7

MANUFACTURE AND TESTING OF H.P. AIR CYLINDERS.

The greatest care must be taken in the selection of materials and in the manufacture of H.P. air cylinders to ensure absolute reliability, and the following detailed description is given of the many processes of manufacture and test. The process described is known as the hot drawing process, that is to say, one in which no cold work is done on the material during the operations which precede machining.

1. **The Ingot or Billet.**—Either an ingot as cast, with the discard removed from top and bottom, or a rolled or forged billet may be used. In general, an ingot would be employed for large cylinders as there is no necessity for any rolling or forging operations prior to punching and drawing. Further, an ingot would be less costly in such a case and the only tests required at this stage are visual inspection of the ingot for soundness after removing the discards and the taking of drillings for chemical analysis.

The discards are 40 per cent. from the top of the ingot and 5 per cent. from the bottom.

The normal analysis required is :—

Carbon	0·43 to 0·48 per cent.
Silicon	0·3 per cent. max.
Manganese	0·5 to 0·9 per cent.
Phosphorus	0·045 per cent. max.
Sulphur	0·045 per cent. max.
Iron	Remainder.

Most steels now contain traces of Nickel, Chromium and Copper. The complete elimination of these elements is now almost impossible in practice as apart from their presence in portions of the charge to the melting furnace, they are often present in the linings of the furnace. The presence of Nickel in particular is beneficial and improves the tenacity and the resistance to impact of the material. It may be present up to 0·5 per cent. without the steel being classed as a nickel steel.

The weight of the ingot is calculated to suit the process adopted and the operations it is intended to carry out. A suitable form is shown in Fig. I. The actual form is fixed to some extent by the ingot moulds available and by similar factors which affect the steel maker. Cases may arise in which it is economical to select a form which suits the melting plant and afterwards to put a preliminary forging or " dumping " operation on the ingot. If this is done, the " dumping " operation should be carried out in a die.

2. Before punching the ingot may be given a " centre " as shown in Fig. II. This serves as a lead for the punch. Alternatively, a guide ring may be used in punching, as described in (3) below.

3. **Punching.**—This operation (*see* Fig. III) produces a cup or cylinder having one closed end, of the form required to pass to the first drawing process.

The operation is carried out in a vertical hydraulic press. The illustration (Fig. IIIA) shows a suitable press of 1,000 tons capacity with a working pressure of 5,000 lbs. per sq. inch.

The die is carried on a sliding table, hydraulically operated, which moves on a bed fixed below the floor level. When the hot ingot has been placed in the die, with the table in the " loading position," the table is moved under the punch (the position shown in Fig. IIIA), and the ingot is first forced well down into the die. The table is then moved back to its loading position and a guide ring placed on top of the die. The guide ring is prevented from moving laterally with respect to the die by a spigot turned on its lower face and which engages with the bore of the die or with a corresponding recess turned in the upper face of the die holder. The object of the guide ring is to start the punch centrally and prevent the formation of eccentric walls in the punched ingot. With this guide ring in place the punch is forced into the hot ingot for about half the stroke required. The punch can then be withdrawn, the guide ring removed and the punch forced down to the full depth required. The length of stroke is determined by the thickness required through the closed bottom of the cylinder. The stroke of the punch may be limited either by positive stops or by bringing the crosshead down to a previously determined mark.

During this punching operation the displaced hot metal is forced upwards between the punch and the walls of the die, and forging work is done on the lower part of the cup due to the compression between the end of the punch and the bottom of the die.

The press power required for any given case depends on the area of cross section of the punch, the shape of the punch and the taper in the die. The work must of course be at a good forging temperature when it leaves the heating furnace—about 1,000° C.

After the punching operation has been performed the punch is withdrawn and the table moved back to its loading position when it comes vertically over an hydraulic ejector ram. This ram on rising encounters a false bottom in the die and forces it upwards ejecting the cup from the die far enough to allow the open end of the cup to be gripped by a grab or tongs, with which the cup is lifted out of the die by an overhead crane.

The cup is now ready for the first drawing operation, and if the heating and punching have been properly done the work should still be at a temperature which will permit the first drawing operation to be carried out at once without reheating.

4. **First Drawing Operation.**—This operation (Fig. IV) is done in a horizontal Drawing Press. Fig. IVA shows the diehead end of a suitable press. This particular press gives a total load of 1,000 tons with a working pressure of 5,000 lbs. per sq. inch. In the

type of press illustrated the drawing punch is carried out from a double eye mounted on the crosshead. This allows the punch to be swung sideways (Fig. IVB) to receive the punched ingot. The work is slid on to the punch, which is then swung back to its central position (Fig. IVA) and the ram advances the work to the die. When the work has been drawn completely through the die a horse-shoe shaped stripper, which is housed in a slot in the die head, is dropped over the punch in rear of the work. The ram and punch are then withdrawn leaving the drawn tube on the front side of the stripper and die holder.

Various materials have been used for dies, but possibly the most satisfactory is chilled cast iron, which is very hard and will stand prolonged use. To give the die enough resistance to bursting, a steel hoop is shrunk over it so that in section the drawing die is as shown in Fig. IVC. Steel with a carbon content of 0·3 to 0·5 per cent. is often used for the punches both in punching and in drawing. Where, however, the quantity to be manufactured justifies the expense, it is better to use a higher grade steel, such as 3 per cent. to 4 per cent. Nickel Steel. This steel has not the same tendency to crack and split after frequent changes of temperature.

A dressing of blacklead, or graphite, is useful for both punches and dies in punching and in drawing. It facilitates the action of the tools and makes stripping easier.

5. **Expanding and Second Draw.**—The work is reheated and taken back to the horizontal drawing press. The operation is performed in two stages (Fig. V). For the first stage—expanding—the punch is larger than for the first draw so that it must be forced into the tube. In the second stage the work, while still on this punch, is drawn through a die.

Expanding is done by entering the punch into the cylinder and then swinging the punch and work into the central position, so that the closed end of the cylinder can be made to bear against a cupped block secured to a beam which is in turn held by nuts on the press tie rods. One such arrangement is illustrated in Fig. VA. The ends of the beam are slotted out in a horse-shoe form, so that they drop easily over the tie rods. When in place these ends bear against nuts provided for the purpose on the tie rods. The punch is forced home expanding the cylinder for its whole length. The ram is then withdrawn, carrying with it the punch and the work, and the die is put in place in the die head. The second stage is then completed by drawing the work through the die as in IV. It is worth noting that expanding at this stage would not be necessary if the hole originally punched in the ingot were large enough. This, however, involves a greater displacement of metal in the first punching operation. Cases may arise in which the available power of the press may not be enough to give that displacement. It is then that expanding becomes necessary. The considerations which determine its employment are obviously the cost of the operation as compared with the interest and depreciation on the cost of a larger punching press and the higher cost of operating it.

6. **Final Draw.**—The work is now reheated and given a final draw (Fig. VI) in the horizontal press, its dimensions on leaving this operation being such that enough material is left on the diameters for turning and boring, and on its length to provide for test pieces and the bottling operation on the open end.

