MANUFACTURE OF SOLID DRAWN STEEL TUBES FOR WAR SHIPS.

The steel tube firms confine themselves exclusively to their special trade of tube making, and their output consists entirely of tubes and articles made directly from tubes, such as gas bottles, axles, manipulated structures of aircraft, motors and cycles, box spanners.

It is a trade with which the naval officer is brought little in contact, and the following notes are an attempt to describe briefly the various processes in this interesting branch of engineering.

During the war the output from all steel tube works in the country averaged about 316,700 tons, or 235,000,000 feet per annum.

The principal Admiralty requirements were for hull and machinery purposes for warships, for mines, bombs, gun equipments, paravanes and otters, and represented an average output of 20,800,000 feet per annum. About 75 per cent. of this total was for tubes for water-tube boilers.

Some of the chief services which clashed directly with Admiralty work were aeroplane tubes, loco. tubes for railways, trench warfare mortars and bomb sticks, military cycles and transport.

As Admiralty requirements had first priority, it was less difficult to arrange for supplies than for other services, which were considered not to be of such vital importance. The Admiralty programmes were more definitely fixed, and it was possible to approximate to naval needs much more closely than to those for other Departments which dealt with new implements of war.

As an instance of the largely increased demands of some of the Services the requisition for steel tubes for aircraft had increased to 4,000,000 feet per month at the time of the Armistice —or an increase of over 300 per cent. during the preceding twelve months.

It is proposed to deal here with the manufacture of those steel tubes with which the engineer officer has chiefly to deal on board ship, and these are—

A. Boiler tubes for water-tube boilers.
B. Steam and hydraulic pipes.
C. Telegraph and control shafting.

The specified ultimate tensile strengths of the above are—

A. Not more than 26 tons.
B. Between 24 and 27 tons.
C. Between 30 and 35 tons.

Steel.—The chemical analyses to give the required tensile tests, to withstand the processes of manufacture, and to comply with other specified tests should be approximately :—

	A.	B.	C.
	%	%	%
Carbon - - -	·13	·20	·28
Silicon - - -	Trace	Trace	·15
Sulphur - - - } Phosphorus - - }	·035 max.	·035 max.	·035 max.
Manganese - -	·45	·45	·45

In the above analyses good average figures are given for the carbon and manganese, and (in C.) for the silicon. For instance, for steel A. the carbon might be as low as ·09 per cent., or as high as ·16 per cent.

The Swedish steel makers were the pioneers in the manufacture of tube steel. For many years exhaustive researches and experiments were carried out in that country. There was a large trade between Sweden and this country for steel billets for the manufacture of cycle tubes. Chiefly owing to the researches of Professors Brinell and Wahlberg, it was discovered that it was possible by thoroughly working the charge until it was practically free from silicon, and by teeming it at a suitable temperature, to cast ingots which were free from pipe, but in which the blow holes were in such position that when the ingots were produced into tubes, they (in a welded-up condition) would be somewhere midway between the external and internal walls. This is known as "wild" or "Swedish grade," as distinct from "piped" or "solid" steel.

Experiments were carried out in Sweden on ingots of "solid" steel, by drilling from the exteriors towards the axes and then plugging to such a depth that artificial blow holes were made. These ingots were cogged down and rolled into billets. Tubes were manufactured from the billets when it was found that the most suitable position for the blow holes was, measuring from the exterior of the ingot a distance of between $\frac{d}{4}$ and $\frac{d}{6}$ where "d" is the mean diameter of the ingot.

Investigations showed that on casting "solid" steel, the external surfaces are subject to blow holes, air bells and other defects and that the resulting tubes were generally "rokey" and "reedy." The importance of clean external surfaces will be recognised when it is pointed out that in the majority of cases, as will be seen hereafter, the outside of the ingot, after working, becomes without any machining whatever, the outside of the finished tube. This differs from, say, an ingot required for a forging, where to produce the finished article a very large amount of metal is machined from the surfaces.

It is found in practice that if "wild" steel ingots are cogged down at a suitable temperature, say, between 1,100° C. and

1,250° C., the blow holes will effectually weld up and if the steel has been properly made it is suitable for making tubes of the highest quality. The tubes for Classes A. and B. in Admiralty war ships have been invariably made from this class of steel.

In practice the sulphur and phosphorus in tube steel must be kept as low as possible, certainly below ·035 per cent., otherwise the material will not withstand the hot work in the mill and the cold drawing on the benches, nor would the tubes yield the specified mechanical tests. The function of the manganese is to de-oxidise the steel and to give it toughness in hot working.

Tubes " A " and " B " are almost invariably made of basic open-hearth steel. Foremen in rolling and plate mills, where both acid and basic steel is worked, generally testify that the latter works sweeter than the former. This is a very important consideration in a tube mill. Also on the basic hearth the carbon and silicon are more readily reduced.

Swedish steel is world famous, the companies which supply the tube trade own mines which yield some of the purest ores, blast furnaces and rolling mills. It is thus possible for them to supply the highest class steel at comparatively cheap rates. The sulphur and phosphorus in Swedish tube billets averages about ·02 per cent.

In this country it is usual to use haematite pig of ·04 specification, that is containing under ·04 per cent. sulphur and phosphorus and low in silicon. About 40 per cent. pig and 60 per cent. acid scrap is a good proportion and melted on a basic hearth should give chemical results nearly equal to Swedish.

Figures 1 and 2 show longitudinal sections of " solid " and " wild " steel ingots.

It is found impossible to manufacture satisfactorily " wild " steel containing over about ·23 per cent. carbon. Also in higher carbons it is less difficult to obtain the exact percentage aimed at with the acid process. Tubes of Class C. are therefore made from solid steel by the acid open-hearth process.

