intensifier, and the muzzle end, a connection to a high pressure gauge. Each end of the forging is prepared to receive packing and screwed-in plugs.

641. Equipment.—An intensifier is a unit where the pressure of an hydraulic pump is conducted into a large cylinder having a piston connected to a plunger of smaller diameter which works in another cylin-

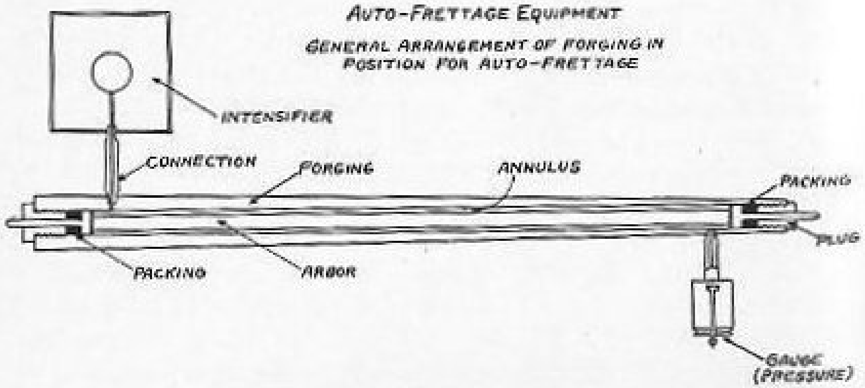


FIG. 604.

der, and is employed to create the great pressures necessary for radial expansion. The liquid, glycerine, from the intensifier passes through a high pressure pipe connection to an annulus between the *arbor* or core-bar and the forging. The arbor, several hundredths of an inch less in diameter than the bore of the forging, is inserted in the bore, thus reducing the amount of liquid necessary for expansion. Packing, at each end of the bore, is held in position by screwed-in plugs to seal the liquid under pressure.

642. Radial Expansion.—The intensifier sets up a pressure between about 45,000 and 100,000 pounds in the connection, the annulus, the gauge connection, and the gauge. As the pressure is applied, the dilations of the forging are measured and checked against a theoretical curve showing the relation between the bore pressure and the dilation of the outside diameter. When the internal pressure has reached such a value that the metal of the outer surface of the forging has been brought to its elastic limit in circumferential tension, the end of the semi-plastic period is reached and the pressure is not further increased. The pumps are stopped and this pressure is held for several minutes. On release of the pressure, which is done by lowering the ram of the hydraulic pump and allowing the plunger of the intensifier to be forced out, the interior wall of the forging closes in, but is unable to return to its original dimensions. The bore and the external diameters will have been slightly enlarged because of the permanent deformations set up by the liquid pressure, but the release of the pressure leaves the inner half of the forging under a compressive stress, which is a maximum at the bore, the outer half under a stress of tension, which is a maximum at the outside, and at the center of the forging a point of zero stress.

A mild heat treatment is then given to the forging, which has the effect of making permanent the increased elastic strength acquired by the autofrettage pressure.

The forging is again set up and the autofrettage pressure is reapplied several times. The bore, the outside diameter, and the length are measured to find what alterations in size have taken place. The surplus material at each end of the forging is cut off, and the forging is then finished bored, turned, and rifled similarly to the process described for built-up guns.

643. Present limits of the radial expansion process.—At present the radial expansion process, as applied to monoblock (1-piece) guns, has been limited in our service to 6-inch guns and those of smaller calibers, because of the difficulty in obtaining the required physical characters (*i.e.*, elastic limit and ductility), and homogeneous metal, in a larger single forging. There are no physical limitations, however, to extending the process to the manufacture of guns having *more* than one layer. Such guns would still have fewer layers, each of much greater thickness, than the present built-up guns whose members are assembled by heating and shrinkage. On this basis the Navy has built 8-inch, 2-piece guns, composed of a jacket shrunk over a radially expanded tube. The jacket acts as an additional strength member and serves to stiffen the gun to prevent excessive droop. The weight of the jacket also maintains the center of gravity at about the same point as in the built-up gun. Furthermore, the additional weight is necessary in order to avoid excessive recoil forces, for it must be realized that the force of recoil of a lighter gun will require a correspondingly heavier mount structure. The 8-inch radially expanded gun weighs roughly 28,000 pounds less than the 8-inch built-up gun designed for the same muzzle velocity, and it is not necessary to sacrifice all this saving in weight for a heavier mount.

644. Advantages of radially expanded guns.—When compared with a built-up gun of similar caliber, length, muzzle velocity and rifling, the radially expanded gun is stronger, and, hence, will withstand higher explosive pressures. The latter permits a smaller chamber volume, smaller chambrage, and a slightly smaller charge. A smaller charge will reduce slightly the erosion rate. The outside of the gun is smaller. Most important of all, the weight is considerably less. The cost and time to build is greatly reduced. Less labor is required. Less machine and other work is necessary. The construction output may be greater.