The number of " draws " is fixed by the reduction which can be made in the wall thickness at each draw without any danger of causing rupture of the material. If the successive reductions are not properly staged, or if the taper at the mouth of the die is too abrupt, the two most likely consequences are either perforation of the base of the cylinder by the punch, or stripping and tearing of the material from the outside of the work.

In all drawing operations of this nature a jet of water is directed on to the inside surface of the closed end before the work is put on to the punch. This reduces slightly the temperature of the hemispherical end in contact with the punch and so increases its resistance. The jet has the additional advantage of washing out scale from the closed end and thus ensures a better finish from the punch and facilitates machining at a later stage.

7. **Annealing to Facilitate Machining.**—This operation is not essential. It may be carried out if the material is difficult to machine. In that case annealing would be done at a temperature of about 800° C. for one up to two hours, when the work would be withdrawn from the furnace and allowed to cool in air. It should be clearly understood that this operation does not form part of the definite heat treatment given to the cylinder at a later stage. A coal-fired annealing furnace, with its pyrometers, is shown in Fig. VII.

8. **Cutting of Test Ring.**—The open end is now cut to the length required for bottling. The ring so parted off provides the test pieces required :—

One impact test piece taken parallel to the axis of the cylinder (longitudinal impact) ; one bender taken in the same direction (longitudinal bender) ; one tensile test piece taken circumferentially or at right angles to the axis of the bottle (transverse tensile) ; one impact test piece taken in the same direction (transverse impact). These are shown in Fig. VIII.

This ring and the cylinder from which it has been cut now bear corresponding numbers stamped on them, the numbers being the cast number for the material and the identification number of the cylinder. The ring is set aside and at the heat treatment stage is charged into the furnace with the cylinder from which it was cut.

9. **Centre from Bore.**—The cylinder is now centered for machining, the centre being true with the bore (Fig. IX). This can be done by placing the cylinder over a mandril held in a lathe chuck.

10. **Rough Turn Body and Base.**—This is a lathe operation and is shown by Fig. X.

11. **Rough and Finish Bore Walls and Base.**—A boring machine or lathe operation shown by Fig. XI.

12. **Finish Turn Body and Base.**—The cylinder is reset in a lathe from the finished bore and finished externally as shown by Fig. XII.

13. **Rough Drill Base Nipple.**—*See* Fig. XIII.

14. **Inspection before Bottling** (*i.e.*, **Closing Cylinder End**).—This is a visual examination of the interior of the cylinder for defects and finish. It is important that the inspection of the inside surfaces should be thorough at this stage as visual examination is more difficult after bottling. After bottling, artificial internal lighting has to be used for inspection and the resulting shadows are sometimes confusing and misleading. For example, a shallow depression, say 0·003 in. deep at its middle (*see* Fig. XIV, in which an exaggerated section is shown), which is well within the tolerances on wall thickness and which would not give rise to any doubt when viewed by direct lighting, will produce later (after bottling), when viewed through the nipple, a very marked shadow which gives the impression of a deep groove, and may easily cause some anxiety in inspection unless the visual examination before bottling has been thorough and the extraordinary optical effect of these shadows is appreciated.

15. **Angle for Bottling.**—This machining operation is shown by Fig. XV. The effect of bottling is to thicken the walls locally, the thickening effect increasing from the spring of the radius towards the nipple formed by bottling. Since gauging for form by using a template or profile gauge can only be done during bottling by applying the gauge to the outside of the cylinder, the thickening is allowed for by reducing the wall thickness as shown in Fig. XV. This avoids much unnecessary machining of the inside radius later. Thickening at the nipple itself does not matter, as this is afterwards drilled and tapped and in practice the nipple is closed up solid, or nearly so, in the bottling operation.

16. **Bottling.**—The final result of this operation is shown by Fig. XVI. It consists in reheating the open end of the cylinder for a short distance and closing in the end between swages of the proper shape. The reheating and swaging proceeds by stages and is repeated until the final form is reached. The length of the heated portion is varied to suit each stage and is determined by the portion on which it is desired to get work done. An illustration of a bottling machine is shown in Fig. XVIA. This machine is self-contained. The swages S are operated by hydraulic rams which are interlocked so that they must move in unison. The pump is motor driven. Each forward stroke drives water into the swaging cylinders; during the return stroke of the pump the return rams

drive the swage rams back so that the water driven out of the swage cylinders returns to the main pump cylinder and follows the pump ram back. No water except that in the self-contained system is required. Leakage, if any, is made up from a low pressure main. The swage rams make 90 strokes per minute.

The hydraulic system is arranged to provide pressure to release a clutch on the square shaft A (housed between the two bottom tie rods) while work is being done by the swages. This shaft A is therefore stationary while the forging stroke is being made and rotates as soon as the swages recede from the work. In consequence, the spur wheel B which is driven through gearing from the shaft A will only rotate in the intervals between the forward, or forging, strokes of the swages. The cylinder is held in a carrier which engages with a driver on the spur wheel B, so that the cylinder can only rotate between each swaging stroke. This arrangement gives the necessary rotation of the cylinder mechanically but prevents any twisting of the cylinder while it is gripped by the swages during the actual bottling stroke.

The cylinder is advanced into the swages and fed forward during bottling by the wheel and screw D which moves the frame E forward.

17. **Rough Drill Bottled End.**—Fig. XVII shows this operation, which is the last one prior to heat treatment.

18. **Heat Treatment.**—The treatment is a two-stage one. In the description which follows, the terms "Normalising" and "Annealing" are used in the sense in which they are generally understood and with the meaning given to them by Report No. 75 of the British Engineering Standards Association.

Normalising means heating a steel to a temperature above its upper critical point, maintaining it for a short time at the temperature and then allowing it to cool freely in air. Annealing simply means reheating followed by slow cooling. If the object of annealing is to remove stresses and to produce some degree of softness, the temperature at which it is carried out is quite arbitrary. If, however, it is desired to refine the structure and to produce uniform test results the temperature must be taken to just above the upper critical point. It is this second method of annealing which is required in the case of an H.P. cylinder. Fig. XVIII is what may be called the "Carbon-Iron Diagram." It shows, approximately, the changes of state in plain carbon steels containing carbon up to 0·8 per cent. for ordinary rates of heating and cooling.

Referring to the diagram and taking as an example a carbon content of 0·45 per cent., the diagram shows that a change of state occurs at 725° C. and a second at 790° C. on heating. Similarly, on cooling slowly a state change occurs at 760° C. and a second at 685° C. The ranges 790° C. to 760° C. and 725° C. to 685° C. are called the upper and lower critical ranges respectively.

The first stage of the Heat Treatment is Normalising. The cylinders with their test rings (*see* 8 above) are charged into the furnace in batches, the number in each batch depending simply on the size or capacity of the furnace. They are brought up to the Normalising temperature and maintained at that temperature long enough to ensure that every part has reached that temperature. From what has just been said in connection with the Carbon-Iron Diagram, it would appear that the proper temperature should be somewhat above the upper critical range. In practice, however, it is desirable that the temperature should reach that at which forging finished. This may vary from 800° C. to about 870° C. The normalising temperature is therefore, in practice, 900° C. The cylinders are maintained at that temperature for an hour and then pulled out of the furnace and allowed to cool in air. When they have cooled down to a temperature below the lower critical range, they are ready for the second stage. In practice, they are allowed to cool down to 500° C. or below (black heat) before the second stage is begun.