Two years before the war, all the tubes for water-tube boilers, steam and hydraulic pipes, telegraph and control shafting for our warships were made from Swedish steel. It was recognised that it would be a very serious matter for the country, in case of war with a first-class Naval Power to be altogether dependent on foreign supplies for such an important commodity. The Germans were fully alive to the position for they took steps to acquire controlling interests in some of the most important Swedish Steel Companies.

Prior to 1912 some small trial orders were executed in British steel, and in that year it was ordered in the specification that all boiler tubes for repairs in H.M. Dockyards should be made from British steel. It was further arranged that the boiler tubes of two of the ships of the " Queen Elizabeth " Class should also be made from home material. The results were highly

SOLID STEEL INGOT

FIGURE 1

"WILD" STEEL INGOT.

FIGURE 2.

LONGITUDINAL SECTIONS OF STEEL INGOTS.

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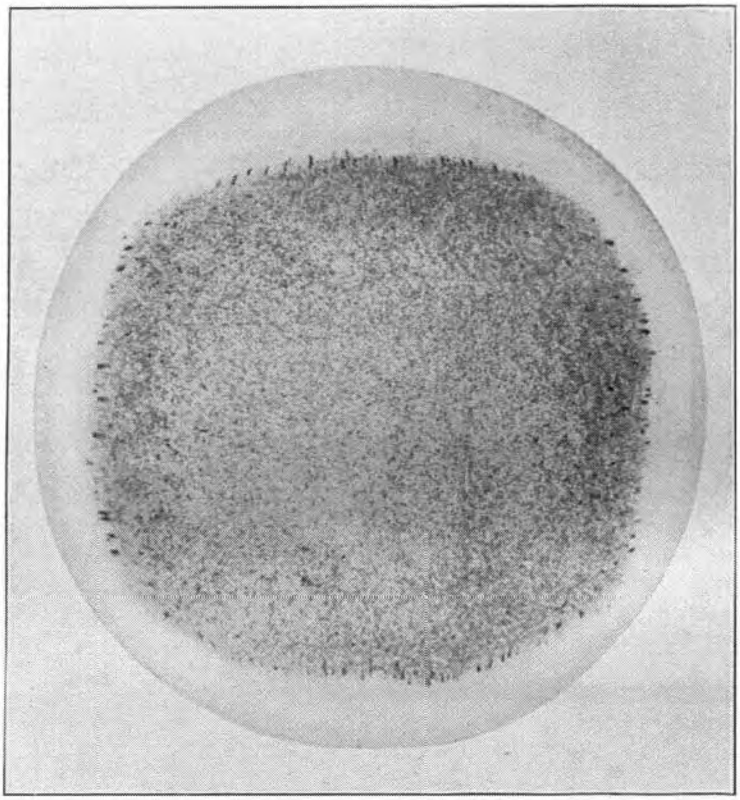


FIG. 3.—SULPHUR PRINT OF SECTION OF 3½″ STEEL BILLET ROLLED FROM "WILD" STEEL INGOT, SHOWING SULPHIDES IN "GOTHIC" FORMATION.

satisfactory, *e.g.*, in the "Malaya" the tubes for which were made by Messrs. Tubes, Ltd., of Birmingham, from steel manufactured by Messrs. Steel Peach & Tozer, Sheffield; of 24,260 tubes manufactured, the rejections at the boiler makers (Messrs. Babcock & Wilcox) on mechanical tests and examination for surface defects after pickling and electro-galvanizing, were 1·5 per cent. This rejection percentage was rarely lower when using Swedish steel of the highest quality.

Since 1913 steel of British manufacture has been exclusively used for all Admiralty tubes, and during the war Messrs. Tubes, Ltd., made the boiler tubes and steam pipes for 158 new warships and maintained an equally satisfactory standard to that referred to above.

The ingots for making Admiralty steel are usually about 1 ton in weight, and 14 in. square at the top, and 16 in. square at the base. In order to obtain clean surfaces, they are usually cast in groups, and the steel is teemed through a central runner or "git." This is known in Sheffield as "bottom pouring" or "teeming-up hill." They are allowed to cool in the moulds, stripped, re-heated to about 1,200° C., taken to the cogging mill and roughed down to a bloom of "Gothic" section. They may then be finished in one heat to bars of 6-in. or 7-in. diameter.

If smaller diameters are required they are re-heated and taken to a finishing mill and rolled down to finished sizes. They are then cut to required length. If of "Swedish grade" quality they are pickled in a hot solution of sulphuric acid and the rokes and other surface defects chipped from the surfaces, but with "solid" steel it is necessary to machine them all over in order to obtain a suitable surface. Here it may be stated that while the microscope is not of much practical assistance in connection with every day questions relating to the quality of tube steel, the process known as auto-sulphur printing often gives useful information.

The specimen to be examined is polished and rendered chemically clean and perfectly dry. Silver bromide paper is soaked in a 2 per cent. solution of H_2SO_4 and placed over the specimen. The acid attacks the sulphides and the liberated hydrogen sulphide acts on and darkens the silver bromide. The print is then washed and fixed by hyposulphate of soda in the usual way.

It is found that in a transverse section of a billet which has been made from "wild" steel the resulting sulphur print shows the sulphides formed into either a square or "Gothic" shape at the centre. Fig. 3 shows the "Gothic" formation. In "solid" steel the sulphides are generally dispersed over the entire surface of the billet.

It has not been possible to cast tubular ingots (as is the case in the metal trades, such as castings for making metal condenser tubes) which could be satisfactorily made into tubes. Attempts have been made but the ingots obtained have been spongy. Round ingots of "solid" steel cast to size and ready for piercing have also been tried. They are generally very deeply piped and have porous surfaces. Billets rolled down from ingots must be used.

We now have the finished billets and arrive at the tube works.

The first process in making a seamless steel tube from a billet is to drill or pierce a hole longitudinally through the centre.