The second stage is Annealing. The cylinders with their test rings are again charged into the furnace and the temperature raised steadily to above the upper critical range. In practice, the temperature reached is about 800° C. to 810° C. The cylinders are given a short soak at this temperature—about half an hour. They can then be withdrawn from the furnace and allowed to cool in air.

This completes the heat treatment and the tensile, bender and impact test pieces can now be selected from each ring, stamped with identification marks, cast number and bottle number and released for machining into the forms required for the testing machines.

Tensile Tests.—Normally the results required from the test piece are :—

Minimum Yield	20 tons per sq. in.
Minimum Break	40 tons per sq. in.
Minimum elongation on 2 in. ..	18 per cent.

The test piece, as described in 8 above, is taken transversely. A longitudinal test piece is of less value as the direction of maximum stress is very much closer to the transverse direction. In a typical case, the stress in the walls due to circumferential tension at the working pressure of 3,500 lbs. per sq. in. would be 10·1 tons per sq. in. The longitudinal stress due to the axial pull at the same internal pressure would be 4·25 tons per sq. in.

For a thick walled cylinder such as this, the test piece is turned to the dimensions for B.E.S.A. test piece C, the diameter being 0·564 in. and the gauge length 2 in.

Bender.—This piece is taken longitudinally and is machined to dimensions 4·5 in. long, 0·75 in. wide and 0·375 in. thick. It is bent, cold, through 180° into the form of a U, in a press, over a $0 \cdot 75$-in. radius, *i.e.*, a radius which is double the thickness of the test piece. It should not show any cracks.

Impact Tests.—Two test pieces are taken, one longitudinally and one transversely. Normally, each piece is machined and ground to the form laid down for B.E.S.A. Notched Bar Test Piece 131/1920/Plate 2/Fig. 5. This is shown in Fig. XIX. The root radius of each notch is $0 \cdot 25$ m.m. As will be seen each piece furnishes three impact tests, and the mean result of each set of three is taken. The pieces are tested in an Izod impact testing machine of 120 ft. lbs. capacity. The longitudinal pieces should give 15-ft. lbs. and the transverse pieces 10-ft. lbs.

19. **Pickle and Wash.**—This operation removes any small amount of scale which has formed during the Heat Treatment process described under 18 above.

It consists in immersing the cylinder in a lead-lined tank containing weak hydrochloric acid—39 parts of water to 1 part of acid—until the scale has been loosened. The bottles are then taken out of the pickle and washed in a separate tank supplied with fresh water.

For the inside surfaces the most effective method is "jingling." For this the cylinder is held to a vertical faceplate by suitable straps. The axis of the bottle is parallel to the surface of the faceplate and is therefore at right angles to the axis of the horizontal shaft which rotates it (Fig. XX). A quantity of plate punchings is poured into the bottle. The nipples are plugged and the face plate revolved. This "jingling" operation is only continued until the inside surface is free of any scale or grit.

20. **Finish Turn Nipple and Radius.**—This is a lathe operation and is shown by Fig. XXI. It is only necessary on the end which has been closed by bottling.

21. **Finish Bore and Screw Nipples.**—This is shown by Fig. XXII.

22. **Clean for Inspection.**—The cylinder is now wiped clean inside and outside and submitted for visual examination. The portion of the interior requiring inspection (by artificial light) is at the end which has been closed by bottling. The remainder has already been dealt with before bottling (*see* 14 above).

23. **Sand Blast and Electro-Galvanise.**—The ends are plugged, one end being closed by an eyebolt with which the cylinder is suspended vertically from a runway which passes through the sand blast chamber and over the galvanising bath.

The cylinder is sand blasted externally to produce a perfectly clean surface free from any traces of rust, oil or grease. Without being touched by the operator's hands it is then run out of the sand blast chamber and lowered into the galvanising bath.

The galvanising bath is made up of approximately 14 lbs. of zinc cyanide to 5 pints of sulphuric acid and 400 gallons of water.

The current passed through the bath is about 78 amperes at 5·5 to 6 volts. The anodes are zinc plates suspended in the bath round the cylinder. The cylinder itself is the cathode. Fig. XXIV shows a cylinder which has just been removed from the sand blast chamber and which is ready to dip, and another cylinder in the blast chamber.

24. **Surface Inspection.**—This is a visual examination of the outside to ensure that the electro-galvanising satisfactorily covers the whole surface.

25. **Gauge Tap and Face Nipples.**—The nipples are now finally tapped and the faces trued up, if necessary, to a joint face.

26. **Hydraulic Pressure Test.**—The arrangement is shown diagrammatically in Fig. XXVII. The cylinder is filled with oil and placed vertically in a container, the space between the cylinder and the container walls being entirely filled with water. Oil pressure from the test pump is admitted directly to the cylinder. The pump is run until the pressure has risen to say 200 lbs. per sq. in. on the gauge when the pump is stopped and the valve above the entrance nipple is opened to release any air in the pressure system. The valve is then closed and with the pressure gauge reading zero, the height of water showing in the gauge glass A is read. This glass A is connected directly to the top of the container and therefore is connected to the water in the space between the cylinder and the container. The pump is restarted and the pressure taken up to the test pressure—5,600 lbs. per sq. in. The cylinder will now have expanded under internal pressure and the amount of the total expansion in volume is obtained from the gauge glass A.

The difference between the readings in cubic inches obtained at 5,600 lbs. per sq. in. and at zero, gives the total expansion, which is obviously equal to the displacement of water from the container into the glass A.

Pressure is left on for about one minute and is then released by opening the valve. If the water in glass A now returns to the original " zero " point, it is evident that there has been no permanent expansion of the cylinder. In that case the total expansion obtained in cubic inches is elastic expansion. If, however, the gauge glass A now shows water standing above the original " zero " point a reading is obtained for permanent expansion. The elastic expansion will be the difference between the total expansion and the permanent expansion.

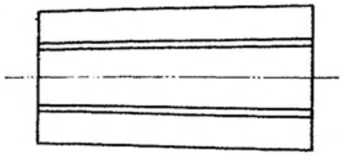
The permanent expansion, if any, should not exceed 2 per cent. of the total expansion.

The hydraulic test just described is the most important test in the cylinder's history and should be regarded as vital.

The cylinder is now removed from the container and a pressure test put on in the open. When the working pressure is reached, the bottle is jarred, after this the test pressure is put on.

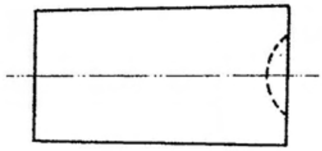
27. **Weighing and Final Inspection.**—The cylinder is wiped clean, dried and weighed and is submitted for final visual inspection.

The cylinder now bears stamps showing cast number, cylinder number, serial number, test pressure, date of test, the manufacturer's name or code, and is ready for delivery.



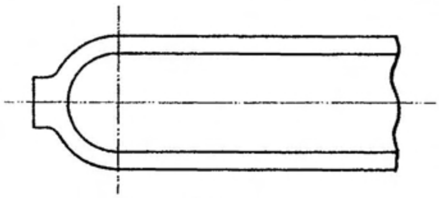
INGOT.

Fig. I.



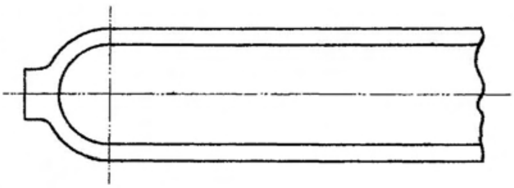
"DUMP" & CENTRE.

Fig. II.



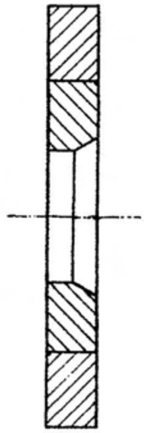
BOTTLE AS PUNCHED.

Fig. III.



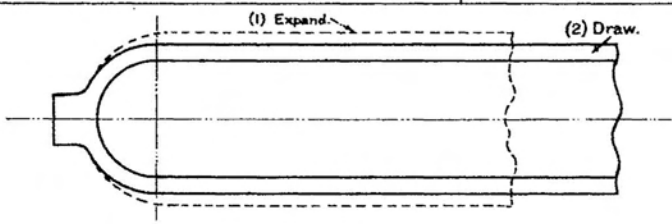
BOTTLE AS DRAWN.

Fig. IV.



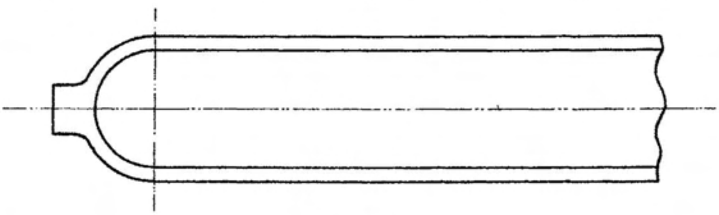
DIE WITH HOOP.

Fig. IV.C.



EXPAND & DRAW.

Fig. V.



FINAL DRAW.

Fig. VI.

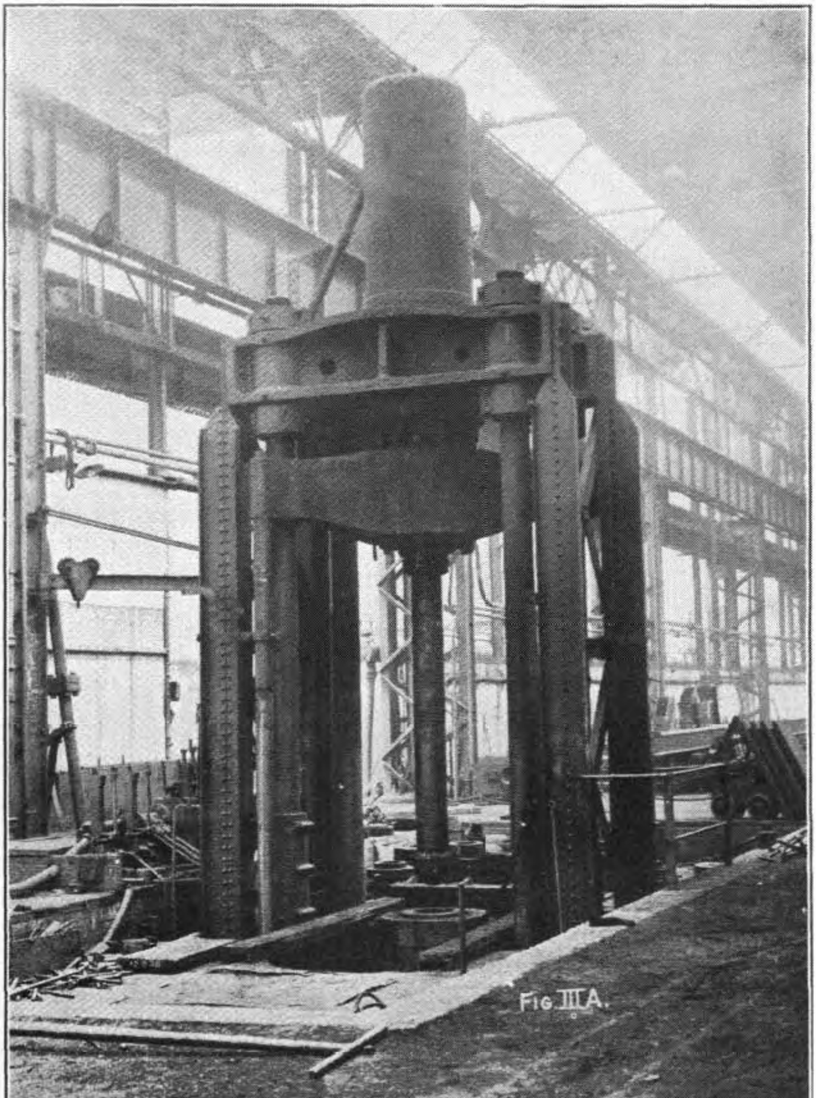


FIG III A.

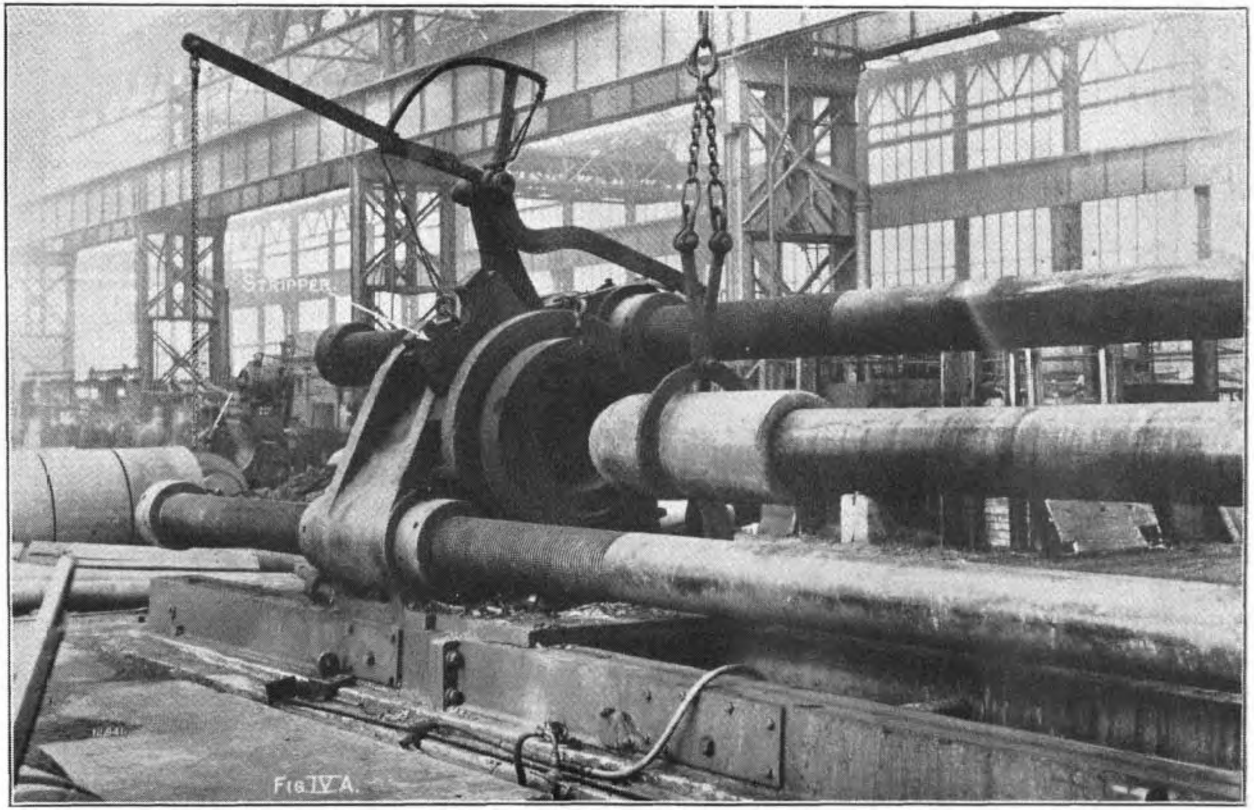


Fig. IV A.