The drilling method was carried out in a suitable machine, frequently with a drill operating simultaneously at each end. This process was very slow and wasteful and possessed no advantage over later methods. It has been discarded except in the case of some alloy steels, *e.g.*, nickel chrome steel for axles for aeroplanes, where on account of the special properties of the metal it is preferable to make the initial hole in the metal at atmospheric temperature.

The hydraulic press superseded the drill and here the billet was heated to what is known as a "mellow" heat, and taken to a press, very similar to those seen up and down the country during the war for the initial stage of shell making. The piercing was carried out by a hydraulic ram.

The great disadvantage of this process in tube making is that the resulting pierced billet or "hollow" is not concentric, and this entails machining, and consequent waste of metal. It is most important that the pierced "hollow" should be truly concentric, for if we proceed to the subsequent processes with a "hollow" of varying thickness of walls, eccentricity will result to the end.

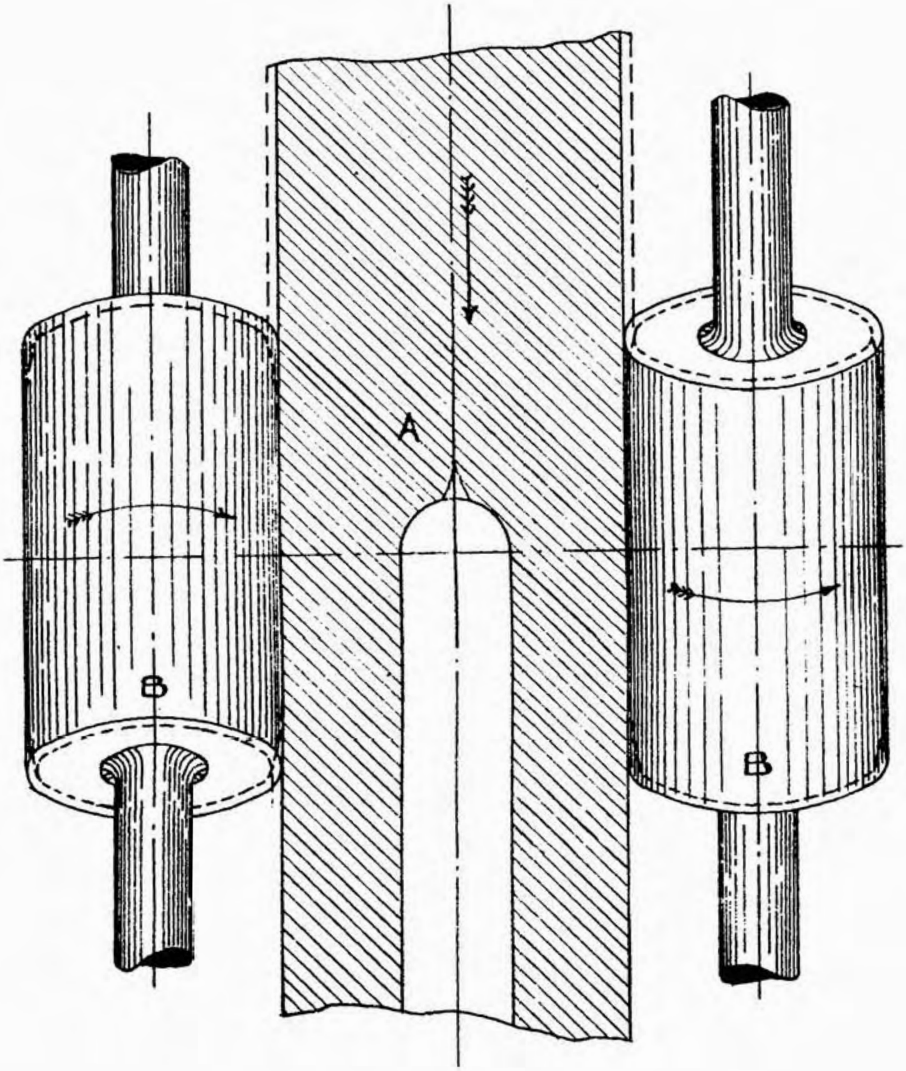
The most up to date process is the Rotary Piercer which is now in general use in all the tube works in the country where Admiralty tubes are made, and has superseded the older methods of drilling and hydraulic piercing in most cases.

The basic principle of the rotary piercer is that a flaw is formed towards the centre of a metal billet or bar in a plastic state on pressure being exerted at the external surfaces.

This may be well illustrated by considering a hoop with a piece of twine stretched across the diameter, A.B. If the hoop is resting on the ground at C, and pressure exerted at D, the points at A.B. will tend to spread laterally and the twine will fracture.

Now suppose the hoop to be turned in the direction of the arrow and the string is as dotted at A_1 B_1 and the points C and D become C_1 D_1 and pressure exerted at D_1 and so on to points B_2, B_3, C_2, C_3, &c., the fracture of the twine will tend to be at the points of intersection $\times$.