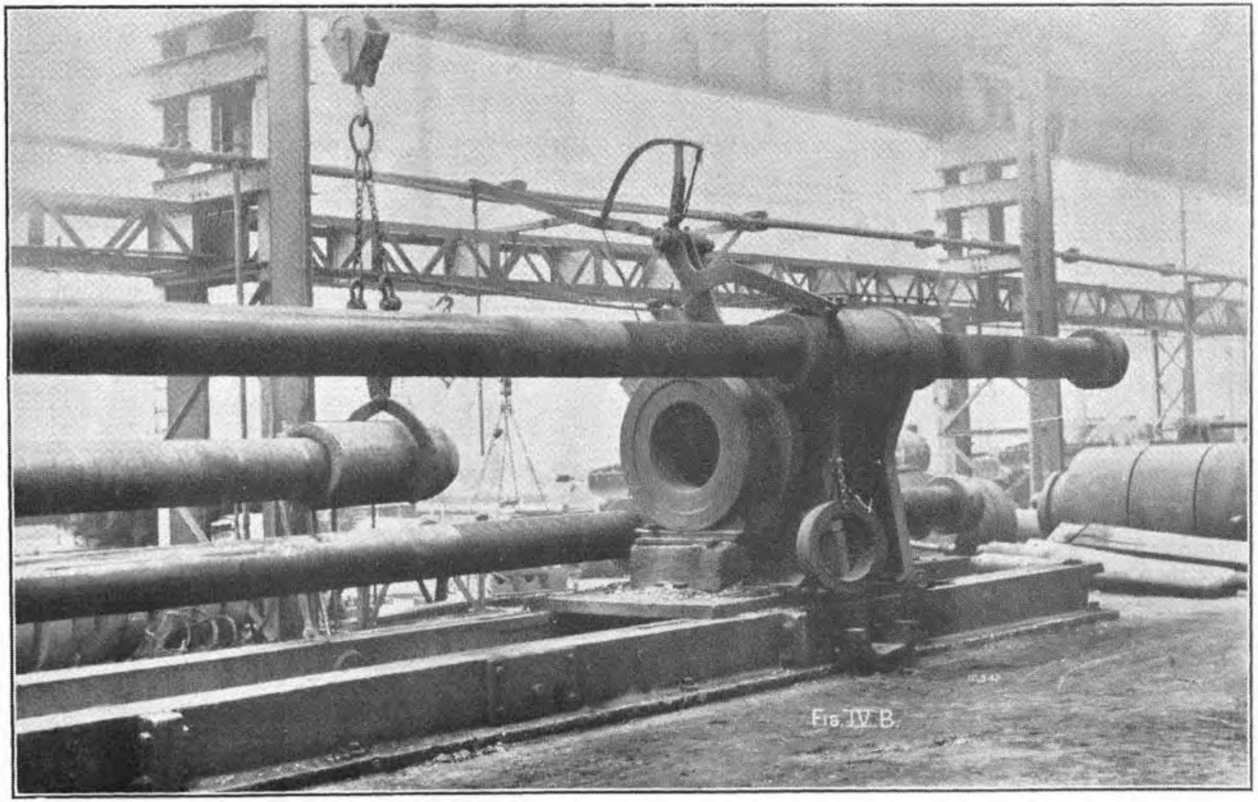


Fig. IV. B.

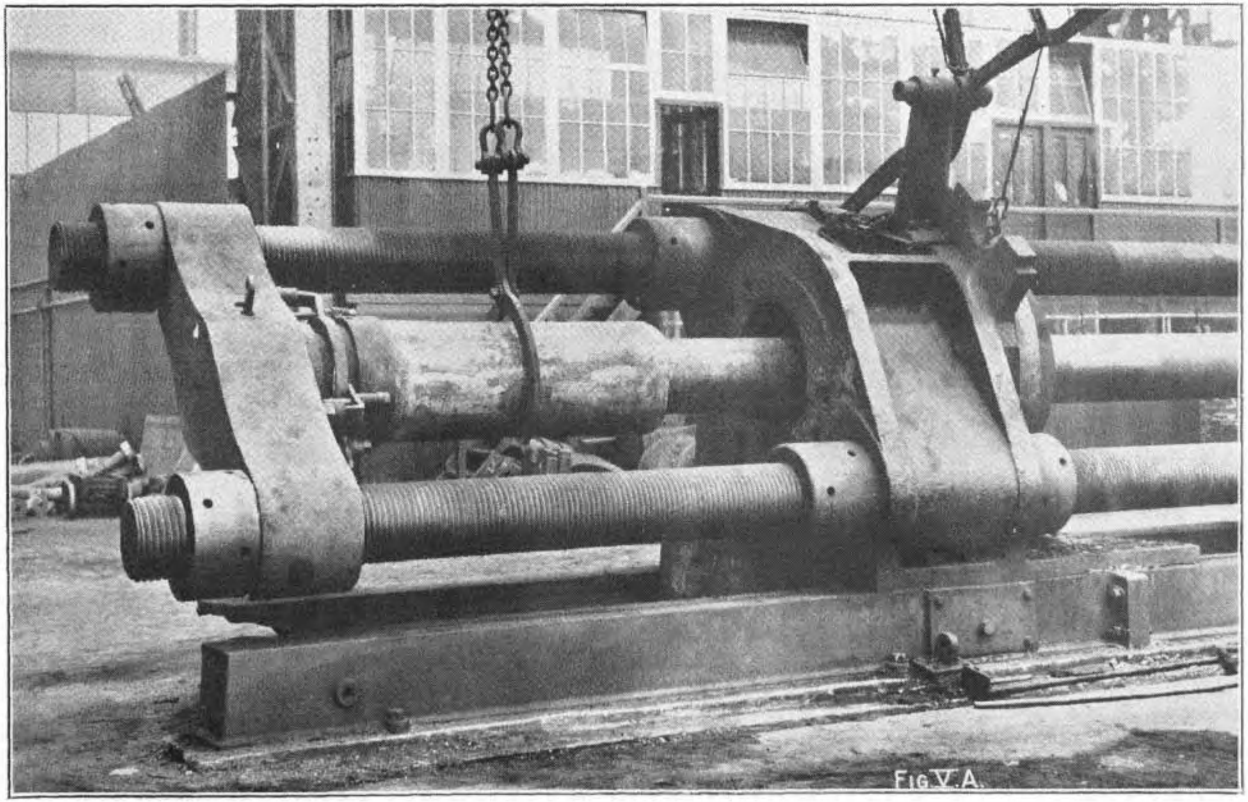
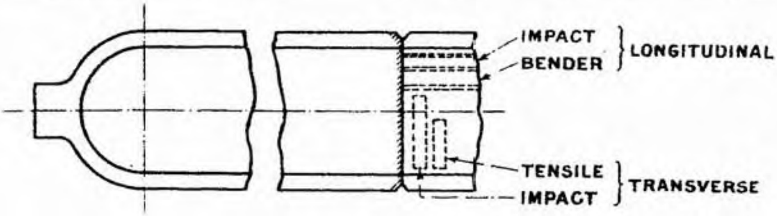


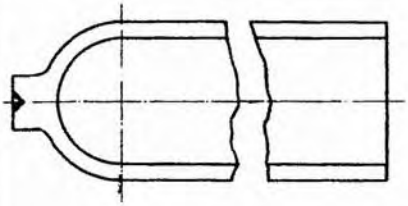
FIG. V. A.


No 9
Fig VII



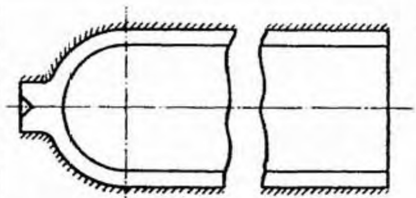
CUT OFF TEST RING.

Fig. VIII.



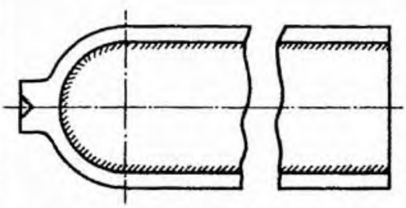
CENTRE FROM BORE.

Fig. IX.



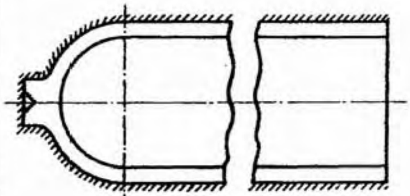
ROUGH TURN BODY & BASE.

Fig. X.



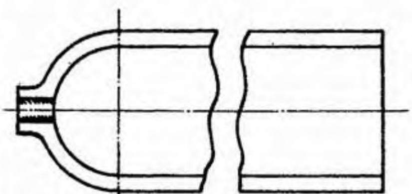
ROUGH & FINISH BORE WALLS & BASE.

Fig. XI.



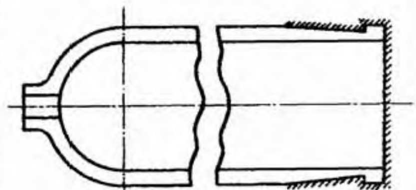
FINISH TURN BODY & BASE.

Fig. XII.



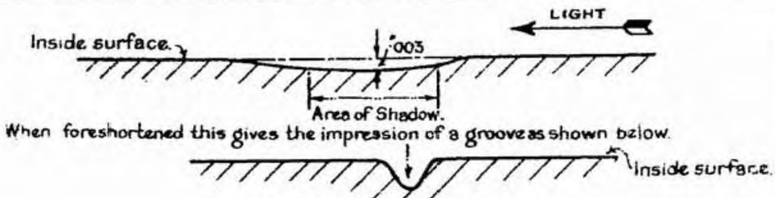
ROUGH DRILL NIPPLE ON BASE.

Fig. XIII.



ANGLE FOR BOTTLING.

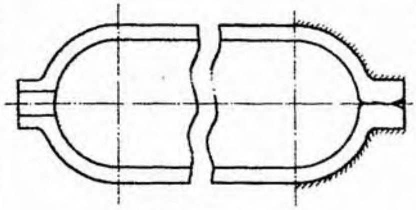
Fig. XV.



WALL INSPECTION.

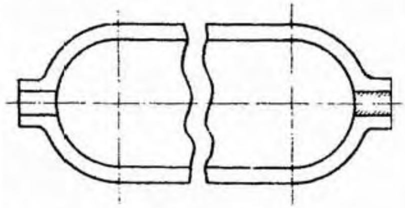
Fig. XIV.

P.4889



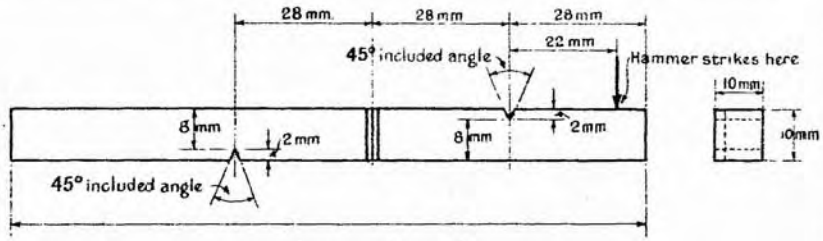
Bottling.

Fig. XVI.



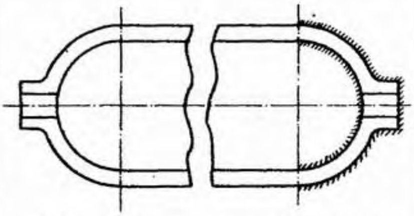
Rough drill bottled end.

Fig. XVII.



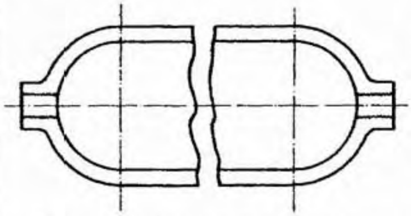
Impact Test Piece.

Fig. XIX.



Finish turn nipple & radius.

Fig. XXI.



Finish bore & screw nipples.

Fig. XXII.