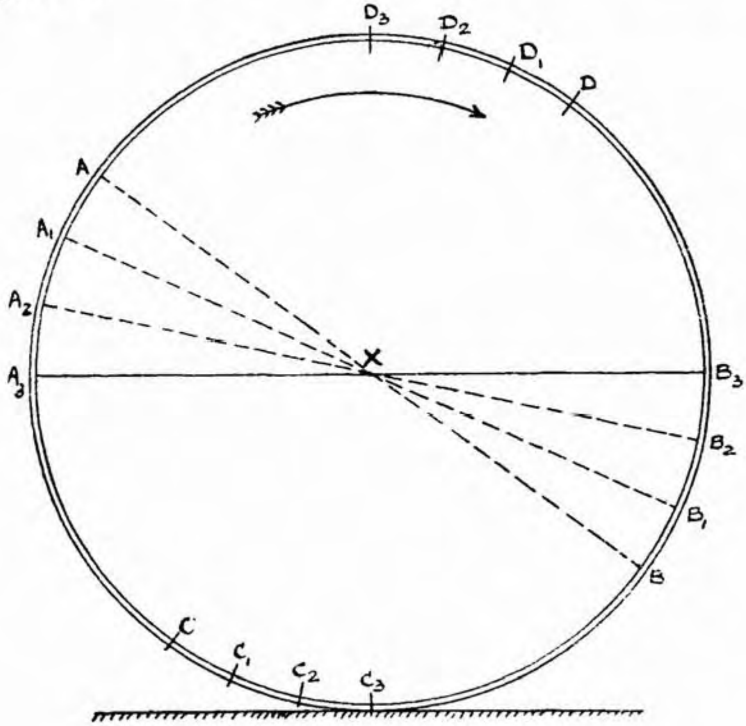
The danger of the tendency of a bar to work hollow is known to every smith, and for this reason he works down his forging by consecutive blows delivered at right angles and finishes off with swage tools.



OBLIQUE ROLLING.

FIGURE 4

In the rotary piercer, longitudinal forces also come into operation.



Suppose two rolls B. B. (*see* Figure 4) are set skew-wise, at the same angles to a bar A, which is free to revolve and move in a longitudinal or axial direction; when the rolls are revolved, if sufficient pressure is exerted between B. B. and A. then the bar will also revolve, and move in a longitudinal direction as shown.

If the bar is so held that axial movement is impossible, then at the points of contact of the rolls with the bar there is an attempt to drive the surface particles of the metal in a longitudinal direction, though this tendency can with rolls of the same diameter throughout have hardly any other effect than to wear the surface.

Now suppose the rolls to be rounded off as shown dotted in Fig. 4, the bar as dotted is held back by the rolls and the external surfaces of the metal are urged forward by the rolls. If the bar is of steel heated to a " mellow " heat, this action extends also to the interior of the bar and the material is drawn out from the middle, and urged forward spirally towards the exterior.

The bar thus hollowed passes over a conically headed mandril, which serves the purpose of producing a tube of an equal thickness of wall, and of giving a smooth internal surface.

In practice the billet passes above or below the centres of the live rolls, and between them and a guide roll (*see* Fig. 5).

In the disc or Steifel piercer (*see* Fig. 6), the fundamental principle is the same. Here the billet passes between two discs revolving in the same direction, and, in order to impart the necessary axial motion to the billet, below the axes. There is a guide ring to keep the billet in position during the pass.

A small hole is drilled or punched in the billet for the bulb of the piercer to enter. In the case of small billets up to about 6-in. in diameter, a man pushes the billet between the rolls until they obtain a bite, but for larger piercers, which deal with billets over this size, hydraulic power is used. The piercing temperature for low carbon steel is about 1,200° C.

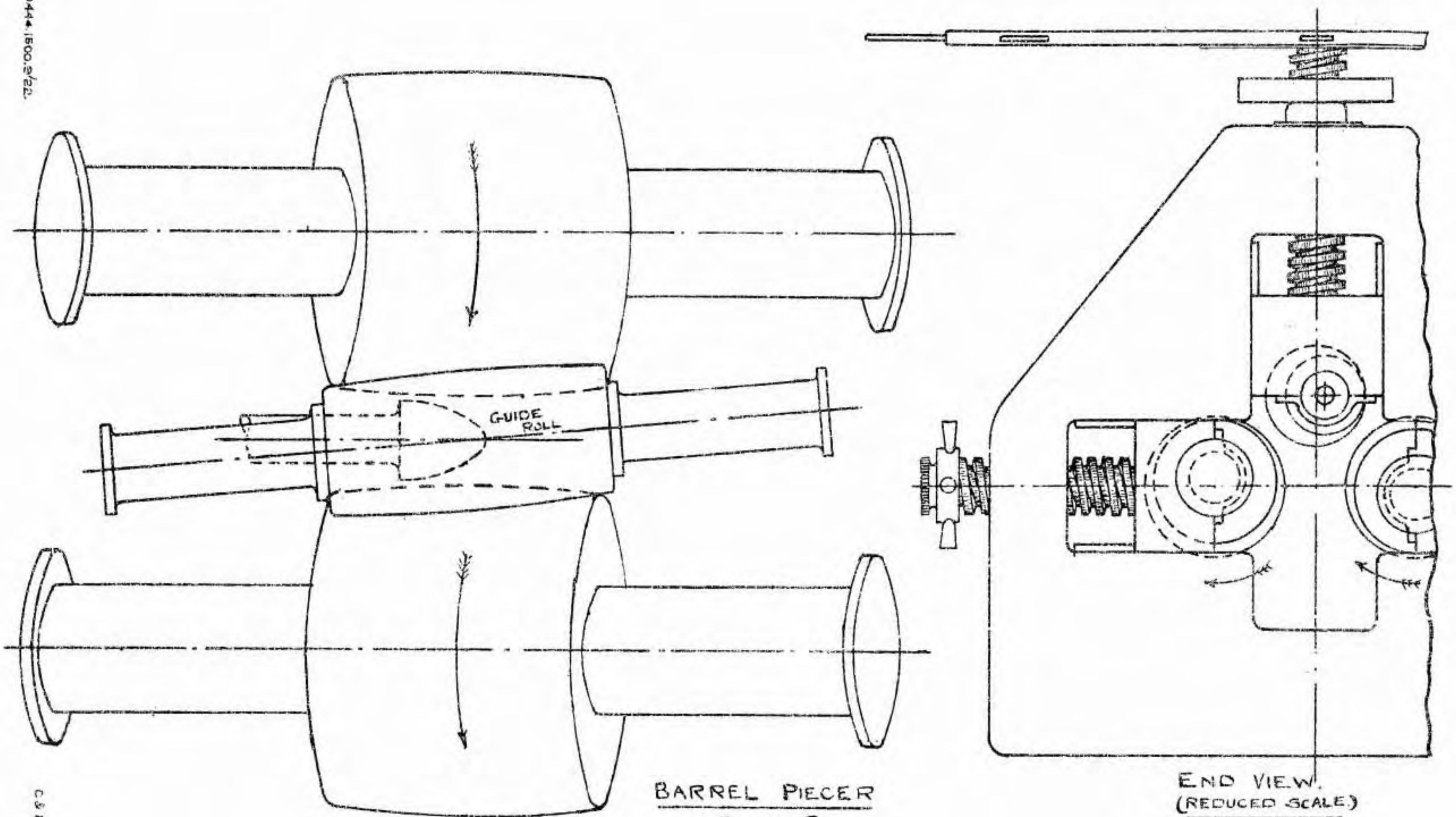
The great advantages of the rotary piercer over the former methods are that a more even thickness of wall is obtained and that there is a great saving of time and heat, and a saving of heat is of the utmost importance in all hot working of metals.