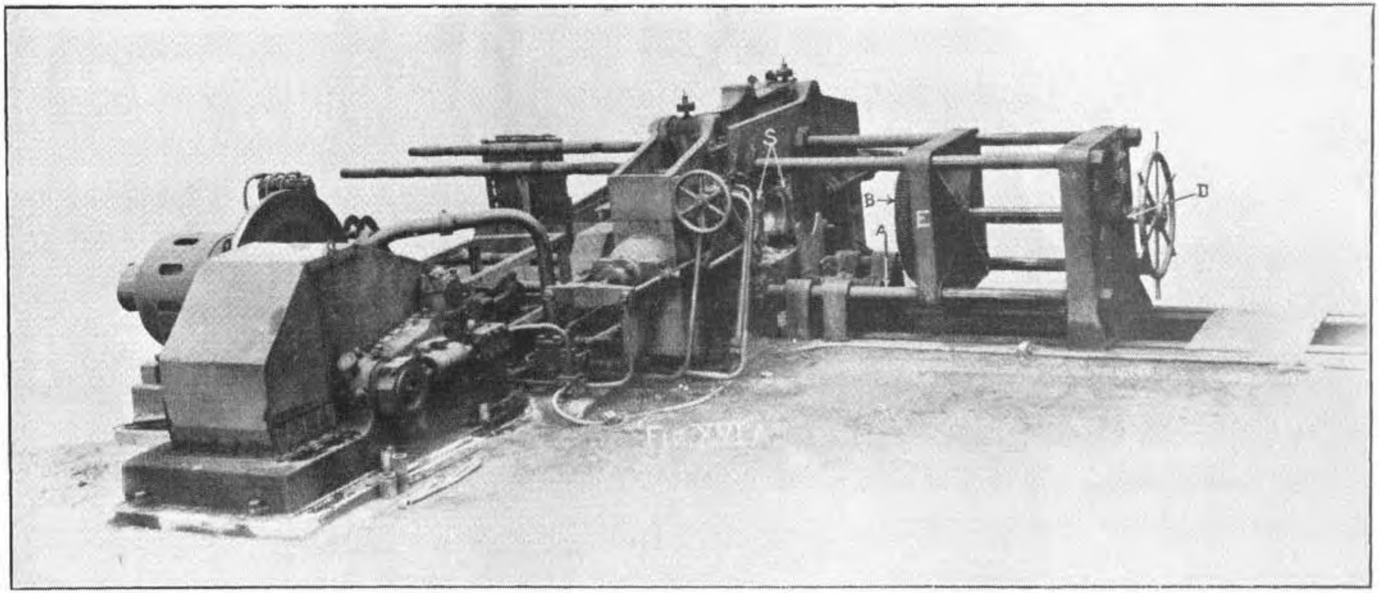

S
B
A
E
D

DIAGRAM SHOWING THE APPROXIMATE CHANGES IN PLAIN CARBON STEELS FOR ORDINARY RATES OF HEATING AND COOLING.

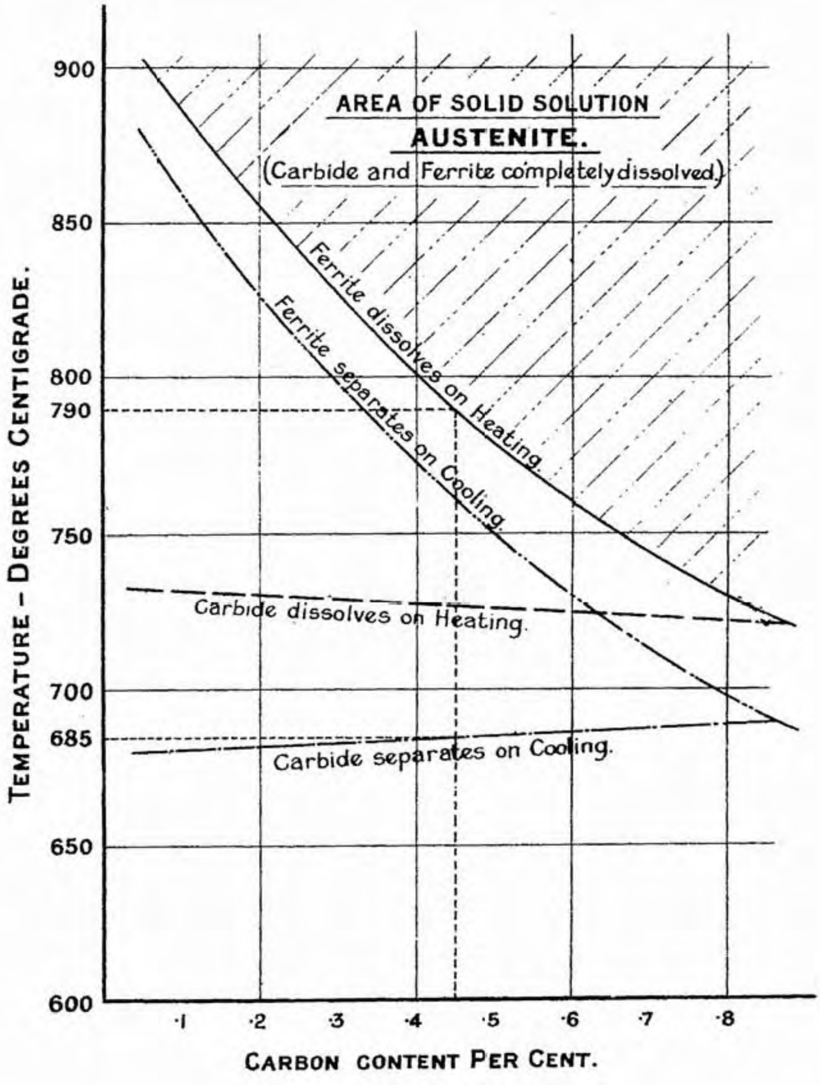


Fig. XVIII.

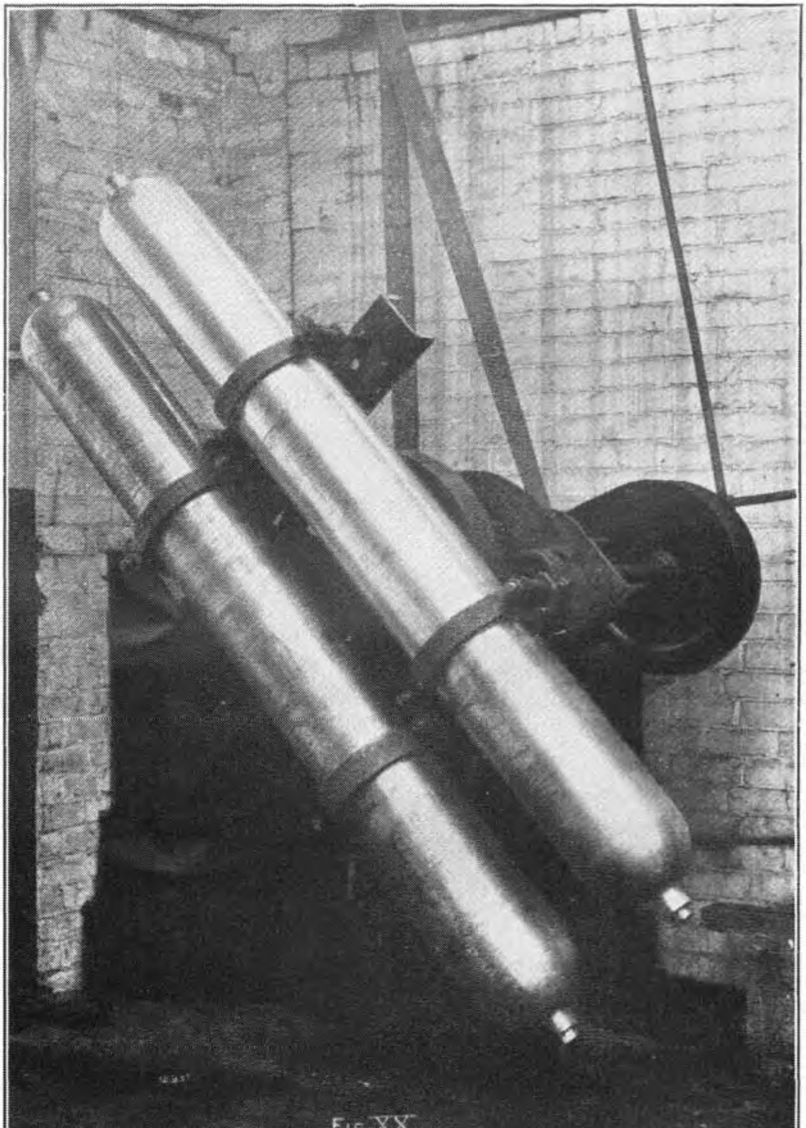


FIG. XX.

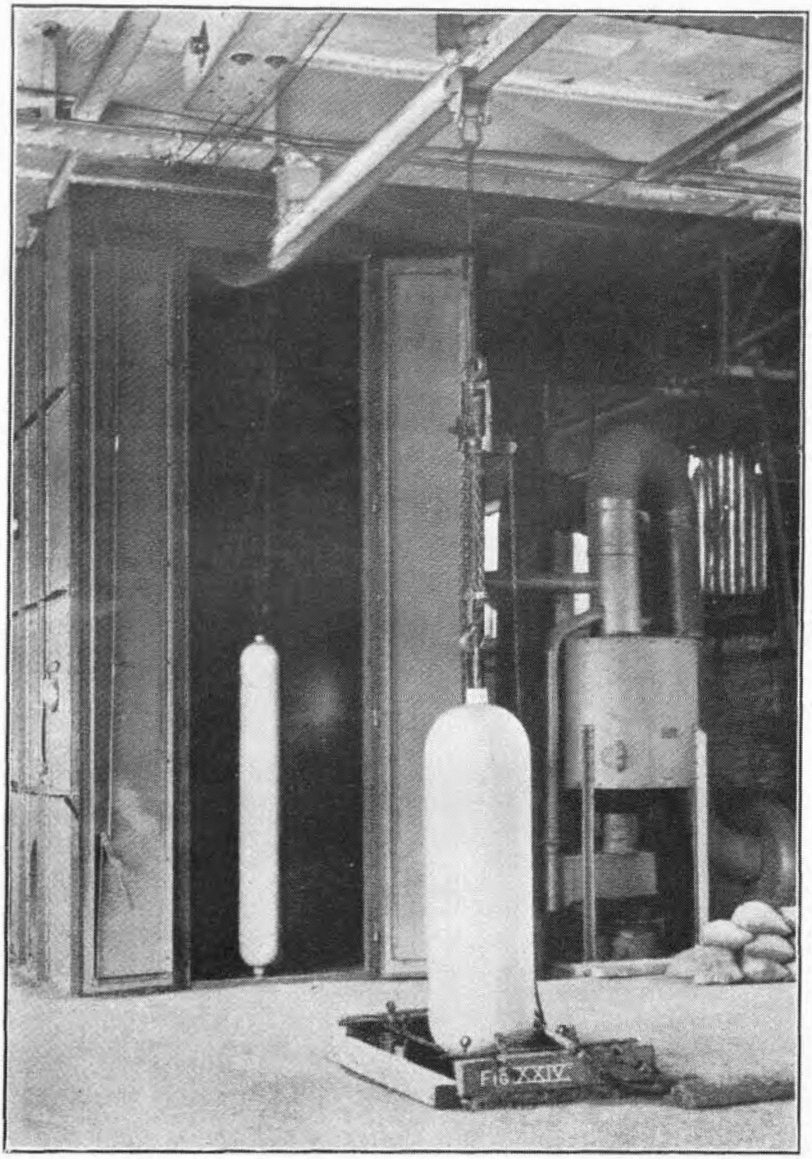


FIG. XXIV

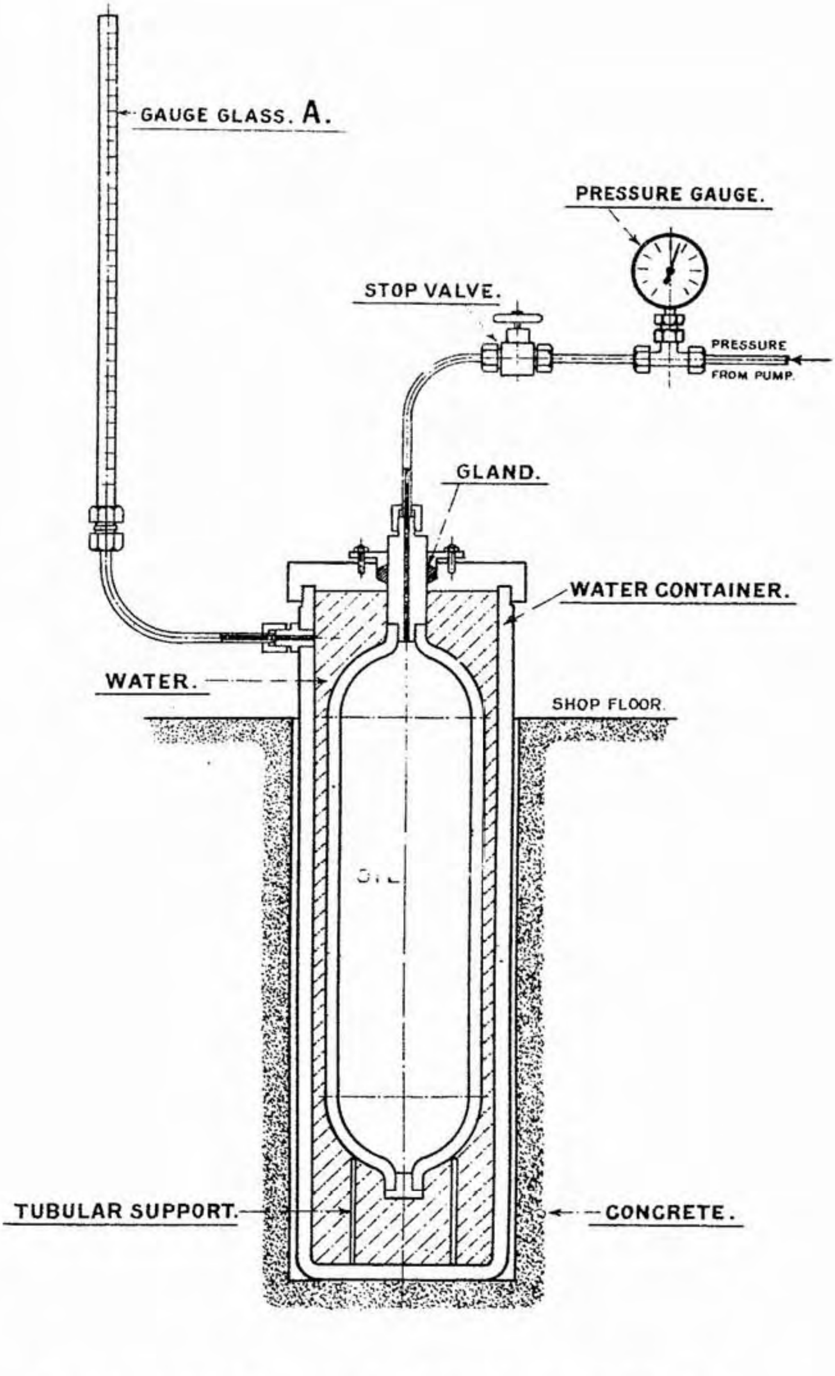


DIAGRAM OF HYDRAULIC TESTING ARRANGEMENT.

Fig. XXVII.