Experiments have been carried out on tubes pierced by the hydraulic process and by the rotary piercer, but no difference in structure could be found, and as far as is known the process by which pierced has no bearing on the length of life of the tubes on service.

The next operation is to hot roll the pierced " hollow " and obtain a hot-rolled tube or what is known in the trade as a "hollow bloom." The older method was to re-heat the pierced billet and to roll it through a stand of barrel rolls over plugs.

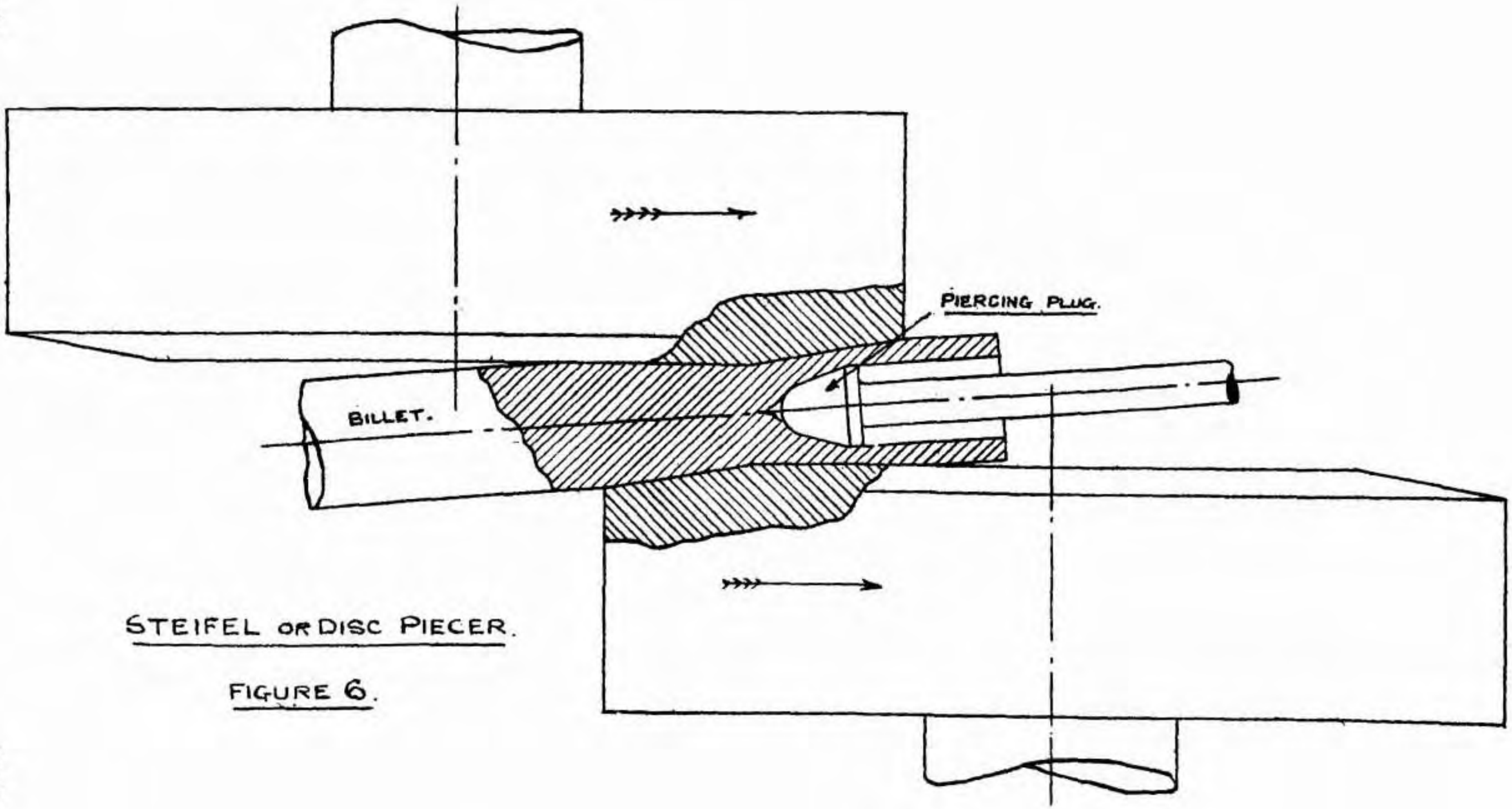
It will be seen that there are greater difficulties in hot rolling tubes than in hot rolling solid bars and plates, where only the external surface has to be dealt with and where it is comparatively easy to deal with the reverse. But in the case of tubes with an internal as well as an external surface there is a plug over which they are hot rolled, and this plug must be supported by a stem fixed to a stand. This apparatus is stationary, so it is only possible to roll in one direction. There are two methods of barrel rolling, " rolling on " and " rolling off " the plug, Figure 7 shows " rolling on." In " rolling on " the stem is in compression, in " rolling off " in tension. In each case the stem has to be removed from the interior of the tube, and the tube man-handled over the rolls. When the bore becomes small, say less than ⅝ in., the stem is not stiff enough to resist the thrust, " rolling off " must be resorted to. Generally a heavier draught may be taken when " rolling off." Between each pass the mill man gives a right-angled turn to the tube to avoid " fins."

There are few more strenuous occupations than barrel rolling, and a squad of rollers at work in a tube mill during the war was an exhilarating spectacle. They consumed much liquid, and there have been occasions when the Ministry of Food was requisitioned for supplies of suitable beer to maintain the required output of Admiralty tubes.



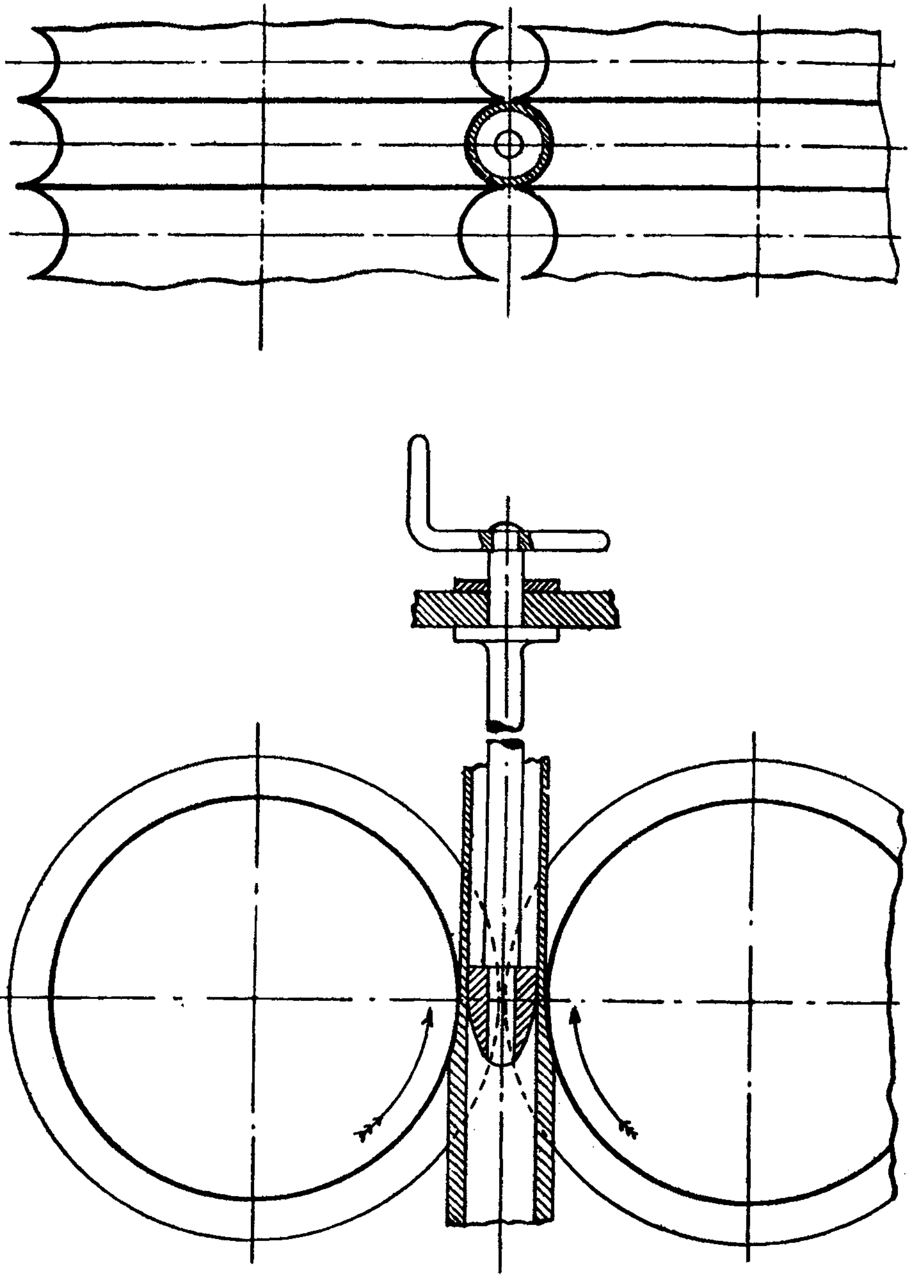
END VIEW.
(REDUCED SCALE.)

BARREL PIECER
FIGURE 5.



STEIFEL OR DISC PIECER.

FIGURE 6.



BARREL ROLLS. (ROLLING ON.)

FIGURE 7

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The two great objections to barrel rolling are—

(1) Loss of time, and more important, waste of heat;
(2) Inside seaming.

The more modern method of rolling is with "step" or "pilger" rolls. The first rolls were made in Germany and the name arises from the practice at a shrine in Bohemia where it is usual for the pilgrims to take alternately one step forward and half a step backward, in order to prolong their approach and thus show their reverence and humility.

The rolls, set in suitable housings, revolve at, say, 120 revolutions a minute. The "hollow" heated to a "mellow" heat is threaded on a bar of about 50 tons tensile steel, and is kept up to the rolls by springs or by a pneumatic cylinder. The rolls are so shaped that there is an attacking and finishing sector, and a clearance sector. The attack forces the "hollow" back, and the rolls revolving bring the clearance space to the work. As the bite of the rolls is released the "hollow" is again forced forward, and so this step by step action continues, till the whole of the hollow billet has been rolled into a "hollow bloom." The feed is regulated by a fork at the back of the rolls, or by a suitable screw device. At the back of the carriage is a spiral, with a one-way mechanism, which allows the "hollow" to take a turn through 90° during each revolution at such a time when the rolls are not biting. This is to avoid "fins" on the exterior of the tube and to give a good finish.

It will be seen that the inside of the tube only travels a comparatively short distance along the bar, so a much better finish is obtained than with barrel rolling, where the tube moves the whole distance over a plug.

Figure 8 shows sections of pilger rolls.

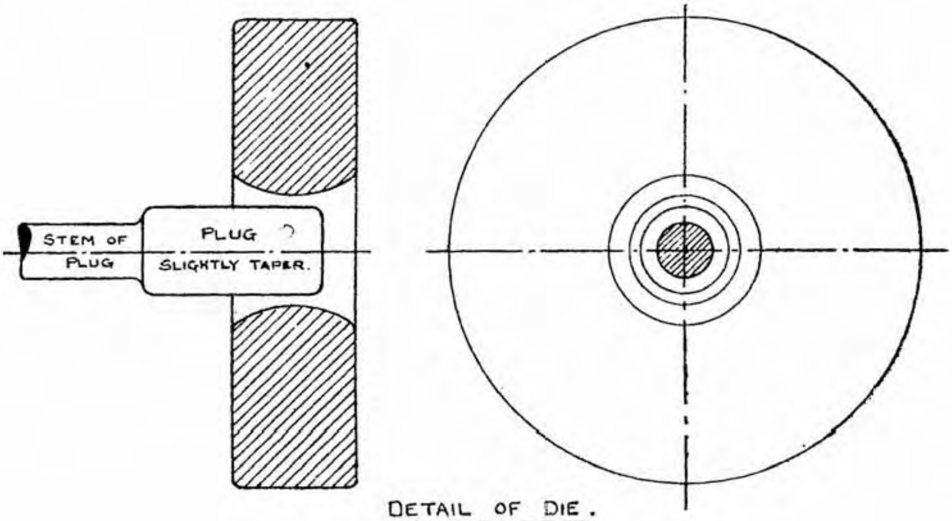
One of the great expenses in connection with pilger rolling is the cost of the mandril bars. There is usually a special shop with hydraulic upsetting presses for bringing the bars to the proper diameter after wear. They are then finished between dies and smoothed in a cool state by steam or power-driven hammers.

In large pilger mills, say for dealing with tubes over 5 in. diameter, the work is too heavy to be man-handled and machine power is necessary.

If a "hot finish" tube is required, such as would be fitted in marine type boilers, the hollow bloom is taken to a set of sizing rolls, or a hot draw bench and "sunk" to finished size. "Sinking" is a trade term, which denotes that a tube is reduced in diameter through rolls or through a die with no plug or bar inside to reduce the gauge.

To give the tube a higher finish, to insure that it has perfectly even walls and will conform to Admiralty requirements, the "hollow bloom" is taken to the cold draw department. The first operation is to heat one end and to reduce it between a set of power-driven hammers, so that it may be gripped by the dog chuck.

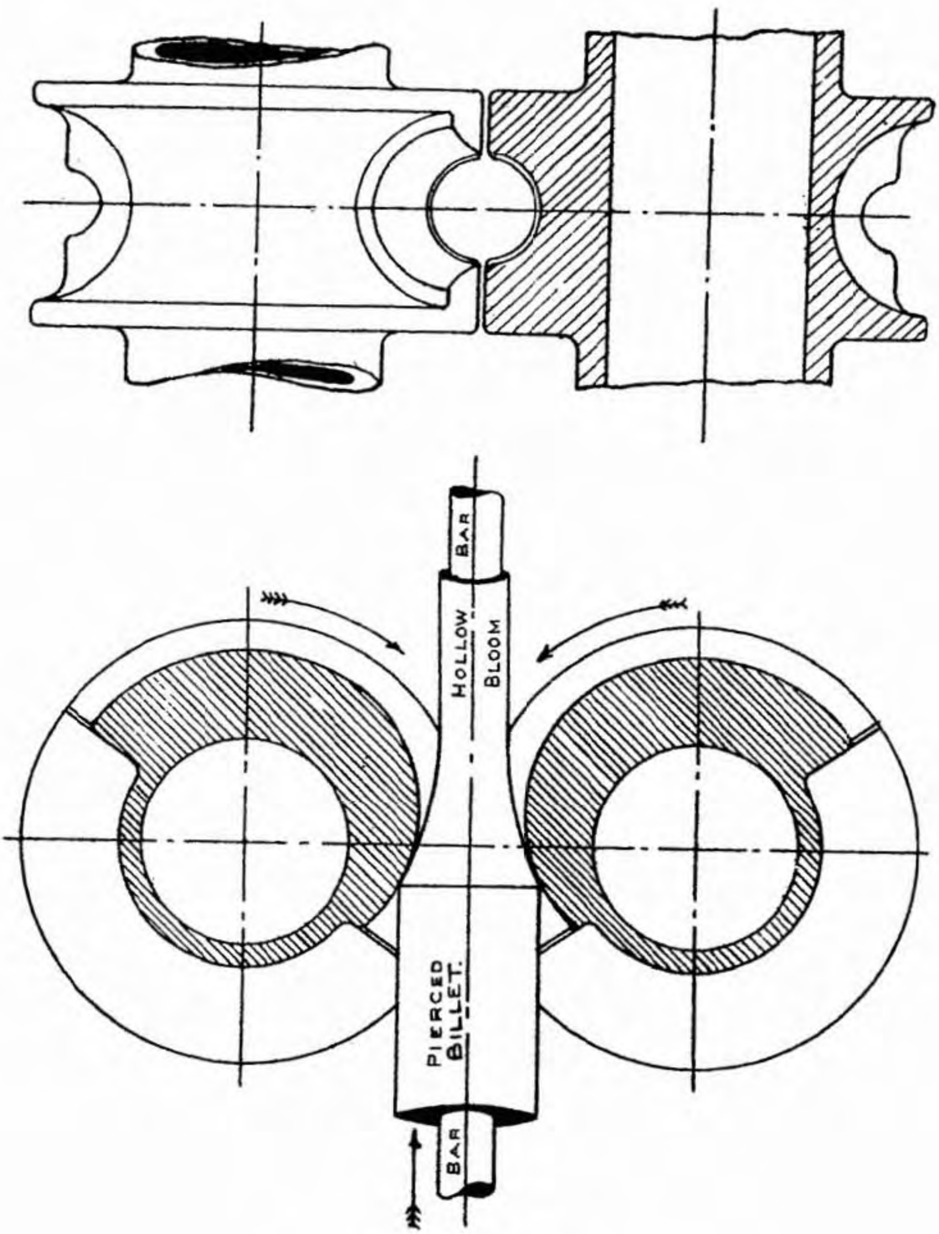
This is known as "tagging" the tube. It is then annealed and pickled to remove scale and taken to the cold draw bench. This is constructed on the same principle as shown in the paper on Manufacture of Condenser Tubes, in Vol. II. of "Papers on Engineering Subjects," but is of a heavier pattern. Admiralty boiler tubes and small steam pipes are invariably drawn over plugs of about ·6 per cent. carbon. A sketch of a plug in relative position to the die is shown here.



DETAIL OF DIE.

The tubes harden on drawing, so must be annealed between each pass, this operation being carried out in an ordinary muffle at a temperature of about 650° C. The tubes are then pickled in a hot bath of dilute sulphuric acid to remove the scale caused by annealing. It is found that the tubes draw sweeter if they are rusted. The rusted surface appears to be very suitable to contain the lubricant, which usually consists of soap and water. They are examined "in the bright" before the last pass and the finishing pass reduces by about half a gauge or 5/1,000 of an inch.

The tubes must be finished about half a gauge heavy, otherwise it is extremely likely that a considerable number will be under-gauge, and therefore not comply with the specification. They are then straightened for cutting to the required length, examined for surface defects in the bright and gauged for thickness; close annealed in "pots" (the "pots" consist of tubes, say, 10-in. in diameter, closed at one end, with caps sealed by fireclay at the other), straightened after annealing, cleaned internally by rags and compressed air, and finally inspected.



PILGER ROLLS.

FIGURE 8.

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The following are actual figures showing the dimensions at the various stages of manufacture of standard tubes for Yarrow boilers ($1\frac{1}{8}$-in. × 11 gauge).

Billet - - - - -	$3\frac{1}{2}''$ in diameter.
Pierced to - - - -	$3\frac{1}{4}''$ o.d × .$1\frac{7}{8}''$ i.d.
Hot rolled to - - -	$1\frac{7}{8}''$ o.d. × $1\frac{1}{2}''$ i.d.
Cold drawn in 5 passes to -	$1\frac{1}{8}''$ × ·120″ thick.

The tubes after receipt by the Dockyard or Boilermaker are pickled in the specified pickle (1 of HCl to 39 of water) electro galvanised and examined for surface defects.

The hardening effect of pickle on steel is well known and this effect is greater on high carbon and alloy steels than on low carbon steel.

The following are mean results given on twelve $1\frac{1}{8}''$ × 11 gauge Yarrow tubes.

Seven test pieces were taken from each tube and these test pieces treated as follows :—

———	Breaking load in tons per square inch.	Elongation per cent. on 8 in.
Tube as close annealed - - - -	21·6	36·4
Pickled for 1 hour in 1 part HCl to 39 H_2O - -	21·5	36·2
" 2 " " "	21·7	34·1
" 3 " " "	21·7	31·2
" 4 " " "	21·9	28·1
" 6 " " "	21·9	26·6
" 8 " " "	22·2	23·8

Further experiments showed that the length of time pickled was a more determining factor on the hardness of the tube than the strength of the pickle.

In the manufacture of large-sized steam pipes the same methods of manufacture are followed. Hydraulic power is used for cold drawing, and a cast iron or steel bar replaces the plug.

After giving the steam pipe a cold pass on the bar it is necessary to put it through a machine called a " reeler " which consists of a pair of skew rolls and a guide roll and is on the same principle as the barrel piercer. The external pressure on the tube tends to reduce it slightly in gauge, this increases its diameter and renders it possible to extract the bar.

The largest solid-drawn steam pipes so far fitted in British war ships are in the Flotilla Leaders, and are·$13\frac{1}{2}''$ bore by ·34″ thick.

Examination.—Admiralty tubes are subject to a very searching examination by the tube makers between the various operations, and finally before they are placed before the Overseer.

It is instructive to watch a " looker over " at his work for he will throw out tubes for marks which the ordinary observer has difficulty in seeing, even when they are specially pointed out to him. The tubes are again examined externally and internally and gauged for thickness by the Admiralty representative at the tube works before they leave for the boiler makers.

It requires long experience before an Inspector can be sure of his ground and not reject material which is suitable for service. It is advisable, in case of doubt, to lightly file the tube externally to see if the markings are of any depth, or are simply die lines or scratches. Internal surfaces may be similarly searched with a scraper.

It should be borne in mind that when viewing through a bright tube internal marks may be sometimes seen which on the tube being cut totally disappear.

As far as it is known there was no accident during the war to boiler tubes or steam pipes which could be directly attributable to bad steel, or to defective manufacture at the tube works, and this reflects credit to all concerned. The life of tubes during the war certainly was very much shorter than in normal times, but it is considered that this was not due to defective steel or to manufacture, but rather to the more stringent conditions of service.